Multiscale Residual Stress Tailoring of Spent Fuel Canister CISCC Resistance

PI: Janelle P. Wharry (Purdue University)

Collaborators: Maria A. Okuniewski (Purdue University); Rebecca Schaller (Sandia National Laboratories); Mychailo Toloczko (Pacific Northwest National Laboratory)

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Advisory Board: Kenneth Ross (Pacific Northwest National Laboratory), Jonathan K. Tatman (Electric Power Research Institute), Vijay K. Vasudevan (University of North Texas)

ABSTRACT:

The objective of this project is to understand the role of residual stress in chloride-induced stress corrosion cracking (CISCC) of austenitic steel, then tailor CISCC initiation and propagation through engineered multiscale residual stress distributions. Domestically, more than 86,000 metric tons of nuclear waste are held in dry storage stainless steel canisters within concrete overpacks. But regulators and utilities have grown increasingly concerned about CISCC of the stainless steel canisters, due to chloride salt deliquescence together with tensile residual stresses along vertical seam arc welds. These residual stresses are inherently multiscale, with macroscopic residual stresses from welding, and microscopic residual stresses associated with elasto-plastic mismatches along features such as grain boundaries and dislocation lines. Recent NEUP-supported work – including by this project team – has shown that compressive macroscopic residual stresses can delay CISCC initiation. But, CISCC is not entirely eliminated, likely due to microscopic residual stresses, which affect both initiation and propagation of transgranular CISCC. Hence, if canisters are to be designed for resilience against CISCC, there is a critical need to understand how residual stress controls pitting and cracking across multiple length scales.

We hypothesize that microscopic tensile residual stresses can generate electro-chemical environments favorable for, highly localized pitting and crack acceleration, even in a region with macroscopic compressive residual stress. We will test this hypothesis through an iterative loop approach that will systematically vary microscopic and macroscopic residual stresses through cold working and cold spraying. A novel sequence of advanced, site-specific, correlative characterization techniques will enable us to directly link multiscale residual stress, electrochemistry, pitting, cracking, and crack tip plasticity. Notable techniques include direct current potential drop (DCPD) *in situ* monitoring of CISCC, kelvin probe force microscopy (KPFM), high resolution electron backscatter diffraction (HR-EBSD), synchrotron X-ray diffraction (XRD), and X-ray micro-computed tomography (μ-CT). Results will guide the design of a residual stress distribution expected to demonstrate CISCC resistance; fabricating and testing such a specimen will represent the final iteration of the project loop.

The scientific outcome will link CISCC initiation and propagation behaviors to microstructure and local electro-chemical potentials, in a landscape of varying microscopic and macroscopic residual stresses. These results will also shed light on the pit-to-crack phenomenon. More broadly, project results will provide critical validation data for a technical basis white paper supporting the eventual ASME Section XI Code Case for cold spray mitigation of canister CISCC. This project is relevant to the DOE-NE Office of Spent Fuel and Waste Science and Technology because it will ensure long-term structural integrity of used nuclear fuel and wastes.