Development of Repair and Mitigation Methods for Enhancing Stress Corrosion Cracking Resistance of Austenitic Stainless Steel Spent Nuclear Fuel Canisters

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ABSTRACT:

This team composed of five co-investigators from two Universities and one national lab, and nuclear industry collaborator, will investigate and develop the novel and promising techniques of laser-assisted cold spray (LACS) and MELD (formerly additive friction stir-AFS) processing to repair pits and cracks, in combination with laser shock peening (LSP) and ultrasonic nanostructure surface modification (UNSM) to mitigate adverse tensile residual stresses arising from welding and repair in order to enhance the resistance to chloride-induced stress corrosion cracking (CISCC) and extend life of austenitic 304 SS spent nuclear fuel (SNF) dry storage canisters (DSC). A major concern facing the existing large fleet of welded 304SS DSCs is the potential occurrence and failure from pitting and SCC. A cost effective repair of this damage, which can be performed in situ, is low heat input, without causing sparks or placing high mechanical loads/deformation and results in a long term and reliable solution is needed, which also helps avoid the enormous costs and the significant safety concerns associated with canister replacement.

Accordingly, this project employs a holistic sp3 processing-structure-property-performance framework to provide solutions to the above challenges, with quantitative rigor and mechanistic insight. Mockup welds will be obtained and additional parallel and circular welds will be fabricated. These will be tested under conditions to produce pits and SCC cracks. Subsequently, **processing** by LACS with 304SS powders, as well as AFS/MELD with 304SS rods, will be applied to repair the pits and cracks, followed by mechanical surface treatments of LSP and UNSM to produce a favorable state of compressive residual stress and microstructure. The **microstructure** and residual stress state of the processed weldments will be characterized in detail using a host of diffraction (X-ray, neutrons) and analytical electron microscopy tools and mechanical **properties** (hardness, strength, ductility, etc) will be determined. **Performance testing** for pitting and SCC crack initiation and crack growth will be conducted under conditions of relative humidity, temperature and chloride salt chemistry that simulates the anticipated service conditions that might lead to SCC. A mechanistic understanding of processing-structure-property-performance relationships will be achieved by correlations of the results and integrated with cohesive zone models (CZM) to enable calculation of K_{IC} and K_{ISCC}, in combination with cohesive finite element method (CFEM) and extended finite element method (XFEM) models in MOOSE to yield a predictive model of SCC of the weldments in the long-term service environment.

The proposed project directly addresses FC-4.2 workscope relating to DSCs. The results will not only provide profound insight into the relevant processing-structure-property-performance relationships, but also deliver quantitatively rigorous and scientifically validated solutions for repair and mitigation of SCC for greatly extending the lifetime of the current fleet of austenitic SS DSCs, as well as other LWR SS components, which are ubiquitous, providing significant cross-cutting cost savings and health/safety benefits to the plant owner/ operator, the nuclear energy industry and society. Lastly, this project will help mentor early-career faculty and scientists, as well as provide graduate students with significant hands-on experience in cutting-edge methods of processing, characterization, and testing of advanced engineering materials and opportunities to interact with lab/industry scientists and thereby better prepare them for careers in the nuclear sector. In these many ways, this project will contribute positively to mankind.