Extending the in-service life of welded assemblies through low-energy solid-state joining

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ABSTRACT:

The objective of the project is to develop a low-energy Friction Stir Welding (FSW) process and to document improvements over baseline fusion welding methods in prototypic fission reactor environments. Recent work has shown that control of the thermal input to very low levels during FSW welding can lead to significantly improved mechanical properties in the weld zone. This project will document those property advantages and demonstrate how low-energy FSW can contribute to the goal of extending the service life of welded components.

The service life of a weld is a function of the as-welded microstructure, the residual and applied stresses, and the environment that the weld is exposed to in-service. The weld microstructure and residual stress state of the welded assembly is determined by the welding method. The fundamental problem with a conventional fusion-welded joint is that the original optimized microstructure of the base material is disturbed by the welding process. The initial metal microstructure is transformed through a melt and solidification process into a cast microstructure surrounded by parent metal that has undergone a thermal event up to the melting temperature of the base metal. Peak temperature, time at temperature, and cooling rate create microstructures that are vastly different than in the original material, and usually represents a region that will show reduced life when exposed to the operational environment.

For a wide range of alloy systems being considered in the Advanced Reactor and the Small Modular Reactor R&D Programs, welded joints represent the weak link in the life of a fabricated assembly. Predicting the life of fusion welded materials in high temperature aggressive environments is a significant challenge in multiple reactor designs. For example, well documented cases of early Type IV creep failure in 9-12Cr steels, or stress corrosion cracking (SCC) in sensitized austenitic steels illustrate some of the degradation mechanisms causing concern for reactor safety and lifetime. Advanced joining methods that neither melt nor excessively heat the base material may provide better potential to preserve the original microstructure and performance of the base material. Numerous solid state welding methods exist that satisfy these criteria, but FSW stands out for its particular combination of advantages in mechanical properties, joint versatility, speed, low fabrication cost, high weld quality, and application to modular construction.

The project will investigate the improvements of using low-energy FSW on residual stress, creep, creep/fatigue, and SCC susceptibility for alloys of interest to LWR, VHTR and SFR designs and specifically those of interest to small modular reactor (SMR) designs. The development process will focus on weldments in two alloy families relevant to Advanced Reactor and SMR applications: austenitic stainless steel and Ferritic/ Martensitic steels. The project will deliver the FSW process parameters and quantitative experimental results of mechanical and environmental testing. A key outcome will be the ability to calculate design knockdowns and performance expectations that will allow designers to factor FSW properties into component design. No such data exists for friction stir welds in these alloy classes. In addition, the project will deliver data on aspects of the process of interest to modular fabrication, including weld speed, cost, tool life, and practical aspects of fixturing, power and process control.