Capacitive Discharge Resistance Welding of 14YWT and Ferritic ODS Alloys for Cladding Applications

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ABSTRACT:

Ferritic steel alloys containing a dispersion of fine, incoherent oxide particles (usually yttria) are attractive materials for cladding applications in Light Water Reactors (LWRs) owing to their improved creep resistance, oxidation performance at temperatures of >1200°C, and radiation damage tolerance relative to current materials. These alloys are often based on the Fe-Cr-Al system and are referred to as FeCrAl ODS (oxide dispersion strengthened) alloys.

The recently developed nano-structured ferritic alloy (NFA), 14YWT containing nano-clusters (NC) rich in Y, Ti and O, show even greater promise relative to FeCrAl ODS alloys for LWR applications. Results have shown that NCs are thermally stable for long times up to 800°C and for short durations up to 1300°C. NFAs, such as 14YWT, provide better tensile strength relative to similar ODS alloys with improved fracture toughness.

Several challenges exist with joining of ODS materials. The key to their desirable properties is the retention of a uniform dispersion of fine, incoherent oxide particles that do not coarsen or agglomerate at service temperatures. These challenges are particularly acute with processes that involve melting. The oxide particles tend to agglomerate rapidly into clusters and/or float to the melt surface thereby damaging the microstructural features that provide key properties. Similar joining issues exist with the retention of the NCs that impart the key properties to NFAs. Use of solid-state welding (SSW) processes substantially reduces these concerns with both ODS and NFA alloys.

The objective of the proposed work is to examine the feasibility for using capacitor-discharge resistance welding (CDRW) to join samples of 14YWT alloy and a FeCrAl ODS alloy. CDRW is a solid-state welding (SSW) process that offers extremely rapid thermal cycles with very low overall heat input. We hypothesize that the very rapid thermal cycles and lower heat input inherent to CDRW will produce solid-state welds on FeCrAl ODS alloys with greater retention of strength, radiation damage resistance, and creep resistance properties relative to those achieved previously with other SSW processes. Moreover, we theorize that CDRW will prove applicable for joining of 14YWT while also retaining the small grain size and NC size/distribution that provide its desired mechanical and radiation tolerance properties.

CDRW will be performed on samples of the two materials at the Industrial Partner site. Process (I, force, energy and displacement vs time), and thermocouple data will be acquired during the trials. The resulting data will be correlated with the process and microstructural results through statistical techniques.

Irradiation testing of welded samples of both alloys using protons (H+) and Fe2+ will be conducted at two partner Nuclear Science User Facilities (NSUF). Proton irradiation tests will be conducted at 350°C to impart either damage levels of 1 dpa and 10 dpa at one facility. Irradiation trials at the second NSUF will be run at 350°C and 450°C to impart either damage levels of 10 dpa and 100 dpa.

Characterization experiments will also be undertaken to compare and contrast microstructures in welded and welded/irradiated sample regions versus the initial material using optical microscopy and pertinent electron microscopy techniques by the University Partner. Nano-indentation force-displacement measurements will also be taken to reveal changes in matrix hardness and elastic modulus induced by welding and irradiation.

The concepts outlined in the proposed work are potentially transformative relative to the application of NFA and FeCrAl ODS alloys for nuclear fuel cladding applications. Given the success of other SSW processes and the potential for CDRW to provide even greater retention of microstructural features and performance in reactor environments, the proposed work will provide a significant advance in the state of the knowledge for joining of these materials. Consequently, success of the proposed work will overcome current joining obstacles for these alloys and permit their greater application with increased confidence.

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