High-dose Ion Irradiation Testing and Relevant Post-irradiation Examination of Friction Stir Welded ODS MA956 Alloy

PI: Ramprashad Prabhakaran, PNNL

Collaborators: Indrajit Charit - University of Idaho; Yaqiao Wu - Center for Advanced Energy Studies/Boise State University; Lin Shao - Texas A&M University; Glenn Grant - PNNL; KL Murty - North Carolina State University

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ABSTRACT:

As part of prior DOE-funded project, efforts were made to successfully optimize friction stir welding (FSW) technique with regard to joining ODS MA956 (Fe-Cr-Al-Y_2O_3) alloy. Microstructures and mechanical properties of the parent and processed materials (i.e., friction-stir-welded) were characterized, and the results showed FSW did not significantly degrade MA956, unlike fusion welding. Later, parent and processed materials were irradiated (1 and 2.5 dpa; 190°C) in the Advanced Test Reactor (ATR) through a NSUF Irradiation Experiment Award. Microstructural investigation of the first-ever neutron irradiated friction-stir-welded ODS alloy (1 dpa) revealed encouraging results, and the particles responsible for the superior properties appeared stable under irradiation. In addition, the hardness (evaluated through a Rapid Turnaround Experiment Award) of the friction-stir-welded MA956 did not degrade after neutron irradiation (1 dpa).

To better understand the effect of irradiation on parent and friction-stir-welded MA956, it is essential to study higher dose (50-100 dpa) samples, so that the general trend of microstructural evolution and the resulting radiation-hardening can be deduced. It is critical to understand the progressive change in the parent and processed microstructure with irradiation dose to have a comprehensive understanding of the void formation, changes in dislocation density, second phase formation, and other changes that can lead to swelling, hardening, and embrittlement. Currently, ion irradiations are considered the only way to achieve doses beyond ~50 dpa in a practical time frame relevant to alloy and welding development programs.

Thus, the proposed work aims to utilize neutron preconditioning procedure, where lower dose neutron irradiated parent and friction-stir-welded MA956 (2.5 dpa; with appropriate starting microstructure and microchemistry) would be subjected to ion irradiation (Texas A&M University) to ensure that neutron-relevant microstructures are produced during subsequent ion irradiations (50 and 100 dpa; 190ºC was the actual neutron irradiation temperature). Efforts will also be made to perform ion irradiation on unirradiated samples to achieve similar doses (2.5, 50 and 100 dpa; 190ºC and 320ºC, actual neutron irradiation and LWR relevant temperatures, respectively). Advanced experimental techniques such as FIB, TEM, APT and nanoindentation (Center for Advanced Energy Studies) would be employed to understand and compare the effect of ion, neutron and neutron+ion irradiations on friction-stir-welded MA956, and to successfully develop appropriate structure-property-dose-temperature correlations.

Neutron irradiation studies have not been performed on friction-stir-welded ODS alloys to date by other researchers to the best of our knowledge. Hence, our team can begin to fill the void in the literature by successfully completing the proposed work. In addition, the proposed work could open up new opportunities for FSW (for ODS alloys) and could be developed as an 'enabling technology' for nuclear applications. The outcome of this study will provide insights to understand the effect of high-dose irradiation on friction-stir-welded MA956 that is being considered as a candidate structural material for advanced reactors. The results of the proposed work could be extended beyond MA956, and it would be relevant to many ODS alloys. The proposed work is significantly at the forefront to contribute to the scientific and nuclear materials community at large. In addition, the results of the proposed work will have cross-cutting appeal and greatly benefit the Fuel Cycle R&D program, and Nuclear Energy Advanced Modeling and Simulation (NEAMS) program by providing experimental results that would enable models to extrapolate it to the wider range of in-service conditions of future advanced reactors. Thus, the proposed work is fully consistent with the Office of Nuclear Energy's missions and vision for the deployment of next-generation advanced reactors.