Effect of neutron irradiation on friction stir welded Ni-based ODS MA754 alloy

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ABSTRACT:

Advanced nuclear reactors require high performance materials that can serve under harsh service conditions, such as higher temperatures, radiation doses, and extreme corrosive environment. Currently, Ni-based alloys are being considered for several reactor concepts (MSR, VHTR, SCWR). At high temperatures, Ni-based alloy is a superior structural material due to its higher creep resistance (>600°C) compared to austenitic stainless and ferritic-martensitic steels, and higher swelling resistance compared to austenitic steel. However, the application of Ni-based alloys for nuclear reactors is generally limited because of the loss in ductility after neutron irradiation, due to the embrittlement caused by transmutation-produced helium (He) and radiation-induced precipitation of second phases at grain boundaries.

The oxide dispersion strengthened (ODS) alloy approach could provide a means to overcome the deficiencies related to radiation-induced loss of ductility and swelling resistance observed in Ni-based alloys while retaining/enhancing their elevated temperature properties and excellent corrosion resistance in various media. These alloys contain a fine dispersion of nanoscale oxide particles that are stable at elevated temperatures and can also act as copious trapping/sink sites for He produced due to transmutation reactions, and for radiation-produced defects to reduce the accumulation of displacement damage, thereby increasing the radiation tolerance. However, in order to consider ODS alloys for nuclear applications, it is important to identify a suitable welding technique. *Conventional fusion welding techniques applied to ODS alloys (Fe-based and Ni-based) leads to excessive level of porosity, agglomeration and non-uniform distribution of fine oxide particles. Hence, it is important to identify and develop innovative joining techniques for ODS alloys that do not have drawbacks inherent to the fusion welding techniques. Friction stir welding (FSW), an advanced solid-state joining technique can play a vital role in improving the weld quality of ODS alloys and have real implications for their use in nuclear applications.*

As a part of our prior DOE-NE funded study, efforts were made to successfully optimize FSW technique with regard to joining Ni-based ODS MA754 and Fe-based ODS MA956 alloys. Microstructures and mechanical properties of parent and processed materials (i.e., friction stir welded) were characterized, and the results showed that FSW did not significantly degrade these ODS alloys, unlike fusion welding. Later, we won a NSUF Irradiation Experiment award (#08-96) to perform the first-ever neutron irradiation (1 dpa and 2.5 dpa) on parent and friction stir welded ODS alloys.

Neutron irradiation studies (PIE) have not been performed on parent and friction stir welded Ni-based ODS alloys. *Hence, the objectives of the proposed NSUF PIE project are to obtain three critical information: (a) neutron irradiation behavior of Ni-based ODS alloy; (b) potential of FSW for nuclear applications; (c) compare the neutron irradiation performance of ODS (advanced structural materials) and FSW (innovative manufacturing/joining) concepts, using samples irradiated in similar conditions: Ni-based (proposed PIE study: Oct'21-Sep'23) vs. Fe-based alloy (our existing PIE study #18-14787: ending Sep'21). In order to consider Ni-based ODS alloys and FSW technique for nuclear applications, it is important to understand the microstructural evolution and concomitant changes in mechanical properties of parent and friction stir welded Ni-based MA754 after neutron irradiation.* Experimental techniques such as FIB, TEM, APT, Vickers microhardness and shear punch testing would be employed to understand the progressive change in parent and processed microstructures with irradiation dose, to evaluate resulting radiation-hardening and to develop appropriate processing-structure-property-dose correlations.