Direct Production of ODS Ferritic Alloys for Long-life Reactor Fuel Bundles: Sheet Material for Ducts and Tube Preforms for Cladding

PI: Sid Pathak, Iowa State University

Collaborators: Prof. Iver Anderson (Iowa State University)
Dr. Emma White (Ames Laboratory)
Dr. Stuart Maloy (Los Alamos National Laboratory)
Dr. Hyosim Kim (Los Alamos National Laboratory)
Mr. Clinton B. Armstrong (Industry advisor, Westinghouse Electric Co)

Program: Nuclear Energy Enabling Technologies (NEET) Crosscutting Technology Development (CTD)

ABSTRACT:

Austenitic stainless steel (316L) alloys and tool steel (D9) alloys have historically been used as duct material in reactor applications but suffer from irradiation assisted stress corrosion cracking (IASSC) and void swelling at high doses. Ducts made of an alternative tool steel (HT-9) show much better swelling resistance where very little swelling was observed up to 155 dpa. However, for the more challenging radiation conditions and temperatures of more advanced reactors, it is known that new materials for fuel bundle components all need improved tolerance to swelling and other irradiation effects, especially at elevated temperatures. Ferritic stainless steels are more resistant to stress corrosion cracking and suffer less swelling than austenitic steels and many tool steels, while maintaining oxidation resistance that is superior to zircaloy. Furthermore, high temperature creep resistance and radiation tolerance of ferritic alloys can be improved by the addition of ODS particles that precipitate as highly stable nano-clusters with proper processing.

ODS ferritic alloys cannot be made by conventional melt/solidification processing due to the requirement to maintain well-distributed, but spatially dense nanoscale oxide dispersions. The current inefficient method for fabrication of ODS alloy materials consists of making and blending multiple powder types and long-time (at least 40 hours) of agglomeration and mechanical alloying by high energy ball-milling in inert atmosphere. Conventional tube or sheet manufacturing processes, when applied to MA-type ferritic ODS alloys can result in microstructures with anisotropic mechanical properties from alignment of stringers of coarse oxides and led to an expensive, inhomogeneous material with little commercial acceptance that was largely withdrawn from the marketplace in spite of its special performance potential in fission reactors for power generation.

This project seeks to exploit the inherent uniformity, reasonable compressibility, and thermally-activated sintering of gas atomization reaction synthesis (GARS) precursor oxide dispersoid strengthened (ODS) ferritic steel powder to produce full density powder compacts by conventional vacuum warm pressing. After vacuum sintering of the compacts, resulting billets will be cold cross-rolled to ODS sheet material and formed into duct shapes. Hollow preforms also will be produced using the same vacuum warm pressing and sintering parameters developed for GARS powder billets, but will incorporate a dissimilar powder core that can be readily removed from the resulting billet. These “mother tubes” can be pilgered by our industry partner (Westinghouse) to produce ODS ferritic steel cladding in final shapes. Thus, low-cost conventional powder and deformation processing will be used with innovative GARS powder to give new life to these promising nuclear materials without the high-cost of prolonged mechanical alloying (MA)-based processing to replace swelling-prone austenitic steels in fuel bundle duct and oxidation-sensitive zircaloy cladding.

Our proposal integrates collaborative research by two national laboratories and one university partner, with guidance from industry, to perform crosscutting R&D in new materials (GARS ODS precursor powder) to enable advanced reactor designs and fuel technologies. By GARS ODS alloy performance being validated, a cost-effective strategy to high-performance structural materials for nuclear reactors will result, improving competitiveness and advancing U.S. nuclear technologies to meet our energy needs. These robust GARS ODS materials will enhance the long-term viability and competitiveness of existing reactors by being drop-in ready to replace sheet and tube forms of current reactors. Also GARS ODS alloys maintain our National strategic supply chain infrastructure by a U.S. manufacturing route demonstration to provide these advanced alloys for new reactor designs and enabling concepts, such as higher temperature operation and longer lifecycles.