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Advancing Diffusion Bonding for Compact Heat Exchangers

PI: Todd R. Allen
University of Michigan

Collaborators: Fei Gao-Michigan
Mark Anderson-Wisconsin
Mohamed Elbakhschwan-Wisconsin
Ian Jentz-Wisconsin
Jim Stubbins-Illinois
William Nollet-Fort Lewis
Ryann Rupp-INL
Mark Messner-ANL
John Shingledecker-EPRI
Robert Keating-MPR
Suzanne McKillop-MPR

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ABSTRACT:

Advanced nuclear systems are being proposed for many new applications beyond large plants for electricity generation. Many of these concepts envision supporting integrated energy systems where nuclear generated heat can be used for electricity, thermal storage for later use, industrial heat, or district heat. Nuclear designs need to be economically competitive in any proposed applications. Cost competitiveness can be achieved through a combination of 1) higher operational temperatures for improved efficiency; 2) reduced capital cost for construction and deployment, and 3) reduced operation and maintenance (O&M) costs.

A key enabling technology that portends lower costs is compact heat exchangers (CHXs). Compact type heat exchangers have high effectiveness approaching 95%. Printed circuit heat exchangers (PCHE) and hybrid printed circuit/formed plate (H2X) compact heat exchangers provide space and weight savings, using significantly less material than typical shell and tube heat exchangers. They also provide high thermal efficiencies, low-pressure drops, and moderate to high design pressure capabilities. These types of heat exchangers are currently being integrated into non-nuclear service at a fast rate for many industrial and power processes including oil, gas, and solar thermal technologies. They are used for heat recuperation, heat removal, and heat storage. These same heat exchangers are desired in nuclear service for coupling advanced nuclear reactors to more efficient power cycles such as the supercritical CO2 cycle, helium Brayton cycle, and air Brayton cycles, concepts being considered by many advanced reactor developers.

Recent work across the scientific community has revealed that current commercial diffusion bonding practice results in a material where the mechanical strength of the bonded interface is degraded from that of the base metal when operating at elevated temperature. This work has identified a need for improvement in bonding science and the development of bonding criteria for diffusion bonded material in nuclear applications. This proposed research program will improve the scientific basis of diffusion bonding and propose acceptance criteria commercial use. The project will focus on diffusion bonding of Alloy 617. Alloy 617 has the highest temperature application limit in ASME Section III and thus is of interest to many advanced reactor developers. Initial work will also be conducted on 316H Stainless Steel, also in ASME Section III, as significant, validated, diffusion bond evolution and microstructure plasticity modeling work are established for 316H and provide guides for the work on Alloy 617.

The research will focus on:

- Modeling and theory of interfacial bonding, including the resulting crystal plasticity and the identification of the key microstructural and bonding fabrication conditions that ensure optimal bonds.
- High throughput bonding procedures to allow rapid analysis of the materials properties (e.g., grain size and orientation, surface condition, precipitation) given specific process conditions (e.g., time, temperature, and pressure) that are critical to bonding performance
- Mechanical performance testing (e.g., tensile, creep, fatigue, creep-fatigue) of the resulting bonds to characterize structural integrity and to develop acceptance criteria.
- Detailed microstructural characterization of bonded interfaces and post-mechanical testing failure analysis
- Scaling bonding processes identified through the high throughput tasks to commercial scale, verifying the results, and developing appropriate acceptance criteria.

The project will provide scientific understanding to optimize the bonding process and develop acceptance criteria for bonding processes that could be implemented by the ASME BPVC committees. These results will inform future code cases for the use of these compact heat exchangers.