Irradiation Effect on Thermophysical Properties of Hafnium-Aluminide Composite: *A Concept for Fast Neutron Testing at ATR*

Heng Ban – Utah State University (USU) – heng.ban@usu.edu

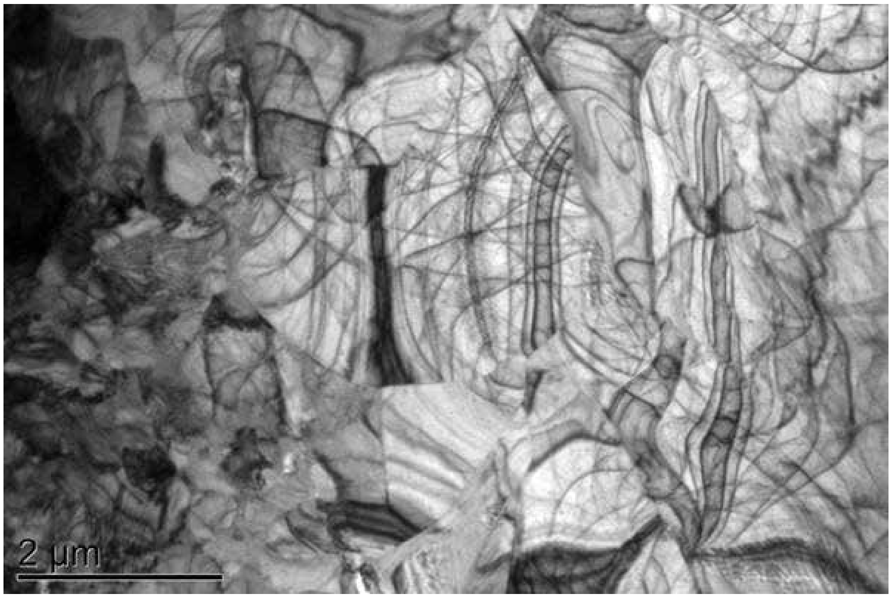


Figure 1. TEM bright-field image of irradiated material showing smaller grains and bend contour, which indicates strain-release during annealing process.

A metal matrix composite material comprised of hafnium aluminide (Al_3Hf) intermetallic particles in an aluminum matrix has been identified as a promising material for fast-flux irradiation testing applications. This material can filter thermal neutrons while simultaneously providing high rates of conductive cooling for experiment capsules, which experience significant heating in the reactor. An experiment was performed wherein material specimens were irradiated in the Advanced Test Reactor (ATR). Thermal and mechanical properties of the material were measured on irradiated specimens and compared to those for the unirradiated material. The effects of irradiation on this new material are being assessed.

Project Description

The capability for conducting fast neutron irradiation tests is essential to meet fuels and materials development requirements for future nuclear reactors. The lack of domestic fast neutron testing capability hinders the development of advanced reactors. The concept behind this project is to use one of the ATR corner lobes with the addition of a thermal neutron filter to absorb the thermal neutrons and booster fuel to augment the neutron flux. An absorber material comprised of hafnium aluminide (Al_3Hf) particles (~28.4% by volume) in an aluminum matrix (Al_3Hf-Al) can absorb thermal neutrons and transfer heat from the experiment to pressurized water cooling channels. Thermal analyses

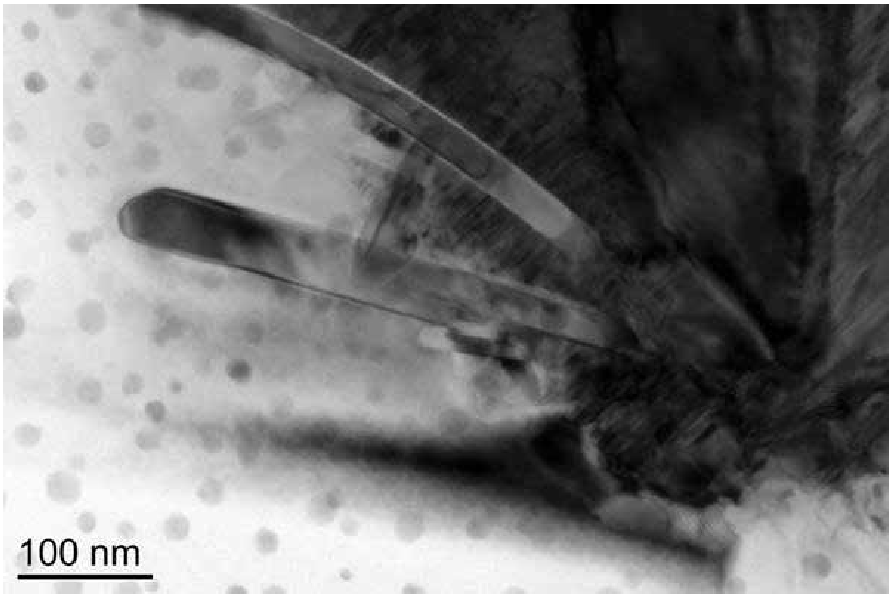


Figure 2. TEM bright-field image of irradiated material showing columnar-shaped grains at phase boundary; the smaller sphere-like particles are oxidation contamination.

conducted on a candidate configuration confirmed that the design of the water-cooled Al_3Hf-Al absorber block is capable of maintaining all system components below their maximum allowable temperature limits.

However, the thermophysical properties of Al_3Hf have never been measured and the effect of irradiation on these properties has never been determined. It is essential to obtain data on the effect of irradiation on the thermophysical and mechanical properties of the Al_3Hf intermetallic and Al_3Hf-Al composite. Other information, such as corrosion behavior and radioactive decay products, are also necessary to proceed with the design and optimization. The purpose of the project is to determine the necessary properties and behavior of this new material. Specific objectives are to determine the:

1. Thermophysical and mechanical properties of Al_3Hf intermetallic and Al_3Hf-Al composite at different temperatures.
2. Effect of irradiation on the thermophysical and material properties of the Al_3Hf intermetallic and Al_3Hf-Al composite, and physical/morphological, metallurgical, and microstructural changes of the Al_3Hf-Al composite after different cycles of irradiation.
3. Decay products of hafnium (Hf-179m1 versus Hf-179m2) and corrosion behavior of the Al_3Hf-Al composite.

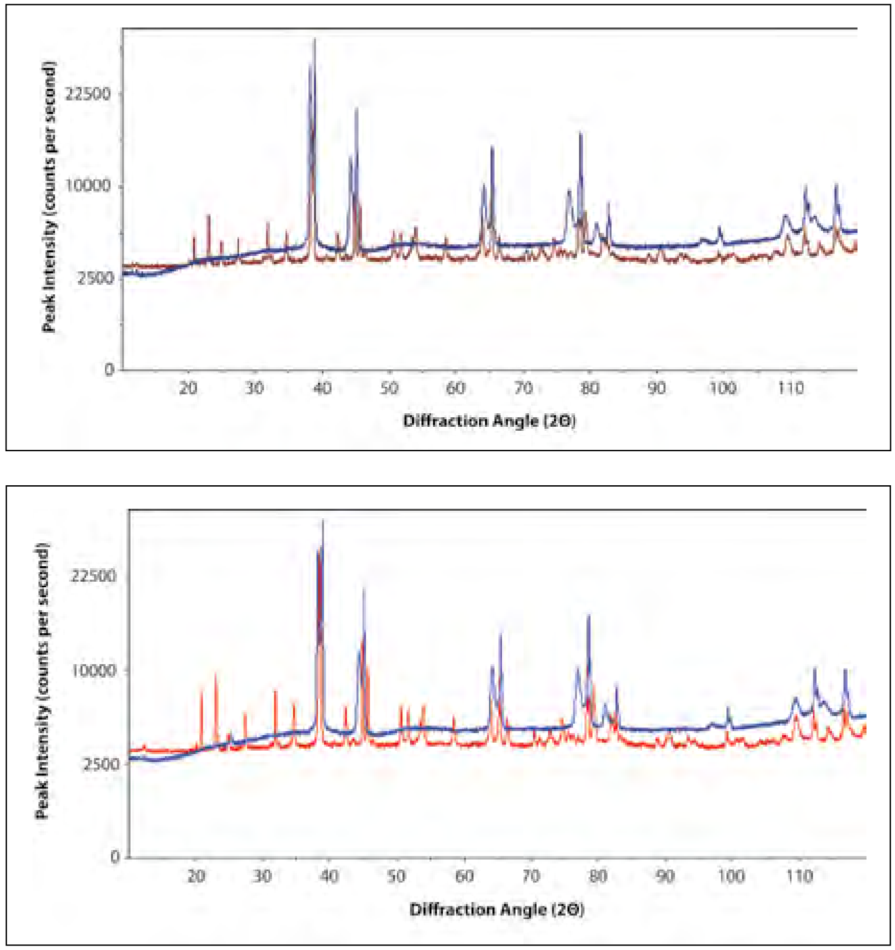
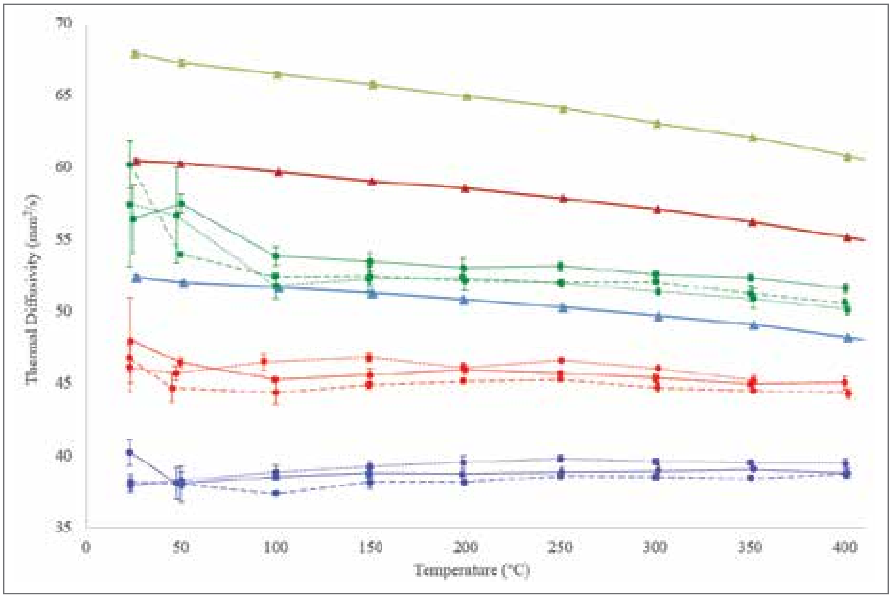


Figure 3. Diffraction patterns of heat treated and non-heat treated samples that have undergone (a) three cycles of irradiation, and (b) four cycles of irradiation.

Successful completion of the project will: (1) provide necessary data for the development of fast neutron test capability at ATR, (2) fill a knowledge gap on the basic properties of the Al_3Hf intermetallic and Al_3Hf-Al composite, and (3) advance the scientific understanding of the irradiation effects on these materials. The end result, in terms of data and fundamental understanding obtained, will directly support DOE's mission and benefit the science community in general.

Accomplishments

During FY 2015, a 3-D microstructural reconstruction was performed for irradiated specimens of the $HfAl_3$-Al metal matrix composite material developed for the Utah State University NSUF project. Focused Ion Beam (FIB) milling and Electron Backscatter Diffraction was done using the FEI Quanta 3-D field emission gun (FEG) located at the Center for Advanced Energy Studies (CAES). The gallium ions from the FIB were found to be



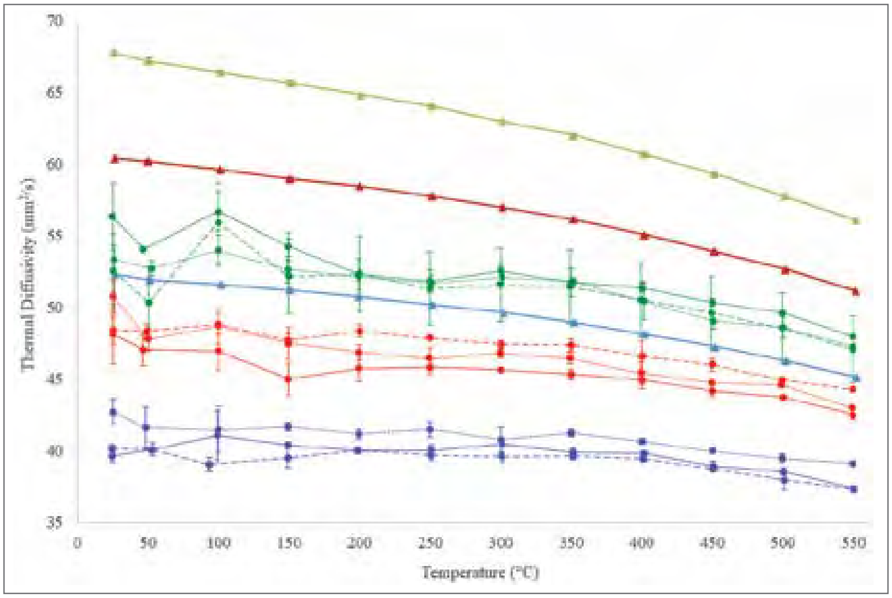


Figure 4. Comparison of measured thermal diffusivity of unirradiated with unannealed irradiated material (top) and annealed irradiated material (bottom).

Irradiated Data: 36.5 vol%, 28.4 vol%, 20 vol% Al_3Hf
Unirradiated Data: 36.5 vol%, 28.4 vol%, 20 vol% Al_3Hf

"The insight provided into the changes in properties of this new material resulting from irradiation have enormous value to the nuclear community, as well as to the students who have been inspired to pursue advanced degrees."

— Donna Post Guillen, Distinguished Research Engineer

very damaging to the $HfAl_3$-Al; thus, a new procedure was developed to enable the acquisition of acceptable Kikuchi patterns. The serial scans were reconstructed using Dream.3D software and visualized using ParaView. This work is pioneering in that 3-D microstructural reconstruction has never before been attempted for this material.

Post-irradiation examination completed during FY 2015 includes: (1) measurements of thermal conductivity using the laser flash method and specific heat using differential scanning calorimetry on nine specimens, (2) thermal expansion measurements on three specimens, (3) 3-D EBSD of one specimen, and (4) transmission electron microscope (TEM)/local electrode atom probe (LEAP) of one specimen.

Future Activities

Research yet to be completed on the irradiated material includes tensile and hardness tests on 12 specimens. This will be conducted at PNNL's Material Science and Technology Laboratory. Also to be completed are thermal diffusivity and differential scanning calorimetry measurements on the irradiated intermetallic material.

Publications and Presentations*

1. Guillen, D. P., and H. Ban, "Characterization and Modeling of a New Material for Nuclear Reactor Applications," *CAES Materials, Modeling, Simulation, and Visualization Workshop, Shore Lodge, McCall, Idaho, May 13–14, 2015.*

2. Guillen, D. P., and H. Ban, "Radiation Effects on the Thermophysical Properties of a New Neutron Absorbing Material," *2015 TMS Meeting, Orlando, Florida, March 15–19, 2015.*

3. Guillen, D. P., and H. Ban, "Development of a Metal Matrix Composite Material for Nuclear Reactor Applications," *2015 TMS Meeting, Orlando, Florida, March 15–19, 2015.*

**See additional publications from other years in the Media Library on the NSUF website.*

This NSUF project has enabled us to obtain the first-ever data on a new two-phase metal matrix composite material developed to enable the testing of fast reactor fuels and materials in an existing LWR.

Distributed Partnership at a Glance	
NSUF and Partners	Facilities and Capabilities
Center for Advanced Energy Studies	Microscopy and Characterization Suite
Idaho National Laboratory	Advanced Test Reactor, Hot Fuel Examination Facility Analytical Laboratory, Electron Microscopy Laboratory
Pacific Northwest National Laboratory	Materials Science & Technology Laboratory
Collaborators	
Idaho National Laboratory	Donna Post Guillen (principal investigator)
University of Nevada, Las Vegas	Thomas Hartmann (co-principal investigator)
Utah State University	Heng Ban (principal investigator), Zilong Hua (postdoctoral researcher)