Understanding the Performance of SiC-SiCf Composite Cladding Architectures with Cr Coating in Normal Operating and Accident Conditions in LWRs and Advanced Reactors

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ABSTRACT:

The SiC-SiC$_f$ composite (SiC fiber in a SiC matrix) as a cladding material has been investigated in recent years as a long-term accident tolerant fuel (ATF) option for both light water reactor (LWR) and advanced reactors such as the high-temperature gas-cooled reactor because of its superior oxidation resistance in high-temperature steam condition, high melting point, and excellent high-temperature strength. SiC-SiC$_f$ composite claddings of various architectures with an outer monolithic CVD SiC layer to enhance the hydrothermal corrosion resistance and hermeticity are currently under development. Nevertheless, there are concerns for the SiC as a structural material regarding hydrothermal corrosion during normal operation in LWR and fission gas release through the microcrack during the DBA events. Application of a protective metal layer on the SiC cladding is being investigated, and recent research has shown enhancement of corrosion resistance by applying Cr coating. The improved hermeticity and mechanical strength using Cr coating has been attributed to relatively ductile characteristics of the metallic coating. In addition to the performance benefit, the Cr coating can provide economic benefits by reducing the fabrication cost in two levels: it can potentially (i) reduce costs by bypassing unnecessary final polishing steps, which are cost-intensive due to the high hardness of SiC, and (ii) replace the outer monolithic SiC layer that is presently used to minimize corrosion along the fiber-matrix interface with better hermeticity. However, a limitation of previous research is that the effect of Cr-coating was not tested with the actual tubular SiC-SiC$_f$ composite cladding including the fiber-matrix composite structure, which inherently contains some defects. For the deployment of the Cr-coated SiC-SiC$_f$ composite cladding, the new clad design should be tested under various normal operation and accident conditions such as the LOCA for LWR and depressurized loss of forced cooling for gas-cooled reactor. Evaluating the performance of the new fuel/clad design under accident conditions is an essential step from licensing perspective.

The goal of this research is to investigate the functionality and performance of Cr-coated SiC-SiC$_f$ composite cladding under normal and accident conditions in both LWR and gas-cooled reactors for better performance and for reducing manufacturing cost. Cr-coatings will be deposited by PVD on three types of claddings: (i) with a polished outer monolithic SiC layer, (ii) with an unpolished outer monolithic SiC layer, and (iii) without the outer monolith SiC layer. The potential defects of the uncoated and Cr-coated SiC-SiC$_f$ composite cladding will be evaluated using the Non-Destructive Evaluation (NDE) methods, including the 3-D X-ray Computed Tomography by GA and the Pulsed Infrared Thermography (PIT) by Argonne National Laboratory. To test the performance of the Cr-coated SiC-SiC$_f$ composite cladding, high-temperature helium corrosion, water reflood, and burst tests will be performed. The post-test characterization will be performed to observe defects and to understand failure mechanisms. Eventually, the helium leak test for the hermiticity will be performed using the facilities at GA and POSTECH. PIT will be applied to detect relevant defects for a better understanding of the Cr-coated SiC-SiC$_f$ composite cladding performance. The performance of Cr-coated SiC-SiC$_f$ composite cladding will be implemented into the MELCOR code to investigate how the coating influences the LWR and FMR safety analysis compared to the uncoated cladding. The project strongly aligns with the long-term ATF research at GA.