Synchrotron X-Ray Characterizations of Advanced Accident-tolerant Cladding

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Advanced intermetallic coatings on zircaloy cladding have great potential for improving resistance to oxidation and radiation damage.

This research aims to characterize the microstructural development of intermetallic coated zircaloy, an advanced cladding material, after heavy ion irradiation. The intermetallic coatings on the zircaloy were developed using atomic layer deposition (ALD) technique. With the protection of the coating, the oxidation resistance of the zircaloy has been significantly improved. However, the performance of the coating in a highly radioactive environment is not yet understood. In this study, the synchrotron X-ray available at the Materials Research Collaboratory Access Team (MRCAT) beamline at the Advanced Photon Source (APS) was utilized to study the materials' performance after high-energy heavy ion irradiation. An X-ray absorption fine structure (XAFS) experiment was conducted to study the ion radiation damage on the zircaloy sample with advanced coatings.

Project Description

Advanced intermetallic coatings have great potential for improving resistance to oxidation and radiation damage in nuclear materials. The Fukushima Daiichi nuclear accident has clearly demonstrated to the world that improvement of the safety performance of operating light water nuclear reactors (LWRs) is an imminent need. The reactors at the Fukushima Daiichi Nuclear Power Plant experienced a loss of coolant accident (LOCA) during which the zirconium alloy (zircaloy) cladding (sealed tubes that protect the UO^2 fuel material from contact with the environment) experienced severe oxidation. Large amounts of hydrogen were generated as steam reacted with zirconium at high temperature, eventually leading to hydrogen explosions. In response to the accident, the U.S. Department of Energy (DOE) Office of Nuclear Energy (NE) has placed strong strategic importance on developing LWR fuels with enhanced accident

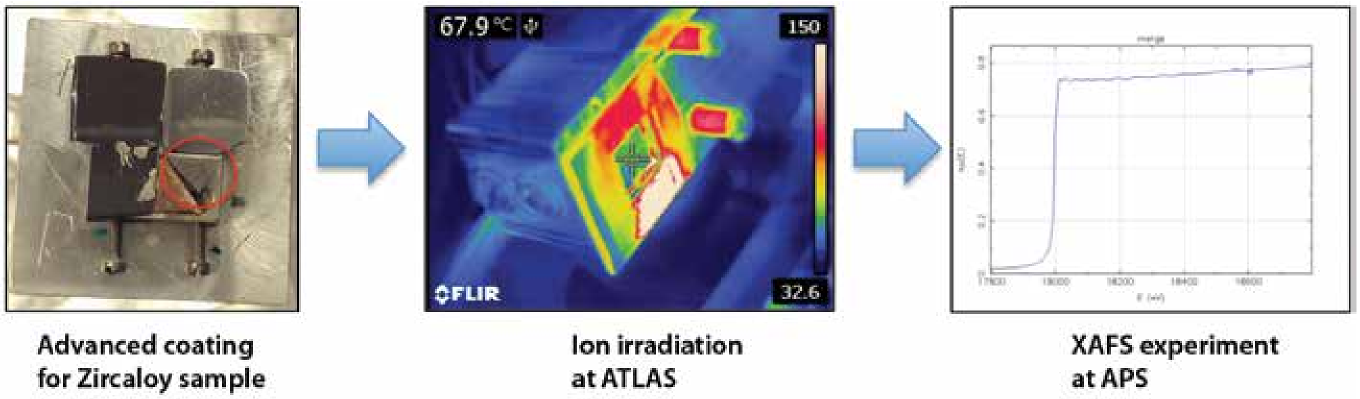

Figure 1. Experimental procedure.

tolerance characteristics. In comparison with standard UO_2+Zircaloy systems, an enhanced accident tolerant fuel/cladding system will release significantly less energy, resultant hydrogen, and fission products to the environment during beyond-design-basis LOCA events. In this context, improving the performance of zircaloy cladding under accident conditions has become a central issue of great interest to both DOE and the nuclear industry. Corrosion resistance (resistance to oxidation) of zircaloy has been studied since long before the Fukushima accident. Meanwhile, the ALD technique available at Argonne National Laboratory (ANL) has been demonstrated as a very effective coating technique, which significantly improves adhesion between the coating and the zircaloy compared to other coating techniques used in the past, such as vapor deposition techniques. Although the oxidation resistance has been significantly improved, the radiation resistance of the coating is unknown. This experiment aims to study the microstructural development of advanced cladding materials following heavy ion radiation. A comprehensive understanding of the performance of advanced cladding materials will be needed to validate their improvement in performance during both normal and transient scenarios.

Synchrotron X-rays provide us with unique insight about the radiation damage in advanced fuel cladding materials.

— Kun Mo, Materials Scientist, Nuclear Engineering Division, Argonne National Laboratory

Accomplishments

Zircaloy samples were coated with ALD techniques and thermally treated to form intermetallic coatings at ANL. The coated samples were then irradiated by 55-MeV Fe ions at the Argonne Tandem Linac Accelerator System (ATLAS) at ANL. The samples were exposed to a 1pnA beam for 1 hour, then a 50pnA beam for 15 hours at ~100°C. After irradiation, the samples were characterized using XAFS technique at the MRCAT beamline at APS. Since the ion-irradiation damage zone is only a few µm from the surface, the samples were tilted to three different angles (90°C, 45°C, and 25°C) to the X-ray beam to study radiation damage at different depths. The experimental procedure is summarized in Figure 1. A typical K-edge absorption spectra for an irradiated zircaloy specimen (25°C to the X-ray) is shown in Figure 2. Further data analysis and interpretation of the X-ray Absorption Fine Structure data are needed. This research was conducted primarily by Kun Mo and Jeff Terry, and facilitated in large part by staff in the Nuclear Engineering Division at ANL and Illinois Institute of Technology, including Yinbkin Miao (ANL), Sumit Bhattacharya (ANL), Laura M. Jamison (ANL), Bei Ye (ANL), Walid Mohamed (ANL), Di Yun (ANL), Abdellatif M. Yacout (ANL), Daniel Velázquez (IIT), and Rachel Seibert (IIT).

Future Activities

The experiment is completed. Data processing and results analysis will be finished in FY 2016.

Distributed Partnership at a Glance	
NSUF and Partners	**Facilities and Capabilities**
Illinois Institute of Technology	Materials Research Collaborative Access Team (MRCAT) facility at Argonne National Laboratory's Advanced Photon Source
Collaborators	
Argonne National Laboratory	Kun Mo (principal investigator), Di Yun (collaborator), Walid Mohamed (collaborator)
Illinois Institute of Technology	Jeff Terry (collaborator)