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Effect of Ion Irradiation on the Microstructure and Properties of Chromium Coatings on Zircaloy-4 Substrate

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Abstract : To enhance the safety of Light Water Reactor, accident tolerant fuel (ATF) claddings materials are under development. In the framework of CEA-AREVA-EDF collaborative program on ATF cladding materials, CEA has engaged specific studies on chromium coated zirconium alloys. Especially for Loss-of-Coolant-Accident situations, chromium coated claddings have shown some additional 'coping' time before achieving full embrittlement of the oxidized cladding, when compared to uncoated references – both tested in steam environment up to 1300°C. Nevertheless, the behavior of chromium coatings and the stability of the Zr-Cr interface under neutron irradiation remain unknown. Two main points are addressed: 1. Bulk Cr behavior under irradiation: Due to its BCC crystallographic structure, Cr is prone to Ductile-to-Brittle-Transition at quite high temperature. Irradiation could be responsible for a significant additional DBTT shift towards higher temperatures. 2. Zircaloy/Cr interface behavior under irradiation: Preliminary TEM examinations of un-irradiated samples revealed a singular Zircaloy-4/Cr interface with nanometric intermetallic phase layers. Such particular interfaces highlight questions of how they would behave under irradiation - intermetallic zirconium phases are known to be more or less stable under irradiations. Another concern is a potential enhancement of chromium diffusion into the zirconium-alpha based substrate. The purpose of this study is then to determine the behavior of such coatings after ion irradiations, as a surrogate to neutron irradiation. Ion irradiations were performed at the Jannus-Saclay facility (France). 20 MeV Kr8+ ions at 400°C with a flux of 2.8x1011 ions.cm-2.s-1 were used to irradiate chromium coatings of 1-2 µm thick on Zircaloy-4 sheets substrate. At the interface, the calculated damage is close to 10 dpa (SRIM, Quick Calculation Damage mode). Thin foil samples were prepared with FIB for both as-received and irradiated coated samples. Transmission Electron Microscopy (TEM) and in-situ tensile tests in a Scanning Electron Microscope are being used to characterize the un-irradiated and irradiated materials. High Resolution TEM highlights a great complexity of the interface before irradiation since it is formed of an alternation of intermetallic phases – C14 and C15. The interfaces formed by these intermetallic phases with chromium and zirconium show semi-coherency. Chemical analysis performed before irradiation shows some iron enrichment at the interface. The chromium coating bulk microstructures and properties are also studied before and after irradiation. On-going in-situ tensile tests focus on the capacity of chromium coatings to sustain some plastic deformation when tested up to 350°C. The stability of the Cr/Zr interface is shown after ion irradiation up to 10 dpa. This observation constitutes the first result after irradiation on these new coated claddings materials.

Keywords : accident tolerant fuel, HRTEM, interface, ion-irradiation
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