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Internal Stresses and Structural Evolutions in Zr Alloys during Oxidation at High Temperature and Subsequent Cooling

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Abstract : In some hypothetical accidental situations, such as during a Loss Of Coolant Accident (LOCA) in pressurized water reactors, fuel cladding tubes made of zirconium alloys can be exposed for a few minutes to steam at High Temperature (HT up to 1200°C) before being cooled and then quenched in water. Under LOCA-like conditions, the cladding undergoes a number of metallurgical changes (phase transformations, oxygen diffusion and growth of an oxide layer...) and is consequently submitted to internal stresses whose state evolves during the transient. These stresses can have an effect on the oxide structure and the oxidation kinetics of the material. They evolve during cooling, owing to differences between the thermal expansion coefficients of the various phases and phase transformations of the metal and the oxide. These stresses may result in the failure of the cladding during quenching, once the material is embrittled by oxidation. In order to progress in the evaluation of these internal stresses, X-ray diffraction experiments were performed in-situ under synchrotron radiation during HT oxidation and subsequent cooling on Zircaloy-4 sheet samples. First, structural evolutions, such as phase transformations, have been studied as a function of temperature for both the oxide layer and the metallic substrate. Then, internal stresses generated within the material oxidized at temperatures between 700 and 900°C have been evaluated thanks to the 2θ diffraction peak position shift measured during the in-situ experiments. Electron backscatter diffraction (EBSD) analysis was performed on the samples after cooling in order to characterize their crystallographic texture. Furthermore, macroscopic strains induced by oxidation in the conditions investigated during the in-situ X-ray diffraction experiments were measured in-situ in a dilatometer.

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