The development of self–healing coating on zirconium alloy for light water reactors

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Abstract: For the extension in burnup and enhancement in safety margin within a short term, a new conception of a self-healing coating has been proposed. The selection of the candidate material for the coating, the coating fabrication, and verification of the self-healing property will be conducted sequentially.

Keywords: self-healing, coating, zirconium alloy, fuel cladding,

1. Introduction

During the development of advanced fuel claddings for light water reactors (LWRs), the waterside corrosion of the fuel claddings is generally recognized as one of the main limitations to burnup extension of nuclear fuels, reducing operator refueling downtime. Moreover, accelerated hydrogen uptake in the claddings was observed at high burnups, which is also one of the most important issues limiting high burnup fuel performance from the viewpoint of cladding integrity. Many new Zr-based alloys with higher resistance to uniform corrosion and hydrogen uptake have been created by optimizing the metallurgical composition and/or manufactural process, which, however, was considered that the likelihood of further improvements making a significant difference was limited. Currently, the coating technology has been widely applied in cladding to increase water corrosion and wear resistance due to its outstanding profits. The major benefit is the economics as the resistances can be improved using a coating on existing Zr-based claddings without the necessity to modify the base materials, contributing to the possibility for commercial application in the very near term (5 years or less). Additionally, coated Zr-based alloys are characterized by superior properties i.e. higher melting point, lower hydrogen absorption and generation at elevated temperature, thereby mitigating severe accident consequences. In addition, the self–healing coating, which can repair the damages automatically, or by an external trigger, is much more attractive.

2. Results and conclusion

In this research, two schemes have been proposed to achieve the self-healing property. For the first scheme, the coating was designed to contain two or more kinds of oxides, at least one of which is the healing agent while others are the matrix of the coating to protect the former during the normal operation. The healing agent would be hydrated into hydrous diffusing into the crack and then transferred back to oxide form under irradiation or in loss-of-coolant-accident(LOCA), thereby repairing the cracks. What's more, the healing agent also can be induced from the coolant as the dispersion. On the other hand, the oxidation-induced crack healing was applied in the second scheme. Metal powders, disposed in the stable oxides, would be oxidized into oxides or hydroxides, accompanied by volume expansion and the formation of chemical connection in the crack wall if the metal powders were exposed to the service environment. The preliminary study has been performed to select the candidate materials for the coating according to each crack-healing mechanism. The interconversion between of the oxide powders, Fe_2O_3, ZrO_2, Cr_2O_3, NiO, Al_2O_3, ZnO, SiO_2, and TiO_2, and their corresponding hydroxide powders were investigated by autoclave experiments and γ-ray irradiation. Two SiO_2 pellets with 10wt.%Fe and 10wt.%Cr, respectively, were sintered to estimate the feasibility of the oxidation-induced crack healing. The corresponding coating fabrication also would be studied in the next step.

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