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 combination reactions between MoO_3 and the transition metal ions coming from the corrosion product of the structural materials to form the insoluble molybdate compounds were applied as the self-healing reactions. The chemical stability of the candidate materials in autoclave and furnace were assessed. The rate of the self-healing reactions will be calculated by the investigation of the effects of temperature and exposure time on the formation of molybdate compounds in the autoclave.

Keywords: self-healing, zirconium alloy, fuel cladding, molybdate compound

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. 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. In addition, the self–healing coating, which can repair the damages automatically, or by an external trigger, is much more attractive.

2. Self-healing concept

If the corrosion products of the structural materials, main consisting of the transition metal ions or compounds, could react with MoO_3 to form the insoluble molybdate compounds, these reaction products will deposit and fill the crack in the coating. Based on this idea, a self-healing concept was proposed for the coating on the fuel cladding. The coating was design to consist of two layers: MoO_3 layer and protective layer. The protective layer is to protect the MoO_3 from being dissolved while MoO_3 layer is to react with transition metal ions or compounds if a crack occurs. Therefore, the preliminary research is being conducted to assess the stability of the candidate materials and confirm the combination reactions.

3. Results and conclusion

As the candidate materials for the protective layer, the chemical stability and the compatibility with MoO_3 of Fe_2O_3, Cr_2O_3, Al_2O_3, ZrO_2, SiO_2, and TiO_2 were assessed by the autoclave and furnace experiments. The investigation on the rate of combination reaction between MoO_3 and Fe_2O_3, FeOOH, ZrO_2, $Zr(OH)_4$, NiO and $Ni(OH)_2$, respectively, is being conducted by changing the exposure time and temperature of the autoclave experiments. Preliminary results show MoO_3 could react with Fe_2O_3, FeOOH, ZrO_2, $Zr(OH)_4$, NiO and $Ni(OH)_2$ to form the corresponding molybdates, which indicate that this self-healing mechanism is promising to be applied for the coating on the fuel cladding.

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