Evaluation of irradiation induced hardness and microstructure of Zry-2 under applied stress (2)

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Abstract: To understand the degradation behavior of Zircaloy-2 under neutron irradiation, it is helpful to elucidate the mechanisms of dislocation loop formation and precipitate dissolution under the service environment. The microstructure and energy-dispersive spectroscopy analysis of irradiated Zircaloy-2 with and without applied stress were studied. The dissolution of Fe-rich precipitates was detected. However, the effect of stress and temperature on the dissolution rate of Fe-rich precipitates was minor.

Keywords: zirconium alloy, applied stress, dislocation loop, ion irradiation, energy-dispersive spectroscopy

1. Introduction

Zircaloy-2 is used as the fuel cladding tube in boiled water reactors. The previous experimental results showed the formation and evolution of a-loops during the initial stage of irradiation, which leads to significant radiation-induced hardening. As the irradiation dose rises to a higher level, hydrogen content increases dramatically, and hydrides are formed, along with the appearance of c-loops. To understand the behavior of the material, EDS analysis and observation of microstructural changes were conducted on samples after different ion irradiation conditions.

2. Experimental

Zircaloy-2 was used with an alloy composition of 1.38 Sn, 0.15 Fe, 0.09 Cr, and 0.05 Ni in wt.%. Specimens were annealed at 630 ˚C for 2 h, followed by air cooling, and then irradiated with 3.2 MeV Ni^{3+} ion at 300˚C and 400 ˚C up to 35dpa. During the irradiation, applied stress was induced nearly parallel to the c plane using a small tensile sample stage. Thin foils for TEM were prepared with FIB to observe the microstructure after the irradiation. The samples were milling by a low-energy Ar ion at 1.5-3.0kV to minimize the damage of FIB. The dissolution of precipitates was analyzed using a spherical aberration (Cs)-corrected STEM combined with EDS.

3. Conclusion

TEM observation shows that c-loops start to nucleate only above a threshold dose of 20 dpa at 400 ˚C. STEM observation shows that the hydrides decreased in density and size in the irradiated region compared to the unirradiated region. The pre-existing hydrides are observed almost parallel to the stress direction. Fe atom dissolved of Zr $(Fe, Cr)_2$ precipitates by the irradiation was detected with EDS (shown by Fig.1). But $Zr_2(Fe, Ni)$ precipitates were stable under the same irradiation condition.

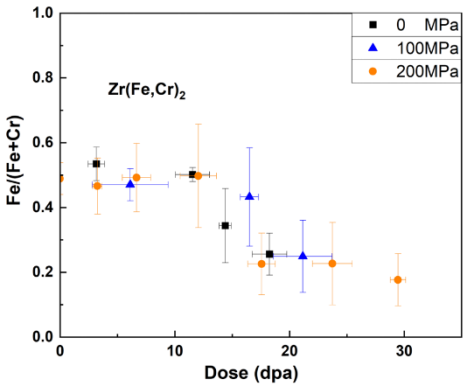

Fig 1. Effect of the dose and stress on elemental content ratios of $Zr(Fe,Cr)_2$ precipitates at 300 ˚C.