Effects of 140 MeV C^{4+} irradiation on the microstructure and mechanical properties in Zr-1.8Nb alloys

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Abstract

This study was performed to understand the effects of high energy ion irradiation (140 MeV C^{4+}) on the microstructure and mechanical properties in Zr-1.8Nb alloys. Obvious irradiation strengthening was observed via tensile tests and irradiation defects were characterized via TEM observation. Based on these results, the mechanism of irradiation induced strengthening was further discussed.

Keywords: fuel cladding material, Zr-Nb alloy, irradiation, strengthening

1. Introduction

The specification required for the fuel cladding tubes applied to high fuel burn-ups and extended fuel cycle operations is excellent integrity in corrosion resistance, less absorption of hydrogen, reasonable mechanical strength, and irradiation resistance under in-reactor environment. Zr-Nb alloys have been developed to exhibit a superior performance to the conventional Zircaloy-4 in corrosion resistance and less absorption of hydrogen. Whereas, there is still some lack of knowledge about their irradiation resistance, as irradiation induced hardening is recognized as one of the main performance degradations in Zr-based fuel cladding tubes. The purpose of this study is therefore to investigate the irradiation effects on the microstructural and mechanical changes in Zr-Nb alloys.

2. Experimental

The material utilized in the present study is Zr-1.8Nb (wt.%) alloy fuel cladding tube, from which the SSJ-type tensile specimens were prepared. These tensile specimens were subjected to 140-MeV C^{4+} irradiation at 573 K in Cyclotron and Radioisotope Center, Tohoku University. An energy degrader was applied to introduce the spatially-uniform irradiation damage. After irradiation, tensile test was conducted to evaluate their mechanical properties. TEM were used to characterized the irradiation induced defects.

3. Results and Conclusion

Tensile tests show that the yield strength increased quickly especially at low doses below 1 dpa, then gradually saturated at a center value. The yield strength at 5.3 dpa was ~150 MPa greater than that of the un-irradiated specimen. On the other hand, the elongation to fracture at 5.3 dpa was 15% less than of the un-irradiated one, indicating the obvious strengthening and embrittlement induced by irradiation. From the TEM observation in 3.1 dpa specimen, <a>-type loops with the averaged size of 7.2 nm was analyzed to possess a number density of 1.2 x $10^{21}/m^3$; for <c>-type loops, the average size and number density of <c>-type loops were determined as 15.4 nm and 6.5 x $10^{20}/m^3$, respectively. According to the dispersed barrier theory, the mechanism of irradiation induced strengthening was quantitatively discussed. The calculation demonstrates that the irradiation induced dislocation loops were approximately responsible for the strength increment in the irradiated specimen.

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