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Effect of alloying elements on the tensile properties of hydrided zirconium alloys

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1. Introduction

Recent popular trends in pressurized water reactor (PWR) fuel management are to extend the cycle length and to employ the high burnup core designs for economic efficiency. So fuel cladding which have integrity at the high burnup condition is developed

In fuel cladding, the charged hydrogen amount will be increased at the high burnup condition (high temperature and long cycle life). And high hydrogen concentration cause hydride embrittlemen in fuel cladding. Therefore, the hydride embrittlement of cladding is one of the important factors to secure the nuclear fuel integrity.

In this study, we performed the tensile test of various zirconium alloys in order to investigate the effect of alloying elements on the tensile properties of hydrided zirconium alloys.

2. Materials

The used materials in this study were pure Zr, Zr-1.0Nb, Zr-2.0Nb, Zr-1.0Sn and Zr-1.0Nb-1.0Sn.

Figure 1 showed manufacturing process. Materials were manufactured by hot rolling and cold-rolling after beta treatment and to have partially recrystallized microstructure, manufactured materials were heat treated at 510 °C for 2.5 hour.

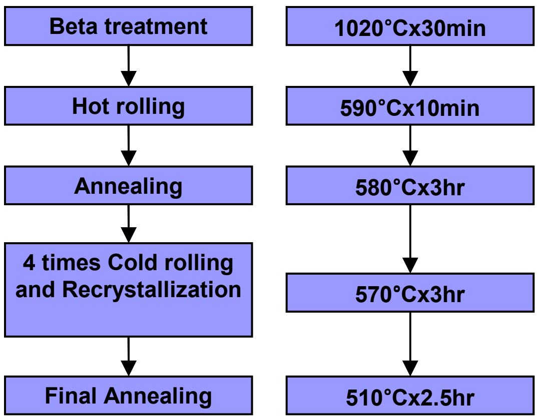


Figure 1. The manufacturing process of zirconium alloys

3. Experimental procedure

The samples were charged with hydrogen using high temperature cathodic hydrogen charging method [1]. Hydrogen was charged with current density of 0.2 A/cm^2 at 80 °C in 1N H_2SO_4 solution and hydrogen concentration (C_H) was controlled by charging time.

Sheet type tensile test specimen was cut from samples such that such that the tensile axis was in the transverse direction of the plate. It have gage length of 12.5 mm and thickness of 0.88 mm. Tensile test was performed at between room temperature and 340°C, at a strain rate of 10^{-4} s^{-1}. C_H in each specimen was measured after tensile test.

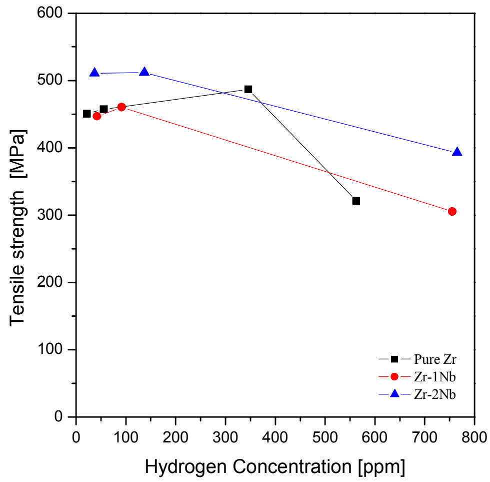
4. Result and Discussion

4.1. Tensile property of zirconium alloys

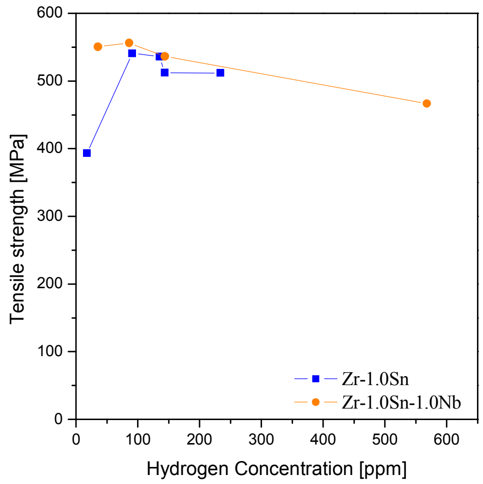
Tensile test of hydrided zirconium alloys was performed. Figure 2 shows tensile properties of hydrogen charged specimen as a function of C_H.

Tensile properties of pure Zr increased with C_H below 400 ppm of C_H. however, the tensile properties were reduced sharply at about 550 ppm. When there is only niobium in zirconium alloy, tensile properties decreased with increasing of C_H as shown in figure. 2(a)

In case of Zr-1.0Sn, tensile properties of hydrogen charged specimen were higher than as-received specimen. However, Zr-1.0Sn-1.0Nb showed the reduction of tensile properties with increasing of C_H. This tendency of Zr-1.0Sn-1.0Nb was similar to Zr-Nb alloys.



(a) Zr-Nb alloy



(b) Addition of 1%Sn

Figure 1. Tensile strength of hydrogen charged Zr alloys as a function of hydrogen concentration

4.2. Hydride morphology

To investigate the effects of alloying elements on hydride embrittlement of zirconium alloys, hydride morphology was observed by optical microscopy.

Figure 3 shows the hydride morphology of zirconium alloys which have similar CH. In pure Zr, length of hydride was short and its orientation was random because of recrystalized grain. The hydride of all the alloys was precipitated along the tangential direction. In case of zirconium alloy which have no Sn, the hydrides was thicker than Sn added zirconium alloy.

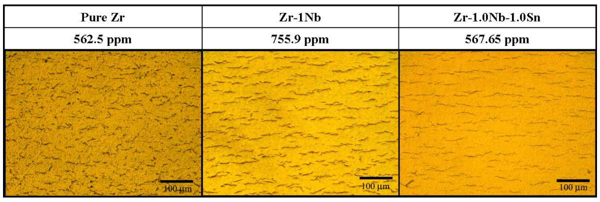


Figure 2 the hydride morphology of zirconium alloys

4.3 SEM observation: Fracture surface

After tensile test, fracture surfaces of hydrided Zr alloy were observed by SEM as shown in Figure 4.

The fracture surface of pure Zr showed cleavage surface. In case of the other specimens except for pure Zr, the fissures appeared at fracture surface. The fissures were parallel with hydride orientation and the cleavage fracture was observed around the fissures.

In case of Zr alloys with addition of Sn, the length of the fissures was much longer compared with Sn-free Zr alloys.

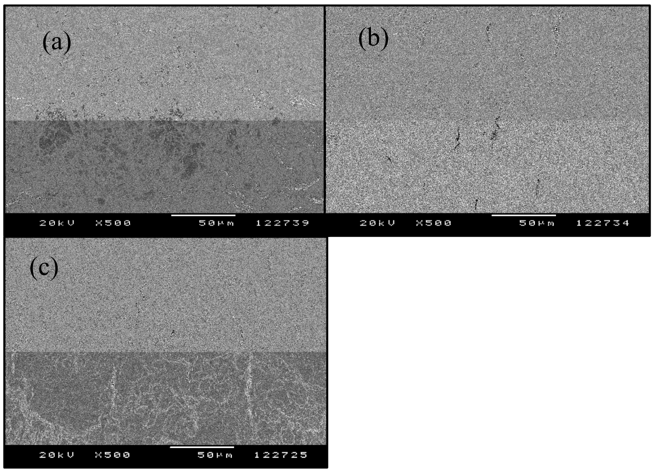


Figure 4. The fracture surface of hydrided Zr alloys of (a) pure Zr, (b) Zr-1Nb and (c) Zr-1.0Sn

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