Effects of a Heat-treatment on the Mechanical Properties and Corrosion Behavior of Zr-Nb Alloy

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1. Introduction

The metallic fuels, such as U-Zr alloy, have drawn wide attention as the nuclear fuel for fast reactors [1-2]. As one of the fabrication processes of metallic fuels, the billets composed of the metallic fuel and cladding materials can be extruded, and then heat-treated [3]. If Zr-Nb alloy is considered as the cladding material for the metallic fuels, the heat-treatment conditions become a subject of concern [4]. In this study, the effects of a heat-treatment on the mechanical properties and corrosion behavior of extruded Zr-Nb alloy were evaluated.

2. Methods and Results

2.1. Experimental procedure

The Zr-Nb alloys were extruded at 700℃ and heat-treated at 480 and 580℃ for 3, 8, 16, 32 hours. The tensile tests were performed at room temperature and 400℃. The corrosion behavior was observed in an ammonia aqueous solution at 360℃ for 100 days by using a static autoclave.

2.2. Microstructure

Fig. 1 shows the TEM images of the Zr-Nb alloys. The as-received Zr-Nb alloy showed recrystalized structure. Most of the precipitates were identified to be a β-enriched phase with a Nb-concentration range of 20~70at.%. The precipitates range in size was 10~50nm, and the precipitates showed a round shape (Fig. 1 a). In the as-extruded Zr-Nb alloys, there were many dislocations around the grain boundary formed during plastic deformation by an extrusion as shown in the Fig.1 b. In the grain boundaries, two kinds of Nb-containing precipitates, β-Zr and β-enriched phases were observed. Most of them were β-Zr with a Nb-concentration of less than 20at. %. The heat-treatments of the Zr-Nb alloys at 480 and 580℃ produced a grain growth along with the reaction of a phase transformation from β-Zr to α-Zr and β-enriched, resulting in an increase of the Nb-concentration in the precipitates to over 55at. %(Fig.1 c~f).

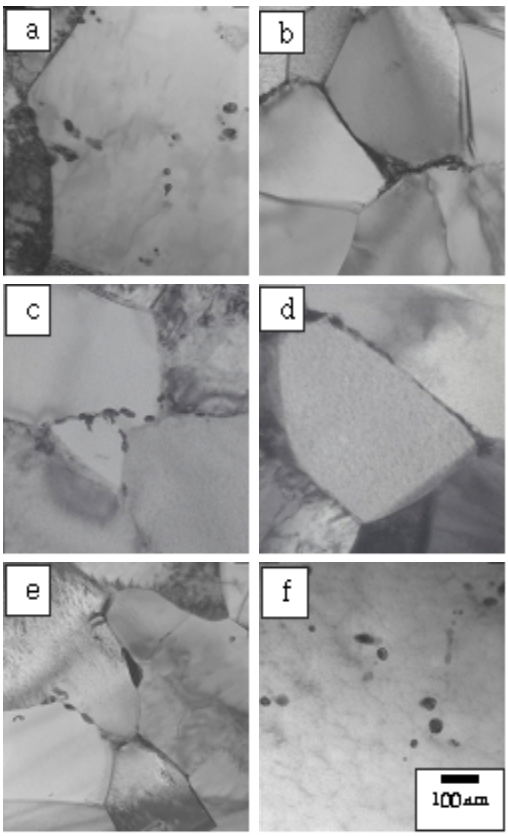

Fig. 1 TEM images of the Zr-Nb alloys;
(a) As-received, (b) As-extruded, (c) 480℃/8hrs,
(d) 480℃/32hrs, (e) 580℃/8hrs, (f) 580℃/32hrs.

Fig. 2 shows the grain sizes of as-extruded and heat-treated Zr-Nb alloys as a function of time. The grain size increased with an increase in heat-treatment time at 580℃ while it remained almost constant during a heat-treatment at 480℃.

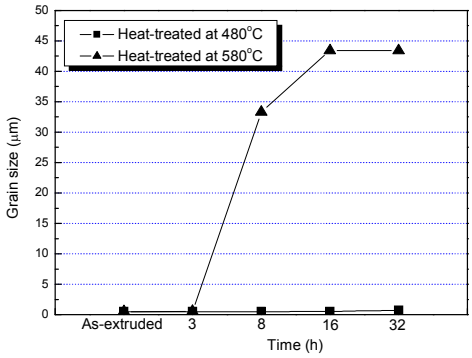

Fig. 2 Grain size of Zr-Nb alloy.

2.3. Mechanical properties

Fig. 3 shows the results of the tensile tests of the Zr-Nb alloys at room temperature and 400℃. The yield strengths were reduced by a heat-treatment, and decreased with an increase in heat-treatment time. At the room temperature, the yield strengths after a heat-treatment at 580℃ were lower than those heat-treated at 480℃. It could be attributed to the grain growth at 580℃. On the other hand, at the 400℃, the yield strengths of heat-treated at 480 and 580℃ were similar to each other.

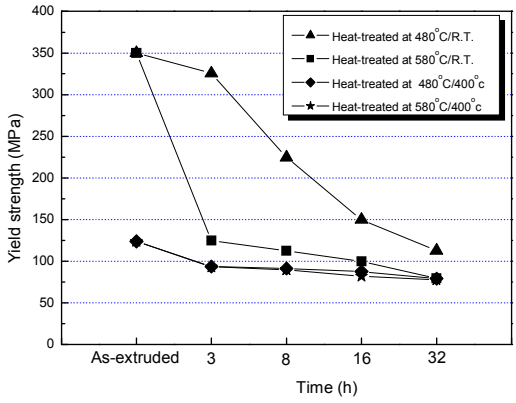

Fig. 3 Yield strengths of Zr-1Nb at R.T. and 400℃.

2.4. Corrosion behavior

Fig. 4 shows the final weight gain of the as-extruded and heat-treated Zr-Nb alloys after corrosion in an ammonia aqueous solution at 360℃ for 100 days. The final weight gain of the as-extruded specimen was observed to be 60 mg/dm^2 whereas that of the heat-treated Zr-Nb alloys was under 55 mg/dm^2. The corrosion resistance of the extruded specimen was enhanced by a heat-treatment. The specimen heat-treated at 480℃ has a better corrosion resistance characteristic than those of heat-treated at 580℃. The corrosion resistance was enhanced with an increasing heat-treatment time. It could be mainly attributed to a change in the composition, size and phase transformation of the precipitates (β-Zr → α-Zr + enriched-β) by a heat-treatment.

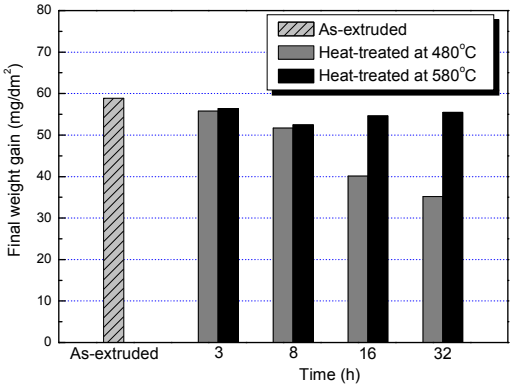

Fig. 4 Effect of heat-treatment on the corrosion of Zr-1Nb alloys at 360℃ in an ammonia aqueous solution.

3. Conclusion

With a heat-treatment, the grain size was increased and the yield strengths decreased. The corrosion resistance was enhanced after a heat-treatment. It could be ascribed to a microstructural change; the grain growth and phase transformation of the precipitates from β-Zr to α-Zr and enriched-β by a heat-treatment. It is thus concluded that the longer heat-treatment at 480℃ is performed, the better corrosion resistance is provided. But it makes the Zr-Nb alloy decrease in the tensile strength.

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