Phase Transformations in Zr-Nb-Fe-Sn System Alloys

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Introduction

The SPPs are formed during deformation and anneals; composition is determined by β-Zr after hot rolling in (α+β) region and its decomposition. The studies of Zr alloys with Fe and Nb has led to understanding of the role played by Fe (fastest diffusing and strengthening element)- basic transformations and their properties.

Objectives - to acquire data on structure-phase state and phase transformations in the Zr-Nb-Fe-Sn alloys to study dependence of phase dissolution and precipitation on compositions of the alloys and temperature.

Materials and Procedures

Recrystallized tubes from standard and modified alloys based on E110 and E635 - different phase compositions. Samples - quenching from 600-940°C (10°C/sec) to determine the phase transformation temperature and the regions of β-Nb, β-Zr, (Zr,Nb),Fe, and (Zr, Nb),Fe. Using TEM, SEM the w→α→β→α and SPPs transformation temperature have been determined. The ratio R(Fe/Fe+Nb-0.3) - a relative concentration of elements in SPPs.

Results

Zr-(1-2.5) % Nb alloys (R<0.05) - single SPP type - β-Nb (Zr-90%Nb), size 40 nm, BCC, а0=0.32 nm.
Zr-1%Fe alloys with Fe (R=0.1-0.4) - β-Nb and Laves phase Zr(Nb,Fe)2 (size 100 nm, HCP, а0=0.54 nm, c0=0.87nm).
E635 alloy with Fe (R=0.2-0.3) - extra Nb (deficient iron) - β-Zr, (Zr,Nb)2Fe.
Zr-1%Fe alloys with Fe (R=0.1-0.4) - β-Zr, Zr(Nb,Fe)2 and (Zr,Nb)2Fe. Using TEM, SEM the SPPs have been formed during deformation and anneals; composition is determined by β-Zr after hot rolling in (α+β) region.

Identification of the β-Nb and Laves phase SPP in the Zr-(1-2.5)%Fe alloy by EDS line scanning β-Nb (Zr,Nb)2Fe β-Nb β-Nb.

Volume fraction of the β-Zr phase vs heating temperature prior to the quenching of alloys Zr-1Nb (O), Zr-2.5Nb (□), E635 (△).

The quenching of alloys having the relative high iron content results in an incomplete α→β(α') martensitic transformation and retention of α-grains.

In Zr-1%Fe alloys (R=0.1-0.4) - β-Zr and (Zr,Nb),Fe begin to form or grow at T=640-660°C after dissolution of the Laves phase and β-Nb.

A high Fe content in the alloy increases the volume fraction of (Zr,Nb)2Fe - Nb content in matrix decreases to 0-0.2 %, that is why even if Laves phase particles are dissolved no β-Zr phase is formed but the quantity of the T-phase increases.

The process of the dissolution of the Laves phase Zr(Nb,Fe)2 and formation of the β-Zr and (Zr,Nb),Fe (T-phase) precipitates (BF, DF).
The influence of the rate of heating prior to quenching (0.1 - 100 °C/sec) and the oxygen content (0.04% - 0.10%) on the volume fraction of β-Zr in E635 alloy. An increase in the heating rate lead to the delaying of the Laves phase dissolution and β-Zr formation: phase transformation temperature rise (α+β→β′(α′) transformation-to 910-940°C).

Slow cooling (annealing) leads to β-Zr phase enriched with Nb and Fe.

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The influence of the rate of heating (0.1-100 °C/sec) prior to quenching on the β-Zr volume fraction in the E635 alloy vs temperature.

The influence of the oxygen content (0.04% - 0.10%) on the β-Zr volume fraction in the E635 alloy vs temperature.

The formation of β-Zr at 640-680°C in the alloys with R>0.4 delays because of the existence and growth of the (Zr,Nb)2Fe phase.

As the annealing/quenching temperature rises above 600-660°C, the (Zr,Nb)2Fe begin to dissolve at T ≥ 640 to 680°C in the alloys with R>0.4 delays because of the existence and growth of the (Zr,Nb)2Fe phase.

Conclusion

Temperature of the α→α+β transformation of Zr-1Nb and Zr-2.5Nb alloys is 600-610°C. In Zr-1Nb alloy with 0.1 %Fe β-Zr phase begin to form at 640°C and with 0.3 %Fe - at 660°C.

As the annealing/quenching temperature rises above the (α/α+β)-transformation, the volume fraction of Zr(Nb,Fe)2 and β-Nb particles decreases, and the β-Zr and (Zr,Nb)2Fe are formed.

β-Nb and Laves phase SPPs begin to dissolve at T ≥ 640-660°C, completely dissolved at T ≥ 750 °C, the (Zr,Nb)2Fe phase – at 800°C.

The formation of β-Zr at 640-680°C in the alloys with R>0.4 delays because of the existence and growth of the (Zr,Nb)2Fe phase.

An increase in O content and the heating rate prior to quenching in the E635 lead to the phase transformation temperature rise.

The formation and dissolution of metastable phases (intermetallics, β-Zr) are defined by different diffusion mobility of Nb and Fe.