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Thermal Conductivity for U-Zr-Ce Metallic Fuels

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1. Introduction

In Korea, a sodium-cooled fast reactor (SFR) has been adopted. U-Zr and U-Pu-Zr metallic fuel are used in the SFR. KAERI has designed metallic fuels and evaluated their performance in a SFR [1]. Recently, the fuel fabrication technology has also started to be developed.

The spent fuel is transformed into new fuel materials through a pyroprocess. An electrorefining process produces U, Pu, and minor actinides (MA) along with a carryover of rare earth (RE) elements. Thermophysical properties of metallic fuels for a SFR could be varied by an influence of the RE. The thermal conductivity is one of the most important parameters dominating the in-reactor performance of these fuels.

In this work, we have investigated the variation of the thermal conductivity for U-Zr fuel containing Ce. By examining the microstructural characteristics of U-Zr-Ce, the thermal conductivity of the alloy was estimated by using macroscopic mixture models. A measurement of the thermal properties of U-Zr-Ce was also performed to compare the evaluated results with the experimental data.

2. Microstructure of U-Zr-Ce alloy

Fig. 1 shows the microstructure of the U-10Zr-6Ce alloy taken in a backscatter image with an SEM. Large stringer-like precipitates with a length of 50-100 μm were distributed all over the specimen. They are found to be the Zr-rich phase which is thought to be stabilized by ingress of oxygen. Meanwhile the Ce-rich precipitates are seen with a higher magnification. They are formed as very small round-shape particles. The average Ce content in the specimen is less than 3 wt%. It seems that a fraction of Ce was not dissolved due to the oxidation of Ce. The cerium concentration in the matrix is likely to be less than 0.5 at%. The small particles were confirmed as Ce-rich phases by EDX analyses.

3. Estimation for U-Zr-Ce Alloys

The effect of the Ce precipitates on the effective thermal conductivity is evaluated based on models for the thermal conductivity bounds for heterogeneous materials [2]. The upper and lower bounds are calculated by means of the series and parallel models, respectively. Narrower bounds are provided with two forms of the Maxwell models. Bruggeman's asymmetric theory and symmetric theory are also applied.

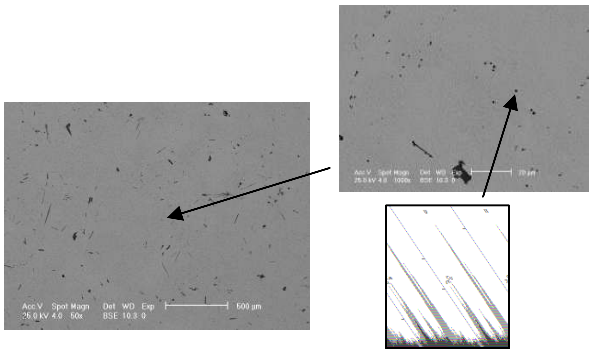

Figure 1. Microstructure of U-Zr-Ce alloy in a backscatter electron SEM, and the Ce-rich precipitates in the U-Zr matrix under a higher magnification.

Fig. 2 shows the estimated thermal conductivities as a function of temperature for U-Zr alloys containing Ce from 2, 4, and 6 wt%. The addition of Ce up to 6 wt% is estimated to lower the thermal conductivity of the U-Zr alloy by less than 5%. This small change is attributable to the low volume fraction of the Ce phase, and the relatively high thermal conductivity of Ce. Thermal conductivity of the U-Zr alloy is reduced almost linearly with an increasing Ce content at all temperatures.

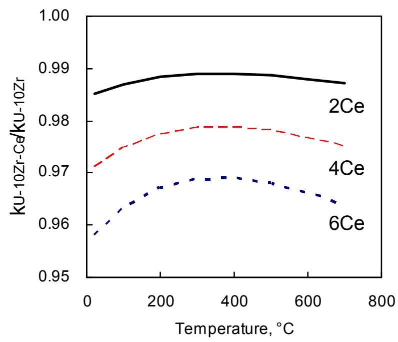

Figure 2. Effect of the Ce content on the thermal conductivity of U-10Zr.

4. Measurement of the thermal properties

Thermal properties of the U-Zr-Ce alloy were measured. Specimens were prepared by melting Ce together with U and Zr. Thermal diffusivity was measured by a laser flash method on a disc specimen with dimensions of 8~12 mmϕ × 1 mm. Density was determined by an immersion technique. Kopp-Neumann's law was used to estimate the specific heat of the specimen.

The density of the Ce-containing U-Zr alloy decreased monotonically with an increasing elevation in the length of the specimen. The density of the specimen for the diffusivity measurement was close to that of U-10Zr alloy. It was also found that the diffusivity of the U-Zr-Ce specimen was reduced. This means that the Zr content is less than 10 wt% to account for the density increase, and the diffusivity decrease due to the Ce addition, which was confirmed by EDX analyses.

The measured thermal conductivity of the U-Zr-Ce alloy is plotted in Fig. 3. Thermal conductivity was calculated by the product of the thermal diffusivity, density, and specific heat. The contribution of the density change to the thermal conductivity is more significant than those of the other. Thermal conductivity of U-Zr lies in between the reported ones [3,4]. It is slightly decreased by adding Ce of which the content is also below the target value as stated previously. Therefore, the effect of Ce on the thermal conductivity of U-Zr alloy is well described by the present heterogeneous mixture models.

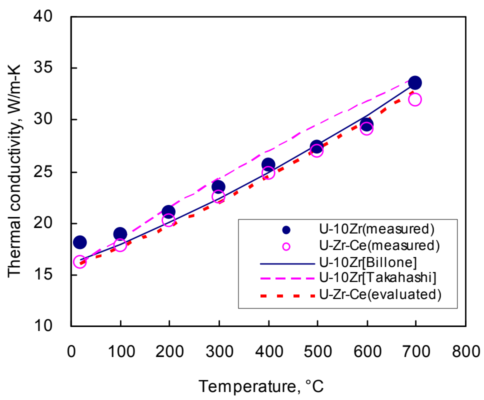

Figure 3. Comparison of the thermal conductivities for U-Zr-Ce alloys.

5. Concluding Remarks

Thermal conductivity of Ce-bearing U-Zr fuels was investigated. Under an assumption of a Ce-rich phase forming a macroscopic mixture with the matrix, the thermal conductivity was estimated for U-Zr-Ce alloy. It was evaluated that the thermal conductivity of the U-Zr fuels would be lowered by less than 5 % due to the addition of Ce. The measurement of the thermal properties of U-Zr-Ce supported the present estimation.

Acknowledgements

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