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Interaction of U-10wt.%Zr Melt with Y_2O_3-Coated Graphite Crucible during Casting

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1. Introduction

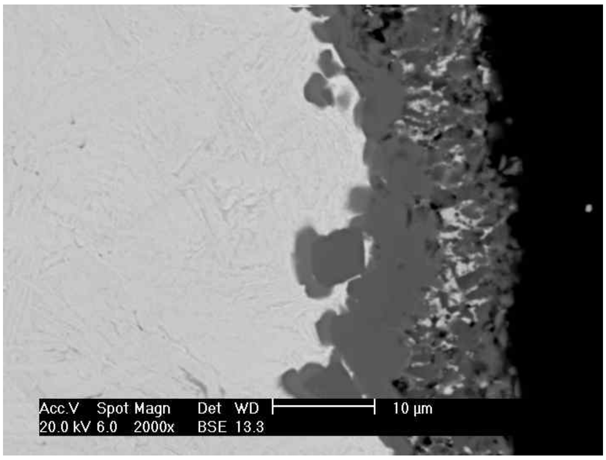
Metallic fuels have been developed for the sodium-cooled fast reactor. Metallic fuels have many advantages such as a simple fabrication procedure, high thermal conductivity and excellent compatibility with sodium coolant when compared with oxide and carbide fuels [1-3]. In the fabrication process of U-Zr metallic fuel, a graphite crucible is commonly used for melting and casting. In general, Y_2O_3 is coated on the inner surface of the graphite crucible to prevent the contamination of molten U-Zr alloy. It is even more important to prevent the interaction between melt and crucible during the casting process of recycled fuel.

In this study, to evaluate the compatibility of Y_2O_3 coating, we investigate the interaction between U-Zr molten alloy and Y_2O_3-coated graphite crucible. Microstructure in the surface region of the melt-residue of U-Zr alloy was characterized using Scanning electron microscopy (SEM) equipped with Energy-dispersive X-ray spectroscopy (EDS). The surface of the melt residue was examined to identify the phases using X-ray diffractometer (XRD)

2. Methods and Results

A depleted uranium metal and zirconium sponges were prepared for the melting of U-Zr alloy. U-10wt.%Zr alloy was melted using injection casting apparatus which is an induction furnace. The Y_2O_3 plasma-spray coating with thickness of 150 μm was carried out inner graphite crucible. Raw materials consisting of zirconium sponge and uranium metal were put in the Y_2O_3 coated graphite crucible in the order named. The materials were superheated at 1,600°C and cooled in the furnace after casting. The surfaces of the U-10wt.%Zr alloy on the side and bottom regions were investigated to clarify the contamination characteristics of the molten U-10wt.%Zr alloy using SEM-EDS and XRD.

The cross-section of the surface region of U-10wt.%Zr alloy is shown in Fig. 1. As the results indicate, on the whole, the contaminants were observed on the surface. In contrast, the dark layer mostly consisted of C, O, Y and Zr and bright matrix consisted of U and Zr. The thickness of reaction layer was about 10 μm at side region and 5 μm at bottom region. The side region had the thickest reaction layer among whole surface due to the heat source position. The thickness of the contamination layer was assumed as the depth penetrated into the U-Zr matrix from the graphite crucible depending on the volume of the zirconium, melting temperature and time.



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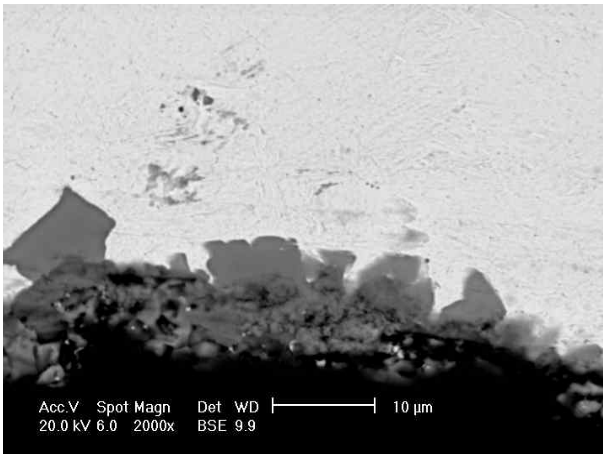

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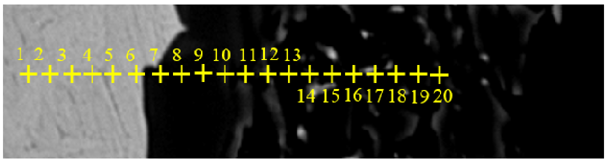
Fig. 1. Scanning electron micrographs of U-10wt.%Zr alloy fabricated using Y_2O_3 coated graphite crucible; (a) side region, (b) bottom region



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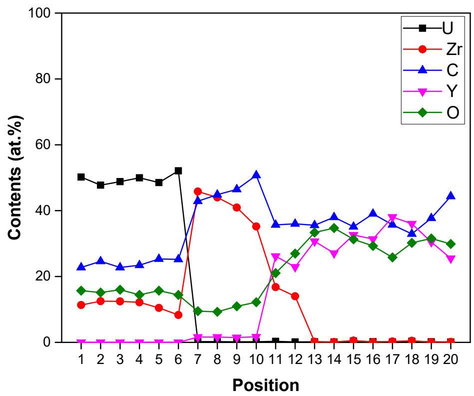

(b)

Fig. 2. Chemical compositions of the contamination layer of U-10wt.%Zr melt residue measured using EDS; (a) scanning electron micrograph, (b) C, O, Y, Zr and U contents of the surface in melt residue

Fig. 2 shows the chemical composition of the contaminants for the surface of the U-10wt.%Zr alloy obtained using EDS analysis. The result indicates the inside carbonization of Zr in U-10wt.%Zr alloy from the graphite crucible during melting at high temperature. The C, O, Y and Zr contents of the contamination layer varied and the contamination layer had a tendency to be inversely proportional between Zr and C contents.

X-ray diffraction patterns of the surface of melt residue were examined to clarify the contaminants. As a result of the XRD analysis, α-U, ZrC and Y_2O_3 were detected as shown in Fig. 3. In comparison with SEM-EDS results, the matrix consists of α-U while the contamination layer consists of ZrC and Y_2O_3.

In this research, although Y_2O_3 has many advantages such as excellent thermal and chemical stability, high melting point and extremely negative Gibbs formation energy as a reaction barrier coating material, the contamination occurred from graphite. The cracks of coating layer and interaction between graphite crucible and Y_2O_3 are likely major causes of this contaminations. In a previous research, chemical interaction occurred between graphite and Y_2O_3 over 1,400°C [4]. So, buffer layer coating or new coating materials development is necessary to prevent the contamination from graphite.

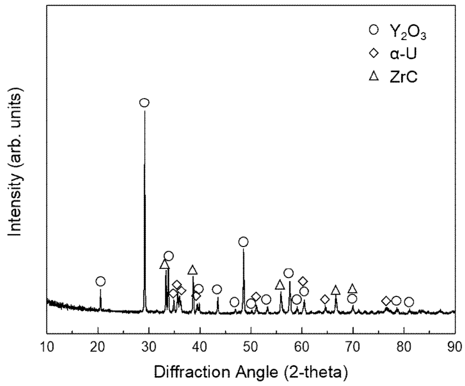

Fig. 3. X-ray diffraction patterns of the surface of U-10wt.%Zr melt residue

3. Conclusions

In this study, U-10wt.%Zr alloy was fabricated to examine the reactivity between uranium, zirconium and Y_2O_3 coated graphite crucible. The contamination layer was found to form on the surface of melt residue. Zr was commonly reacted with C and Y_2O_3 and it was adhered to surface of melt residue. As a result, the compatibility of Y_2O_3 coating on the graphite needs to be further improved for melting the U-Zr alloy.

REFERENCES

[1] D. E. Burkes, R. S. Fielding, D. L. Porter, Metallic fast reactor fuel fabrication for the global nuclear energy partnership, J. Nucl Mater. 392 (2009) 158.
[2] G. L Hofman, Metallic fuels, Mater. Sci. & Tech. (2015) 1.
[3] T. Ogata, Metal fuel, Comprehensive Nuclear Materials (2012) 1.
[4] J. W. Koger, C. E. Holcombe, J. G. Banker, Coatings on graphite crucibles used in melting uranium, Thin Solid Films 39 (1976) 297-303.