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Fabrication of U-Zr-RE Fuel Slugs for SFR

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1. Introduction

Metallic fuels, such as the U-Pu-Zr alloys, have been considered as a nuclear fuel for a sodium-cooled fast reactor (SFR) related to the closed fuel cycle for managing minor actinides and reducing the amount of highly radioactive spent nuclear fuels since the 1980s. The reference fuel for the Korean sodium-cooled fast reactor (SFR) being developed by the Korean Atomic Energy Research Institute (KAERI) is a metallic alloy. The fabrication process for SFR fuel is composed of (1) fuel slug casting, (2) loading and fabrication of the fuel rods, and (3) fabrication of the final fuel assemblies. To increase the productivity and efficiency of the fuel fabrication process waste streams must be minimized and fuel losses quantified and reduced to lower levels. In this study, U-Zr alloy system fuel slugs were fabricated by a gravity casting method. After casting a considerable number of fuel slugs in the casting furnaces, the fuel loss in the melting chamber, the crucible, and the molds have been evaluated quantitatively. After loss evaluation, the casting soundness and the chemical and microstructural characteristics of the cast fuel slugs were identified and analyzed.

2. Experimental Procedure

The elemental lumps of depleted uranium (DU), zirconium, and RE(Nd 53%, Ce 25%, Pr 16%, La 6%) was used to fabricate U-10wt.%Zr-5wt.%RE alloy fuel slugs. Graphite crucibles coated with Y_2O_3 and quartz molds coated with ZrO_2 was used. The weights of the melting & casting parts and the fuel material before and after melting were measured using an electronic balance. After fabricating a considerable amount of fuel slugs in the casting furnace, the fuel loss in the crucible assembly and the mold assembly have been evaluated quantitatively. After evaluation, the soundness, chemical and microstructural characteristics of the cast fuel slugs were also identified and analyzed. As-cast fuel slugs were inspected by gamma-ray radiography. A scanning electron microscope (SEM) was used to study the microstructure of as-cast fuel slugs. Chemical compositions of as-cast fuel slugs were measured by energy-dispersive spectroscopy (EDS).

3. Results and Discussion

The typical material balance in the crucible assembly and the mold assembly after melting and casting of fuel slugs are shown in Table 1. A considerable amount of dross and melt residue remained in the crucible after melting and casting; however, most charged materials were recovered after melting and casting of the fuel slugs. The mass fraction of fuel loss relative to the charge amount after fabrication of U-10wt.%Zr-5wt.%RE fuel slugs was low, about 0.3% respectively. It is thought that a lower fuel loss in case of casting of U-10wt.%Zr-5wt.%RE fuel slugs was related to melting of the U-Zr-RE alloy in a densely plasma-sprayed graphite crucible with high-temperature ceramic materials, compared with melting & casting of fuel alloy in a sparsely slurry-sprayed graphite crucible with high-temperature ceramic materials.

Table 1. Typical material balance after casting of U-10wt.% Zr-5RE fuel slugs.

	Melting/casting part	Weight (g)	Fraction (%)
Before casting	Crucible	2,461.3	100
After casting	Crucible assembly	122.4	5.0
After casting	Mold assembly	2331.7	92.7
Fuel loss		7.2	0.3

The sound U-10wt.%Zr-5wt.%RE fuel slugs could be fabricated by adjusting the melting process parameters. The surrogate U-Zr-RE fuel slugs were melted and cast with the gravity casting furnace under Ar atmosphere, as shown in Fig. 1. Visual inspection of the as-cast metallic fuels was performed to check the soundness of the metallic fuel pin. The surface roughness was coarse, and a few defects were observed on the fuel surface, but the as-cast fuels were generally sound. The metal fuel slug had the diameter of 5mm and the length of about 300mm. The alloy composition and the density of the metal fuel slugs were shown in Table 2.

Fig. 1. Typical U-10%Zr-5RE fuel slugs, fabricated with the gravity casting furnace

Table 2. Typical alloy composition and the density of U-10wt.% Zr-5RE fuel slugs.

Element	U (wt.%)	Zr (wt.%)	RE (wt.%)	C (ppm)	O (ppm)	N (ppm)
	84.1	12.2	2.9	760	560	40

Density(g/cm^3)	Top	Middle	Bottom
	14.5	14.7	14.7

The gamma radiography of as-cast metallic fuels was also performed to detect internal defects such as cracks and pores of the metallic fuel pins. The gamma radiography results for U-10wt.%Zr-RE fuel slugs are shown in Fig. 2. Internal pores were detected in the upper part region of the fuel slugs. However, the internal integrity of as-cast metallic fuel pins is generally believed to be satisfactory.

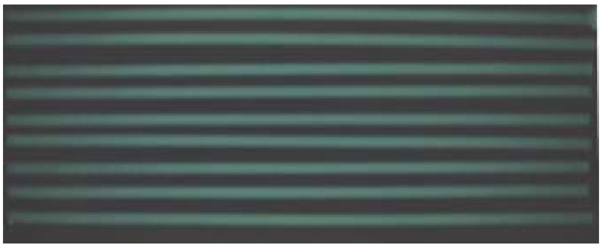

Fig. 2. Gamma radiography for internal defects detection of as-cast fuel slugs; U-10wt.%Zr-5RE.

Scanning electron micrographs of the fuel slugs were shown in Fig. 3. Fuel slugs had lots of dispersion particles including RE component, distributed in the homogeneous and fine state. The microstructure showed a laminar structure which is beneficial to a fast fission gas release with fiber morphology which was arranged alternatively with uranium and Zr-rich phase. Matrix of alloy was not modified by the addition of RE element. The refinement in the laminar structure of the fuel could greatly increase the release rate of gas bubble, due to well inter-connected path of fission gas bubble with metal fuel for SFR. In addition, it is expected to contribute in preventing the swelling of metallic fuel caused by a bubble-driven swelling mechanism. Some defects such as pores and cavities formed during cast were also observed.

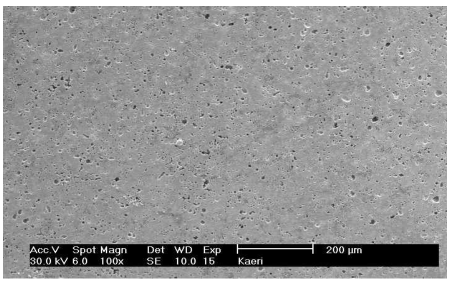

Fig. 3. Scanning electron micrographs of U-10wt.%Zr-5RE fuel slugs.

4. Summary

The fabrication method of surrogate U-Zr-RE fuel slugs for SFR was evaluated in view of the soundness of the fuel slugs and the fuel losses. The material balance in the crucible assembly, and the mold assembly after gravity casting of fuel slugs was evaluated quantatively. After evaluation, the chemical and the microstructural characteristics of the cast fuel slugs were also identified and analyzed.

5. Acknowledges

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6. References

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