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U-Zr-RE Fuel Alloy with Minor Actinides

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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. Metallic fuels fit well with such a concept owing to their high thermal conductivity, high thermal expansion, compatibility with a pyro-metallurgical reprocessing scheme, and their demonstrated fabrication at engineering scale in a remote hot cell environment. 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 an injection 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. Methods and Results

In this section experimental methods and results are described.

2.1 Experiment 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 and quartz molds coated with Y2O3 were 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. 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).

2.2 Results

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 was 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-10wt.%RE fuel slugs was low, about 0.1% respectively. It is thought that a lower fuel loss in case of casting of U-10wt.%Zr-10wt.%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.

Fig. 1. Typical U-10Zr-10RE fuel slug fabricated with the injection casting process under modest pressure.

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

	Melting/casting part	Weight (g)	Fraction (%)
Before casting	Crucible	539.5	100
After casting	Crucible assembly	456.0	83.6
	Mold assembly	83.1	16.3
Fuel loss		0.4	0.1

The sound U-10wt.%Zr-10wt.%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 injection 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. It was seen that losses of RE elements can be effectively controlled to below detectable levels using modest argon overpressures [1-2]. Based on these results there is a high level of confidence that RE losses will also be effectively controlled by application of a modest amount of overpressure.

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

		U (wt.%)	Zr (wt.%)	Si (ppm)	Ce (wt.%)	La (wt.%)	Nd (wt.%)	Pr (wt.%)
Upper	1	83.9	10.3	118	0.108	3.143	3.116	0.514
	2	83.2	10.1	147	0.102	3.014	2.990	0.497
	3	84.9	10.0	137	0.089	2.640	2.602	0.443
Middle	1	83.5	10.0	149	0.101	3.072	3.056	0.510
	2	83.1	10.1	168	0.098	2.956	2.934	0.490
	3	84.0	10.2	236	0.093	2.851	2.821	0.474
Bottom	1	83.2	10.3	558	0.105	2.513	3.120	0.513
	2	83.5	10.0	683	0.139	2.625	3.539	0.581
	3	82.12	10.28	938	0.183	2.857	4.115	0.675

Scanning electron micrographs of the fuel slugs were shown in Fig. 2. U-10wt.%Zr-10wt.%RE fuel slugs had lots of dispersion particles including RE component, distributed in the homogeneous and fine state in U-10wt.%Zr-10wt.%RE alloy.

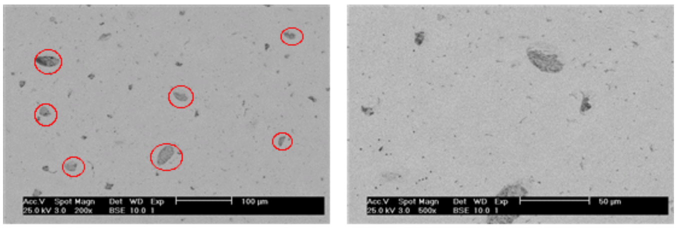

Fig. 2. Scanning electron micrographs of U-10wt.%Zr-10RE fuel slugs.

3. Conclusions

U-10wt.%Zr-10wt.%RE fuel slugs were cast using Depleted uranium (DU) with the injection casting furnace under Ar atmosphere. Visual inspection, micro-structure analysis, and chemical analysis were performed. 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 injection casting of fuel slugs was evaluated quantitatively. After evaluation, the chemical and the microstructural characteristics of the cast fuel slugs were also identified and analyzed.

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