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A Study on the Possibility of Fuel Slug Manufacturing according to the RE content of Recycled Fuel

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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 [1]. For the development of manufacturing process for U-Pu-Zr fuel, which contains with rare-earth material, the validity of fuel fabrication feasibility by using improved injection casting technique which is developed by nuclear power (nuclear) technology are necessary [2]. However, as a result of the evaluation of the recovery rate of the high-content rare earth-fuel slug, the density and the chemical analysis of the high-content rare earth specimens showed a difference between the RE loading amount and the RE content in the fuel core. It was necessary to identify the cause. In this study, in order to investigate the cause of the decrease of the rare earth content in the fuel slug for developing the rare earth high content fuel casting technology, casting in which the rare earth content was increased to 5 wt.%, 7 wt.%, and 10 wt.% was carried out. The recovery rate, density, and microstructure analysis of the fuel slug and debris, and their properties were evaluated.

2. Methods and Results

In this section experimental methods and results are described.

2.1 Experiment Procedure

The injection casting system was used in this experiment. Injection casting uses the pressure difference between the mold's interior and the furnace's gas pressure to drive the molten metal up into the quartz tube. 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 and quartz molds coated with Y_2O_3 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, 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.

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 0.16% 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	1,027.63	100
After casting	Crucible assembly	873.80	85.03
	Mold assembly	152.23	14.81
Fuel loss		1.60	0.16

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 250mm.

Compared with the mass balance, the fuel loss rate of the high content rare-earth fuels was in the range of 0.1 ~ 0.2%, and the higher the rare earth content (10%), the greater the reaction between the crucible and the melt. Re 10% showed the reaction loss with the crucible of about 8g of the total charge. In the case of RE 7%, the reaction loss with the crucible of about 2g showed that the reaction loss with the crucible was larger as the charged rare earth content increased. In the comparison of residue, the RE rich layer was thicker with larger rare earth content on the cutting edge of the remaining residue. The volume ratios of the RE rich layer to the remaining residue were measured in RE10% and RE 7%. The volume ratio in the experiment was well matched when the upper part estimated as RE rich layer was composed of RE and the lower part was composed of 5% RE.

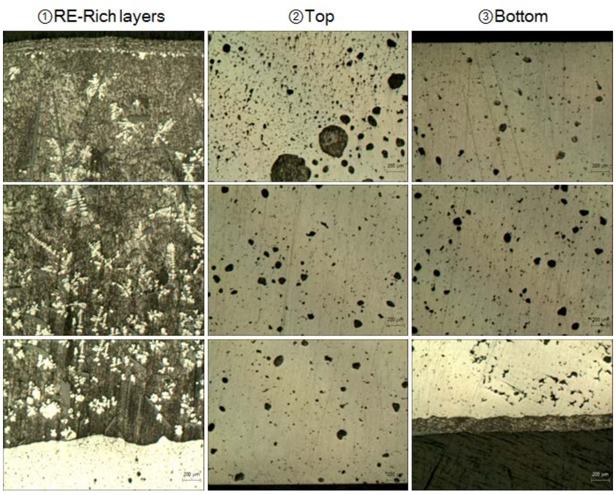

Fig. 2. Scanning electron micrographs of U-10wt.%Zr-10RE melt residue.

This tendency was also observed in the density comparison, and in the lower part of the residue, the density measurement was consistent with that of the U-10Zr-5% RE, but the density decreased sharply in the upper part of the RE rich layer. This shows the density of the RE rich layer. OM, SEM and EDX analyzes were performed by microstructural analysis. In the RE rich layer, as shown in Fig. 2, RE was mostly observed. In the remaining residue, a precipitate phase having a size of 2,000 μm which is relatively large in size was observed on the surface of the residue. In the remaining part of the residue, the precipitation phase with a size of 50 μm or less was homogeneously distributed, which was consistent with the experimental results. Therefore, based on the experimental results obtained from the residue analysis and the fuel slug analysis, the experimental results show that when the RE content exceeds 5%, only 5% RE is used in the casting and exists in the form of precipitate, and the excess of 5% is raised to the upper part due to the density difference to form the RE rich layer. The RE rich layer was formed thicker as the rare earth charge amount was larger, and the reaction with the crucible was judged to be larger due to this layer.

3. Conclusions

U-10wt.%Zr-RE fuel slugs were cast using depleted uranium (DU) with the injection casting furnace under Ar atmosphere. 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 recovery rate, density and the microstructure of the cast fuel slugs and melt residue were also identified and analyzed to investigate the cause of the decrease of the rare earth content in the fuel slug for developing the rare earth high content fuel casting technology.

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