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Low Loss Metallic Fuel Slug Casting Evaluation

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1. Introduction

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. Metallic fuel has been studied and is also considered a leading candidate for advanced driver and transmutation fuels under the Fuel Cycle Research and Development (FCRD) program, formerly the Advanced Fuel Cycle Initiative (AFCI) program. 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. Fuel slug casting is the dominant source of fuel losses and recycled streams in this fabrication process. These losses and waste streams result in lowering the productivity and economic efficiency of fuel production. Losses occur during mold and crucible interactions, crucible coating infiltration, fuel particle adherence to the mold material and in the case of volatile element-bearing alloys volatilization. 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. Volatile species can be retained through the use of cover gas over pressure, covered crucibles, and short cycle times [1-2]. In this study, a gravity casting method of metallic fuel slugs for SFR was evaluated in view of the fuel loss and the casting soundness.

2. Experimental Procedure

The elemental lumps of depleted uranium (DU), zirconium, and manganese were used to fabricate ternary U-10wt.%Zr-X(: Ce, Mn) alloy fuel slugs. Graphite crucibles coated with slurry-spray coating and plasma-spray coating method and quartz molds coated with slurry-coating method 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 the alloying characteristics of the cast fuel slugs were also identified and analyzed.

3. Results and Discussion

The typical material balance in the crucible assembly and the mold assembly after fabrication of volatile surrogate U-10wt.%Zr-Mn and U-10wt.%Zr-Ce fuel slugs are shown in Table 1 and Table 2. A considerable amount of dross and melt residue remained in the crucible after melting and casting; however, most charge materials were recovered after fabrication of the fuel slugs. The weight fractions of the fuel losses relative to the charge amount after fabrication of U-10wt.%Zr-Mn and U-10wt.%Zr-Ce fuel slugs were so low, about 1% and about 0.1% respectively.

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

	Melting/casting part	Weight (g)	Fraction (%)
Before casting	Crucible	1,122	100
After casting	Crucible assembly	67	6.1
After casting	Mold assembly	1037	92.4
Fuel loss		18	1.5

Table 2. Typical material balance after casting of U-10wt.% Zr-Ce fuel slugs.

	Melting/casting part	Weight (g)	Fraction (%)
Before casting	Crucible	1,464	100
After casting	Crucible assembly	167	6.1
After casting	Mold assembly	1295	92.4
Fuel loss		2	0.1

The volatile surrogate U-10wt.%Zr-Mn and the U-10wt.%Zr-Ce fuel slugs were melted and cast with the gravity casting furnace under Ar atmosphere, as shown in Fig. 1. The metal fuel slug had the diameter of 5mm and the length of about 250~300mm. The volatile surrogate U-10wt.%Zr-Mn fuel slugs were fabricated with the gravity casting furnace under ambient atmosphere, as shown in Fig. 2. The casting of the fuel slugs under a higher atmospheric pressure brought segmentation phenomena due to gas filling in quartz molds. 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 and U-10wt.%Zr-Mn fuel slugs are shown in Fig. 3. Internal pores were detected in the upper part region of the fuel slugs. Fig. 4 shows the effect of charge amount on the standard deviation of Zr vontent after casting of U-10wt.%Zr and U-10wt.%Zr-Mn fuel slugs. As charge amonut increases, the standard deviation of Zr content generally decreases. Fig. 5 shows the effect of casting temperature on the yield of ternary alloying element (Mn) after casting of U-10wt.%Zr-Mn fuel slugs. As casting temperature increased, the yield of ternary alloying element (Mn) generally decreased.

Fig. 1. Typical U-10%Zr-Mn (upper) and U-10wt.%Zr-Ce (lower) fuel slugs, fabricated with the gravity casting furnace under low atmospheric pressure.

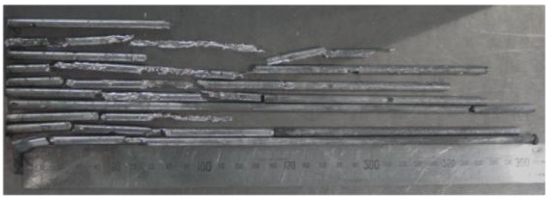

Fig. 2. The volatile surrogate U-10wt.%Zr-Mn fuel slugs, fabricated with the gravity casting furnace under ambient atmosphere.

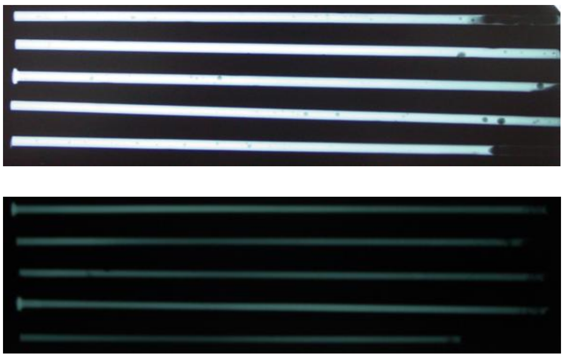

Fig. 3. Gamma radiography for internal defects detection of as-cast fuel slugs; (upper) U-10wt.%Zr, (lower) U-10wt.%Zr-Mn.

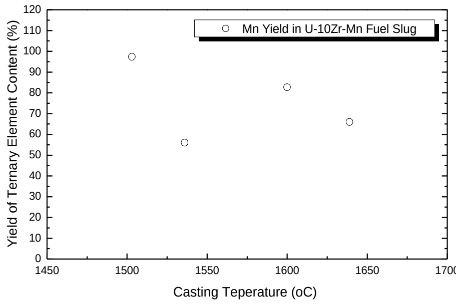

Fig. 4. The effect of charge amount on the standard deviation of Zr vontent after casting of U-10wt.%Zr and U-10wt.%Zr-Mn fuel slugs.

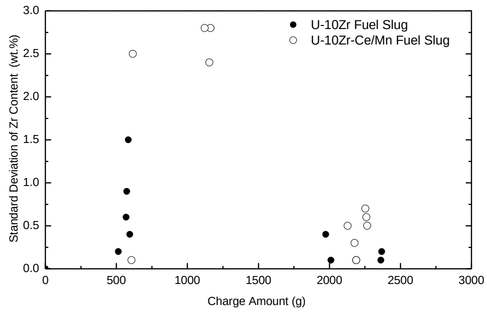

Fig. 5. The effect of casting temperature on the yield of ternary alloying element (Mn) after casting of U-10wt.%Zr-Mn fuel slugs.

4. Summary

The fabrication method of U-Zr system fuel slugs for SFR was evaluated in view of the casting 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 casting soundness and the alloying characteristics of the cast fuel slugs were also identified and analyzed.

5. Acknowledges

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6. References

[1] C.L. Trybus, J.E. Sanki, S.P. Henslee, Journal of Nuclear Materials, Vol.204, pp.50, 1993.
[2] R.S. Fielding and D.L. Porter, Proc. of Annual Meeting of American Nuclear Society, pp.859-860, 2010.