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Low Loss Advanced Metallic Fuel Casting Evaluation

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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 were selected for fueling many of the first reactors in the US, including the plutonium production reactors operated at Hanford, the Experimental Breeder Reactor, and the Dounreay Fast Reactor (DFR) in the UK [1-4]. The fabrication process for SFR fuel is composed of (1) fuel slug casting, (2) loading and fabrication of the fuel rods, and (3) the fabrication of the final fuel assemblies. Fuel slug casting is the dominant source of fuel losses and recycles streams in the fabrication process. Recycle streams include fuel slug reworks, returned scraps, and fuel casting heels, which are a special concern in the counter gravity injection casting process because of the large masses involved. Large recycle and waste streams result in lowering the productivity and the economic efficiency of fuel production. To increase efficiency the fuel losses in the furnace chamber, crucible, and the mold, after casting a considerable amount of fuel alloy in the casting furnace, will be quantitatively evaluated. After evaluation the losses will be identified and minimized. It is expected that this study will contribute to the minimization of fuel losses and the wastes streams in the fabrication process of the fuel slugs. Also through this study the technical readiness level of the metallic fuel fabrication process will be further enhanced.

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 characteristics of the cast fuel slugs were identified and analyzed.

2. Methods and Results

Elemental lumps of depleted uranium (DU), zirconium, and manganese or cerium were used to fabricate U-10wt.%Zr and U-10wt.%Zr-X(: Mn, RE((RE: 53% Nd, 25% Ce, 16% Pr, 6% La)) alloy fuel slugs. Graphite crucibles coated with slurry-spray coating or plasma-spray coating method and quartz molds coated with slurry-coating method were used. The mass of the melting and casting parts and the fuel material before and after melting were measured using an electronic balance. After fabricating a representative number of fuel slugs in the casting furnace, the fuel losses in the crucible assembly and the mold assembly were quantitatively evaluated. After evaluation, the soundness and the characteristics of as-cast fuel slugs were 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).

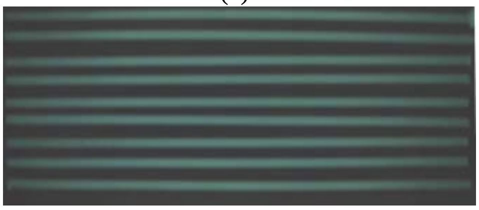
Casting development has been conducted in KAERI. The fuel losses were evaluated after casting a considerable number of U-Zr fuel slugs. After evaluation the losses were identified and minimized. The typical material balance in the crucible assembly and the mold assembly after fabrication of U-Zr alloy system fuel slugs is shown in Table 1. The metal fuel slugs had the diameter of 5mm and the length of about 300mm. The fuel losses after fabrication of U-10Zr system fuel slugs relative to the charge amount were low, approximately 0.1%.

Table 1. Typical material balance after casting of U-10Zr system fuel slugs.

	Melting/casting part	Weight (g)	Fraction (%)
Before casting	Crucible	1,464	100.0
After casting	Crucible assembly	167	11.3
	Mold assembly	1,295	88.6
Fuel loss		2	0.1

The modification of casting equipment was carried out to improve the casting performance such as the increased melting & casting temperature, the increased preheating temperature of the distributer, and the increased batch size. The U-10Zr-RE system fuel slugs were melted and cast with the gravity casting furnace under low atmospheric pressure, as shown in Fig. 1. The metal fuel slugs had the diameter of 5mm and the length of about 300mm. The fuel losses after fabrication of U-10Zr-RE fuel slugs relative to the charge amount were low, approximately 0.3%. This result shows that gravity casting technology is a feasible approach to reach the goal of the fuel losses of 0.1% or less.

(a)



(b)

Fig. 1. Typical fuel slugs (a), fabricated with the gravity casting furnace under low atmospheric pressure, and gamma-ray radiography (b) for internal defects detection.

Several designs were used throughout the project to test various parameters and to optimize casting results. After the equipment parts were modified such as the diameter of the fuel slugs from 5mm to 5.4mm, several casting runs were completed to fabricate fuel slugs and to provide statistically viable fuel loss data. Elemental lumps of uranium, zirconium, manganese, and rare earth element were used to fabricate ternary U-10wt.%Zr-RE fuel slugs. Ceramic coated graphite crucibles and quartz molds coated with a high temperature ceramic were also used. To deter interaction behavior between U-Zr melt and the crucible a coating was applied to the crucible through a plasma spray coating method. This method produces a thicker and more uniform coating compared to the earlier slurry coating. A slurry spray method was used to coat all quartz molds. After fabricating a considerable number of fuel slugs in the casting furnace, the fuel losses in the crucible assembly and the mold assembly were quantitatively measured using an electronic balance. The fuel losses after casting a considerable amount of fuel alloy in the casting furnace were quantitatively evaluated, and then, the fuel losses were identified and minimized.

In order to soundly fabricate U-Zr/U-Zr-RE fuel slugs and reduce the fuel losses, Casting equipment parts and developed gravity casting process of the fuel slugs were improved in KAERI. Metallic fuel slugs were successfully fabricated with 19 slugs/batch having diameter of 5mm and length of 300mm. Fuel loss was quantitatively evaluated in casting process for the fuel slugs. Fuel losses of the fuel slugs were so low, 0.1~1.0%. Injection casting experiments have been performed to reduce the fuel loss and improve the casting method. U-10Zr fuel slug having Φ5.4-L250mm was soundly fabricated with 0.1% in fuel loss. U-TRU-10Zr fuel slug having diameter of 4.5mm was soundly fabricated with 0.05% in fuel loss. The fuel losses could be minimized to 0.1%, which showed that casting technology of fuel slugs can be a feasible approach to reach the goal of the fuel losses of 0.1% or less in commercial scale.

4. Conclusions

In order to soundly fabricate U-Zr/U-Zr-RE fuel slugs and reduce the fuel losses, Casting equipment parts and developed gravity casting process of the fuel slugs have been improved in KAERI. Metallic fuel slugs were successfully fabricated with 19 slugs/batch with diameter of 5mm and length of 300mm. Fuel losses was quantitatively evaluated in casting process for the fuel slugs. Fuel losses of the fuel slugs were so low, 0.1~1.0%. Injection casting experiments have been performed to reduce the fuel loss and improve the casting method. U-Zr fuel slug having Φ5.4-L250mm was soundly fabricated with 0.1% in fuel loss. The fuel losses could be minimized to 0.1%, which showed that casting technology of fuel slugs can be a feasible approach to reach the goal of the fuel losses of 0.1% or less in commercial scale.

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