Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 7-8, 2015

Alternative Fabrication of Recycling Fast Reactor Metal Fuel

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1. Introduction

Metal fuels such as U-Zr/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 a high radioactivity levels since the 1980s [1-2]. In order to develop innovative fabrication method of metal fuel for preventing the evaporation of volatile elements such as Am, modified casting under inert atmosphere has been applied for metal fuel slugs for SFR [3-4] Alternative fabrication method of fuel slugs has been introduced to develop an improved fabrication process of metal fuel for preventing the evaporation of volatile elements. In this study, metal fuel slugs for SFR have been fabricated by modified casting method, and characterized to evaluate the feasibility of the alternative fabrication method.

2. Methods and Results

Elemental lumps of depleted uranium, zirconium, manganese as a surrogate of volatile Am, and rare-earth elements were used to fabricate U-10wt.%Zr-RE(RE: 53%Nd, 25%Ce, 16%Pr, 6%La; 1, 3, 5, 7, 10wt.%RE) and U-10wt.%Zr-5wt.%Mn fuel slug by modified casting method. Mn was selected as a volatile surrogate alloy since it possesses an equivalent total vapor pressure to the minor actinide-bearing fuel. Graphite crucibles coated with high-temperature ceramic plasma-spray coating and quartz molds coated with high-temperature ceramic by slurry-coating were used. Various casting variables, e.g., casting temperature and pressure, pressurizing rate, mold coating method were adjusted in modified casting process. At a predetermined superheat, the mold was lowered, immersing the open tip into the metal melt. U-10wt.%Zr-Mn fuel slugs were fabricated by modified casting method. Metallic fuel alloys containing volatile radioactive constituents, such as Am, is problematic in the conventional injection casting method, because the furnace containing the fuel melt is evacuated. Mn element was used for surrogate for Am radioactive constituents. The casting stage commences with the application of vacuum in order to evacuate the molds which are then inserted into the melt. The evaporation of Mn element depends on the time applied to vacuum during casting process. After fabricating the fuel slug in the casting furnace, the fuel losses in the crucible assembly and the mold assembly were quantitatively evaluated after casting of the fuel slug under vacuum state and inert atmosphere. The soundness and the chemical composition of as-cast fuel slug were identified and analyzed. As-cast fuel slug were inspected in casting soundness by gamma-ray radiography. The densities of the fuel slug were also measured by Archimedean immersion method. A scanning electron microscope (SEM) was used to study the microstructure of as-cast fuel slug. Chemical compositions of as-cast fuel slugs were measured by energy-dispersive spectroscopy (EDS).

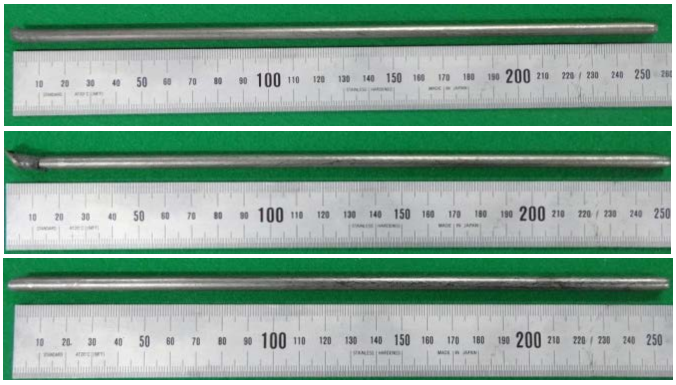

Fig. 1. (a) U-10wt%Zr-3wt.%RE, (b) U-10wt%Zr-7wt.%RE, and (c) U-10wt%Zr-10wt.%RE fuel slug (Φ5xL250 mm), fabricated by modified injection casting.

U-10wt.%Zr-RE fuel slugs was soundly fabricated with dimensions of Φ5 – L250mm by modified injection casting method, as shown in Fig. 1. Applying a modified injection casting method, U-10Zr-RE(RE: 53%Nd, 25%Ce, 16%Pr, 6%La; 1, 3, 5, 7, 10wt.%RE) fuel slugs were fabricated and characterized to investigate the feasibility of the casting technology of fuel slugs with high-content RE elements. U-10Zr-RE fuel slugs having high-content RE elements have been soundly fabricated with dimensions of Ø5xL250mm, adjusting the casting process parameters. Through precise melting and casting temperature of ±1^{o}C, the fabrication process has been stabilized and drastically reproduced.

The RE fuel slugs showed that RE content over the fuel slugs is considerably uniform with the density deviation of about ±0.2g/cm^3 in a fuel slug. RE inclusions were randomly dispersed in the matrix and more inclusions were observed as the charged amount of RE increased. The RE precipitates are somewhat uniform distributed in the fuel slug. The fuel loss is so small as about 0.15% after casting. Minimum fuel losses relative to the initial charge amount were 0.1, and 0.2% % for the U-Zr fuel slugs containing 7 and 10 wt.%RE, respectively. Major impurity content of C, H, O, N element is controlled below 2,000ppm.

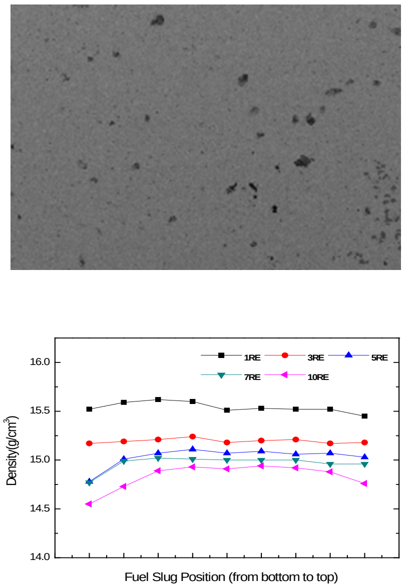

Fig. 2. (a) Microstructure showing RE precipitates, (b) immersion density according to RE content, fabricated by modified injection casting.

The modified injection casting method, an original fabrication technology in KAERI, had higher RE yield and lower fuel loss compared with a gravity casting method for fuel slugs. Through successive fabrication of sound RE fuel slugs, the feasibility of high-content RE fuel slugs has been investigated with an original casting technology in KAERI.

Table 2. Alloy compositions and loss characteristics of U-10wt.%Zr-5wt.%Mn fuel slug.

Item \ Inert Atmosphere Pressure		400 torr	600 torr
Alloy Composi-tion	U (wt.%)	85.0	85.2
	Zr (wt.%)	10.3	10.1
	Mn(wt.%)	5.1	5.2
	Si (ppm)	180	144
Density (g/cm^3)		14.92	14.94
Fuel loss (%)		0.06	0.04
Evaporation ratio of Mn element (%)		Not detectable	Not detectable

Management of minor actinides (MA) became an important issue because direct disposal of the long-lived MA can be a long-term burden for a tentative repository up to several hundreds of thousand years. In order to prevent evaporation of volatile elements such as Am and improve quality of fuel slugs, alternative fabrication methods of metal fuel slugs have been studied in KAERI. U-10Zr-5Mn fuel slug containing volatile surrogate element Mn was soundly cast by modified injection casting under modest pressure.

General appearance of the slug was smooth, and the diameter and the length were 5.4mm and about 250mm, respectively. Vacuum injection casting showed fuel loss of 2.6% due to considerable evaporation of Mn. Modified injection casting had fuel loss to 0.2% with prevention of Mn evaporation. Alternative casting method showed much lower fuel loss than vacuum injection casting. Evaporation of Mn during alternative casting could not be detected by chemical analysis. Mn element was most recovered with prevention of evaporation by alternative casting. Modified injection casting has been selected as an alternative fabrication method in KAERI, considering evaporation prevention, and proven benefits of high productivity, high yield, and good remote control.

3. Conclusions

Applying a modified injection casting method, U-10Zr-RE(RE: 53%Nd, 25%Ce, 16%Pr, 6%La; 1, 3, 5, 7, 10wt.%RE) fuel slugs were fabricated and characterized to investigate the feasibility of the casting technology of fuel slugs with high-content RE elements. U-10Zr-RE fuel slugs having high-content RE elements have been soundly fabricated with dimensions of Ø5xL250mm, adjusting the casting process parameters. In order to prevent evaporation of volatile elements such as Am and improve quality of fuel slugs, alternative fabrication methods of metal fuel slugs have been studied in KAERI. U-10Zr-5Mn fuel slug containing volatile surrogate element Mn was soundly cast by modified injection casting under modest pressure. Evaporation of Mn during alternative casting could not be detected by chemical analysis. Mn element was most recovered with prevention of evaporation by alternative casting. Modified injection casting has been selected as an alternative fabrication method in KAERI, considering evaporation prevention, and proven benefits of high productivity, high yield, and good remote control.

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