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Peculiarities of fuel slugs prepared by Gravity Casting Method

Jong-Hwan Kim*, Hoon Song, Hyung-Tae Kim, Jung-Won Lee, Ki-Hwan Kim, Chan-Bock Lee
Korea Atomic Energy Research Institute, 1045 Daedeokdaero, Yuseong, Daejeon, Korea, 305-353
*Corresponding author: jhk9@*kaeri.re.kr*

1. Introduction

KAERI seeks to develop and demonstrate the technologies needed to transmute the long-lived transuranic actinide isotopes in spent nuclear fuel into shorter-lived fission products, thereby dramatically decreasing the volume material requiring disposal and the long-term radio-toxicity and heat load of high level waste sent to a geological repository. Metallic fuel has advantages such as simple fabrication procedures, good neutron economy, high thermal conductivity, excellent compatibility with a Na coolant and inherent passive safety [1].

A practical process of metallic fuel fabrication for an SFR needs to be cost efficient, suitable for remote operation, and capable of mass production while reducing the amount of radioactive waste. Injection casting was chosen as the most promising technique, in the early 1950s, and this technique has been applied to fuel slug fabrication for the Experimental Breeder Reactor-II (EBR-II) driver and the Fast Flux Test Facility (FFTF) fuel pins [2, 3]. However, casting alloys containing volatile radioactive constituents, such as Am, are problematic in a conventional injection casting method, when the furnace containing the fuel melt is evacuated. Therefore, it is necessary to minimize the vaporization of the components and the volume of radioactive wastes during melting and casting.

In this study, an alternative fuel casting technique has been developed to fabricate metallic fuel for an SFR that controls the transport of volatile elements during the melting and casting of a fuel. U-Zr-RE and U-RE-Mn fuel slugs were fabricated and their properties were evaluated. RE is a rare-earth alloy consisting of 53% Nd, 25% Ce, 16% Pr, and 6% La by weight. Mn was selected as a volatile surrogate alloy since it possesses the equivalent total vapor pressure to the minor actinide-bearing fuel.

2. Experimental Procedures

Figure 1 shows the gravity casting system used in this experiment. The gravity casting method used in this study does not require a reduced pressure in the crucible’s melting chamber, which is a great advantage when it comes to controlling the transport of volatile elements by using the higher pressure of the inert gas. During the casting of a fuel rod in the gravity casting, the crucible chamber was pressurized by inert gas and the mold chamber was evacuated to facilitate an inflow of the melt into the mold assembly. The higher pressure of the crucible chamber and crucible cover reduces the vaporization of the volatile element, Mn. Casting alloys were heated by induction heating at a frequency of 3 kHz and a maximum power of 30kW in the upper chamber. The quartz tube mold assembly was heated to about 1000 ℃ in the lower chamber. When the crucible temperature reached about 200 ℃ higher than the melting point, it was held and stirred electromagnetically by applying an induction heating cycle from 0% to 100% to ensure the homogeneity of the melt [3-5].

Uranium losses were quantitatively evaluated after casting, and the soundness of the cast samples was measured by gamma-ray radiography. The density of each location was measured using an Archimedean immersion method. The microstructures and compositions were analyzed using scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDX). Chemical analyses were also carried out to confirm the actual compositions of the fuel slugs and other impurities using inductively coupled plasma atomic emission spectrometry (ICP-AES).

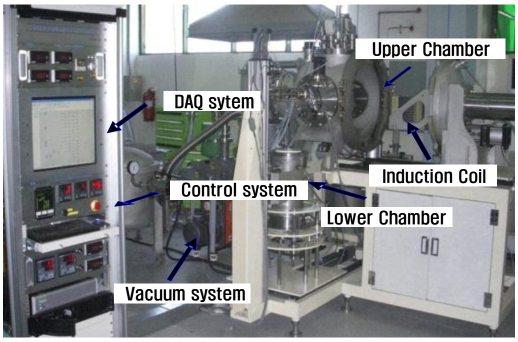
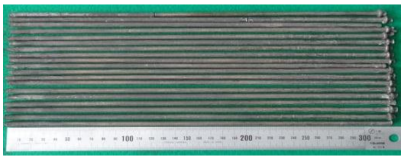


Fig. 1 An appearance of the gravity casting apparatus

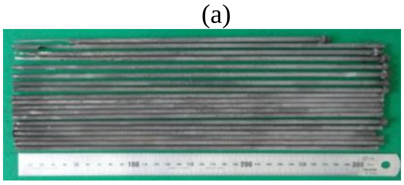
3. Results and Discussion

Figure 2 shows the typical U–Zr–RE and U–Zr–RE–Mn fuel slugs fabricated with a gravity casting system. Nineteen fuel slugs with a diameter of 5.4 mm were fabricated per batch; the gravity direction was from right to left in the photograph. The surface at the lower region of the slugs was smooth, whereas the upper region, which was continuously heated by the high-temperature melt during the melting and casting processes, was slightly coarse. However, the as-cast fuel slugs were generally sound and fabricated to the full length of the mold.

Gamma-ray radiography of the fabricated fuel slugs was performed to detect internal defects such as cracks and pores (Fig. 3). The internal defects were not detected in the U-10Zr-1RE and U-10Zr-3RE fuel slugs. However, some fuel slugs of U-10Zr-5RE-5Mn showed some internal defects as shown in Fig. 3c and 3d. The defects observed at the upper region of the U–10Zr–5RE-5Mn fuel slugs were typical shrinkage defects occurring in the casting areas where the feed metal is not available to compensate for the shrinkage as the molten metal solidifies.



(a)



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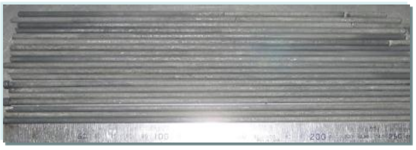
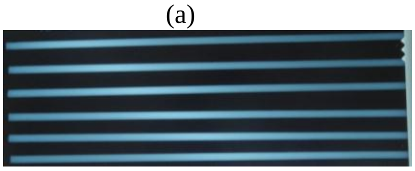


(c)

Fig. 2 photographs of (a) U-10wt%Zr-1wt%RE, (b) U-10wt%Zr-3wt%RE, and (c) U-10wt%Zr-5wt%RE-5wt%Mn by low pressure gravity casting.

(a)



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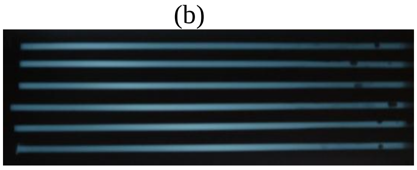

(c)

Fig. 3 Gamma radiographs of (a) U-10wt%Zr-1wt%RE, (b) U-10wt%Zr-3wt%RE, and (c) U-10wt%Zr-5wt%RE-5wt%Mn fuel slugs fabricated by low pressure gravity casting.

4. Conclusions

An alternative fuel casting technique was developed to fabricate metallic fuel for an SFR. The appearance of the as-cast fuels was generally sound and the internal integrity was found to be satisfactory through gamma-ray radiography. The U and Zr contents were uniform throughout the matrix, and the impurity contents of oxyen, carbon, and nitrogen satisfied the specification of total impurities of less than 2000 ppm. The losses of the volatile element, Mn, could be effectively controlled using modest argon overpressures in the gravity casting.

5. Acknowledges

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6. References

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