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Fabrication of Rare-earth Bearing Fuel Slug by Injection Casting Method

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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, and excellent compatibility with a Na coolant [1].

The spent fuel generated in nuclear power plants is converted into uranium and TRU, a raw material for SFR nuclear fuels obtained through pyroprocessing which possesses intrinsic technical proliferation resistance. The spent fuel is converted into the uranium metal by the electroreduction process, and the uranium is recovered by the electrorefining process [2]; the remaining uranium and TRU are recovered in an ingot state by the electrowinning process [3]. The recovered surplus uranium is either recycled or disposed of as the low-level waste, and the U-TRU ingots are used in the SFR nuclear fuel [4]. This process has many benefits over the conventional aqueous process; e.g., it produces a smaller amount of secondary radioactive wastes and it needs compact equipment. However, the purity of MA separated from the spent fuel is lower than that obtained by the aqueous process. It is expected that pyroprocessing accompanies comparable amount of RE elements, whose chemical properties are very similar to those of MA [5, 6].

In this study, U–Zr fuel slugs containing 1, 3, and 7 wt%RE were fabricated by an injection casting method and their characteristics were evaluated. The compatibility of fabrication components in contact with the fuel melt and the fuel loss were also evaluated based on the amount of RE elements present in the fuel slugs.

2. Experimental Procedures

The RE sample was purposely fabricated by arc melting using exactly weighed amounts of more than 99.95 wt% pure Nd, Ce, Pr, and La. The sample was composed of 53% Nd, 25% Ce, 16% Pr, and 6% La by weight. The inhomogeneities of the alloy composition were removed by turning over the bead and remelting. The lumps of depleted uranium, RE, and sponge zirconium were weighed in proportion to the alloy compositions and charged into a melting crucible to fabricate fuel slugs. Zirconium was loaded into the bottom of the graphite crucible followed by RE and uranium. The idea was to allow the lower-temperature melting material to flow over and consume the other alloy. The graphite crucible and quartz molds were coated with Y_2O_3 to protect them against reactions with the uranium alloy melt. This selection was done on the basis of the free energy needed for oxide formation. A sheathed thermocouple was placed inside the crucible for directly monitoring the temperature of the molten alloy. Graphite insulation was wrapped around the crucible to prevent any significant heat loss to the induction coil and furnace chamber.

Figure 1 shows the vacuum injection casting system used in this experiment. The casting alloys were heated by induction heating at a frequency of 3 kHz and a maximum power of 30 kW in the upper chamber. The mold assembly was heated to approximately 1000°C in the lower chamber. When the crucible temperature reached approximately 200°C higher than the melting point, the alloy melt was held and stirred electromagnetically by applying an induction heating cycle from 0% to 100% to ensure the homogeneity of the melt. The flow of the molten material was driven into the quartz mold by the pressure of argon. After solidifying the melt in the quartz mold, the metallic fuel slug was removed from the mold.

Fig. 1. An appearance of the vacuum injection casting apparatus.

3. Results and Discussion

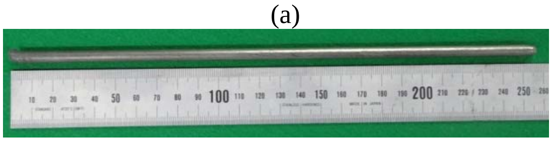
Figure 2 shows photographs of the U–10wt%Zr, U–10wt%Zr–3wt%RE, and U–10wt%Zr–7wt%RE fuel slugs prepared with the injection casting system; the left part of the slug was immersed into the melt for injection and gravity direction is from right to left in the photograph.

The as-cast fuel slugs were fabricated to the full length of the mold and visual inspection generally revealed them to be sound with no evidence of cracks or voids. The upper regions of the slugs were found to be smooth, whereas the lower regions, continuously heated by the high-temperature melt during the casting processes, had a slightly coarse surface.

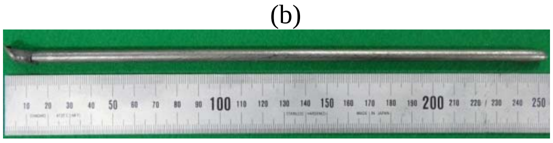
The amount of dross formed on the surface of the melt was found to increase with its charged RE content, as did the reaction areas of the graphite crucible. The melt residue in the crucible and the melting crucible are shown in Figs. 3a and 3b, respectively, after casting the U–10wt%Zr and U–10wt%Zr–7wt%RE fuel slugs. Dross generally forms due to reactions of the melt with oxygen when the casting is not performed under high-vacuum condition, or from interactions with the casting components in contact with the melt. Since the two fuel slugs were cast under the same conditions, the increase in the amount of dross observed here for the second slug must mainly be the result of its higher charged RE content.

The casting yields were quantified by measuring the material balance before and after injection casting. Assuming their soundness, the casting yields of the U–10Zr, U–10Zr–3RE, and U–10Zr–5RE fuel slugs were approximately 15.9%, 15.8%, and 13.4%, respectively, indicating that the casting yield decreases as the charged RE increases. The yields with injection casting are lower than using other casting methods such as gravity casting because a large portion of the charge occupies the bottom of the crucible. This problem can be solved to an extent by large-scale production and by optimizing the depth of the molten fuel in the mold and the array pattern of the mold bundle

(a)

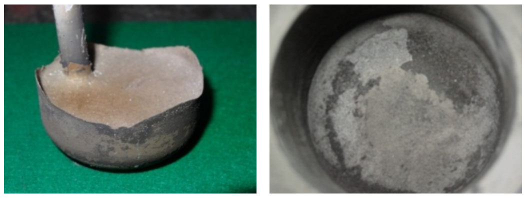


(b)

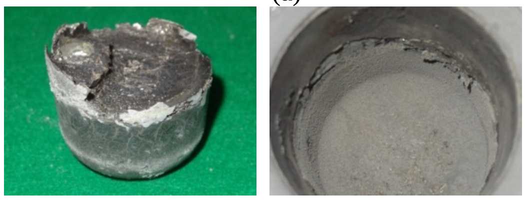


(c)

Fig. 2. Photographs of U–10wt%Zr fuel slug containing (a) 0wt%RE, (b) 3wt%RE, and (c) 7wt%RE after injection casting



(a)



(b)

Fig. 3. Photographs of a melt-residue (left) and a crucible (right) after casting the (a) U–10wt%Zr and (b) U–10wt%Zr–10wt%RE fuel slug

4. Conclusions

Herein, U–10wt%Zr fuel slugs containing 0, 3, and 7 wt%RE were prepared by an injection casting method and their characteristics were evaluated.

The as-cast fuel slugs were generally sound and fabricated to the full length of the mold. However, the increased amount of the charged RE noticeably deteriorated the quality of the casting components such as melting crucible. Chemical analysis of the U–10Zr and U–10Zr–3RE slugs showed that the target composition was matched to within 1.0 wt%. In contrast, the composition of the U–10Zr–7RE fuel slug differed by as much as 4.6 wt% from the target. Therefore, more protective casting variables should be considered, when casting high RE-bearing fuel slugs.

5. Acknowledges

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6. References

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