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Fuel Casting Development for Reducing Volatilization of Metallic Fuel

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1. Introduction

U-Zr metal fuel for SFR is now being developed by KAERI as a national R & D program of Korea. In order to recycle transuranic elements (TRU) retained in spent nuclear fuel, the generation of long-lived radioactive wastes and a loss of volatile species should be minimized during the recycled fuel fabrication step. The development of the vacuum injection casting method for fuel slugs was initiated in 1956. Because the injection casting process is simple and compact, it is cost efficient and has the advantage of mass production while reducing the amount of radioactive waste. However, casting 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. Although injection casting has been a well-established fabrication method for metal fuel for decades[1], Am addition to the metal fuel hampers conventional fuel fabrication processes because of the high vapor pressure of Am at the melting temperature of the uranium alloys[2]. It is necessary to minimize the vaporization of Am and volume of radioactive wastes[3].

In this study, fuel slug fabrication method has been introduced to develop an innovative fabrication process of metal fuel of SFR for preventing the evaporation of volatile elements such as Am. Metal fuel slugs were fabricated an improved injection casting method in KAERI. Volatile species can be retained through the use of a cover gas with over pressure and covered crucibles

2. Methods and Results

The feasibility of improved injection casting method including melting under an inert atmosphere was evaluated in a small-size induction-melting furnace. As experimental equipment, its primary purpose was to explore and define various casting variables, e.g., casting temperature and pressure, pressurizing rate, and mold coating method. For a preliminary test, pure copper was selected as a surrogate material, which has a melting temperature similar to uranium. The crucible is inductively heated up to 1400^{o}C, which is sufficiently higher than the liquidus temperature of the surrogate material. All operations were done under an argon atmosphere. At a predetermined superheat, the mold was lowered, immersing the open tip into the metal melt. When the metal has solidified, the mold is raised. After cooling, the surrogate fuel slug is taken out of the mold. Graphite crucibles coated with a high-temperature ceramic plasma-spray coating method and quartz molds coated with a high-temperature ceramic by a slurry-coating method were used.

After fabricating the fuel slugs in a casting furnace, the fuel losses in the crucible assembly and the mold assembly were quantitatively evaluated. The soundness and chemical composition of the as-cast fuel slugs were identified and analyzed. As-cast fuel slugs were inspected by gamma-ray radiography. The densities of the fuel slugs were also measured using an Archimedean immersion method. After a surrogate fuel slug was generally soundly cast by the improved injection casting method under an inert atmosphere, U-Zr fuel slugs by improved casting method have been successfully fabricated in KAERI for the prevention in evaporation of volatile elements such as Am.

Through the experience of the surrogate fuel slug, U-10wt.%Zr-5wt.%Mn fuel slugs containing a volatile surrogate element, Mn, shown in Fig. 1, were soundly cast by improved injection casting for prevention of evaporation of volatile elements such as Am under various atmospheres such as a vacuum state, reduced atmosphere, and an inert atmosphere. The gamma-ray radiography of the as-cast surrogate slug was performed to detect internal defects such as cracks and pores. The general appearance of the slug was smooth, and the diameter and length were 5.4mm and about 200-250mm, respectively. The density variations according to the location of the fuel slugs are shown in Table 1. The density of the fuel pins prepared using an injection casting method shows a different way in accordance with the casting process conditions. The U-10Zr(#S13-03) fuel pins when the surrogate Mn for volatile radioactive constituents was not added showed the highest density because of the lighter density of Mn elements, but the others such as U-10Zr-Mn(#S13-04, #S13-05, #S13-06) by adding an equal amount of Mn elements such as 5wt,% showed a difference owing to the conditions of the casting process. The density of the fuel pins in an inert atmosphere showed the lowest value, which means the lowest evaporation because of the consumption for light elements. However, the U-10Zr-Mn fuel pins(#S13-04) for a reduced atmosphere in which a vacuum was applied for a short time showed a higher density even when the volatile amount of Mn was small compared to the other casting method. The U-10Zr-Mn fuel pins(#S13-05) in a vacuum state showed the highest density as expected.

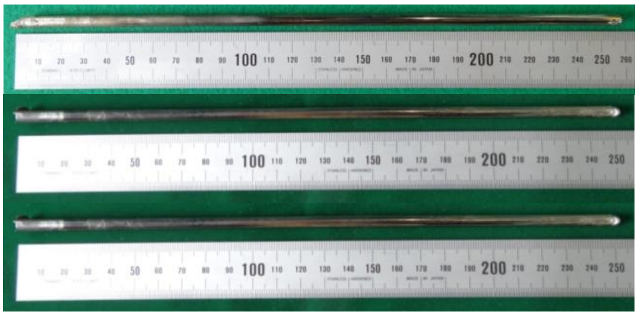

Fig. 1. Output U-10wt.%Zr-5wt.%Mn fuel slugs fabricated by improved casting method; (a) vacuum, (b) reduced atmosphere, and (c) inert atmosphere.

Table I: Alloy Density of U-10Zr Fuel Pins Prepared by Injection Casting Method.

		U-10Zr (S13-03)	U-10Zr-Mn (S13-04)	U-10Zr-Mn (S13-05)	U-10Zr-Mn (S13-06)
Upper (g/cm^3)	1	15.7	8.8	15.3	14.9
	2	15.7	14.9	15.3	14.9
	3	15.7	14.9	15.3	14.9
Middle (g/cm^3)	1	15.6	14.9	15.4	14.8
	2	15.7	14.9	15.3	14.8
	3	15.8	14.9	15.3	14.8
Bottom (g/cm^3)	1	15.8	14.9	15.4	14.8
	2	15.8	14.8	15.3	14.8
	3	15.73	14.8	15.3	14.8

3. Conclusions

In order to prevent the evaporation of volatile elements such as Am, fabrication methods of metal fuel slugs have been applied and examined with an improved injection casting method at KAERI. After a surrogate fuel slug was generally soundly cast by improved injection casting method under an inert atmosphere, U-Zr fuel slugs have been successfully fabricated at KAERI. Limited experiment results show that the Mn was not volatilized and conserved in the inert gas conditions compared to the vacuum condition. The volatility of Mn can be controlled by changing the casting process, and minimal Mn (and Am) loss is possible. An improved casting method under an inert atmosphere is more effective in the prevention of vaporization than casting under a vacuum and reduced atmosphere. In addition, improved casting under a reduced atmosphere shows a considerable effect in the prevention of vaporization.

REFERENCES

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