Characterization of U-10wt.%Zr-5wt.%RE Fuel Slugs Recycling Metallic Fuel Scrap

Seung-Uk Mun [a,b], Ki-Hwan Kim [b*], Seoung-Woo Kuk[b], Sun-Ig Hong [a]
[a] *Department of Advanced Materials Engineering, Chungnam National University, Daejeon, Republic of Korea*
[b] *SFR Nuclear Fuel Development Division, Korea Atomic Energy Research Instite, Daejeon, Republic of Korea*
[*] *Corresponding author: khkim2@kaeri.re.kr*

1. Introduction

Metallic fuel slugs have been developed as a nuclear fuel for sodium fast-cooled reactor (SFR) because metallic fuels are related to excellent reactor safety and fuel cycle economy. Metallic fuel slugs are fabricated using a modified injection casting method [1,2]. Generally, half of the raw material is formed as uranium-mixture waste after modified injection casting. Uranium recycling technology has the advantage of reducing uranium lose rate and increases the utilization of uranium resource. In this study, mechanical method was used to reduce radioactive liquid waste and improve safety. The sound fabrication of recycled metal fuel slugs must be satisfied the requirements (C + N + O + Si < 2000 ppm) with the same suitable impurity content such as the pure metallic fuel slug. In this study, refabricated metallic fuel slugs was characterized using SEM-EDS, ICP-EA, XRD to evaluation the qualities of metallic fuel slug condition.

2. Methods and Results

The manufacture of refabricated metallic fuel slugs was performed by modified injection casting. In addition, the metallic fuel slugs were re-fabricated by mixing the surface treatment by mechanical methods heel residue with pure metal at ratio of 4:6 (heel residue : pure metal raw material). Fig.1 shows the heel residue before and after mechanical surface treatment. Y_2O_3 plasma-spray coated crucible and Y_2O_3 slurry-coated quartz mold were used to prevent reaction with uranium, rare-earth elements, and zirconium elements during modified injection casting process [3]. The dissolution conditions in modified injection casting were maintained for 5 minutes after heating to 500℃ to remove water after charging raw material, then heated to 1470℃ and maintained for 10 minutes for sufficient mixing of the molten metal. After the molten metal is sufficiently mixed, the quartz mold preheated at 600 ℃ is immersed in the molten metal, and the injection casting is performed with Ar gas at a pressure of 0.2 MPa. During this process the pressure of the Ar gas is maintained at 400 torr to prevent evaporation of the raw material. The metallic fuel slugs were then cooled in the furnace. In the bottom part of the heel residue, the RE layer was present on the surface and the RE elements and the Y_2O_3 plasma spray coating layer formed the reaction layer. The reaction layer of Y_2O_3 and RE in the lower part of the heel residue was formed to a thickness of 30 to 50 μm.

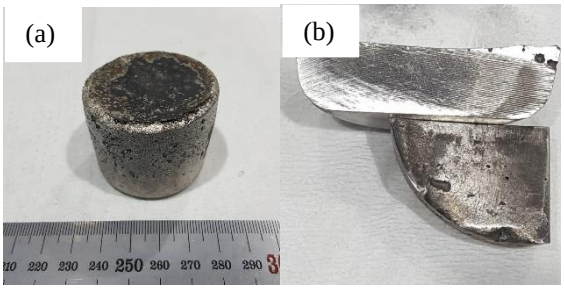

Fig 1. U-10wt.%Zr-5wt.%RE Heel residue ; before and (b) after surface treatment by mechanical

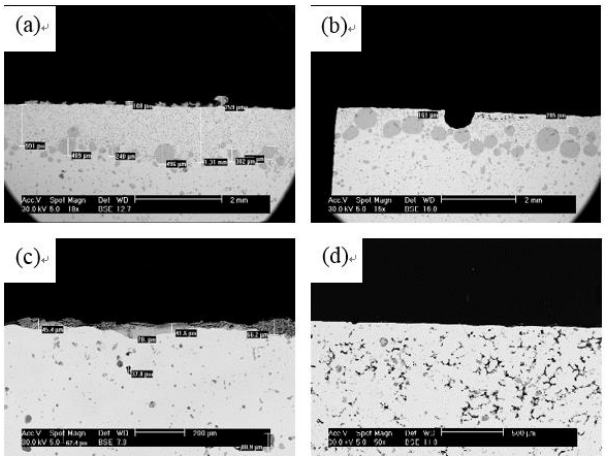

Fig 2. Cross-sectional SEM micrographs showing before and after surface treatment by mechanical method heel residue each part ; top part (a) before and (b) after , bottom part (c) before and (d) after

In the modified injection casting process, the RE elements float on top of the heel residue due to the density difference. The surface treatment range was set by referring to the SEM-EDS analysis results. The range was up to about 1mm in the top part and about 70 μm in the bottom part.

U-10wt.%Zr-5wt.%RE metallic fuel slugs with a diameter of 5.54mm and length 30mm were re-fabricated by modified injection casting method using an induction melting furnace. The metallic fuel slugs were casted into a graphite crucible and Y_2O_3 coated quartz mold. The surface of the metallic fuel slugs was casted to generally smooth surface.

Table 1. Chemical composition of refabricated U-10wt.%Zr-5wt.%RE metallic fuel slugs.

	Re-fabricated metallic fuel slugs			Pure metallic fuel slugs		
	Top	Middle	Bottom	Top	Middle	Bottom
U (wt.%)	87.0	86.8	86.3	86.4	86.3	86.1
Zr (wt.%)	10	9.7	9.8	9.7	9.8	9.8
Ce (wt.%)	1.1	1.1	1.1	1.1	1.1	1.1
Nd (wt.%)	1.9	1.9	1.9	1.9	1.9	1.8
Pr (wt.%)	0.6	0.6	0.5	0.6	0.6	0.6
La (wt.%)	0.1	0.1	0.1	0.1	0.1	0.1
C (ppm)	40	60	100	40	80	110
N (ppm)	60	50	70	120	80	130
O (ppm)	140	190	310	200	240	320
Si (ppm)	<50	<50	<50	<50	<50	<50

The impurity content, which is the evaluation criterion of Casting integrity, is an important criterion. The impurity content was measured by ICP-EA analysis of metallic fuel slugs divided into top, middle, bottom parts. Table 1 shows the results of the ICP analysis for each part of the re-fabricated metallic fuel slugs. The maximum value (C+N+O+Si) of the total impurities of the refabricated metallic fuel slugs in each part has values of 290ppm, 350ppm and 530ppm respectively from top to bottom, which is less than 2000ppm.

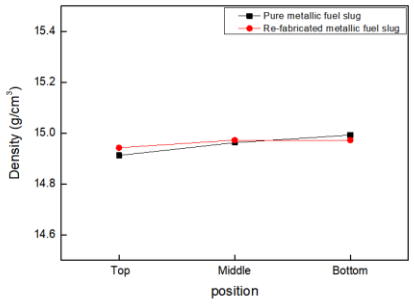

Fig 3. Measured density of pure metallic fuel slugs and refabricated metallic fuel slugs fabricated by modified injection casting.

Figure 3 shows density data for pure metallic fuel slugs and refabricated metallic fuel slugs. The average densities of metallic fuel slugs in each casting condition were measured as approximately 14.96 $g \cdot cm^{-3}$, 14.97$g \cdot cm^{-3}$, 14.9 $g \cdot cm^{-3}$ respectively. The average density of refabricated metallic fuel slugs was similar to pure metallic fuel slugs casted under the same conditions.

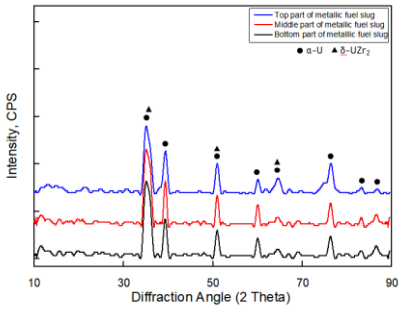

Fig 4. X-ray diffractometry (XRD) peaks of re-fabricated metallic fuel slugs each part

In previous studies, the results of XRD for U-10wt.%Zr and U-10wt.%Zr- 5, 10wt.%RE pure metallic fuel slugs were generally correspond to α-U and δ-UZr_2 phases [4,5]. Fig.4 shows the XRD results of the re-fabricated metallic fuel slugs for each part. As a result of XRD analysis, the XRD diffraction peak was the peak of the α-U and δ-UZr_2 phase, the results were similar to those of the previous studies. Thus, U – 10wt.%Zr – 5wt.% RE metallic fuel slugs were soundly fabricated during the modified injection casting process.

3. Conclusions

U-10wt.%Zr-5wt.%RE metallic fuel slugs were sound and fabricated to the full length and full diameter of the quartz mold. The results of ICP-EA analysis for casting soundness evaluation showed that the total impurity content of the re-fabricated metallic fuel slugs was lower than the impurity allowance criterion (C + O + N + Si <2000 ppm). The precipitate inside the metallic fuel slug was RE rich phase and Zr rich phase, and the matrix consisted of U-Zr component. The XRD patterns of the refabricated metallic fuel slugs were similar to each part (top, middle, bottom). This result is also similar to the result of the pure metallic fuel slugs. In the present study, the mechanical treatment of metallic fuel slugs was similar to that of pure metallic fuel slugs and satisfied various criteria.

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