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Re-fabrication of U-10wt.%Zr-5wt.%RE Fuel Slugs by Recycling of Fuel Scraps

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1. Introduction

The conventional injection casting method of metallic fuel slugs for Gen-IV nuclear power system has the advantages of high productivity and excellent remote control, but shows a considerably low fabrication yield of about 50%, resulting in considerable amount of metallic fuel scraps containing a residue and fuel slug butts [1-3]. Hence, the recycling technology of the metallic fuel scraps has been studied using chemical and mechanical surface treatment method in KAERI since 2016. U-10wt.%Zr-5wt.%RE fuel slugs can be re-fabricated with recycling metallic fuel scraps, met with the quality criterion of metallic fuel.

In this study, mechanical surface treatment method using with an electric brush were applied to fabricate metallic fuel slugs, in order to reduce the radioactive wastes in minimum and increase the fabrication yield of the metallic fuel in maximum. The metallic fuel slugs have been re-fabricated and characterized for the recycling of the fuel scrap to evaluate the feasibility of the recycling of the fuel scraps.

2. Methods and Results

The fuel scraps of U-10wt.%Zr-5wt.%RE metallic fuel have been prepared by injection casting. RE is a rare-earth alloy consisting of 53wt.%Nd, 25wt.%Ce, 16wt.%Pr, and 6wt.%La. The fuel scraps have been cleaned on the impurity layer by the mechanical surface treatment methods by an electric brush. The U-10wt.%Zr-5wt.%RE metallic fuel scraps after injection casting were used as raw materials for re-fabrication of fuel slugs. Casting variables, e.g., casting temperature and pressure, pressurizing rate, mold coating method were adjusted with graphite crucibles coated with ceramic plasma-spray coating and quartz molds coated with slurry-coating. At a predetermined superheat, the mold was lowered with pressurization of atmospheric gas, immersing the open tip into the metal melt. The metallic fuel slugs were re-fabricated using cleaned fuel scraps by injection casting method. The alloy compositions of the metallic fuel slugs were investigated using inductively coupled plasma atomic emission spectroscopy (ICP) and an elemental analysis (EA). The microstructure and the composition of the fuel slugs were analyzed using scanning electron microscopy (SEM), energy-dispersive spectroscopy (EDS), and X-ray diffractometer (XRD) to examine the microstructure and the composition.

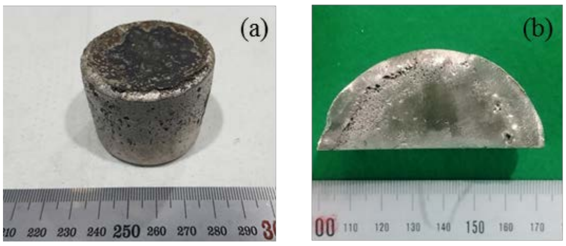

Fig. 1. The surface states of U-10Zr-5RE fuel melt residues in as-cast state (a) and after (b) mechanical surface treatment with an electric brush.

Fig. 2. U-10Zr-5RE metallic fuel slugs fabricated recycling fuel melt residue by mechanical surface treatment using an electric brush.

The surface states of U-10wt.%Zr-5wt.%RE fuel melt residue in as-cast state and after mechanical surface treatment with an electric brush are shown Fig. 1. Metallic fuel slugs consisting of U-10wt.%Zr-RE with a diameter of about 5.5 mm and a length of about 300 mm were re-fabricated per batch. They were generally sound without cracks or thin sections, as shown in Fig. 2.

Fig. 3 shows scanning electron micrographs and energy-dispersive X-ray spectroscopic maps according to the part of re-fabricated U-10Zr-5RE metallic fuel slugs. Lots of inclusions were distributed randomly in the U-10Zr-5RE matrix layer. The RE elements were separated as an inclusion from the U-Zr alloy because of their immiscibility. The dispersion phases were composed of RE element inclusions smaller than 20 μm. Distributions of RE-rich inclusions in the fuel matrix are important in spent fuel-burning reactors because the elements react with the stainless steel cladding during irradiation, and the reaction products lower the cladding-melting point.

From the specifications of the fuel slugs, the Zr content well matches the target composition to within 10% difference satisfying the criteria for the fuel slug. This result suggests that the concentration of U and Zr is relatively uniform throughout the matrix. The total impurities of carbon, nitrogen, oxygen, and silicon must be less than 2,000 ppm. The chemical compositions of the fuel slugs, prepared with pure metal and mechanically cleaned scraps as raw materials for injection casting, showed that the total impurities were satisfied with the specification requirements irrespectively of the composition of fuel slugs, as shown in Table 1.

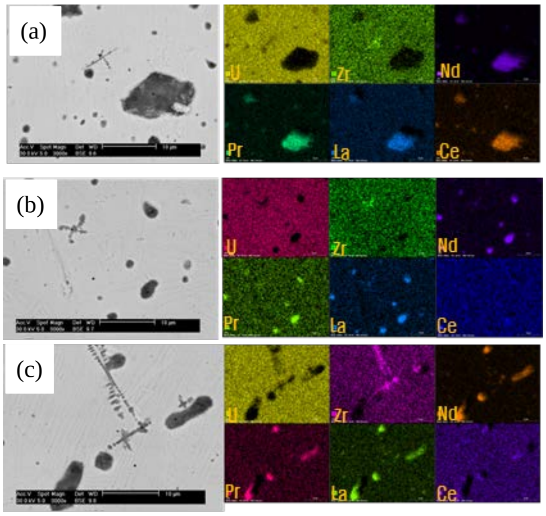

Fig. 3. Scanning electron micrographs and energy-dispersive X-ray spectroscopic maps showing U-10Zr-5RE metallic fuel slugs recycling fuel melt residue by mechanical surface treatment using an electric drill.
; (a) top, (b) middle, and (c) bottom.

Table 1. Average chemical compositions of U-10Zr-5RE fuel slugs, prepared with pure metal, and recycled scraps cleaned by mechanical methods with a hand brush and an electric brush.

Alloy content	U-10Zr-5RE		
	Pure metal	Mechanical Method (hand brush)	Mechanical Method (electric brush)
U (wt.%)	86.2	83.9	86.7
Zr (wt.%)	9.8	11.9	9.9
RE (wt.%)	3.8	3.4	3.9
C (ppm)	77	50	67
N (ppm)	110	<10	60
O (ppm)	253	427	213
Si (ppm)	50	464	50
C+N+O+Si (ppm)	490	951	390

3. Conclusions

The recycling of metallic fuel scraps is necessary to increase the fabrication yield of the metallic fuel in maximum and to maximize the utilization of the uranium resources. U-10wt.%Zr-5wt.%RE metallic fuel slugs were re-fabricated recycling metallic fuel scraps. The fuel slugs were generally sound and fabricated to the mold length of 300 mm. The total impurities of oxygen, carbon, nitrogen, and silicon were less than 2,000 ppm for the recycled metallic fuel slugs. The feasibility of the recycling of the fuel slug scraps has been demonstrated by the re-fabrication of the metallic fuel slugs.

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