Re-fabrication of U-Zr Alloy System Fuel Slugs Recycling Metallic Fuel Scraps

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1. Introduction

Metallic fuels such as U-Zr and U-TRU-Zr alloy are being developed for the sodium-cooled fast reactor (SFR) to be built in Korea [1-3]. TRU recovered through the pyro-electrochemical processing of spent LWR fuels are used to fabricate the metal fuel. The extracted uranium and TRU including Pu and long-lived minor actinides (MA) such as Np, Am, and Cm are used to fabricate the metallic fuel. This fuel recycling can solve the problem of PWR spent fuel accumulation by reducing the volume of PWR spent fuel, and increase the utilization of uranium resources while maintaining high proliferation resistance. A vacuum injection casting method has been applied to fabricate metallic fuel slugs of the SFR. Although the injection casting has been a well-established fabrication method for metallic fuel for decades, it has a drawback of low yield upto 55% because of the formation of lots of metallic fuel scraps such as the heel of melt residue and the butts of fuel slugs.

In this study, the fuel scraps such as the heel residue have been washed with chemical treatment. Metallic fuel slugs have been re-fabricated for the recycling of the fuel scraps. The re-fabricated fuel slugs were characterized to evaluate the feasibility of the recycling of the fuel slug scraps.

2. Methods and Results

2.1 Experimental Methods

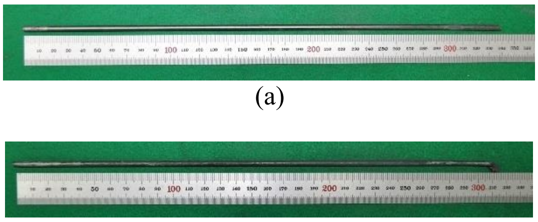
The heel residues of U-10wt.%Zr and U-10wt.%Zr-7wt.%RE (rare-earth elements) fuels after modified injection casting were used as raw materials for re-fabrication of metallic fuel slugs. RE is a rare-earth alloy consisting of 53wt%Nd, 25wt%Ce, 16wt%Pr, and 6wt%La. The fuel scraps were pickled using 2M nitric acid for an hour using a bubble-washing equipment.

Pickled heel residues and mixed pickled heel residues with pure metals such as uranium, zirconium, and RE alloy at a ratio of 1:1 were used to fabricate U-10wt%Zr and U-10wt.%Zr-7wt.%RE fuel slug by injection casting methods. 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 fabricated using recycled metallic fuel scraps by injection casting method.

To examine the soundness of the metallic fuel slugs, the density of the metallic fuel slugs was measured using an Archimedean immersion method. The alloy compositions and impurities 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 metallic fuel slugs were analyzed using scanning electron microscopy (SEM) and energy-dispersive spectroscopy (EDS). In addition, X-ray diffraction spectroscopy (XRD) was carried out for a comparison with metallic fuel slugs fabricated using pure metal materials.

2.2 Experimental Results

Metallic fuel slugs consisting of U-10wt%Zr and U-10wt%Zr-7wt%RE with a diameter of about 5.5 mm and a length of about 300 mm were fabricated per batch. They were generally sound without cracks or thin sections. The densities of the U-10wt%Zr metallic fuel slugs were measured as 15.70 (heel 100%) and 15.75g/cm^3 (heel 50%). The densities of the U-10wt%Zr-7wt%RE metallic fuel slugs were measured as 14.93 (heel 100%) and 14.8 g/cm^3 (heel 50%). The results show that the U-10wt%Zr metallic fuel slug fabricated using the 100% heel residue was similar to that of the 50% heel residue. The results show that the U-10wt%Zr-RE metallic fuel slug fabricated using the 100% heel residue was higher than that of the 50% heel residue. The density of the metallic fuel slugs slightly differed according to the composition of fuel alloys.



(a)

(b)

Fig. 1. Typical re-fabricated metallic fuel slug; (a) U-10wt%Zr, (b) U-10wt%Zr-7wt%RE.

Table 1. Chemical composition of recycled metallic fuel slugs

Chemical Composition	U-10Zr	U-10Zr-7RE
U (wt%)	90.6	86.6
Zr (wt%)	9.6	9.9
Nd (wt%)	-	1.9
Ce (wt%)	-	1.2
Pr (wt%)	-	0.5
La (wt%)	-	0.2
C (ppm)	154	199
N (ppm)	10	210
O (ppm)	617	647
Si (ppm)	201	426

Table 1 shows the chemical compositions of re-fabricated U-10wt%Zr and U-10wt%Zr-7wt%RE fuel slugs. From the specifications of the fuel slugs, the total impurities of carbon, nitrogen, oxygen, and silicon must be less than 2,000 ppm. The total impurities of the metallic fuel slugs fabricated using a heel residue of 100% were higher than those of the slugs fabricated using a heel residue of 50%. It is originated from the high impurity content produced when fabricating a metallic fuel slug. The total impurities are satisfied with the specification requirements. The RE content of recycled U-10wt%Zr-7wt%RE fuel slugs were 3.8 weight percentage. The RE content of recycled metallic fuel slugs was increased compared with the fabricated U-10wt%Zr-7wt%RE metallic fuel slug using pure metal materials. The yield of the RE content in the recycled U-10wt%Zr-7wt%RE fuel slugs is generally low because RE elements are immiscible with U element.

3. Conclusion

The re-fabrication of the metallic fuel slugs for SFR has been studied for the recycling of fuel scraps. The fuel slugs have been refabricated for the recycling of the fuel scraps. The recast fuel slugs were characterized to evaluate the casting soundness. 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 such as the residue heel has been demonstrated by the re-fabrication and the characterization of the metallic fuel slugs.

ACKNOWLEDGEMENTS

This work has been carried out under the Nuclear Research and Development Program supported by the Ministry of Science, Ict and Future Planning in the Republic of Korea.

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