Fabrication and Characterization of U-10wt.%Zr-RE Fuel Slugs Recycling of Metallic Fuel Scraps

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The recycling of metallic fuel scraps is necessary to maximize uranium resources and minimize radioactive waste. The fabrication of high-content RE containing fuel slugs for Sodium-cooled Fast Reactor has been studied for the recycling of metallic fuel scraps. U-10wt.%Zr-RE fuel slugs were fabricated and characterized to evaluate the feasibility of the recycling of the fuel slug scraps. The fuel slugs were soundly fabricated up to 300 mm in length. The total impurities of oxygen, carbon, nitrogen, and silicon were also less than 2,000 ppm for the fabricated metallic fuel slugs. The feasibility of the recycling of fuel slug scraps, such as the residue heels, has been demonstrated through the fabrication and characterization of high-content RE containing metallic fuel slugs.

I. Introduction

TRU recovered through the pyro-electrochemical processing of spent LWR fuels are used to fabricate a 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 a high proliferation resistance. Metallic fuels such as U-Zr and U-TRU-Zr alloy are being developed for a sodium-cooled fast reactor (SFR) to be built in Korea [1-3]. A vacuum injection casting method has been applied to fabricate metallic fuel slugs of SFR. Although injection casting has been a well-established fabrication method for metallic fuel for decades, it has a drawback of a low yield of up to 55% because of the formation of many metallic fuel scraps such as the heel of the melt residue and the butts of the fuel slugs. In this study, U-10wt.%Zr-RE fuel scraps, such as the heel residue, have been washed with a chemical treatment. High content RE-containing fuel slugs have been fabricated for the recycling of metallic fuel scraps. The U-10wt.%Zr-RE fuel slugs were characterized to evaluate the feasibility of the recycling of the fuel slug scraps.

II. Result and Discussion

The heel residues of U-10wt.%Zr-RE (rare-earth elements) fuels after modified injection casting were used as raw materials for the fabrication of metallic fuel slugs. RE is a rare-earth alloy consisting of 53wt%Nd, 25wt%Ce, 16wt%Pr, and 6wt%La. The surface impurities of the fuel scraps such as uranium oxide were removed using a chemical method or a mechanical method. Mixed 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-RE fuel slug through injection casting methods. Casting variables, e.g., the casting temperature and pressure, the pressurizing rate, and the mold coating method, were adjusted using graphite crucibles coated with ceramic plasma-spray coating and quartz molds coated with a slurry coating. At a predetermined superheat, the mold was lowered with the pressurization of atmospheric gas, immersing the open tip into the metal melt. The metallic fuel slugs were re-fabricated using recycled metallic fuel scraps using an 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 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. Metallic fuel slugs consisting of 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. 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 fuel slugs satisfy the specification requirements. The RE content of

the recycled U-10wt%Zr-RE fuel slugs were much lower than the target content of the fuel slugs. 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 the U element. The Zr and RE element precipitates were distributed uniformly at the top, middle, and bottom positions. The dispersion phases were composed of Zr and RE element precipitates of about 5 to 10 μm and 10 to 40 μm in size, respectively. Thus, all fabricated U-10wt%Zr-7wt%RE metallic fuel slugs were soundly fabricated during the injection casting process.

III. Conclusions

The fabrication of high content RE containing U-10wt.%Zr-RE fuel slugs for an SFR has been studied for the recycling of fuel scraps. High-content RE containing fuel slugs have been re-fabricated and characterized to evaluate the feasibility of the recycling of the fuel slug scraps. The fuel slugs were generally sound and fabricated to the full 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 fabrication and characterization of U-10wt.%Zr-RE fuel slugs.

ACKNOWLEDGMENTS

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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