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

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## 1. Introduction

Sodium cooled fast reactors (SFRs) are considered Gen-IV reactors. The spent fuel generated in nuclear power plants is converted into uranium and TRU, a raw material for SFRs [1]. The U-TRU-Zr-RE metallic fuel slug has been developed as a candidate fuel slugs for SFR. It has many advantages such as simple fabrication procedures, good neutron economy, high thermal conductivity, excellent compatibility with a Na coolant, and inherent passive safety [2,3]. It is fabricated using an injection casting method. The efficient fabrication process of U-TRU-Zr-RE metallic fuel slug is largely based on an injection casting method. Nevertheless, reducing radioactive waste has been an important challenge worldwide and thus recycling of the slug should be considered. A considerable amount of metallic fuel scraps upto 50% of charge amount for injection casting has been made consisting of the heel of the melt residue and unsuitable fuel slugs.

In this study, to increase the yield rate of injection casting by re-fabricating metallic fuel slugs using metallic fuel scraps, at first the melt residues of U-10wt.%Zr and U-10wt.%Zr-RE(RE: rare-earth elements) metallic fuel have been examined after injection casting. And then the melt residues have been treated on the impurity layer of the surface using chemical or mechanical method. U-10wt.%Zr and U-10wt.%Zr-RE alloy metallic fuel scraps have been characterized, and metallic fuel slugs have been re-fabricated for the recycling of the fuel scraps to evaluate the feasibility of the recycling of the fuel slug scraps.

## 2. Methods and Results

The melt residues of U-10wt.%Zr and U-10wt.%Zr-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 metallic fuel residues have been cleaned on the impurity layer by the surface treatment method such as chemical or mechanical method. The fuel residues have been characterized before the surface cleaning process, using scanning electron microscopy (SEM), energy-dispersive spectroscopy (EDS), and X-ray diffractometer (XRD) to examine the microstructure, the composition, and the phase of the metallic fuel residues.

The metallic fuel scraps such as heel residue and slug butts of U-10wt.%Zr and U-10wt.%Zr-RE fuels 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 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 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, the composition, and the phase of the fuel slugs.

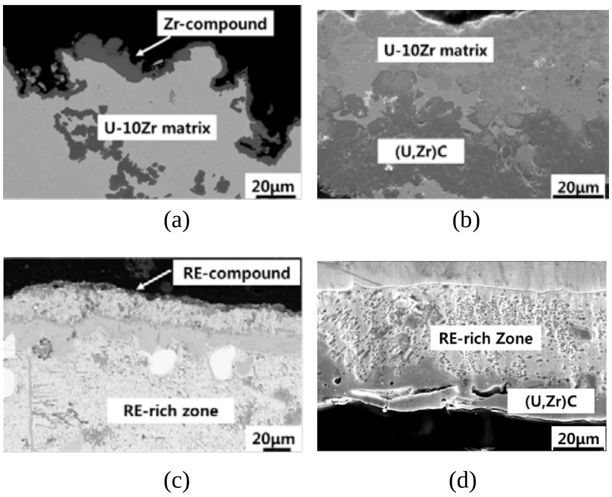


Fig. 1. Typical cross-sectional scanning electron micrographs of U-10wt.%Zr and U-10wt.%Zr-RE melt residues; (a) U-10Zr, top part, (b) U-10Zr, bottom part, (c) U-10Zr-RE, top part, (d) U-10Zr-RE, bottom part.

The cross-sectional scanning electron micrographs of U-10wt.%Zr and U-10wt.%Zr-RE melt residues are shown in Fig. 1. According to the integrated results of SEM, EDS and XRD analyses, the impurity layer ranging from 5 to 10 μm in thickness is composed of Zr-carbide and Zr-oxide phases as main phase in the top surface of the U-10Zr melt residue. The impurity layer of about 50 μm in thickness is mainly composed of Zr-carbide and U-carbide phases in the bottom surface of the U-10Zr melt residue. In the other hands, the U-10Zr-RE melt residue showed RE-compounds ranging from 5 to

10 μm in thickness as the first impurity layer on the top surface and RE-rich layer ranging from 1 to 2mm in thickness as the second impurity layer. The U-10Zr-RE melt residue showed $Y_2O_3$ plasma-spray coating layer of about 20 μm in thickness as the first impurity layer on the bottom surface and RE-rich layer of about 40 μm in thickness as the second impurity layer.

Metallic fuel slugs consisting of U-10wt.%Zr and U-10wt.%Zr-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, as shown in Fig. 2. From the specifications of the fuel slugs, the Zr content well matches the target composition to within 10% difference satisfying the criteria for a 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 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 I and Table II.

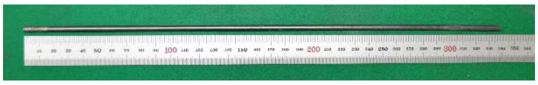

Fig. 2. Typical metallic fuel slug fabricated recycling fuel scraps.

Table I: Average chemical compositions of U-10Zr fuel slugs, prepared with pure metal, and recycled scraps cleaned by chemical method and mechanical method.

| Alloy content | U-10wt.%Zr | | |
|---|---|---|---|
| | Pure metal | Chemical method | Mechanical method |
| U (wt.%) | 89.7 | 90.6 | 88.5 |
| Zr (wt.%) | 10.3 | 9.6 | 11.3 |
| C (ppm) | 60 | 87 | 200 |
| N (ppm) | 20 | 10 | 17 |
| O (ppm) | 47 | 653 | 1017 |
| Si (ppm) | <100 | 239 | 408 |
| C+N+O+Si (ppm) | <227 | 989 | 1,642 |

## 3. Conclusions

The recycling of metallic fuel scraps is necessary to maximize the utilization of the uranium resources. The impurity layers are composed of Zr-compound and U-oxide phases as main phase in the surface of the U-10Zr melt residue. The U-10Zr-RE melt residue showed RE-compounds as the first impurity layer on the top surface and RE-rich layer as the second impurity layer. The U-10Zr-RE melt residue showed $Y_2O_3$ plasma-spray coating layer as the first impurity layer on the bottom surface and RE-rich layer as the second impurity layer. Metallic fuel slugs were fabricated using metallic fuel scraps including heel residue and unsuitable fuel slugs. 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.

Table II: Average chemical compositions of U-10Zr-5RE fuel slugs, prepared with pure metal, and recycled scraps cleaned by chemical method and mechanical method.

| Alloy content | U-10wt.%Zr-RE | | |
|---|---|---|---|
| | Pure metal | Chemical method | Mechanical method |
| U (wt.%) | 86.4 | 86.1 | 83.9 |
| Zr (wt.%) | 11.0 | 10.1 | 11.9 |
| RE (wt.%) | 2.6 | 4.0 | 3.4 |
| C (ppm) | 197 | 237 | 50 |
| N (ppm) | 13 | 10 | <10 |
| O (ppm) | 237 | 430 | 427 |
| Si (ppm) | 467 | 379 | 464 |
| C+N+O+Si (ppm) | 917 | 1,056 | 951 |

## REFERENCES

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