Characterization of U-10Zr-RE Heel Residue for Recycling of Metallic Fuel Scraps

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1. Introduction

Metallic fuel slugs such as U-10wt%Zr-RE (: Rare-earth elements) have been developed for a sodium-cooled fast reactor (SFR) as a Gen-IV reactor because U-10Zr-RE alloys are related to the reactor safety and fuel cycle economy. In general, metallic fuel slugs have been fabricated using a pure metal material. After casting, a considerable amount of fuel scraps have been made, such as a heel of the melt residue and the butts of the fuel slugs. The recycling of metallic fuel scraps is important to the development of a metallic fuel slug. The recycling of SFR fuel scraps increases the utilization of uranium resources. It can be applied to the treatment of a variety of uranium-mixture waste, and can contribute to an increase in radioactive waste disposal. It is very cost-efficient and has the advantage of reducing the amount of radioactive waste. Traditionally, after fabricating the metallic fuel slug, half of the raw material was produced as uranium-mixture waste. In order to recycle the metallic fuel scraps, there are two necessary characteristics of a metallic fuel slug. A sound fabrication of the metallic fuel slug must be satisfied with the specification requirements, and the suitable impurity content (C + N + O + Si < 2,000ppm) is also required. In this study, the heel residue was characterized using SEM/EDS and XRD to reuse the fuel scrap such as the heel residue. In order to recycle the heel residue, it was pickled with dilute nitric acid to remove impurities on the surface of the heel residue such as oxide compounds. Thereafter, metallic fuel slugs were fabricated using pickled heel residues as the raw material.

2. Methods and Results

Fig. 1 shows metallic fuel scraps such as heel residue. The principal uranium-mixture waste is heel residue after fabrication of metallic fuel slugs. To analyze the heel residue on the surface, the microstructure and composition of the heel residue were investigated using scanning electron microscopy (SEM) and energy-dispersive spectroscopy (EDS). X-ray diffraction spectroscopy (XRD) was also used to investigate the impurities. Fig. 2 shows a surface of heel residue at the top region. The thickness of the RE-rich zone was analyzed to be about 3 mm. The thickness of RE-rich zone normally varies according to the RE alloy content. As the results indicate, three layer was observed consisting of an RE-oxide layer, RE-rich layer, and U-Zr-RE layer in the heel residue. A XRD specimen was obtained by cutting the RE-rich zone between the RE-rich zone and U-Zr-RE layer. As a result of the XRD analysis, impurities such as oxide compounds, hydroxide compounds, and RE elements were detected at the top region. As shown in Fig. 3, the XRD patterns of Pr, Ce, Nd_2O_3, $Pr(OH)_3$, $Ce(OH)_3$ and UZr_2 were measured at the surface. In addition, the patterns of Pr, Ce, and ZrO were measured at the between the RE-rich zone and uranium matrix.

Fig. 4 shows the microstructure and composition of the U-10wt%Zr-7wt%RE heel residue analyzed using SEM/EDS. As shown in Table I, the matrix of the heel residue was detected as RE elements, and the dendrite form was detected as uranium and zirconium elements at the top region. In addition, a sharp form was detected as silicon and zirconium elements. This can be explained by the reacted or mixed quartz mold. As shown in Fig. 5, the metallic fuel slug was soundly fabricated using the pickled heel residue. According to the procedures, the metallic fuel slug was examined using the density, ICP, EA, SEM/EDS, and XRD. As the results, the recycled metallic fuel slug made no difference with metallic fuel slugs fabricated using the pure metallic materials.

Fig.1. U-10wt%Zr-7wt%RE heel residue.

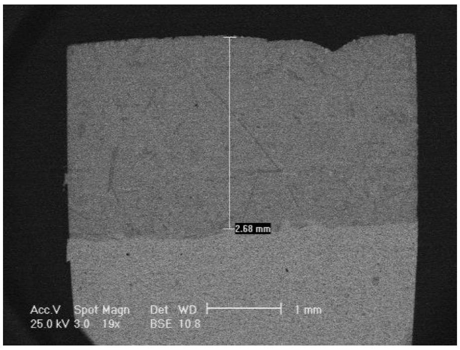
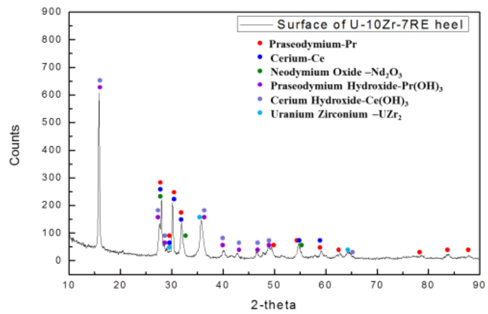
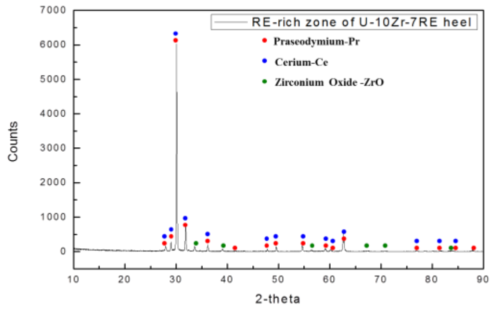


Fig. 2. SEM image of U-10wt%Zr-7wt%RE heel residue.



(a)



(b)

Fig. 3. X-ray diffraction patterns on U-10wt%Zr-7wt%RE heel residue; (a) surface and (b) interface between RE-rich zone and uranium matrix.

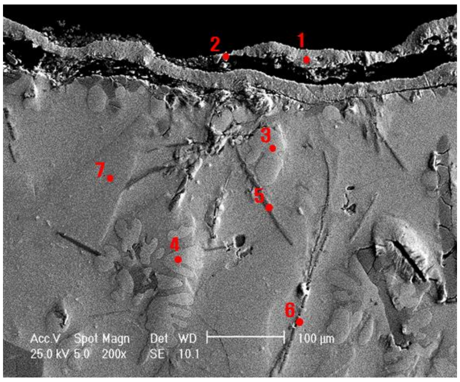


Fig. 4. SEM image of U-10wt%Zr-7wt%RE heel residue.

Table I: Chemical compositions of U-10wt%Zr-7wt%RE heel residue at the RE-rich zone region.

Element (wt%)	#1	#2	#3	#4	#5	#6	#7
U	-	-	52.8	52.1	-	-	-
Zr	-	71.6	41.9	42.6	42.9	21.6	-
La	8.8	0.2	-	-	3.3	5.5	9.0
Ce	21.0	1.4	-	-	7.9	12.9	22.0
Pr	14.9	1.3	-	-	5.8	9.3	15.5
Nd	48.9	4.7	-	-	18.6	30.1	50.0
C	3.8	12.1	3.4	3.6	10.3	13.1	3.6
N	0.4	-	-	-	3.5	-	-
O	2.3	2.5	1.9	1.8	3.1	6.1	-
Si	-	6.3	-	-	4.6	1.4	-

Fig. 5. Recycled U-10wt%Zr-7wt%RE fuel metallic slug.

3. Conclusions

A characterization of the U-10wt%Zr-RE heel residue is needed to recycle the metallic fuel scraps. The characterization of U-10wt%Zr-7wt%RE heel residue could be obtained from an XRD and SEM/EDS analysis. As the results of this study show, RE elements, oxide compounds, and hydroxide compounds were detected at the top region of the heel residue. Three layers were observed consisting of an RE-oxide layer, RE-rich layer, and U-Zr-RE layer in the heel residue. In addition, a large precipitate was observed at the top region of the U-Zr-RE layer. The heel residues were pickled to remove the impurities using dilute nitric acid before fabricating the recycled metallic fuel slug. Not only could the heel residue be applied to the recycling, but the recycled metallic fuel slug could also be successfully fabricated using the heel residue as a raw material. The yield rate of metallic fuel slugs was increased from 60% to about 84%. Hence, the feasibility could be evaluated for the recycling of metallic fuel slug scraps according to the results of the study. This study can be applied to the treatment of a variety of uranium-mixture wastes and may contribute to an increase in the capability of radioactive waste disposal. Thus, this study has great prospects because it is cost-efficient regarding the utilization of uranium resources.

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