Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 26-27, 2017

Microstructural Characterization of Metallic Fuel Slugs Containing Rare-earth Elements

Sang-Hun Lee [a,b], Ji-Hoon Choi [a], Ki-Hwan Kim [b*]
[a]*Materials Science & Engineering, Chungnam National Univerity, Daejeon, 34134, Republic of Korea*
[b]*SFR Fuel Development Division, Korea Atomic Energy Research Institute, Daejeon, 34507, Republic of Korea*
[*]*Corresponding author: khkim2@kaeri.re.kr*

1. Introduction

Metallic fuel has been considered a promising candidate as the nuclear fuel for a sodium-cooled fast reactor (SFR). Because metallic fuel has a lot of advantages, such as simple fabrication procedures, good neutron economy, high thermal conductivity, excellent compatibility with sodium coolant, and inherent passive safety [1,2]. The pyro-processing can maximize the utilization of uranium resources from the spent fuel and maintain a higher resistance to proliferation. Rare-earth (RE) elements from the spent fuel are not separated after pyro-processing, because the chemical properties of RE elements are very similar to those of minor actinides (MA) in the trans-uranium (TRU) [3-5]. It is expected that pyro-processing will be accompanied by the release of a comparable amount of RE elements. The RE elements affect the chemical and physical properties in a metallic fuel slug. The U-Zr-RE alloys are strongly reactive with graphite crucibles and quartz tube molds. For these reasons, reactants of U-Zr-RE alloys negatively affect the composition of metallic fuel slugs. The RE elements do not react with U-Zr alloys, but exist as an immiscible material. The segregation of RE elements in U-Zr-RE alloys is important for the compatibility with stainless steel cladding under irradiation, but because of the high chemical reactivity at high temperature, the life of the cladding materials in contact with U-Zr-RE alloys can be rapidly reduced [3]. Thus, the segregation of RE elements in a U-Zr-RE fuel slug is a significant factor in the development of metallic fuel slug. This study was mainly focused on assessing the microstructure characteristics of inclusions, such as shape, uniformity, distribution, composition in metallic fuel slugs.

2. Methods and Results

The U-10wt%.Zr and the U-10wt.%Zr-5wt.%RE fuel slug were fabricated using an injection casting method. The RE alloy consisted of 53 %Nd, 25 %Ce, 16 %Pr, and 6 %La based on the weight ratio [6]. The diameter of the cast metallic fuel slugs was 5 mm, with a length of 250 mm.

As shown in Fig. 1, the densities of metallic fuel slugs were measured from the samples obtained from the top, middle, and bottom position of metallic fuel slug. The average density values of the U-10wt.%Zr and U-10 wt.%Zr-5wt.%RE metallic fuel slugs were measured approximately 15.5 g cm^{-3} and 14.9 g cm^{-3}, respectively. Although the densities of the metallic fuel slugs show a little variation based on the position, this density values are near the average density values of the fuel slugs. In other word, the metallic fuel slugs were soundly fabricated.

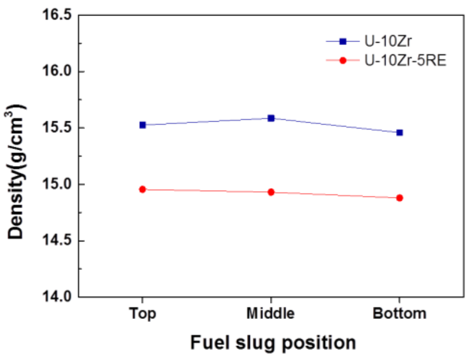

Fig. 1. Distribution of density according to the position of metallic fuel slug.

X-ray diffraction patterns of U-10wt.%Zr and U-10wt.%Zr-5wt.%RE fuel slugs are presented in Fig. 2. The peaks of metallic fuel slugs were similarly observed that corresponded to the α-U phase with the Cmcm space group and the δ-UZr_2 phase with the P6/mmm space group. However, peaks of rare-earth were not indexed as shown in Fig. 2. (b).

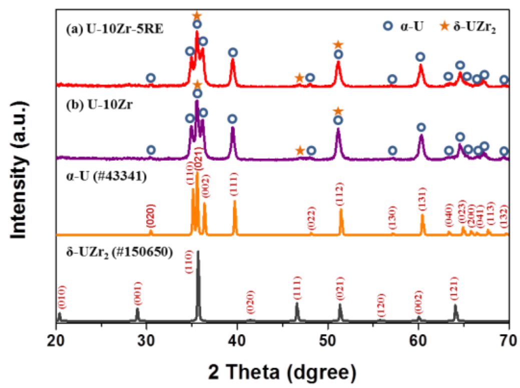

Fig. 2. X-ray diffraction patterns of metallic fuel slugs; (a) U-10wt.%Zr, and (b) U-10wt.%Zr-5wt.%RE.

Fig. 3 shows back-scattered electron micrographs acquired from the cross section of metallic fuel slugs. As shown in Fig. 3 (a) and (b), the inclusions with globular and elongated feature were observed in the matrix. The inclusions are uniformly distributed in a size smaller than 20 μm. Two different inclusions were distributed in the U-10wt.%Zr-5wt.%RE metallic fuel slugs as shown fig. 3 (c), (d). The shape of the light gray inclusion was sphere, also the dark gray inclusion had spherical shape. But, some of dark gray inclusions with needles shape were observed. The dark gray inclusions were more widely observed than light gray inclusions in the U-10wt.%Zr-5wt.%RE metallic fuel slug.

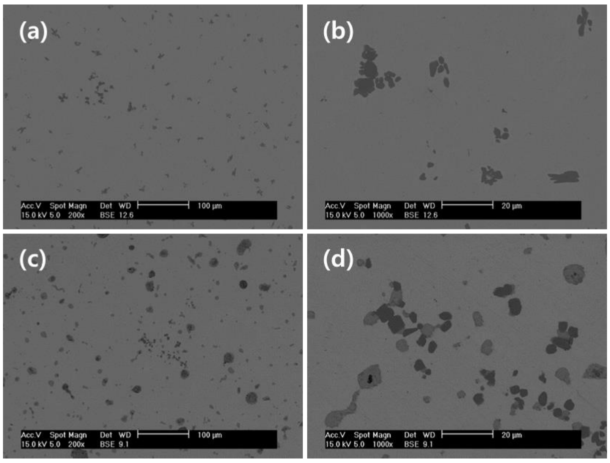

Fig. 3. Back-scattered electron cross-sectional micrographs of metallic fuel slugs; (a) X200, (b) X1000 magnification of U-10wt.%Zr, and (c) X200, (d) X1000 magnification of U-10wt.%Zr-5wt.%RE.

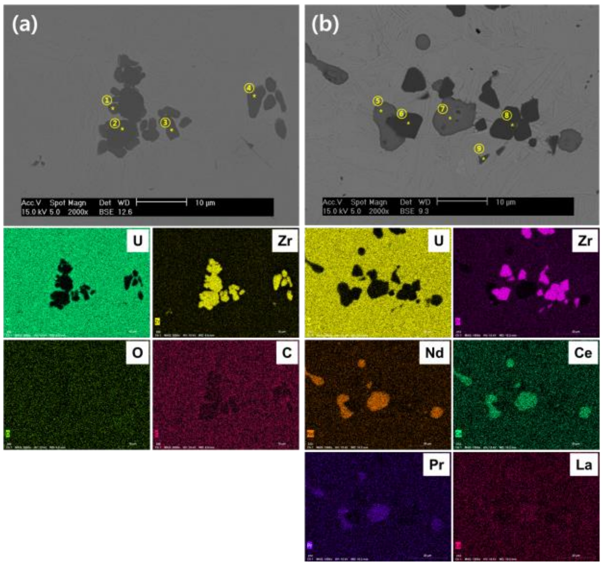

Fig. 4. BSE cross-sectional enlarged micrographs and EDS mapping images of metallic fuel slugs; (a) U-10wt.%Zr and (b) U-10wt.%Zr-5wt.%RE.

The compositions of the inclusions and matrix materials are presented in Table 1. The inclusions are consisted of Zr or Zr-rich phases in Fig. 4 (a). The light gray inclusions were detected as RE elements, and the dark gray inclusions were Zr element in Fig. 4 (b). The compositions of the RE inclusions were not similar to the input contents of the RE elemental lump. But, the composition of the inclusions shows similar tendency.

Table 1. Chemical compositions of U-10wt.%Zr, and U-10wt.%Zr-5wt.%RE metallic fuel slugs measured using EDX.

Element (wt.%)	U	Zr	Nd	Ce	Pr	La	C	O
(a) Matrix	91.6	6.7	–	–	–	–	1.7	–
#1	2.42	94.36	–	–	–	–	–	3.2
#2	–	84.8	–	–	–	–	13.4	1.8
#3	2.2	94.2	–	–	–	–	–	3.6
#4	1.8	94.7	–	–	–	–	–	3.5
(b) Matrix	91.3	8.7	–	–	–	–	–	–
#5	–	–	34.2	37.5	15.5	12.8	–	–
#6	–	100.0	–	–	–	–	–	–
#7	–	–	36.8	35.1	15.8	12.3	–	–
#8	–	96.8	–	–	–	–	–	3.2
#9	–	–	35.2	39.5	13.4	11.9	–	–

3. Conclusions

The U-10wt.%Zr and the U-10wt.%Zr-5wt.%RE metallic fuel slugs were fabricated using the injection casting method and their characteristics were analyzed.

The Zr inclusions are uniformly distributed in the U-10wt.%Zr metallic fuel slug, whereas the Zr inclusions are randomly observed in the U-10wt.%Zr-5wt.%RE metallic fuel slug. It is assumed that the uniformity of Zr inclusions was negatively affected by the RE content. The RE contents was much lower than the input contents of the RE elemental in the U-10Zr-5RE metallic fuel slug. The RE elements were not completely dissolved in the U-Zr fuel slugs, but a small amount of RE elements was distributed as inclusions in the U-Zr matrix. The RE inclusions were randomly dispersed in the U-Zr matrix.

REFERENCES

[1] L.C. Waters, Thirty years of fuels and materials information form EBR-II, J. Nucl. Mater 270 (1999) 39-48.

[2] D.C. Crawford, D.L. Poster, S.L. Hayes, Fuels for the sodium-cooled fast reactors: US perspective, J. Nucl. Mater 371 (2007) 202-231.

[3] J.H. Kim, H. Song, K.H. Kim, C.B Lee, J. Radioanal. Nucl. Chem. 301 (2014) 797-803.

[4] M. Sakata, M. Kurata, T. Hijikata, T. Inoue, J. Nucl. Mater 185(1991) 56-65.

[5] Y. Sakamura, H. Miyasiro, M. Sakata, T. Inoue, T. Matsumoto, TS. Strovick, CL. Krueger, LF. Grantham, JJ. Roy (1993) CRIEPI report T92012

[6] H.J. Maclean, S.L. Hayes, Proceedings of the International Conference on Advanced Nuclear Fuel Cycles and Systems (GLOBAL-2007), Boise, U.S.A., 2007, pp. 9-13.