Contamination Effects at the Edge of Fuel Slugs Depends on the Various RE Elements

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1. Introduction

Sodium-cooled Fast Reactor (SFR) has been considered as a candidate of the next generation reactor [1-2]. As a nuclear fuel for the SFR, the U-Zr alloys are investigated according to the advantage of safety, and economy [3]. In order to fabricate the recycled metallic fuel slug via pyroprocessing [4], researches for the addition of Rare-Earth (RE) elements in the U-Zr alloys are necessary [4-5]. However, previous researches for RE elemental effects in the metallic fuel slug were not enough to use the U-Zr-RE metallic fuel slug as a fuel of SFR [5-6].

In this research, the U-Zr-RE fuel slugs were investigated to demonstrate contamination effects depends on various contents of RE in the metallic fuel slugs. Microstructures at the edge of fuel slugs were analyzed to verify the edge contamination effect. The study of contamination effect depends on RE elements can be used to prevent the contamination by engineering and technical development of coating process.

2. Methods and Results

2.1 Experiments

The RE elemental bump was fabricated by arc melting of constituent materials. Target compositions of the RE elemental bump were 53 wt.% Nd, 25 wt.% Ce, 16 wt.% Pr , and 6 wt.% La, respectively. The fuel slugs were fabricated via injection casting which was modified by Korea Atomic Energy Research Institute (Fig. 1). U-10 wt.% Zr fuel slugs containing 1, 3, 5, 7, and 10 wt.% RE were prepared to verify the effect of RE component at the edge of the fuel slugs. Quartz tube was used as a mold of the injection casting. The quartz tube was slurry coated using yttria (Y_2O_3) to prevent contamination of the fuel slugs. In order to investigate the interfacial contamination between the quartz tube and fuel slugs, cross sectional microstructures of the fuel slugs was investigated using scanning electron microscopy (SEM). Compositions of the contamination layer were characterized by energy dispersive spectroscopy (EDS). The depth of the contamination layer was measured by the image analysis of the SEM microstructures.

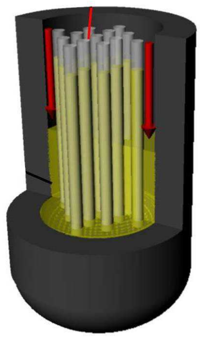


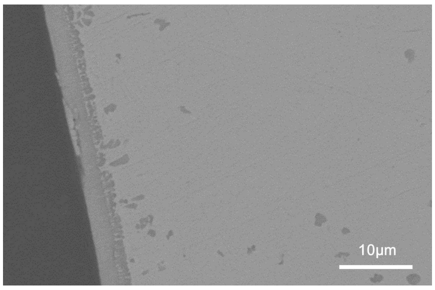
Fig. 1. Schematic of the modified injection casting.

2.2 Microstructures

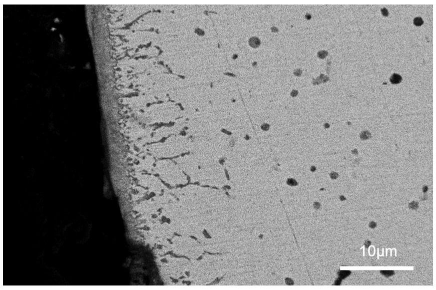
Figure 2(a) to 2(e) presents cross sectional SEM images at the edge of the fuel slugs containing various contents of RE. Although the quartz tube was slurry coated to prevent the contamination of fuel slugs by quartz tube, the microstructures demonstrate that there were contamination layers at the edge of the fuel slugs. It should be noted that the quartz tube was not coated by other deposition methods such as plasma spray coating but coated by slurry coating due to the high aspect ratio of the mold assembly.

Depth of the contamination layer was slightly increased depends on the contents of RE in the fuel slugs. The depth of the contamination layer at the edge of the U-10 wt.% Zr-1 wt.% RE fuel slug was less than 10μm (Fig. 2(a)), and that of the U-10 wt.% Zr-10 wt.% RE fuel slug was more than 30 μm (Fig. 2(e)). The contamination layer of the U-10 wt.% Zr-1 wt.% RE fuel slug was primarily formed by zirconium and silicon which was measured via EDS line scanning (Fig. 3(a)). This indicates that zirconium was agglomerated at the edge of the fuel slugs, and a few micrometers thick of silicon contaminated the edge. On the contrary, contamination layer of the fuel slug containing 7 wt.% RE was mainly composed of silicon, yttrium, zirconium, and RE elements; Ce, Nd, and Pr, which indicates that the edge of the fuel slug was contaminated by the quartz tube mold and the yttria, coating material. Moreover, the zirconium and RE elements were also agglomerated at the edge of the fuel slugs, simultaneously. The yttria component was not uniform at the edge of the fuel slugs which indicates that a few coating layer was detached on the mold assembly and contaminated the fuel slugs.

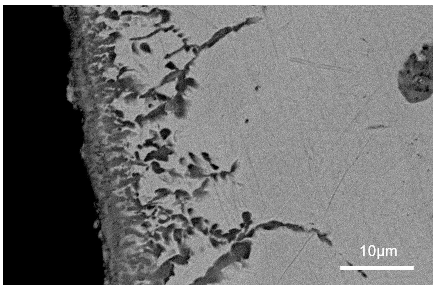
Meanwhile, the fuel slugs assumed to be penetrated by mold material, silicon, because of the composition of the contamination layers. A recent study by Kim *et al.* demonstrated that the interaction between fuel slugs and crucible was affected by the contents of RE due to the reactivity of the RE elements [7]. Likewise, inter-diffusion between fuel slugs and quartz tube was definitely influenced by the contents of RE according to the reactivity of the RE elements.



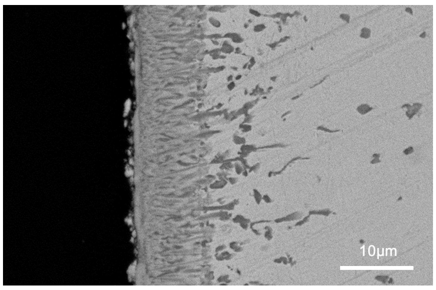
(a)



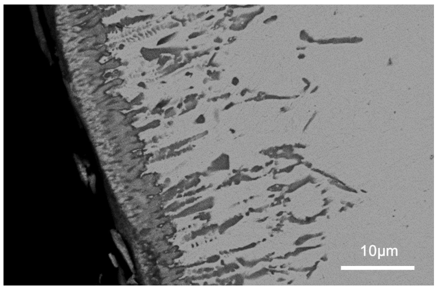
(b)



(c)

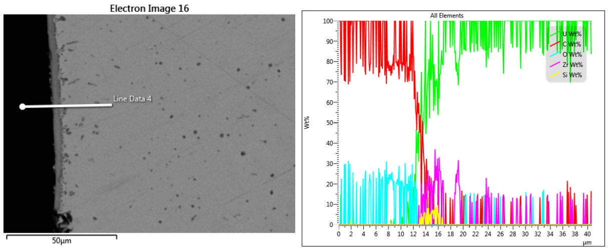


(d)

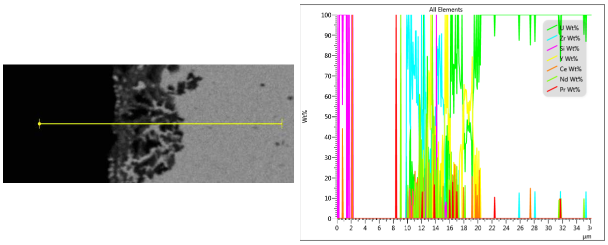


(e)

Fig. 2. Edge of the cross sectional microstructures of the fuel slugs containing (a) 1 wt.%, (b) 3 wt.%, (c) 5 wt.%, (d) 7 wt.%, and (e) 10 wt.% RE elements, respectively.



(a)



(b)

Fig. 3. EDS line scanning of the fuel slugs containing (a) 1 wt.%, and (b) 7 wt.% RE elements, respectively.

3. Conclusions

The zirconium and RE elements were agglomerated at the edge of the fuel slugs. Si coating layer was detached on the mold assembly and contaminated the fuel slugs. The mold material, silicon, penetrated the fuel slugs. The zirconium and silicon was primarily formed at the edge of the fuel slugs containing 1 wt.% RE elements. In contrast, contamination layers of the fuel slugs containing 7 wt.% RE were mainly composed of silicon, yttrium, zirconium, and RE elements, simultaneously. The depth of the contamination layers was slightly increased depends on the contents of RE in the fuel slugs. Likewise, not only the composition but also the depth of the contamination layers at the edge of the fuel slugs were strongly affected by the contents of RE in the fuel slugs.

Acknowledgement

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REFERENCES

[1] DoE, U.S. et al., A Technology Roadmap for Generation IV Nuclear Energy Systems, Generation IV International Forum, 2002
[2] Uranium O.E.C.D., Resources, Production and Demand, OECD NEA publication, Vol. 6891, p. 456, 2009
[3] G.L. Hofman, L.C. Walters, T.H. Bauer, Metallic Fast Reactor Fuels, Progress in Nuclear Energy Vol. 31, p. 83–110, 1997
[4] T. Inoue, L. Koch, Development of Pyroprocessing and Its Future Direction, Nuclear Engineering and Technology Vol.40 p. 183–190, 2008
[5] J.H. Kim, H. Song, K.H. Kim, C.B. Lee, Fabrication and Evaluation of Rare-earth-bearing Fuel Slugs for Sodium-cooled Fast Reactors, Journal of Radioanalytical Nuclear Chemistry, Vol. 303, p. 615–621, 2015
[6] J.H. Kim, H. Song, K.H. Kim, C.B. Lee, Fabrication of Uranium Alloy Fuel Slug for Sodium-cooled Fast Reator by Injection Casting, Journal of Radioanalytical Nuclear Chemistry Vol. 301 p. 797–803, 2014
[7] J.H. Kim, H.T. Kim, K.H. Kim, C.B. Lee, Interaction Phenomena between ceramic coatings and liquid uranium alloys, Journal of Radioanalytical Nuclear Chemistry Vol. 300, p. 1245–1251, 2014