

Development of Reusable Casting Parts for Metallic Fuel Fabrication Process

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1. Introduction

Lanthanides(Ln) containing U-Zr based alloys are investigated as a surrogate of the transuranium (TRU) metallic fuel system. Injection casting method is a candidate to fabricate the U-Zr-Ln metallic fuel for fast reactors [1-2]. In order to secure profitability of the TRU metallic fuel for the fast reactors, it is necessary to control losses of the fuel and to reduce used casting parts as radioactive wastes during casting process. Reaction prevention reusable casting parts can be a solution for those two critical issues of the casting process. Because, crucibles and molds for the casting procedure were interacted with melt during casting and were not reusable after the casting. The used crucibles and molds were considered as radioactive wastes. Moreover, nuclear materials, which were interacted with the casting parts, were not removable from the used casting parts and amounts of the loss reduced casting yields. Therefore, it is necessary to replace the casting parts for interaction protection casting parts.

In this research, candidates of interaction protection materials of the casting parts were studied to reduce radioactive waste and to control the nuclear materials. Interaction behavior of the casting part candidates were evaluated after sessile drop test and injection casting, respectively. Ln materials containing U-Zr base alloys were investigated as a surrogate of the TRU fuels. Because the Ln materials containing U-Zr alloys were highly reactive with casting parts due to the highly reactive Ln materials with the casting parts.

2. Methods and Results

2.1 Experiments

Ln materials were molten in an arc-melting chamber to prepare the lanthanide elemental rods for a mother alloy of the U-Zr-Ln alloys. Target compositions of the Ln materials mother alloy was 53 wt.% Nd, 25 wt.% Ce, 16 wt.% Pr, and 6 wt.% La, respectively. Uranium ingots, zirconium sponges, and the Lns mother alloy were prepared to charge into the crucible of the casting chamber, respectively. Target composition of the fuel slugs were 85 wt.% U-10 wt.% Zr-5 wt.% Ln. Quartz molds for the casting were sand blasted to enhance adhesion between ceramic coating layer and mold. The sand blasted quartz molds were slurry coated by Y_2O_3 to prevent interaction between the mold and alloys. Y_2O_3 slurry coated Graphite molds were also prepared as a reusable casting parts.

ED-4 grade graphite crucibles were fabricated by IBIDEN graphite Co., Ltd.. Because thermal expansion coefficient(CTE) of the grade, $6.5 \times 10^{-6}/^{\circ}C$, is higher than that of other grade graphite, which is more similar value to the CTE of candidate ceramic materials, La_2O_3 ($8\sim 10.5 \times 10^{-6}/^{\circ}C$ at $162 \sim 924^{\circ}C$)[3], Y_2O_3 (8 wt.%) stabilized ZrO_2 (8-YSZ) ($10.5 \times 10^{-6}/^{\circ}C$)[4] and Y_2O_3 ($8.0 \times 10^{-6}/^{\circ}C$)[5]. The graphite crucibles were degassed and Ar gas was charged into the chamber during heating to prevent oxidation. Thickness of each candidate ceramic liner, $LaYO_3$, YSZ-8, and Y_2O_3 , was 2mm(Fig. 1). Diameter of the ceramic liners was designed to fit for the inside of graphite crucibles. Fabricated fuel slugs were investigated to evaluate reaction behavior. Melt residues and molds were also investigated after casting to demonstrate reaction between crucibles and melt. Fabricated fuel slugs were cut for 0.6 to 1.0 cm thick by sawing machine to use melt samples for sessile drop test.

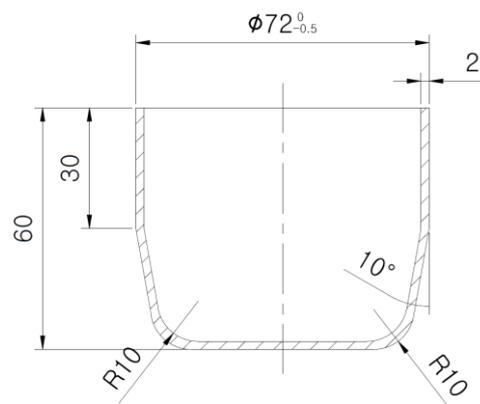


Fig. 1. Cross Sectional Drawing of Ceramic Liners

Interaction behavior of candidate liner materials were investigated by the sessile drop test. $LaYO_3$, 8-YSZ, and Y_2O_3 samples were set on an alumina tube and the melt samples were on each sample. The alumina tube was transferred to the uniform temperature zone of a tube furnace, annealed up to $1450^{\circ}C$, and hold for 1 hour. Heating rates of the experiments were $10^{\circ}C/min$. Interaction investigated samples were analyzed using scanning electron microscopy (SEM) to demonstrate matrix contamination and penetration depth into the protection layers. The compositions of the specimens were characterized using energy dispersive spectroscopy (EDS).

2.2 Interaction prevention ceramic liner development

Y_2O_3 coated quartz molds and graphite molds were charged into the casting chamber to demonstrate reusability of the molds (Fig. 2). Each molds were not fully damaged after casting, but microscopic crack was observed at bottom of the quartz mold which was submerged into the U-Zr-Ln melt. It indicates that the quartz mold was difficult to recycle due to the damaged bottom parts. The fuel slug in the quartz mold was not interacted with quartz mold so the fuel slug was removed without cut the quartz mold. This indicates that control of the submerged bottom part damage is a key to reuse the quartz mold.

Meanwhile, the graphite mold was not damaged after casting as shown in below parts of figure 2. However, a fuel slug in the graphite mold was interacted with the mold. Because thickness of the slurry coated Y_2O_3 was in the graphite mold was not enough though it did in the quartz mold. Moreover, lubrication effect of the thin slurry coated Y_2O_3 was not enough to remove the fuel slug from the mold. Although, the mold and the fuel slug was not attached to each other, they were forced to cut the mod to remove the fuel slug.



Fig. 2. Y_2O_3 coated quartz mold (above molds) and graphite mold (below molds) after casting

2.3 Reusable crucible material development

Interaction protection characteristic of $LaYO_3$, 8-YSZ, and Y_2O_3 coupons were investigated as candidate of crucible liner materials by sessile drop test. Sintering process to make coupons were changed from microwave sintering to cold isostatic pressing(CIP)/sintering and spark plasma sintering(SPS) method, respectively. Densities of the $LaYO_3$ and 8-YSZ materials were increased to $5.85 \sim 5.95 \text{ g/cm}^3$ for enhanced reaction prevention characteristic by the sintering method changes (Fig. 3).

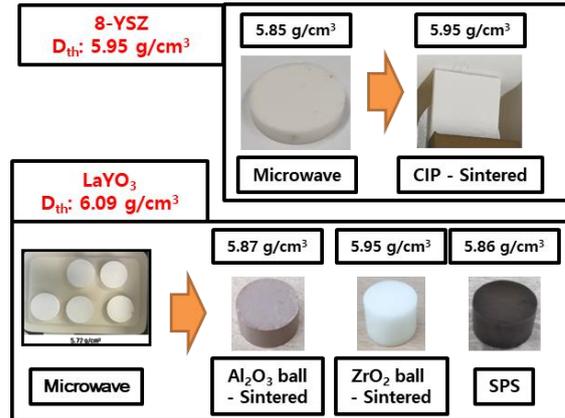


Fig. 3. 8-YSZ and $LaYO_3$ fabrication sintering method change and enhanced density after fabrication

Interaction between Y_2O_3 , $LaYO_3$, and 8-YSZ coupons and U-Zr-Ln melt were investigated by sessile drop test. Interaction thickness between the coupons and U-Zr-Ln melt was decreased significantly as shown in figure 4. Interaction thickness of Y_2O_3 , conventional crucible coating material, was $50 \mu\text{m}$. On the other hand, interaction thickness of $LaYO_3$ and 8-YSZ was 20 and $2 \mu\text{m}$, respectively. The values indicate that interaction thickness was decreased from 2.5 to 25 times than conventional interaction protection layers.

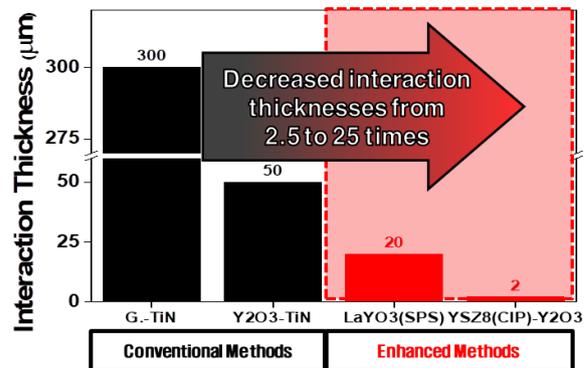


Fig. 4. Cross sectional SEM microstructures of the sessile drop tests for (a) Y_2O_3 coated and (b) YSZ (8wt.% Yttria) interaction prevention layers

3. Conclusions

Interaction protection behavior of casting parts were investigated to reduce radioactive wastes and to increase yields of the U-Zr-Ln metallic fuel casting process. Quartz mold for the casting process was sand blasted and coated by Y_2O_3 . There was fine crack at the submerged bottom part of the quartz but other part was not damaged after casting. Moreover, fuel slugs in the quartz mold was removed easily. Meanwhile, graphite mold was not damaged after casting. Although the mold and the fuel slug was not attached to each other, fuel slug in the graphite mold was not possible to remove without cutting the mold. Density of $LaYO_3$ and Y_2O_3 ceramic coupons was increased to enhance interaction

protection behavior of the materials. Interaction between Y_2O_3 , $LaYO_3$, and 8-YSZ coupons and U-Zr-Ln melt were investigated by sessile drop test. interaction thickness of candidate materials was decreased from 2.5 to 25 times than conventional interaction protection layers.

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