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Loss control of casting methods for metallic fuel fabrication

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1. Introduction

Rare-Earth(RE) containing U-Zr based alloys are investigated as a surrogate of the transuranium (TRU) metallic fuel system. Injection casting is a candidate for a fabrication method of the U-Zr-RE metallic fuel for fast reactors [1-2]. In order to control losses of nuclear materials and to reduce radioactive wastes during casting, reusable casting parts are being developed and re-casting of the melt residues are being attempted as well. Crucibles and molds for the casting procedure were interacted with melt during the injection casting and were not reusable after casting. Used crucibles and molds were considered as radioactive wastes. Moreover, reacted nuclear materials were not removable from parts and amounts of the reaction reduced casting yields.

Meanwhile, reacted melt residues were contaminated from crucibles and oxidized by air, and materials were not reusable without surface treatment. Surface contaminated region of the melt residues were not only increase the contamination factor of the melt residues but also decrease casting yields [3]. Moreover, floating RE elements are highly oxidized in the air and increase the region of oxidation after casting [4]. These issues increase losses of the nuclear materials and decrease yield of the casting process.

In this research, interaction protection layers of the casting parts are studied to reduce radioactive waste and to control the nuclear materials. RE containing U-Zr base alloys are investigated to demonstrate RE effect of the metallic fuels. Because the RE containing U-Zr alloys are highly reactive with crucible during casting. Enhanced reaction prevention layers were investigated to reduce the reaction between melt and the casting parts. In order to reuse the melt residue, surface contamination regions of the residue were removed mechanically. Chemical surface contamination removal processes of the melt-residue are wet processes and are not allowed for pyro-processed TRU fuel, but the mechanical removal processes are dry processes and are allowed for the material. The U-Zr-RE alloys are surrogate of the pyro-processed fuel, so the dry processes are appropriate as cleaning processes of the surrogate materials.

2. Methods and Results

2.1 Experiments

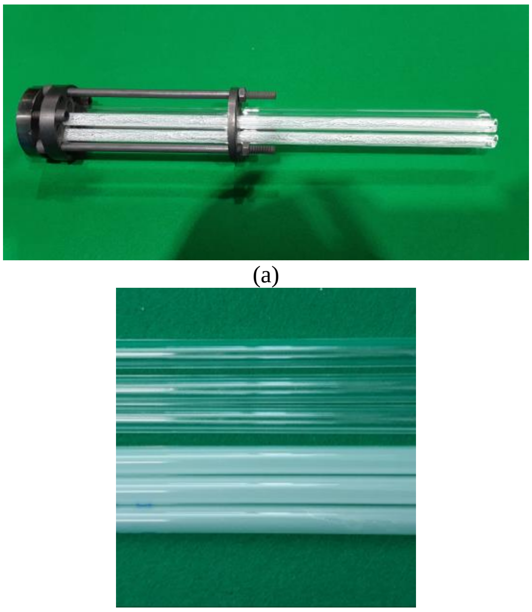
Lanthanides were molten in an arc melting chamber to prepare RE elemental rods for a mother alloy of RE elements. Target compositions of the RE mother alloy was 53 wt.% Nd, 25 wt.% Ce, 16 wt.% Pr, and 6 wt.% La, respectively. Depleted uranium ingots, zirconium sponges, and the RE mother alloys were respectively prepared to charge into the crucible of the casting chamber. Target composition of the fuel slugs were 85 wt.% U-10 wt.% Zr-5 wt.% RE. Quartz mold for the casting was sand blasted to enhance adhesion between ceramic coating layer and mold. The sand blasted quartz mold was slurry coated by Y_2O_3 or ZrO_2 to prevent interaction between the mold and alloys. The crucible was degassed and Ar gas was charged into the chamber during heating to prevent oxidation. Fabricated fuel slug was investigated to evaluate reaction behavior. Melt residues and molds were also investigated after casting to demonstrate reaction between crucible 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. Two different reaction prevention layers were investigated by the sessile drop test. Each of the samples was set on an alumina tube and the melt samples were on each sample. The alumina tube was transferred at the uniform temperature zone of a tube furnace, and annealed up to 1450 ℃, and hold for 5min. Heating rates of the experiments were 20 ℃/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).

Surface contamination of the melt residues and fuel slugs were removed mechanically. In order to charge into a crucible, the melt residues and fuel slugs were cut appropriately, and charged into a crucible. Charged samples were re-cast for the same condition of the inert ingot casting method. Cast fuel slugs and melt residue was analyzed to investigate contamination level of the melt residue and fuel slugs using SEM/EDS.

2.2 Interaction control of the casting mold

Y_2O_3 coated, ZrO_2 coated and uncoated quartz molds were charged into the casting chamber to compare coating effects for interaction behavior (Fig. 1(a)). Figure 1(b) is the comparison between as fabricated quartz molds and sand blasted quartz molds. Average surface roughness of the sand blasted quartz molds were increased from 0.165 kN/m to 0.480 kN/m. Increased surface roughness of the quartz molds enhanced adhesion of the Y_2O_3 and reduced interaction between the mold and the metallic fuel. Figure 2 is the comparison results of the Y_2O_3/ZrO_2 slurry coated/sand blasted quartz molds and fuel slugs after casting. Fuel slugs, which were fabricated using sand blasted quartz molds were less contaminated than the fuel slugs which were fabricated using as fabricated quartz mold (Fig. 2).



(a)

(b)

Fig. 1. (a) Y_2O_3 coated and uncoated quartz molds, and (b) as fabricated quartz molds (above quartzs) and sand blasted quartz molds (below quartzs) to compare interaction behavior between quartz molds and the metallic fuel.

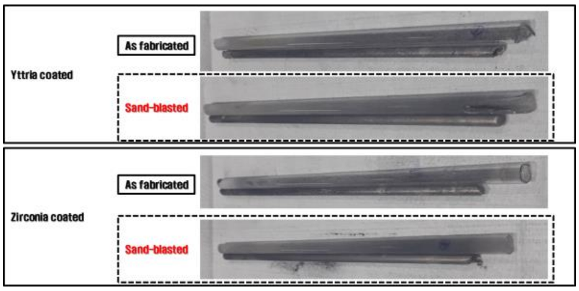
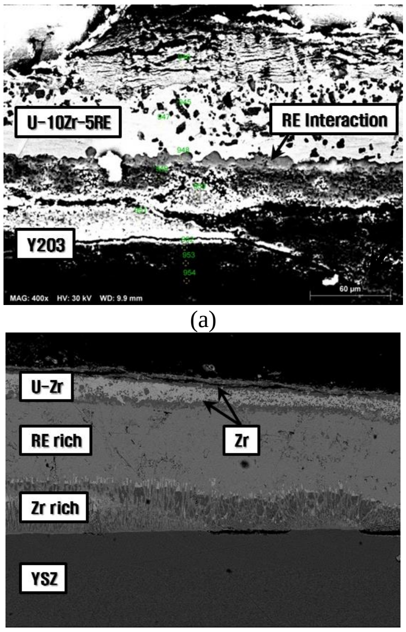


Fig. 2. Comparison of the Y_2O_3/ZrO_2 slurry coated/sand blasted quartz molds and fuel slugs after casting.

2.3 Reusable crucible material development

Y_2O_3 and YSZ (8 wt.% Yttria stabilizer) were attempted respectively as an interaction prevention layer of the casting crucibles. The materials were sessile drop tested before it melts by casting process and cross sections of the results were analyzed using SEM. Both of the materials prevent interaction between the protection layers and melt, but the melt of the YSZ (8 wt.% Yttria stabilizer) sample was contaminated by the coating layers. Zirconium of the coating layer was penetrated into the melt was separated (Fig. 3).



(a)

(b)

Fig. 3. Cross sectional SEM microstructures of the sessile drop tests for (a) Y_2O_3 coated and (b) YSZ (8wt.% Yttria) interaction prevention layers

2.4 Surface treatment of the melt residues

Surface of cast melt residues and fuel slugs were treated to reduce re-casting contamination level of the materials. The surface was removed mechanically by blasting because the method is not a wet type treatment and is appropriate for the treatment method of the TRU materials (Fig. 4). Amount of losses for the treatment was less than 10 g, and almost all the slurries were collected to control the loss materials. Re-casting material was not contaminated, and fuel slugs were fabricated successfully.

(a) (b)

Fig. 4. Images of the surface treated (a) melt residues and (b) fuel slugs

3. Conclusions

Loss control of U-10Zr-RE metallic fuel was attempted to reduce radioactive wastes and to increase yields of the fuel. First, Quartz mold for the casting process was sand blasted and coated by Y_2O_3 and ZrO_2 respectively. The sand blasting was affective to increase adhesion and of the coating materials and uniformity of the coating layers. Second, reusable crucible materials were developed and Y_2O_3 and YSZ (8 wt.% Yttria stabilizer) candidate as a crucible-melt reaction prevention layers. Both of the layers were protected the reaction but nuclear material on the YSZ protection layer was contaminated after sessile drop test. Lastly, Melt residues and fuel slugs after casting were treated to reduce contamination level of the re-casting materials. Treated materials were re-cast and fuel slug was successfully fabricated. Reaction between casting parts and melt was reduced, and melt residues were treated and re-cast successfully.

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