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Enhanced Casting Procedure to Improve Casting Yield and to Reduce Radioactive Wastes

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1. Introduction

The injection casting procedure is one of the most promising procedures used to fabricate fuel slugs for fast reactors [1-2]. U-Zr based alloys are investigated to improve the safety and economy of the metallic fuel system. It is appropriate for recycled fuel to improve the thermal conductivity. Therefore, it is necessary to investigate Rare-Earths (REs) including U-Zr alloys, to research surrogates of recycled fuel ingots. The RE including U-Zr alloys are highly reactive to interact with a crucible during casting. Therefore, casting crucibles were coated using yttrium oxide to prevent interactions between a crucible and the coating layer. However, the coating layer of previous research was easily damaged and detached during heating [3].

In this research, enhanced U-Zr-RE fuel slug fabrication systems were investigated to demonstrate contamination during casting. The casting chamber and crucibles were degassed using a diffusion pump of the casting machine. The degassing time and temperature were controlled to improve the inert air condition of the chamber. Ar gas was charged in the chamber to prevent oxidation of the material during heating. Microstructures at the edge of the melt-residue were analyzed to verify the improved casting condition system. Control of the casting condition can be used not only to protect the crucible coating layers, but also to prevent the RE oxidation effects during heating by the engineering and technical development of the system. Moreover, the improved casting procedure can increase casting yields and can reduce radioactive wastes during casting.

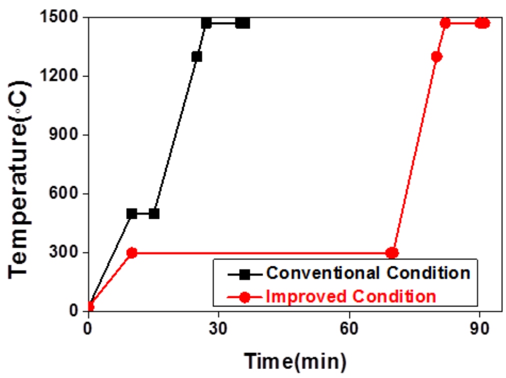
2. Methods and Results

2.1 Experiments

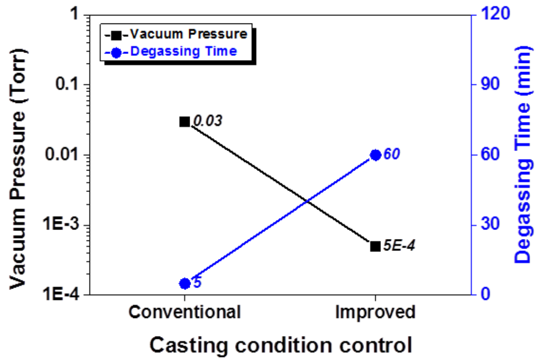
Each of the RE elements was molten in a chamber using an arc melting system to prepare RE elemental rods. The target compositions of the RE elemental rods were 53 wt.% Nd, 25 wt.% Ce, 16 wt.% Pr , and 6 wt.% La. A depleted uranium ingot and zirconium sponges were also prepared to cast fuel slugs. Fuel slugs were fabricated by enhanced injection casting [4]. Target compositions of the fuel slugs were 85 wt.% U-10 wt.% Zr-5 wt.% RE. Y_2O_3 slurry coated quartz tubes were used as a mold of the injection casting. Y_2O_3 was coated on the crucible to prevent interactions between crucibles and melt using a plasma spray coating method. The thickness of the crucible coating layer was 150 µm thick. The crucible was degassed and Ar gas was charged into the chamber during heating to prevent oxidation. Casting conditions were controlled to improve the interaction behavior between crucibles and melt. The coating layers and melt residues were investigated using scanning electron microscopy (SEM). The compositions of the specimens were characterized using energy dispersive spectroscopy (EDS).

2.2 Casting conditions

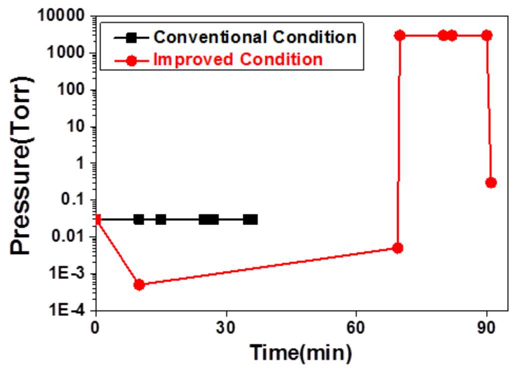
Four different casting factors were controlled as follows (Fig. 1). First, the degassing temperature was decreased from 500 ℃ to 300 ℃ during heating. Although degassing at high temperature can decrease trapped gasses, RE is a material who oxidized easily on high temperature. The previous degassing condition was controlled at 500 ℃, and the RE was highly oxidized during degassing process. It indicates that decreasing the degassing temperature is necessary to reduce RE oxidation. Degassing time is a factor which can improve degassing effect easily. Therefore, degassing time was increased from 5 min to 60min to improve degassing effect, secondly. Third, the vacuum pressure of the chamber was changed from 3 x 10^(-2) Torr to 4 x 10^(-5) Torr using a diffusion pump. The improved vacuum pressure could enhance the degassing procedure. Fourth, Ar was charged after the degassing procedure, at 300 ℃. And the charged Ar was purged for 60 seconds right before casting. The improved casting conditions prevent interactions during casting.



(a)



(b)



(c)

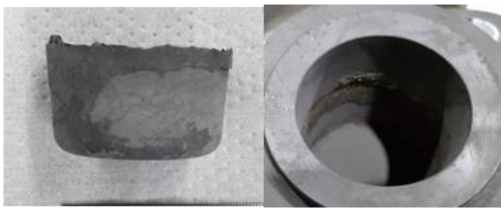
Fig. 1. Previous and improved factors of the casting conditions. Comparison of the (a) casting time and temperature, (b) vacuum pressure, and (c) Ar charging and purging conditions during heating progress.

2.3 Microstructures

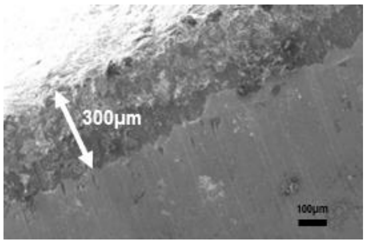
The coating layer was detached from the crucible and contaminated the side wall of the melt residue after casting using the previous conditions (Fig. 2(a), (b)). The coating layer interacted with the crucible, and remained on the wall (Fig. 2(c)). This indicates that the coating layer was not possible to be re-used, and the crucible is a radioactive waste. The side and top of the melt residue was contaminated severely. All of the contaminated layers on the melt residue were necessary to remove for the re-using of the melt residue.

On the contrary, the coating layer remaining on the crucible and side wall of the melt residue was not contaminated after casting with the enhanced casting conditions (Fig. 3(a), (b)). The microstructure of the side wall (Fig. 3(c)) indicates that no coating layers were attached to the side wall of the melt-residue. The remaining coating layer means that the crucible can be re-used and is not a radioactive waste anymore. Besides, the side wall of the melt residue is not necessary to treat for the re-using of the melt residue due to the not contaminated surfaces.

Meanwhile, the coating layer at the bottom of the crucible did not remain owing to the RE interaction. As a surrogate of a fast reactor, the material of the U-Zr-RE insert RE elements in the crucible individually, the preferentially molten RE heavily react with coating layers at the bottom of the crucible. Because, the melting temperatures of the Nd, Ce, Pr, and La (compositions of the RE elements) are 1,024 ℃, 795 ℃, 935 ℃, and 920 ℃, respectively, whereas that of the U-10Zr alloy was 1,300 ℃. However, the RE elements in the feedstock materials of the fast reactor are not stands alone. It indicates that the issue is easily controlled for the casting of the pre-alloyed feedstock materials.



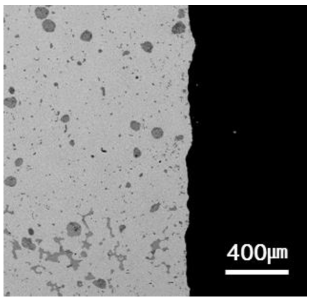
(a) (b)



(c)

Fig. 2. (a) Photographs of the melt residue and (b) crucible, and (c) a microstructure of the coating layer after casting with previous conditions.

(a) (b)



(c)

Fig. 3. (a) Photographs of the melt residue and (b) crucible, and (c) a microstructure of the coating layer after casting with improved conditions.

3. Conclusions

Four different casting conditions, temperature, time, vacuum pressure, and Ar charging, were controlled to reduce the interaction between crucible coating layers and melts. The coating layer remained from the side wall of the crucible, and the side wall of the melt residue was not contaminated after casting with improved conditions. The coating layer at the bottom of the crucible was detached, but the issue is able to be improved easily by a charging of the pre-alloyed surrogate feedstock materials. Increasing the casting yields and decreasing radioactive wastes were researched by enhanced casting procedures.

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