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Investigation of Reusable Crucibles on Uranium Casting by Injection Method

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1. Introduction

Traditionally, to prevent the interactions between melt and material, metallic nuclear fuels, such as the U–Zr alloy proposed for sodium cooled fast reactors (SFR), have been melted and cast in graphite crucibles and quartz molds with a slurry coating. Application of these coatings in a hot cell environment is labor-intensive and operator dependent, and can introduce additional waste streams. In addition, melt/coating interactions and porous coatings can be a source of melt contamination and fuel losses, respectively. Furthermore, slurry applied coatings must be recoated after every batch. Thermal plasma-sprayed coatings of refractory materials can be applied to develop a re-usable crucible coating for metallic fuel. Plasma-sprayed coating can provide a crucible with a denser, more durable, coating layer, compared with the more friable coating layer formed by slurry-coating. Plasma-sprayed coatings are consolidated by mechanical interlocking of the molten particles impacting on the substrate and are dense from the heat applied by the plasma [1]. Although the protective layer is more difficult in a dense coating than in a porous coating, the increased coating density is advantageous because it should not require frequent recoating or U–Zr melt penetration [2-6]. In this study, we used a Vacuum Plasma Spray (VPS) method, which is suitable to prevent oxidization and has a number of advantages such as low defect density and excellent adhesion of the coating layer, to investigate permanent coatings for re-usable crucibles for melting and casting of metallic fuel. After coatings, interaction studies between molten U–Zr alloys and the plasma sprayed coatings were also carried out.

2. Methods and Results

For further investigation to apply a real reusable crucible, the injection casting experiments of U-10wt.%Zr and U-10wt.%Zr-5wt.%RE fuel slugs have been performed in real graphite crucibles with plasma-spray coating. Based on the results from the interactions with U-10Zr and U-10Zr-5RE melt, the TaC(100)-Y_2O_3(100) plasma-sprayed coating methods have been applied to graphite crucibles. Injection casting experiments of U-10wt.%Zr and U-10wt.%Zr-5wt.%RE fuel slugs were then performed to investigate the feasibility of the re-use in the plasma-spray coated graphite crucibles. The general appearance of the metallic fuel slug was smooth and the length was about 250mm after injection casting. As shown in Fig. 1, the surface of the slug was smooth, and the roughness was a little coarse at the lower region. The gamma-ray radiography of the as-cast slug was performed to detect internal defects such as cracks and pores. Internal pores were not detected in the slugs, and thus, the internal integrity of the as-cast slugs was generally believed to be satisfactory.

The coated graphite crucible after injection casting is shown in Fig. 2. The inner surface of the crucible was smooth, and the residue in the graphite crucible separated from the graphite crucible after injection casting. This indicates no reaction layer formation or penetration of U-Zr melt into the coating indirectly. The graphite crucible is reused to fabricate U-10wt.% fuel slug after being cleaned with a brush.

The surface U-10wt.%Zr slug fabricated by injection casting with the re-used graphite crucible was smooth, and the roughness was a little coarse at the lower region, which was similar to the previous result. Internal pores were not detected in the slug from the analysis of gamma-ray radiography like the previous result. The inner surface of the re-used graphite crucible was smooth and the residue in the graphite crucible also separated from the graphite crucible after injection casting (Fig. 3). This means no reaction layer formation or penetration of U-Zr melt into the coating.

The result after interaction of U-Zr-RE melt with coated graphite was similar to that after interaction of U-Zr melt. The general appearance of the metallic fuel slug was smooth and the length was about 250mm after injection casting with coated graphite crucible. Generally, the surface at the upper and middle regions of the slug was smooth, and the roughness was a little coarse at the lower region. Fig. 4 shows the representative U-Zr-RE fuel slug after injection casting with coated graphite crucible.

The graphite crucible coated with TaC/Y_2O_3 after injection casting is shown in Fig. 11. The inner surface of the crucible was smooth (Fig. 5(a)) and the residue in the graphite crucible separated from the graphite crucible after injection casting (Fig. 5(b)). Accordingly, TaC(100)-Y_2O_3(100) plasma-sprayed coatings were thought to be promising candidate coating materials for a reusable graphite crucible to fabricate metallic fuel for an SFR.

Fig. 1. U-10wt.%Zr metallic fuel fabricated by injection casting with the coated graphite crucible.

Fig. 2. The TaC/ Y2O3 coated graphite crucible (a), and the residue in the graphite crucible after injection casting (b).

Fig. 3. The re-used graphite crucible coated with TaC/ Y_2O_3 after injection casting (a), and the residue in the re-used graphite crucible after injection casting (b).

Fig. 4. U-10wt.%Zr-5wt.%RE metallic fuel fabricated by injection casting with the coated graphite crucible.

Fig. 5. Fraction of counts lost with voltage and charge sensitive preamplifiers as a function of the true count rate.

3. Conclusions

We summarized the results of the coating methods. All coated samples maintained good coating integrity in a U-Zr melt, but most of the coating method samples did not maintain integrity in the U-Zr-RE melt because of the cracks or microcracks of the coating layer, presumably formed from the thermal expansion difference. Only the TaC(100)-Y_2O_3(100) DL VPS coated rod survived the 2 cycles dipping test of U-Zr-RE melt. This is likely caused by good adhesion of the TaC coating onto the niobium rod and the chemical inertness of Y_2O_3 coating material in the U-Zr-RE melt. Based on the results from the interactions with U-10Zr and U-10Zr-5RE melt, TaC(100)-Y_2O_3(100) plasma-sprayed coating methods have been applied to real graphite crucibles. Injection casting experiments of U-10wt.%Zr and U-10wt.%Zr-5wt.%RE fuel slugs were then performed to investigate the feasibility of the re-use in the plasma-spray coated graphite crucibles. The graphite crucibles plasma-spray coated with double-layered TaC(100)-Y_2O_3(100) showed a sound state without an interaction layer after injection casting of U-Zr fuel slug up to 2 cycle runs, and showed a sound state without an interaction layer after 1 cycle injection casting of a U-Zr-RE fuel slug.

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