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Study on coating layer of ceramic materials for SFR fuel slugs

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1. Introduction

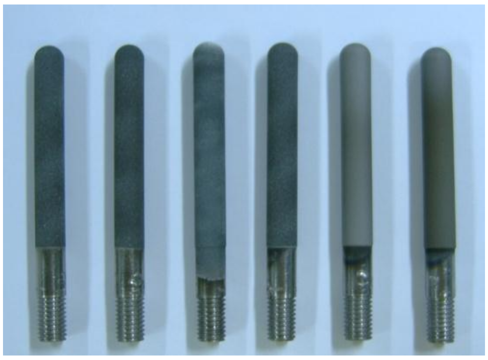
Traditionally to prevent melt/material interactions metallic fuels, such as the U-Zr/U-TRU-Zr fuels for the SFR, have been melted and cast in slurry-coated graphite crucibles and slurry-coated quartz molds. Application of these coatings in a hot cell environment is labor-intensive and operator-dependent, and can introduce additional waste streams. Also, coating reaction and porous coatings can be a source of melt contamination and fuel losses, respectively. Thermal plasma-sprayed coatings of refractory materials can be applied to develop a re-usable crucible coating for metallic fuel. The plasma-sprayed coating can provide the 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 by the heat applied by the plasma [1].

The objective of this study is to develop a coating method and material for crucibles to prevent material interactions with the U-Zr/U-TRU-Zr fuels. Reducing these interactions will result in a fuel loss reduction. According to coating and U-Zr interaction results preformed in previous experience[2,3], Y_2O_3, TiC, and TaC coating materials were selected as promising coating materials Various combinations of coating conditions such as; coating thickness, double multi-layer coating methods were investigated to find the bonding effect on the substrate in pursuit of more effective ways to withstand the thermal stresses.

2. Methods and Results

The substrate was 99.8% pure niobium materials with a diameter of 10 mm. A plasma spray method was used to apply an approximately 100μm thick coating to the 10 mm diameter niobium rods. TaC, TiC, and Y_2O_3 powders, ranging from 10μm to 45μm in size, were vacuum plasma-sprayed (VPS) with a protective atmosphere or atmosphere plasma-sprayed (APS) onto the substrates.

Coating group is composed of a total 6 different coating methods. The coating method I and the method II are the single layer (SL) coating methods. The coating method I is the Y_2O_3 coating with the coating thickness of about 75μm in the Nb rod. The coating method II is the Y_2O_3 coating with the coating thickness of about 125μm. The coating method III is the double-layer(DL) coating with TaC and Y_2O_3 powders, which consists of vacuum plasma-sprayed(VPS) TaC bond coating with the coating thickness of 100μm onto niobium rod and atmosphere plasma-sprayed(APS) Y_2O_3 coating with the coating thickness of 100μm on the top of the bond coating layer. The coating method IV is the double-layer coating with TaC and Y_2O_3 powders, which consists of vacuum plasma-sprayed TaC bond coating with the coating thickness of 100μm onto niobium rod and vacuum plasma-sprayed Y_2O_3 coating with the coating thickness of 100μm on the top of the bond coating layer. The coating method V is the double-layer coating with Y_2O_3 and TaC powders, which consists of vacuum plasma-sprayed Y_2O_3 bond coating with the coating thickness of 100μm onto niobium rod and vacuum plasma-sprayed TaC coating with the coating thickness of 100μm on the top of the bonding coating layer. The coating method VI is the double-layer coating with Y_2O_3 and TiC powders, which consists of vacuum plasma-sprayed Y_2O_3 bond coating with the coating thickness of 100μm onto niobium rod and vacuum plasma-sprayed TiC coating with the coating thickness of 100μm on the top of the bond coating layer. Fig. 1 showed the plasma-coated Nb rods with coating group.



(a) (b) (c) (d) (e) (f)

Fig. 1. Plasma-coated Nb rods, sprayed with (a) Y_2O_3 (75 ㎛), (b) Y_2O_3 (125 ㎛), (c) TaC/ Y_2O_3, (d) TaC/ Y_2O_3, (e) Y_2O_3/TaC, and (f) Y_2O_3/TiC.

To investigate the interaction effect in U-Zr-RE melt, the coated rods were immersed in a U-10wt.%Zr-RE alloy melt contained in a plasma sprayed ceramic coated graphite crucible under an inert atmosphere. Melt dipping tests were conducted by immersing the samples into the melt at 1600℃ for 5 min, and withdrawn and cooling outside the crucible in the inert atmosphere of the induction furnace. After exposure to the U-10wt.%Zr-RE melt, both the Y_2O_3(75) SL VPS and the Y_2O_3(125) SL VPS coated layer showed heavy penetrations of U-Zr-RE melt into Y_2O_3 layer, as shown in Fig. 2(a) and Fig. 2(b). Compared with the previous results that no penetrations were observed in U-Zr melt, these reactions are blamed on reactions with RE elements. Therefore, it can be assumed that U-Zr-RE melt, has a much higher fluidity than U-Zr melt, is able to penetrate along the cracks or the microcracks of the coating layer, presumably formed from the thermal expansion difference between coating layer and substrate. The TaC(100)-Y_2O_3(100) DL APS coated rod and the TaC(100)-Y_2O_3(100) DL VPS coated rod showed no penetration of U-Zr-RE melt into Y_2O_3 layer, as shown in Fig. 2(c) and Fig. 2(d), like the dipping test results in U-Zr melt. The Y_2O_3(100)-TaC(100) DL VPS coated rod showed no penetration of U-Zr-RE melt into TaC coating layer, but the Y_2O_3(100)-TiC(100) DL VPS coated rod had an extensive reaction layer with U-Zr-RE melt. So, it is judged that TaC coating material is more stable in U-Zr-RE melt than TiC coating material.

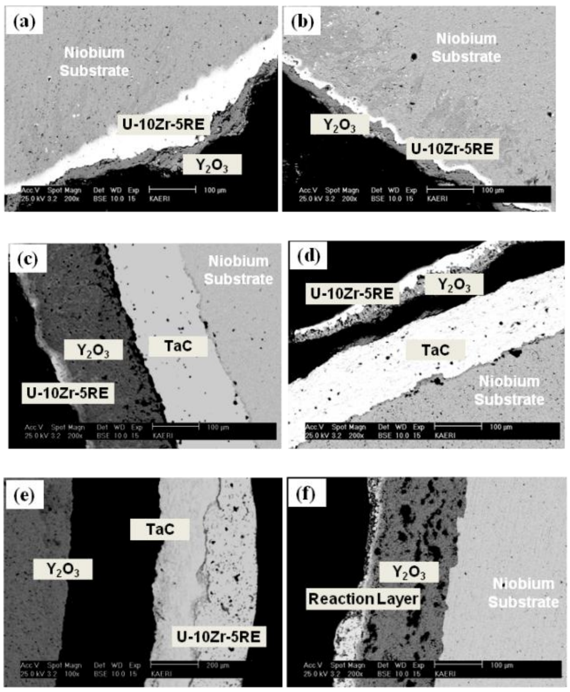


Fig. 2. Cross-sectional BSE micrographs showing the interface between U-10wt.%Zr-5wt.%RE and coating layer on niobium substrate after one dipping at 1600^{o}C for 5min. and cooling in separated state from the melt.

3. Conclusions

To develop a coating method and material for crucibles to prevent material interactions with U-TRU-Zr fuels, the refractory coating was performed using vacuum plasma-sprayed method onto niobium rod. The various combinations of coating conditions such as; coating thickness, double multi-layer coating methods were investigated to find the bonding effect to withstand the thermal stress. Most of coating method samples did not maintain integrity in the U-Zr-RE melt because of the cracks or the microcracks of the coating layer, presumably formed from the thermal expansion difference. Only the double-layer coated rod with TaC and Y_2O_3 powders, which is, which consists of vacuum plasma-sprayed TaC bond coating with the coating thickness of 100μm onto niobium rod and vacuum plasma-sprayed Y_2O_3 coating with the coating thickness of 100μm on the top of the bond coating layer, 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 U-Zr-RE melt.

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