Transactions of the Korean Nuclear Society Autumn Meeting
Changwon, Korea, October 24-25, 2024

Application of Plasma-sprayed $NdYO_3$ Coating for Melting Crucible of Metal Fuel Containing Reactive Rare-earth Elements

Ki-Hwan Kim [a*], Hoon Song [a], Seung-Uk Mun[a,b], Sang-Kyu Park[a], Jun-Hwan Kim[a]
[a]*Korea Atomic Energy Research Institute, Advanced Fuel Technology Development Division,*
989 Beon-gil 111, Daedeokdae-ro, Yuseong-gu, Daejeon, Korea, 34057
[b]*Sungkyunkwan University, Soft Matter Physics Laboratory, School of Advanced Materials Science and Engineering,*
066, Seobu-ro, Jangan-gu, Suwon, Gyeonggi-do, Korea, 16419
[*]*Corresponding author: khkim2@kaeri.re.kr*

***Keywords :** metal fuel, melting crucible, reaction-resistant, plasma-sprayed Coating, $NdYO_3$

1. Introduction

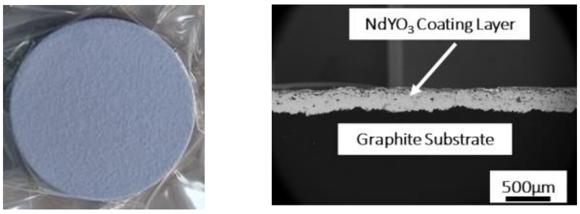
U-TRU-Zr-RE metal fuel generally has a low centerline temperature and a fuel cycle economy. Transuranium elements (TRU) are defined as members of the actinide series beyond uranium, beginning neptunium (atomic number 93). RE is composed of rare-earth elements consisting of 53wt.% Nd, 25wt.% Ce, 16wt.% Pr, and 6wt.% La. Metal fuel slugs have been fabricated with an injection casting process operating under atmospheric pressure [1]. The metal fuel has been melted in graphite crucible slurry-coated or plasma-spray coated with Y_2O_3 to prevent melt/material interactions [2]. Since highly reactive RE is included during pyro-processing process, even the plasma-spray coated Y_2O_3 layer is reacted with RE in the metal fuel and forms the reaction products of RE-Y-O system, producing considerable amount of fuel loss and large amounts of radioactive crucible waste. An alternative $NdYO_3$ has been introduced as a promising candidate material for plasma coating on graphite crucibles [3].

In this study, to investigate an $NdYO_3$ coating layer for preventing reaction of metal fuels containing rare-earth elements, the refractory coatings were prepared and characterized with plasma-spray coating method on graphite substrates. The interaction studies between molten U-10wt.%Zr-5wt.%RE and plasma-sprayed coating layer were investigated the reaction characteristics with the molten fuel at high temperature.

2. Methods and Results

In this experiment, spherical ceramic powders of Nd_2O_3 and Y_2O_3 were used as raw materials. The purity is higher than 99.9 % and the particle size is smaller than 2.5 ㎛ as raw materials. A molar composition ratio of 50mol.%Nd_2O_3 and 50mol.%Y_2O_3 powder were selected. Mixed Nd_2O_3 and Y_2O_3 powders were obtained through wet ball milling for 24 hrs. Subsequently, the powder slurry was annealed by heating at 1000 ℃ for 10 hrs to remove foreign adhering substances and moisture.

Wet ball milling was performed again for 24 hrs to obtain a powder slurry with a uniform composition of the calcined powder. At this time, when the powder slurry was put into the spray-dryer, the rotation speed of the disk was in the range of 6000 rpm to 10,000 rpm. Spherical powder was prepared from the slurry of mixed powders through spray drying and sieving process. Spherical $NdYO_3$ powder of 20 μm to 80 μm in particle size, was prepared after sintering at 1450 ℃ for 10hrs, and plasma-sprayed with a diameter of 30 mm. A coating approximately 250 μm thick was deposited using a torch input power of approximately 15 KW, an arc current of approximately 750 A, and a plasma gas of a mixture of argon and helium. Plasma-sprayed $NdYO_3$ coupon as an alternative reaction-resistant layer shown in Fig. 1-(a) was investigated through sessile drop test to demonstrate the reaction characteristics with U-10wt.%Zr-5wt.%RE alloy at high temperature. The microstructure of the plasma-sprayed $NdYO_3$ specimens was investigated by scanning electron microscopy combined with energy dispersive spectroscopy (SEM/EDS). The phase structure of the plasma-sprayed $NdYO_3$ specimens was examined by X-ray diffraction (XRD).

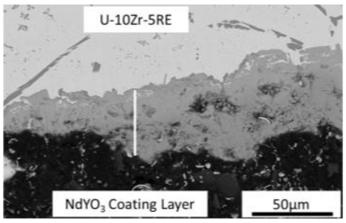


(a) (b)

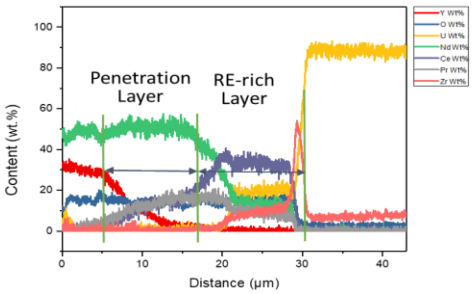
Fig. 1. Typical plasma-sprayed $NdYO_3$ coupon (a) cross-sectional SEM micrograph (b) showing the coating layer plasma-sprayed on a graphite substrate.

Cross-sectional SEM micrograph of the plasma-sprayed $NdYO_3$ coupon is shown in Fig. 1-(b). The $NdYO_3$ coating layer showed a fairly uniform thickness of 250 ㎛ with 6.5 ㎛ in surface roughness, and a good consolidation with some small closed pores. It also exhibited a good interfacial contact between the coating layer and the graphite substrate.

After a sessile drop test of U–10wt.%Zr-5wt.%RE melt at 1500 ºC for 10 min, conventional Y_2O_3 layer plasma-spray coated on a graphite coupon, indicated a significant penetration layer of U-Zr-RE melt with the thickness of about 65 ㎛ formed though grain boundaries [4]. However, after exposure to U-Zr-RE melt at 1500 ºC for 10 min, $NdYO_3$ plasma-spray coated coupon, composed of Nd_2O_3-50mol.%Y_2O_3, was shown with a discrete coating interface between $NdYO_3$ coating layer and U-Zr-RE alloy. The Zr and RE inclusions were distributed in the matrix and the composition of the RE inclusions was similar to that of a charged RE element. Some penetration layer of U-Zr-RE melt with a thickness of approximately 11.6 ㎛ was formed though grain boundaries, as shown in Fig. 2. After a sessile drop test, the penetration depth of U-Zr-RE alloy was reduced by about 82%, compared to conventional Y_2O_3 coating layer. RE-rich layer with the thickness of approximately 11.6 ㎛ existed just above of the penetration layer. It is thought that U–Zr-RE melt penetrates along the grain boundaries, and degrades the $NdYO_3$ coating layer at the interface.



(a)



(b)

Fig. 2. Typical cross-sectional back-scattered electron (BSE) micrograph depicting the interface between U–10wt.%Zr-5wt.%RE and $NdYO_3$ coating layer on the graphite substrate (a), and EDS spectra by line scanning (b) after sessile drop test at 1500 ºC for 10 min.

3. Conclusions

To reduce the loss rate during fabrication of metal fuel, plasma-spray coating of $NdYO_3$ as an alternative crucible material was applied on the graphite substrate. The $NdYO_3$ coating layer had a fairy uniform thickness, and a consolidated layer with some small closed pores. As a result of a sessile drop test of the $NdYO_3$ coating layer after exposure to the U-10wt%Zr-5wt.%RE melt at 1500 °C for 10 min indicated that the coating layer did not form a significant reaction layer between the fuel melt and the coating layer. The $NdYO_3$ coated coupon indicated that the penetration layer is reduced upto about 82% in thickness, compared with about 65 ㎛ in thickness that of conventional Y_2O_3 coating layer in penetration depth of U-Zr-RE alloy after a sessile drop test with U–Zr-RE melt at 1500 ºC for 10 min. Hence, the $NdYO_3$ plasma-sprayed coating showed a promising performance in the reduction of the fuel loss during fabrication of metal fuel.

REFERENCES

[1] J. H. Kim, H. Song, H.T. Kim, K.H. Kim, C.B. Lee, R.S. Fielding, Development of a New Casting Method to Fabricate U–Zr Alloy Containing Minor Actinides, J. Radioanal. Nucl. Chem. Vol.299, p.103-109, 2014.

[2] K. H. Kim, J. H. Kim, K. W. Hong, J. Y. Park, C. B. Lee, Application of High-temperature Ceramic Plasma-spray Coatings for a Reusable Melting Crucible, Surf. & Coat. Technol. Vol.326, p.429-435, 2017.

[3] S. G. Park, K. H. Kim, J. H. Kim, Development of $NdYO_3$ Powder Fabrication as a Reaction Preventing Raw Material for Metal Fuel Casting, Arch. Metall. Mater. Vol.69, p.429-432, 2024.

[4] S. W. Kuk, et. al., Re-usable Crucible and Crucible Coating Technology Development, TR-7002/2017/26, Korea Atomic Energy Research Institute, 2017.