Coating Method Dependence of Tribological Behaviors in CrAl-coated Zr Cladding

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1. Introduction

Coated claddings with high temperature oxidation resistance alloys are considered as one of the strong candidates for accident-tolerant fuel (ATF) claddings [1-3]. Even though new materials such as FeCrAl, SiC/SiC composites showed outstanding corrosion resistance in simulated high temperature steam, there are many problems, such as neutron irradiation and dissolution in high temperature water, to be solved for commercial application. Up to now, Cr and Cr alloys can be applied as coating materials due to their outstanding oxidation resistance in high temperature steam. When coating materials are selected, coating method can be applied for the consideration of economy and safety issues. For example, arc ion plating or cold spray process can be applied to conventional Zr-based fuel claddings without microstructural changes during the coating process. However, interfacial bonding force can be weaken compared with direct energy deposition. Thus, coating methods can be optimized for obtaining applicable performance of coating layers. From previous test results, physical vapor decompositions can be selected as a process suitable for mass production. This is because coating materials can be stably deposited on conventional Zr-based claddings without coating damages such as pore, droplet, cracks, etc. However, coating layer has different oxidation resistance and mechanical properties under different coating methods even though the same coating materials are applied. In this study, the tribological properties of the Cr-5Al coating layers deposited by an Arc Ion Plating (AIP) and Sputtering (SP) method were experimentally evaluated.

2. Experiments

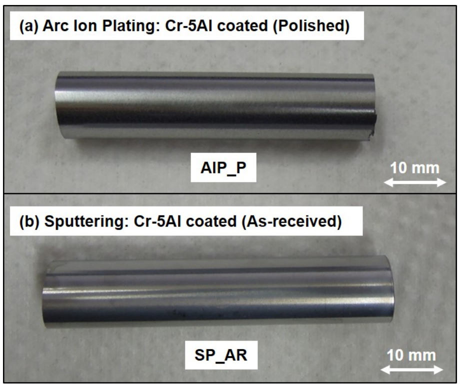

Fig. 1. Cr-5Al coating claddings with different coating methods.

For comparing different coating method effects, indentation and scratch tests were performed using Cr-5Al coated Zr cladding. For indentation test, stylus tip with 200 μm radius was applied at 10~40 N with 10 seconds of holding time. In scratch test, the same stylus in the indentation test was used at 10~50 N, 1mm/s of scratch speed [4]. After each test, indents and scratches are measured by a 3D profilometer. Finally, depth and area are calculated and compared mechanical properties of each coating method with the same coating materials. Fig. 1 shows coated cladding samples with thickness of 10 μm used in this study.

3. Results and discussion

Table I summarized the indentation depth with increasing normal force at both coated claddings. This result indicated that indent depth linearly increased with normal force. However, SP method shows smaller indent depth, indicates high hardness values when compared to AIP process. The main cause of high hardness value in SP process is that the coating layer of SP process shows denser structures due to the decomposition process. Also, as-received roughness of coated cladding is 5.166 μm in AIP process, but 0.499 μm in SP process. Because of the size of deposited particles from source target, denser Cr-5Al coating layers are generated in the SP process, which shows high hardness (i.e., smaller indent depth).

Table I: Summary of indent depth measurement results

Weight	AIP process	SP process
10N	2.3 μm	2.1 μm
20N	5.5 μm	3.2 μm
30N	10.5 μm	6.8 μm
40N	14.7 μm	9.9 μm
Note: Holding time: 10 s, Stylus tip radius: 200 μm		

From the indentation test results at 30 N of normal force at both coated claddings, indent diameter was measured by measurement optical microscope. Theoretically, hardness of Cr-5Al coatings by SP process is about 480 MPa, but that by AIP process is about 338 MPa. So, Cr-5Al coating layer by SP process has higher hardness value about 40%. In this simple test, mechanical properties of coating layer with the same coating materials can be improved by different coating process.

Fig. 2 shows the variation of coefficient of friction with increasing normal force during the scratch tests at both coated claddings. It was apparent that coating layer by AIP process shows stable behavior at the all normal force conditions. However, that by SP process shows irregular behavior, which means the coating layer of the SP process was fractured by stylus tip. This result means that the coating layer by the SP process shows higher hardness, which is difficult to plastic deformation for accommodating severe deformation. However, that by the AIP process shows ductile failures and well-developed scratch traces without severe fractures.

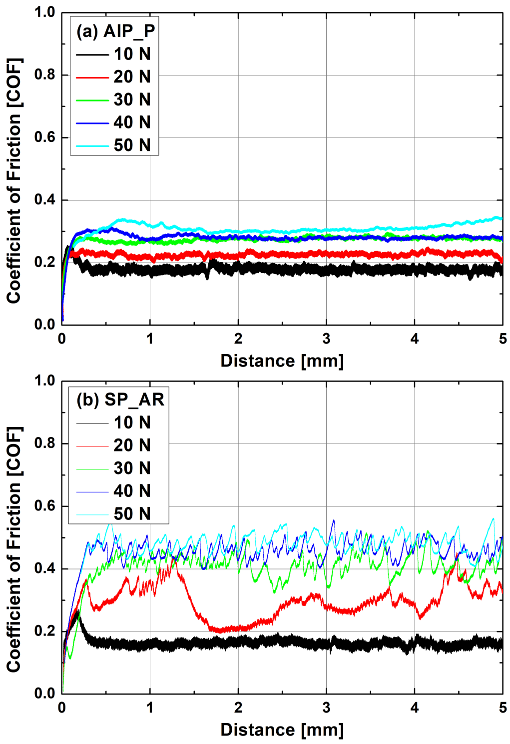

Fig. 2. The variation of coefficient of friction during the scratch tests at both coating claddings.

4. Summary

In this study, the tribological properties of CrAl-coated fuel claddings by an Arc Ion Plating (AIP) and Sputtering (SP) methods, which have excellent oxidation resistance in high temperature steam, were experimentally evaluated focusing on the effect of different coating methods with the same coating materials. From the indentation test, coating layer by the SP method shows well-developed cracks by brittle fractures while that by the AIP method shows negligible cracks by severe plastic deformation. The coating layer by the AIP methods was confirmed to be a scratch mechanism similar to cohesive failure due to tensile or conformal cracking by ductile fracture. In case of the SP method, however, the recovery spallation behavior was observed in the scratch trace and the adhesive failure could be associated with brittle fracture by interfacial peeling and chipping due to compressive stress.

ACKNOWLEDGEMENTS

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REFERENCES

[1] H.G. Kim, J.H. Yang, W.J. Kim, and Y.H. Koo, Development Status of Accident-tolerant Fuel for Light Water Reactors in Korea, Nuclear Engineering and Technology, Vol.48, p.1, 2016.

[2] H.G. Kim, I.H. Kim, Y.I. Jung, D.J. Park, J.Y. Park, and Y.H. Koo, Adhesion property and high-temperature oxidation behavior of Cr-coated Zircaloy-4 cladding tube prepared by 3D laser coating, Journal of Nuclear Materials, Vol.465, p.531, 2015.

[3] J. Bischoff, P. Blanpain, J. Strumpell, Development of Fuels with Enhanced Accident Tolerance, IAEA Technical Meeting on Accident Tolerant Fuel Concepts for LWRs, Oak Ridge National Lab, USA (Oct. 13~14, 2015)

[4] ASTM G171 Standard Test Method for Scratch Hardness of Materials Using a Diamond Stylus.