Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 23-24, 2019

The Stability of Cr Alloy Coating Layer under Mechanical Contact and High Temperature Steam at 1200 °C

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1. Introduction

For improving accident tolerance in current operating LWRs with various coated Zr-based claddings [1-3], their coating layer should be maintained without significant damages during normal operation. This is because the coating layer applied to perform the unique role in accident condition should not be degraded in normal operation. Typical examples of expected damages could be summarized as scratch formation during assembling and handling, coating defects in manufacturing, grid-to-rod fretting (GTRF), and debris fretting under flow-induced vibration. In this study, the scratch and fretting wear behaviors of coated Zircaloy-4 (Zry-4) claddings deposited with a Cr-10Al binary alloy target by the arc ion plating (AIP) method were examined. After the scratch and fretting wear tests, oxidation test was performed to examine the oxidation behavior of damaged coating layer in high temperature steam at 1200 °C.

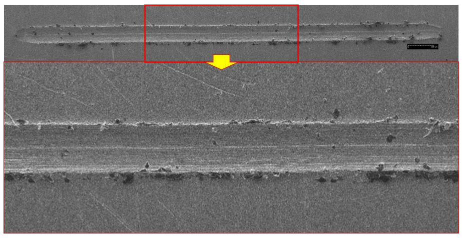
2. Experiments and Results

2.1 Specimen

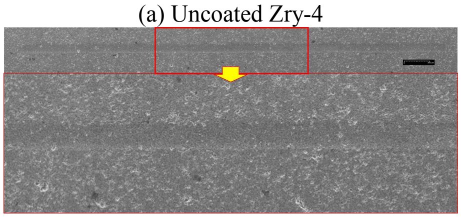
A CrAl-coated Zry-4 sample was prepared by an AIP method with negative bias voltage of 200 V and current of 20 mA in the high vacuum condition. After coating process, the length of the samples was cut to 12.5 mm and applied to all tests. At this time, surface was polished to maintain suitable roughness level of commercial Zr-based cladding. In the fretting wear tests, Zr-based spacer grids were used as the mating materials.

2.2 Scratch Test

A constant load scratch test was performed to evaluate the deformation behavior of CrAl coating layer. In the scratch test, a spherical diamond stylus with a cone angle of 120° and tip radius of 200 μm was used according to the ASTM standard test method [4]. Test conditions are summarized as a normal load of 10~50 N at 10 N intervals using dead weights, a constant scratching speed of 0.1 mm/s, and stroke length of 5 mm. Fig. 1 shows scratched traces of uncoated and CrAl-coated Zry-4 at normal load of 30 N condition. It is apparent that uncoated Zry-4 shows the machined surface with piled-up and well developed groove and ductile chipping at both edge regions. However, CrAl-coated Zry-4 has uniform scratch trace by plastic deformation without material loss. Thus, resistance to severe plastic deformation showed that the CrAl-coated layer was superior to the Zry-4 substrate.



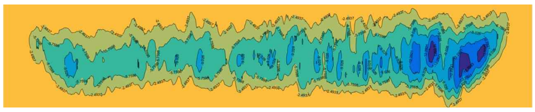
(a) Uncoated Zry-4



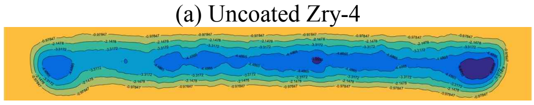
(b) CrAl-coated Zry-4

Fig. 1 Typical examples of scratch trace at uncoated and CrAl-coated Zry-4 under normal load of 30 N.

2.3 Fretting Wear Test



(a) Uncoated Zry-4



(b) CrAl-coated Zry-4

Fig. 2 Typical examples of worn surface profiles at uncoated and CrAl-coated Zry-4 under 10 N, 100 μm, 30 Hz, and 106 cycles in room temperature water.

Fretting wear tests have performed using a peak-to-peak amplitude of 100 μm in the axial direction of the fuel rod, fretting cycles of 10^5~10^6, an initial normal force of 10 N, and a frequency of 30 Hz in room-temperature water. Details of specimen installation and test facility could be found in previous study [5]. After the fretting wear tests, worn surface was observed and measured by SEM and OM for evaluating wear amounts (i.e., wear volume and maximum wear depth) and wear mechanism. Fig. 2 shows typical wear depth profiles of worn surface of uncoated and CrAl-coated Zry-4 against Zr-based spacer grid. In this results, uncoated Zry-4 shows irregular depth profile, which means that wear mechanism can be dominant to the formation of deformation layer and its repeated fracture. However, CrAl-coated Zry-4 has smooth worn surface, which indicates plastic deformation layer are well-developed and further wear progress could be prevented. Consequently, CrAl coating layer shows outstanding wear resistance when compared to uncoated Zry-4.

2.4 High Temperature Oxidation Test

In high temperature steam oxidation test at 1200 °C, a thermogravimetric analyzer (TGA) was used for evaluating steam oxidation behaviors of uncoated and CrAl-coated Zry-4 with fretted and scratched damages at the most severe condition that applied in this test. Test result indicates that no further significant oxidation is found in worn area in CrAl-coated Zry-4 as shown in Fig. 3. In addition, scratch trace is disappeared during high temperature oxidation test due to thermal expansion. Therefore, CrAl coating layer has outstanding protective layer in mechanical contact and high temperature oxidation regardless of localized damages. A detailed explanation of the high temperature oxidation behavior will be discussed at the meeting.

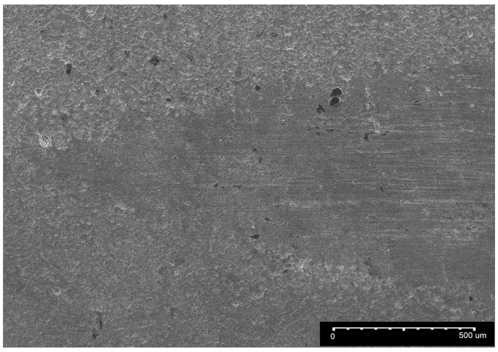


Fig. 1 Typical SEM result of damaged CrAl-coated Zry-4 after high temperature steam oxidation at 1200 °C.

3. Conclusions

From the results of scratch, fretting wear and high temperature oxidation tests, CrAl coating layer deposited on Zircaloy-4 cladding by the arc ion plating method shows the outstanding performance of the protective layer for commercial Zr-based claddings regardless of localized damaged by mechanical contact.

ACKNOWLEDGEMENTS

This work was supported by a National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIP) (No. 2017M2A8A5015058).

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.

[5] H.-K. Kim et al., Fretting wear of laterally supported tube. Wear, Vol. 250, p.535, 2001.