Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 29-30, 2015

Scratch Behaviors of Cr-Coated Zr-Based Fuel Claddings for Accident-Tolerant Fuels

Young-Ho Lee*, Il-Hyun Kim, Hyun-Gil Kim, Hyung-Kyu Kim, Yang-Hyun Koo
LWR Fuel Development Div. Korea Atomic Energy Research Institute
111, Daedeok-daero 989 beon-gil, Yoseong-gu, Daejeon, 34057, KOREA
**Corresponding author: leeyh@kaeri.re.kr*

1. Introduction

After the Fukushima disaster, Accident-Tolerant Fuels (ATFs) has been proposed for enhancing the safety margins under the severe accident conditions by introducing various alternative fuel materials and design concepts [1-5]. Previous researches indicated that various ATF candidate materials, i.e., FeCrAl alloys, SiC/SiC composites, surface modification of Zr alloy, etc., show their outstanding corrosion resistances in high temperature steam when comparing a conventional LWR fuel system (i.e., UO_2-Zr alloy). Among these candidates, the surface modifications of conventional Zr-based alloy with various corrosion-resistant alloying elements are under developing in KAERI and some results on their corrosion resistances of Cr-coated Zr-based alloys and various ATF candidate materials are demonstrated in previous studies [6,7].

As the progression of Fukushima accident is worsened by the runaway reaction at a high temperature above 1200 ºC, it is essential to ensure the stabilities of coating layers on conventional Zr-based alloys during normal operations as well as severe accident conditions. This is because the failures of coating layer result in galvanic corrosion phenomenon by potential difference between coating layer and Zr alloy. Also, it is possible to damage the coating layer during handling and manufacturing process by contacting structural components of a fuel assembly. So, adhesion strength is one of the key factors determining the reliability of the coating layer on conventional Zr-based alloy. In this study, two kinds of Cr-coated Zr-based claddings were prepared using arc ion plating (AIP) and direct laser (DL) coating methods. The objective is to evaluate the scratch deformation behaviors of each coating layers on Zr alloys.

2. Methods and Results

2.1 Scratch Tests

In this study, a scratch tester for evaluating the deformation behavior of coating layer was specially designed as shown in Fig. 1. This system is equipped with a servo motor, a precision table, a biaxial load cell for measuring normal and shear forces, and a displacement sensor for stroke length. This unit has a hard stylus in the form of a 83° cone with a spherical tip of radius 120 μm. Normal loads can be applied continuously from 0 N to 20 N by modifying a slope of specimen table. Three kinds of scratching speed (i.e.. 0.1, 0.5 and 5 mm/s) was applied with an initial force of 2 N and stroke length of 5 mm. For each test, a minimum three scratches were made.

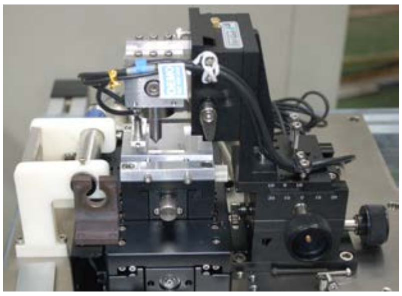


Fig. 1. A specially-designed scratch tester for evaluating Cr-coated layer on conventional Zr-based alloys.

2.2 Frictional Behavior

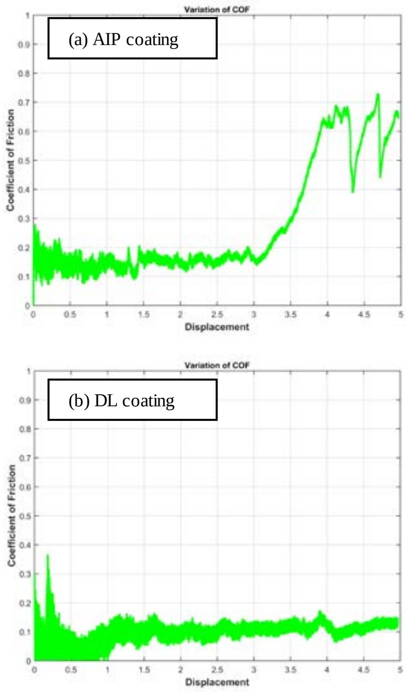


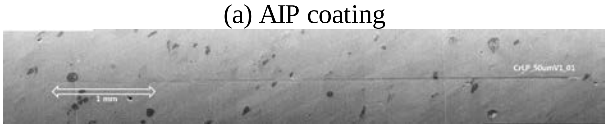
Fig. 2. The variation of the coefficient of friction at stroke speed of 0.1 mm/s.

Fig. 2 shows typical results of the variation of the coefficient of friction (COF) at scratching speed of 0.1 mm/s. It is apparent that initial COF value of both AIP and DL coating layers maintained about 0.1~0.15, but rapidly increase at the AIP coating. This result indicated that a critical load of the AIP coating, which is defined as the minimum load at which damage by lack of adhesion, can be observed below 15 N and need to be improved its adhesion strength with Zr-based alloy. However, the DL coating shows a relatively stable COF value and it is expected that no significant deformation is observed in the DL coating.

2.3 Observation of Scratches

Scratches made under continuously increasing load reveals plastic deformation or severe failure of both AIP and DL coating along the scratch path (Fig. 3). At the AIP coating, the failure was attributed to large scale spallation and this coating layer removed, entirely exposing the surface of Zr-based alloy. This result is a good agreement with the variation of COF value. In DL coating, localized micro deformation and small grooving had also taken place as shown in Fig. 3(b). As the surface hardness of the DL coating is higher than that of the AIP coating, the critical load for failure of coating layer is high compared to the AIP coating. It was observed that the slope of the COF curve changed some distance from the scratch initiation. But this point did not coincide with that where large spallation occurred in AIP coating.

(a) AIP coating



(b) DL coating

Fig. 3. Typical results of scratches at stroke speed of 0.1 mm/s.

3. Conclusions

Large area spallation below normal load of about 15 N appeared to be the predominant mode of failure in the AIP coating during scratch test. However, no tensile crack were found in entire stroke length. In DL coating, small plastic deformation and grooving behavior are more dominant scratching results. It was observed that the change of the slope of the COF curve did not coincide with the failure of coating layer.

ACKNOWLEDGEMENTS

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (No. 2012M2A8A5013146)

REFERENCES

[1] S.J. Zinkle, K.A. Terrani, J.C. Gehin, L.J. Ott, and L.L. Snead, Accident tolerant fuels for LWRs: A perspective, Journal of Nuclear Materials, Vol.448(1), p374, 2014.
[2] L.J. Ott, K.R. Robb, and D. Wang, Preliminary assessment of accident-tolerant fuels on LWR performance during normal operation and under DB and DBA accident conditions, Journal of Nuclear Materals, Vol.448(1), p520, 2014.
[3] Y.H. Koo, J.H. Yang, J.Y. Park, K.S. Kim, H.G. Kim, D.J. Kim, and K.W. Song, KAERI's Development of LWR Accident-Tolerant Fuel, Nuclear Technology, Vol. 186(2), p295, 2014.
[4] K.A. Terrani, S.J. Zinkle, and L.L. Snead, Advanced oxidation-resistant iron-based alloys for LWR fuel cladding, Journal of Nuclear Materials, Vol.448(1), p420, 2014.
[5] K. Yueh, and K.A. Terrani, Silicon carbide composite for light water reactor fuel assembly applications, Journal of Nuclear Materials, Vol. 448(1), p380, 2014.
[6] 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.
[7] Y.-H. Lee, and T.S. Byun, A comparative study on the wear behaviors of cladding candidates for accident-tolerant fuel, Journal of nuclear materials, in press.