Preliminary Study on the Fretting Wear Behavior of Multi-Layer Coatings for Accident Tolerant Fuel Cladding

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1. Introduction

After experiencing the Fukushima accident event, it widened the belt of consensus that high temperature oxidation and creep ballooning resistance have to be improved for considering nuclear power plant safety, which have a tolerance to severe accident [1, 2]. Generally, oxide dispersion strengthened (ODS) alloys were applied as structural materials of nuclear components, where high mechanical strength should be guaranteed at high temperatures of up to 700 ℃ [3, 4]. Regardless of their outstanding mechanical properties, it was difficult to manufacture these type alloys by mechanical alloying method, which dispersing Y_2O_3 particles in metal matrix. Recently, ODS Zr was proposed to improve the strength of conventional Zr-based alloys for enhancing accident tolerance by surface modification. However, the surface treatment by laser beam scanning changes the microstructures of fuel cladding (i.e., heat affected zone, HAZ) below ODS layer, which affects their corrosion resistances and mechanical properties during normal operations. Therefore, it is reasonable to avoid direct exposure of the ODS layer to the primary coolant during normal operations. For resolving this problem, additional arc ion plating coating (AIP) can be applied to ODS-treated Zr cladding for improving or maintaining its corrosion resistance. In this study, the reliability of the CrAl coating layer formed on the outer surface of ODS-treated Zr was experimentally evaluated and compared with uncoated Zr cladding by testing scratch and fretting wear tests.

2. Experiments and Results

2.1 Test condition and scratch test

For evaluating the wear characteristics of multi-layer coating, the fretting wear test was performed using Zr-based spacer grid sample. The applied test conditions are 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]. Fig. 1 shows schematic view of multi-layer coating concept used in this study. After the ODS treatment, the ODS layer was well-developed and the thickness increase was negligible. Also, the outer CrAl coating layer was formed with a thickness of 20~30 μm. Based on the results of the scratch tests, there is no significant difference of the scratching behaviors between single CrAl coating [6] and multi-layer coating.

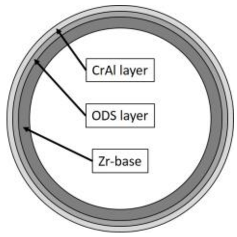

Fig. 1. Multi-layer coating concept used in this study.

2.2 Fretting wear test

Fig. 2 shows fretting wear results of multi-layer coated cladding against Zr-based spacer grid. When compared with previous test results of single CrAl-coated cladding [6], this outer layer of multi-layer coating shows similar wear volume and maximum wear depth. Also, these wear amounts are comparable to those of uncoated Zr cladding, which is at least twice as high. Thus, the formation of CrAl coating layer by AIP process shows good wear resistance regardless of the properties of base materials. So, it can be seen that the formation of multi-layer coatings can improve the oxidation resistance as well as excellent mechanical properties.

2.3 Wear mechanism

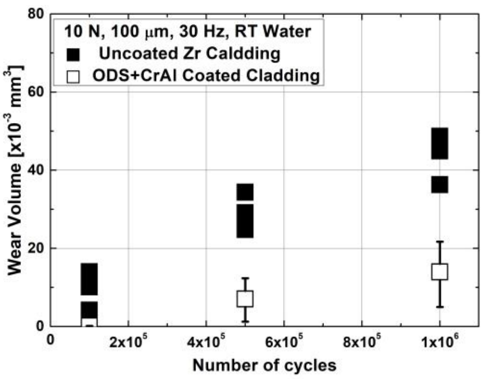

Fig. 2. Measured wear volume of both uncoated Zr and multi-layer coated claddings against Zr spacer grid.

For comparing wear mechanism with uncoated Zry-4 as shown in Fig. 3, multi-layer coated cladding shows smooth worn surface without fractured layers, which indicates that fretting wear mechanism can be affected by the formation of severe plastic deformation layer. In case of uncoated Zr cladding, however, localized abrasive wear marks by fracture of deformed layer or detached wear debris can be dominantly distributed within entire worn surface.

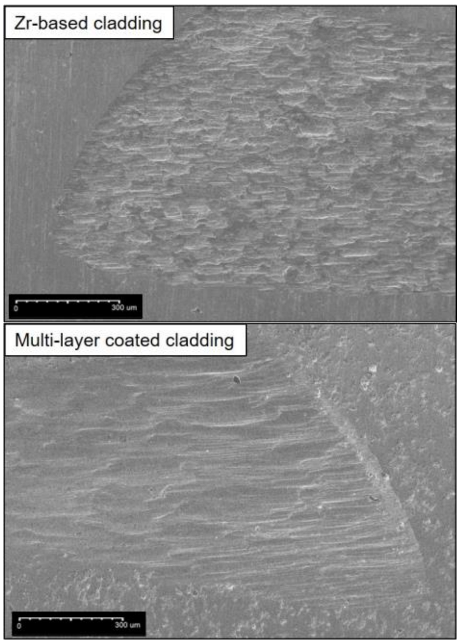

Fig. 3. Typical wear mechanism of Zr-based and multi-layer coated claddings.

3. Summary

The fretting wear behavior of multi-layer coatings (i.e., CrAl coating on ODS layer) was experimentally evaluated, focusing on the dependency of base materials. It was concluded that there is no significant variation of the tribological properties of the outer CrAl coating layer. Therefore, it is believed that the oxidation resistance and good mechanical properties could be achieved by multi-layer coating at the same time.

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