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Tribological Characteristics of Surface-Modified Zr-Based Fuel Cladding against Pre-Oxidized Spacer Grid

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1. Introduction

During the Fukushima accident, the oxidation reaction of Zr-based fuel claddings at high temperature steam produced large amounts of hydrogen gas and then its explosions resulted in failure of outer containments of power plants. Thus, the research and development of new LWR fuel systems with enhanced corrosion resistance (i.e., Accident-Tolerant Fuel, ATF) and their related issues have been widely studied [1]. Among various cladding candidates of multiple research institutes in the world [2, 3], KAERI's research focused on the surface modification methods of current Zr-based cladding because of limited budget and development period. Their results on the outstanding corrosion resistance of surface-coated Zr-based fuel cladding at high temperature steam were demonstrated a decrease in corrosion rate by at least two orders of magnitudes in ATF cladding candidates [4, 5]. Currently, irradiation tests are underway for verifying the stability of radiation-induced damage at test reactors.

However, these candidates should be verified that there are no potential hazards, which experienced in Zr-UO_2 fuel system under normal operating conditions such as grid-to-rod fretting (GTRF). Previous study [6] showed that the supporting materials (i.e., spacer grid) for ATF cladding candidates should be the same materials from the results of the tribological experiments. However, when considering contacts between ATF cladding candidates and Zr-based spacer grid in normal operation (i.e., Lead Test Rod, LTR), surface oxide predominantly generated on spacer grid rather than ATF claddings. This means that the contact conditions gradually modified as metal-to-oxide interaction and need to verify surface oxide effect. For this present work, the fretting wear behavior of a surface-modified Zr-based fuel cladding manufactured by a cold spray method was examined using pre-oxidized spacer grids in room temperature water. The objectives are to compare the wear resistance of ATF cladding with different oxide thickness of spacer grids and to estimate the wear behavior of ATF claddings in normal operations for the application of LTR.

2. Experiments and Results

3.1. Test conditions

A surface-modified Zr-based cladding for the fretting wear tests was manufactured by a cold spray method. The coating layers were formed by FeCrAl alloy (Fe-22Cr-5.8Al). Also, pre-oxidized spacer grids were prepared by oxidation tests of conventional Zr-based spacer grid in an autoclave at 360 ℃ water up to 360 days.

The fretting wear tests were carried out under test conditions of a normal load of 10 N, a relative slip amplitude of 100 μm, number of cycles of 10^5~10^6, and a frequency of 30 Hz in room temperature water. During the fretting wear tests, normal, shear force and displacement were measured for evaluating a supporting ability of the proposed spacer grids and its characteristics of the friction loop. Details of this tester were demonstrated in Fig.1.

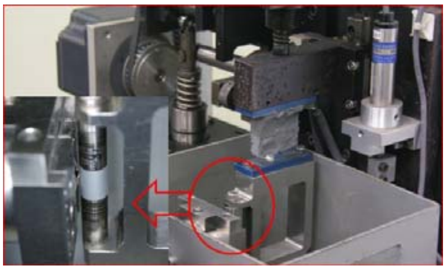
Fig. 1. Fretting wear tester used in this study [7]

3.2. Wear behaviors

Wear test results are summarized in Table 1. With increasing number of cycles, wear rate gradually increased at all test conditions. It is apparent that wear volume of coated fuel rod gradually decreased with increasing oxidation time (i.e., oxide thickness). Note that there is no significant difference between the two oxidized grid specimens up to 5×10^5 cycles and then slightly accelerated at the D180 grid specimen, which is due to the oxide thickness effect.

Table 1. Measurement results of wear volume (x 10^{-3} mm^3)

Label	AR	D180	D360
		Pre-oxidized spacer grid	
Cycles	As-received	180 days	360 days
1×10^5	0.72	0.04	(scratch)
5×10^5	2.12	0.23	0.18
1×10^6	3.09	1.00	0.31

As shown in Fig. 2, the variation of the coefficient of friction (μ_{rms}) indicated that repeated drops and smooth increase at AR and D180 grid specimens are wellmatched with the variation of wear volumes in Table 1. These results mean that the ZrO_2 oxide on spacer grid has beneficial effects on the fretting wear damages if contact between cladding and spacer grid is defined as a reciprocating motion under constant contact force.

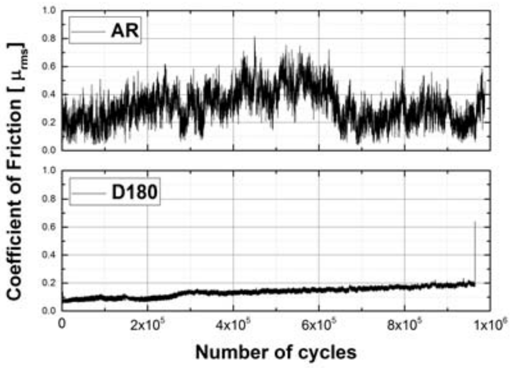

Fig. 2. Variation of CoF (μ_{rms}) with number of cycles.

3.3. Worn surface

Fig. 3 shows the observation results of the worn surface of coated fuel rod with different spacer grids. It is apparent that the worn area of the AR specimen showed distinct reciprocating motion and wear debris are detached from repeated deformation of FeCrAl coating layer. However, it is difficult to find the scratched wear marks of the D180 and D360 specimens and failure of these layers are due to localized contact of protruded region. Thus, both the wear damages and the coefficient of friction under the oxidized spacer grids show negligible changes with the number of cycles and wear damages are gradually decreased.

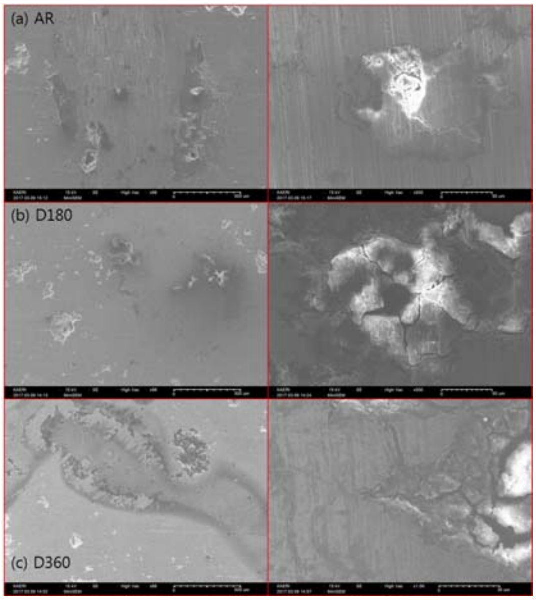

Fig. 3. Worn surface morphology after fretting wear tests.

3. Summary

Fretting wear behaviors of FeCrAl coated Zr-based fuel rod against pre-oxidized spacer grids are examined in room temperature water. Overall wear results including wear amount, frictional behavior and worn surface observation showed that remarkable effect of pre-oxidation of spacer grid on the wear resistance of an ATF cladding candidate was found for the consideration of lead test rod (LTR). Thus, ZrO_2 oxide on Zr-based spacer grid generated in normal operations are expected to have beneficial effects for decreasing expectable contact degradations in ATF cladding.

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