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Fretting Wear Behavior of ATF Cladding against Surface-Treated Spacer Grids

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1. Introduction

The research and development of LWR fuels with enhanced accident tolerance are being conducted after the accident at Fukushima. The Accident-Tolerant Fuel (i.e., ATF) could be defined as new fuel system that will tolerate the loss of active cooling in the core for a considerably longer period of time and to higher temperatures than the current fuel system while maintaining or improving fuel performance during normal operations [1-3]. Among various cladding candidates of multiple research institutes in the world, KAERI's research is focused on the surface coating methods of current Zr-based cladding. Many researcher [4-6] published a paper including an outstanding corrosion resistance of ATF cladding candidates in high temperature steam when compared with current Zr-based fuel claddings. Lee et al. [7] also proposed 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, these candidates should be proven 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) regardless of their higher performances in simulated severe accident conditions. For this present work, the fretting wear behavior of a CrAl-coated cladding candidate manufactured by an Arc Ion Plating (AIP) method was examined using three kinds of surface-treated spacer grids in room temperature water. The objectives are to compare the wear resistance of ATF cladding with different spacer grids and to propose an exclusive spacer grid candidate for ATF claddings.

2. Experiments

A surface-coated cladding on Zr-based alloy was manufactured using AIP method. Also, three kinds of spacer grid specimen were prepared, as summarized in Table 1. In this test, spacer grid specimens are denoted as ZR, CT and Ox, respectively. A ZR grid is a conventional Zr-based spacer grid and a CT is surface-coated grid that applied the same coating method of ATF cladding. An Ox grid is prepared by surface oxidation of ZR grid in an autoclave at 360 ℃ water during 30 days.

The fretting wear tests were carried out under a normal load of 10 N, a relative slip amplitude of 50, 80 and 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 in a real time basis for evaluating a supporting ability of the proposed spacer grids and its characteristics of the friction loop. Details of this tester were illustrated in [8].

Table 1. Data summary of rod and grid specimens

Type	Surface	Layer	Ra [μm]	Norm.K	T [μm]
Rod	AIP	CrAl	1.288	N/A	~ 20
ZR	N/A	N/A	1.047	1	N/A
CT	AIP	CrAl	0.437	1.5	~ 20
Ox	Oxidation	ZrO_2	0.205	1.1	~ 2

3. Results and Discussion

3.1. Supporting abilities

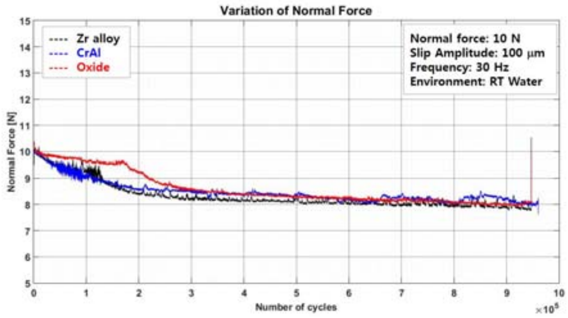

Fig. 1. Variation of normal force with number of cycles.

Fig. 1 shows the typical results of the normal load variation with number of fretting cycles at each grid specimen. Normal loads were gradually decreased due to increase of wear depth and this behavior commonly appeared regardless of the grid surface treatment. In ZR and CT grid conditions, initial unstable load fluctuations were well-developed about $1x10^5$ cycles and this behavior continuously appeared until end of cycles while Ox grid shows stable and delayed load drop. Generally, the decrease of the contact (normal) load indicates an excessive wear progression. So, the wear volume is considerably affected by the amount of the normal load decrease. Also, it is interesting that Zr oxide can be a protective coating against CrAl cladding because Zr oxide on Zr-based spacer grid can delay initiation of gross slip, which results in a relatively small amount of wear.

3.2. Wear Results

After the fretting wear tests, the wear volume and maximum wear depth of the CrAl coated claddings were measured, and their results are described in Fig. 2 and 3. With increasing number of cycles, the wear volume and maximum wear depth are gradually increased in Zr and CT grid conditions. Note that there is no significant difference between the two grid specimens, which is simply due to the negligible effect of CrAl coating effect. This is because the wear rates of CT grid condition are comparable with that of the ZR grid, which shows a similar wear depth with Ox grid condition. Therefore, the CrAl-coated layer on the Zr-based spacer grid by AIP method is not effective in reducing the fretting wear damage when the same coating method is applied to ATF cladding.

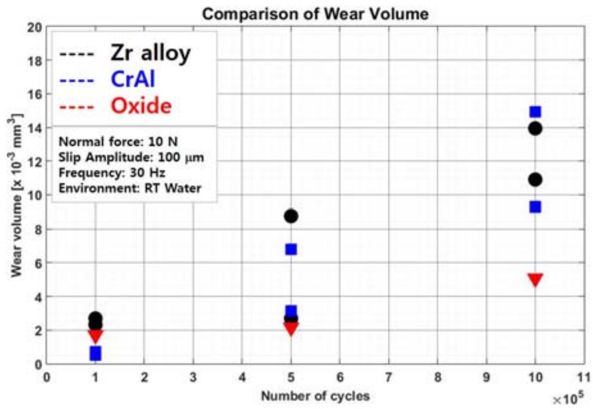

Fig. 2. Comparison of wear volume at each grid specimen.

However, both the wear volume and the maximum wear depth in the Ox grid condition showed no significant change with number of cycles. This result indicates that it is possible to apply above pre-oxide effect as an exclusive spacer grid for ATF claddings as well as conventional fuel cladding.

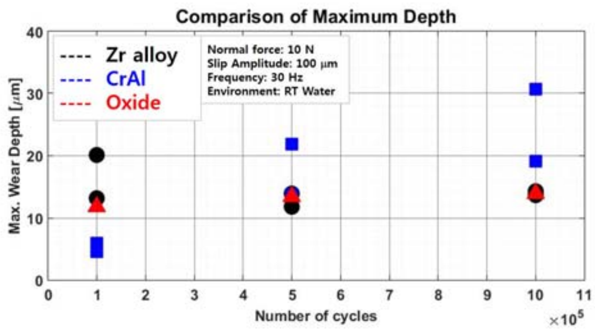

Fig. 3. Comparison of maximum depth at each grid specimen.

4. Conclusions

Fretting wear resistance of ATF cladding against different surface-treated spacer grids is evaluated. Overall wear data including wear volume and maximum depth showed that no remarkable effect of CrAl coating on Zr-based grid by AIP process on the wear resistance of CrAl-coated cladding was found in room temperature water. However, ZrO_2 oxide on Zr-based spacer grid may be a potential coating layer for decreasing expectable contact degradations in ATF cladding.

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