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Determination of a Wear Initiation Cycle by using a Contact Resistance Measurement in Nuclear Fuel Fretting

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1. Introduction

In nuclear fuel fretting, the improving of the contact condition with a modified spring shape is a useful method for increasing the wear resistance of the nuclear fuel rod. This is because the fretting wear resistance between the fuel rod and grid spring is mainly affected by the grid spring shape rather than the environment, the contact modes, etc. In addition, the wear resistance is affected by the wear debris behavior between contact surfaces. So, it is expected that the wear initiation of each spring shape should be determined in order to evaluate a wear resistance. However, it is almost impossible to measure the wear behavior in contact surfaces on a real time basis because the contact surfaces are always hidden. Besides, the results of the worn surface observation after the fretting wear tests are restricted to archive the information on the wear debris behavior and the formation mechanism of the wear scar. In order to evaluate the wear behavior during the fretting wear tests [1], it is proposed that the contact resistance measurement is a useful method for examining the wear initiation cycle and modes.

Generally, fretting wear damages are rapidly progressed by a localized plastic deformation between the contact surfaces, crack initiation and fracture of the deformed surface with a strain hardening difference between a surface and a subsurface and finally a detachment of wear debris [2]. After this, wear debris is easily oxidized by frictional heat, test environment, etc. At this time, a small amount of electric current applied between the contact surfaces will be influenced by the wear debris, which could be an obstacle to an electric current flow. So, it is possible to archive the information on the wear behavior by measuring the contact resistance. In order to determine the wear initiation cycle during the fretting wear tests, in this study, fretting wear tests have been performed by applying a constant electric current in room temperature air.

2. Experimental Procedure

A fuel rod specimen of a commercial Zr alloy was prepared with 50 mm in length and a concave spacer grid spring with a concave shape is used in this study. All the fretting wear tests were performed under a normal load of 10 N, a peak-to-valley amplitude of 100 μm, fretting cycles of $10^4 \sim 3 \times 10^5$, and at a frequency of 30 Hz in room temperature air. A constant current of 0.02 A was applied in order to minimize the corrosion effect because the applied current could be accelerated the oxidation of the generated wear debris. Normal and shear load, slip amplitude and contact resistance are measured in data acquisition system with LabVIEW® on a real time basis. After the wear experiment, the wear volume and the worn area of the fuel rod specimens were measured and calculated by using a surface profilometer and an optical microscope (OM), respectively.

3. Results and Discussion

3.1 Variation of Contact Resistance

Fig. 1 shows a typical result of the variation of a contact resistance during the fretting wear tests. At this figure, the contact resistance was gradually increased with increasing fretting cycle. However, it is apparent that the contact resistance was rapidly increased at the initial fretting cycles. This result is closely related to the surface oxidation due to the frictional heat and debris formation. After this, a signal fluctuation of the contact resistance was clearly shown and this behavior could be explained by the formation and fracture of wear debris layers. So, it enables us to determine the wear initiation cycle during the fretting wear tests.

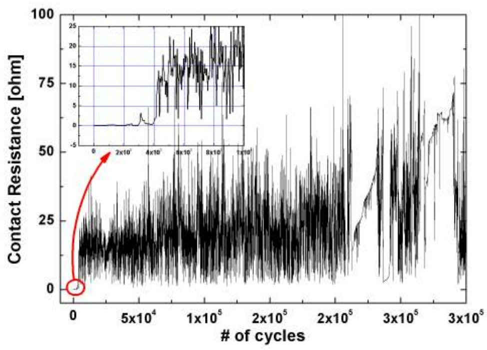

Figure 1. The typical results of the variation of the contact resistance with increasing fretting cycle.

3.2 A Specific Worn Area and Wear Volume

Fig. 2 shows the variation of a specific worn area with increasing fretting cycles. The specific worn area is defined as the ratio of A_t to A_w because a wear scar size (A_t) could be divided into a worn area (A_w) and a protruded area (A_p). With increasing fretting cycles, a specific worn area gradually decreased and reached to a minimum, and then rapidly increased. The decrease of the specific worn area indicated that the wear debris layers are gradually well-developed up to ~10^5 cycles. After this, it is expected that the fracture rate of the wear debris layer exceeds the formation rate of the wear debris one. This behavior could be explained by using the wear volume variation as shown in Fig. 3.

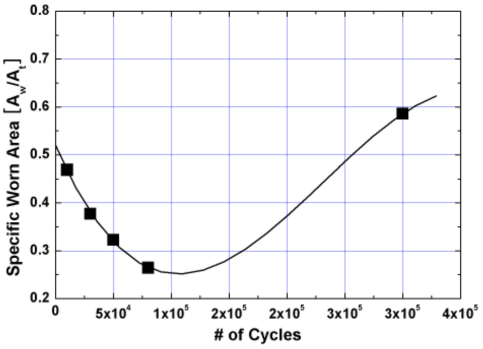

Figure 2. Variation of the specific worn area with increasing fretting cycle.

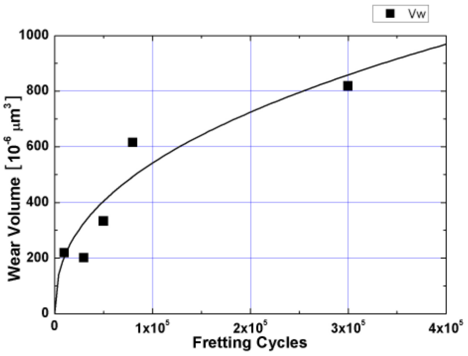

Figure 3. Variation of the wear volume with increasing fretting cycle.

3.3 Wear Volume

Fig. 3 shows the variation of the wear volume with increasing fretting cycles. It is apparent that the wear volume did not have a linear relationship with the fretting cycle. Contrary to our expectations, however, the wear volume rapidly increased at the initiation fretting stage when compared with the result of the specific worn area. This means that the variation of the contact resistance is affected by both the surface oxidation by frictional heat and the formation of the wear debris layer. In other words, the signal fluctuation of the contact resistance indicates the repeated process of the metal-to-metal contact with fracture of the oxidation surface while the average value of the contact resistance seems to be related to the formation of the wear debris layer. Further study will be focused on the development of the examination method for separating these two behaviors.

4. Conclusion

From the above results, it is possible to determine the fretting wear initiation cycle and the formation behavior of a wear debris layer during the fretting wear tests by using a contact resistance measurement. It is expected that the signal fluctuation of the contact resistance indicates the repeated process of the metal-to-metal contact with a fracture of the oxidation surface while the average value of the contact resistance seems to be related to the formation of the wear debris layer.

ACKNOWLEDGEMENTS

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