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A Feasibility Study of a Wear Depth Estimation by using a Wear Scar Analysis (I)

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1. Introduction

Generally, a fretting wear damage of a nuclear fuel rod has been considerably affected not only by the supporting spring shape but also by the test condition such as a normal load, slip amplitude, environment, etc. However, a governing factor to determine a wear-resistant spring shape is only concerned about a wear depth behavior regardless of a high wear volume and wear scar size. This is because the wall opening of the fuel rod during a plant operation is directly related to a release of a radioactive fission gas. From previous studies [1, 2], wear behaviors with a variation of a springs' shape were divided into two situations: one is a rapid depth increase rather than a wear scar increase and the other is the opposite. In addition, the shape of a wear scar was only determined by each springs' shape regardless of the loading conditions (i.e. sliding, impacting, rubbing, etc.) and test environments. This result indicates that it is possible to estimate a wear volume and a wear depth distribution by analyzing the wear scar of each springs' shape.

In order to improve the wear resistance of a nuclear fuel rod, there are various methods such as the development of a new material, an improvement of grid structures, etc. which could be applied in the design of a fuel assembly. Among these, a change of a springs' shape for considering contact mechanics is known as one of the suitable methods. This is based on both the results of analytical studies by considering the contact geometry and load-displacement experiments (i.e. spring stiffness). Due to a high level radiation and an enormous expense, however, there are very few methods to confirm whether the wear-resistance is improved in the operating conditions of nuclear power plants. When considering the development of a long-term operation and a high burn-up fuel, it is necessary to evaluate the wear-resistance of each developed springs' shape even though a fretting wear damage does not reach a wall opening during an operating period. In order to develop a method for estimating a wear depth by using an external surface photograph, fretting wear tests have been performed in room temperature air and water. The objectives of this study are to examine the relationship between the wear scar characteristics and the wear depth distributions and to analysis the possibilities of its application to actual fretting wear damage during a plant operation.

2. Experimental Procedure

2.1 Specimen

A specific spacer grid spring with a flat shape is used in this study. A fuel rod specimen was prepared with dimensions of 9.5 mm in outer diameter, 50 mm in length and 0.6 mm in wall thickness by using a commercial Zirconium alloy.

2.2 Test Condition

All the wear tests were carried out up to 10^5 cycles under a normal load of 10 N, a peak-to-valley amplitude of 50, 80 and 100 μm, and at a frequency of 30 Hz in room temperature air and water. All the measured data (normal and shear load, slip amplitude, etc.) is monitored and recorded on a PC on a real time basis.

2.3 Wear Evaluation

After the wear experiment, the wear volume/depth and worn area of the fuel rod specimens were measured and calculated by using a 2-D surface profilometer and an optical microscope (OM), respectively.

3. Results and Discussion

3.1 Wear Depth Distribution

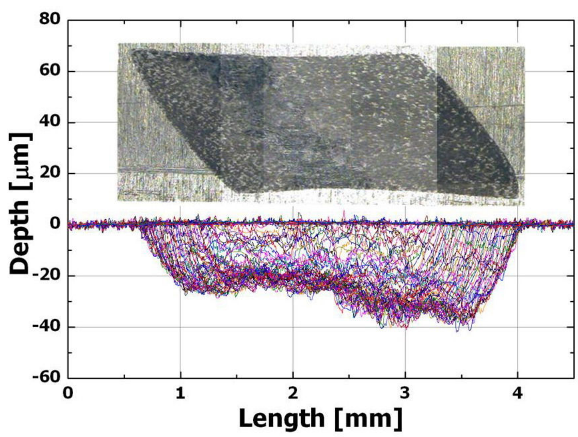

Figure 1. The typical result of the wear scar after wear tests in room temperature air.

Fig. 1 shows a typical result of the wear scar after the wear tests in room temperature air by using a surface profilometer and an OM. It is apparent that a maximum wear depth under the worn surface is comparable with an average wear depth (i.e. wear volume / wear scar size). In other words, a flat shape spring in this study did not show a localized wear that has generally occurred in other springs' shapes (i.e. concave shape in previous studies [1, 2]). When a localized wear happened, it is difficult to obtain a linear or parabolic relationship between a maximum wear depth and a wear scar size in the early stage of the fretting wear tests.

3.2 Maximum wear depth and wear scar size

Generally, the wear scar size (A_t) could be divided into a worn area (A_w) and a protruded area (A_p) as shown in Fig. 1. For a procedure of a volume measurement by using a surface profilometer, a wear volume could be defined as an amount of the removed materials under a fuel rods' surface. Therefore, A_w could be calculated easily by a summation of the unit area in which a surface profile has a negative value. If a relationship between the maximum wear depths and the wear scar characteristics is revealed, it is possible to estimate the maximum wear depth by analyzing the wear scar size. In order to confirm the above hypothesis, the relationship between A_w and A_t and its result is shown in Fig. 2. With increasing A_t, the Aw rapidly increased and saturated to an A_t value above 3 mm^2. This result indicates that the ratio of A_w to A_t of the flat spring used in this study is nearly unity regardless of the size of the A_t.

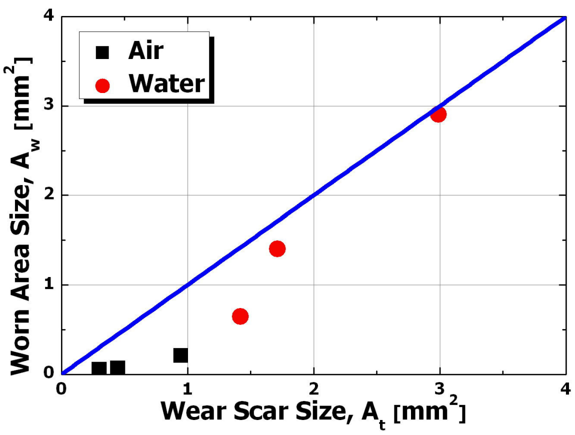

Figure 2. Variation of the worn area size (A_w) with increasing the wear scar size (A_t); Note that the Aw is saturated to the A_t above the A_t of 3 mm^2.

Fig. 3 shows the relationship between the maximum wear depth and the worn scar size (A_w) in this experiment. It is apparent that the variation of the maximum wear depth could be estimated by a variation of A_w even though they did not have a linear relation contrary to our expectations. The reason for this behavior could be explained by using the debris behavior during a fretting wear test. In an unlubricant condition (i.e. room temperature air), a generated debris could easily be oxidized and agglomerated and then form a wear debris layer, which acts as a load-bearing layer. But in a water condition, the debris is easily removed and a relatively severe wear damage occurs. But in this study, some of the debris could be attached in water condition as shown in Fig. 2. But it is expected that these effects would be removed with increasing fretting cycles. From the above results, it is possible to estimate the maximum wear depth by analyzing the wear scar after the wear tests.

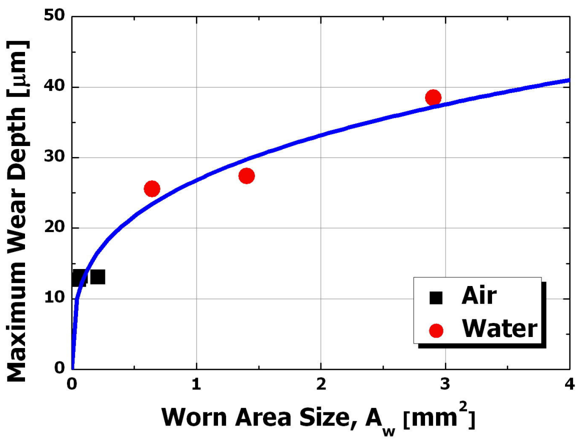

Figure 3. Variation of the maximum wear depth with increasing the worn area size (A_w).

4. Conclusion

In order to examine the relationship between the wear scar characteristics, fretting wear tests have been performed by using a flat shape of a grid spring in room temperature air and water. The results indicated that the ratio of the worn area size (A_w) to the wear scar size (A_t) of the flat spring used in this study is nearly unity regardless of the size of the A_t. It enables us to estimate the maximum wear depth by analyzing the wear scar of various springs' shapes.

ACKNOWLEDGEMENTS

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