Nuclear Fuel Fretting Mechanisms in a Room Temperature Unlubricated Condition

Young-Ho Lee† , Hyung-Kyu Kim
Korea Atomic Energy Research Institute, 1045 Daedeokdaero, Yuseong, Daejeon, 305-353, Korea

1. Introduction

Recently, efforts for evaluating the fretting wear mechanism have been carried out by many researchers in various conditions. In an unlubricated condition, especially, effects of a wear debris and/or its layer on the fretting wear behavior were proposed that the formation of a well-developed glaze layer has a beneficial effect for decreasing a friction coefficient. Otherwise, a wear rate was accelerated by a third-body abrasion. At this time, it is well known that wear debris behaviors are affected by test variables such as a temperature, environment, material characteristics, etc.

In a nuclear fuel fretting, however, its contact condition is quite different when compared with general fretting wear studies and could be summarized as the following; first, a fuel rod is supported by spacer grid springs and dimples that were elastically deformable. This results in a unique friction loop [1] and a different fretting mechanism when a fuel rod is vibrated due to a flow-induced vibration (FIV). Next, it is possible that some region of the wear scar area with a specific spring shape condition could be hidden due to different wear debris behavior. So, some of the wear debris layers could be found on the worn surfaces in previous studies even though fretting wear tests were performed in a water lubricated condition [2]. Finally, initial contact condition could be changed both an actual operating condition in power plants (i.e. high temperature and pressurized water (HTHP) under severe irradiation conditions) and the fretting wear tests for evaluating the wear resistant spring in lab conditions (i.e. from room temperature to HTHP without irradiation conditions) due to material degradations and the formation of the wear scar, respectively. In summary, the spring shape effect and the variation of the contact condition with increasing fretting cycle should be evaluated in order to improve the wear resistance of the spacer grid spring. So, in this study, fretting wear tests have been carried out to evaluate the fretting wear mechanism in a room temperature unlubricated condition by using a concave-shaped grid spring. The objective is to examine the variation of the fretting wear mechanism during the fretting wear tests.

2. Experimental Procedure

A fuel rod specimen of a commercial Zirconium alloy was prepared with 50 mm length and a 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 50, 80 and 100 μm, fretting cycles of $10^5 \sim 10^7$, and at a frequency of 30 Hz in room temperature unlubricated condition. Normal/friction force and slip amplitude are measured in data acquisition system with LabVIEW® on a real time basis. After the wear experiment, the wear volume of the fuel rod specimens was measured by using a surface profilometer. In order to evaluate the fretting wear mechanism, wear debris behavior on the worn surface and debris detachment mechanism under sub surface are observed by using a scanning electron microscopy (SEM).

3. Results and Discussion

3.1 Wear Debris Behavior

Considering the fretting wear procedures, wear debris is generally detached after a severe plastic deformation and final fracture. Under the fretting contact conditions, final wear rate was determined by this debris behavior on the worn surfaces. The most important point is that a removal path of this debris could be affected by the contact spring shape. Fig. 1 shows a SEM result of the worn surface in room temperature unlubricated condition. It is apparent that wear debris folds at both ends are always headed for the center region of the worn surface. This specific directional characteristic is closely related to the wear debris behavior.

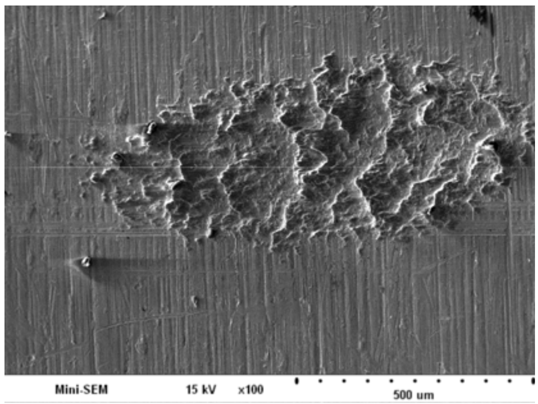

Figure 1. The typical result of the SEM observation after the fretting wear tests in the room temperature unlubricated condition.

When a fuel rod is supported by a grid spring with a concave shape, the wear scar was generated at both ends in the axial direction of the fuel rod. With increasing fretting cycle, two wear scars were gradually increased and finally combined to a large wear scar. So, the wear debris removal path and the direction of wear scar expansion always coincided. Consequently, it is expected that the formation of the wear scar could be determined by the interaction between the generated wear debris and the worn surfaces.

3.2 Wear Debris Detachment

Fig. 2 shows the typical SEM result of the subsurface observation after the fretting wear tests in the room temperature unlubricated condition. It is apparent that a subsurface deformation zone was well developed and its thickness is about 10 μm. Also, near the surface, some microcracks are found. This result indicates that this hardened surface was fractured by the strain difference due to a severe plastic deformation [3] and finally wear debris was detached. Therefore, the fretting wear mechanism of the nuclear fuel rod in the room temperature unlubricated condition could be summarized such as the wear debris detachment by a severe plastic deformation, the synchronized progress of the migration of the wear debris and the expansion of the wear scar, fracture of wear debris folds and final release of wear particles.

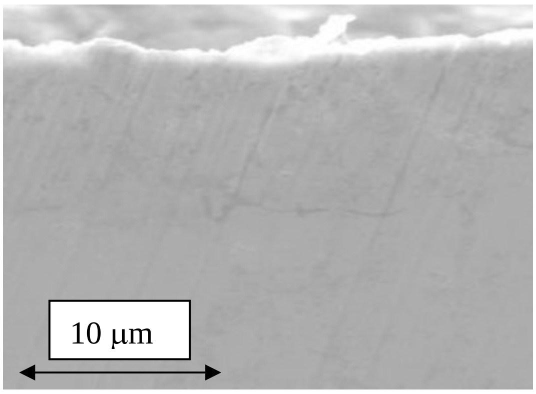

Figure 2. Subsurface deformation results after the fretting wear tests.

4. Conclusion

From the above results, it is possible to verify the fretting wear mechanism in a room temperature unlubricated condition when a fuel rod is supported by a grid spring with a concave shape. From the characteristics of the wear debris folds, a removal path of the wear debris could be affected by the contact spring shape. Finally, the fretting wear mechanism could be summarized such as the wear debris detachment by a severe plastic deformation, the synchronized progress of the migration of the wear debris and the expansion of the wear scar, the fracture of the wear debris folds and the final release of the wear particles.

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