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A Comparative Study on the Formation Mechanism of Wear Scars during the Partial and Full Scale Fretting Wear Tests of Spacer Grids

Young-Ho Lee[*], Chang-Hwan Shin, Dong-Seok Oh and Heung-Seok Kang
LWR Fuel Development Division, 1045 Daeduk-daero Yuseong-gu Deajeon, 305-353, Korea
[*]Corresponding author: leeyh@kaeri.re.kr

1. Introduction

Fretting wear studies for evaluating the contact damages of nuclear fuel rods have been focused on the contact shape, rod motion, contact condition, environment, etc. [1-3]. However, fretting wear mechanism was dramatically changed with slight variation of test variables such as test environments and contact shapes. For example, in an unlubricated condition, effects of wear debris and/or its layer on the fretting wear mechanism showed that the formation of a well-developed layer on the contact surfaces has a beneficial effect for decreasing a friction coefficient. Otherwise, a severe wear was happened due to a third-body abrasion. In addition, in water lubrication condition, some of wear debris was remained on worn surface of fuel rod specimens at both sliding and impacting loading conditions. So, it is apparent that a wear rate of fuel rod specimen was easily accelerated by the third-body abrasion. This is because the restrained agglomeration behavior between generated wear particles results in rapid removal of wear debris and its layer. In case of contact shape effects, previous studies show that wear debris are easily trapped between contact surfaces and its debris layer was well-developed in a localized area especially in a concave spring rather than a convex spring shape. Consequently, localized wear was happened at both ends of a concave spring and center region of a convex spring. So, it is useful for determining the fretting wear resistance of spacer gird spring and dimple by using part unit in the various lubricated conditions.

It is well known that the fretting wear phenomenon of nuclear fuel rod is originated from a flow-induced vibration (FIV) due to the rapid primary coolant. This means that both rod vibration and debris removal behavior were affected by flow fields around the contact regions between fuel rod and spring/dimple. However, all most of the fretting tests were performed by simulating rod vibrating motions such as axial vibration, conservative rod traces without considering flow field effects [4-6]. So, in this study, fretting wear tests of nuclear fuel rod with partial and full scale spacer girds have been performed to compare the morphology of wear scars at each test condition and to verify the flow field effect on the variation of fretting wear mechanism.

2. Experiments and Results

2.1 Fretting wear tests

In case of partial spacer grid spring tests, a fuel rod specimen of a commercial Zr alloy was prepared with 50 mm in length and a concave shape spring was used. The fretting wear tests were performed under a normal load of 10 N, a peak-to-valley amplitude of 100 μm, number of cycles of 10^7, and at a frequency of 30 Hz in room temperature air and water. In 1x1 cell tests, the rod specimen holder is actuated in a simulated circular motion ±300 μm in diameter with a frequency of 30 Hz. In full scale fretting wear tests, a prototype fuel assembly was tested at the fuel assembly compatibility test facility (PLUTO) with a similar thermal-hydraulic condition of commercial PWR power plants. Fig. 1 shows schematic views of fretting wear testers used in this study. After the tests, worn area of fuel rod specimens was examined by an optical microscope and a 3-D surface profilometer.

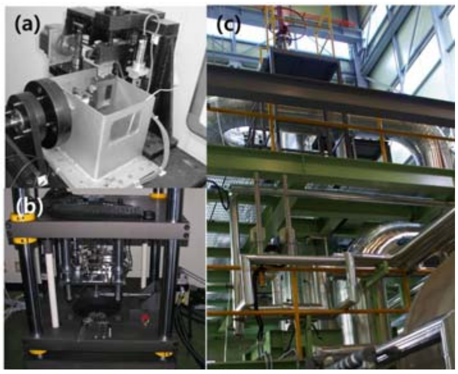
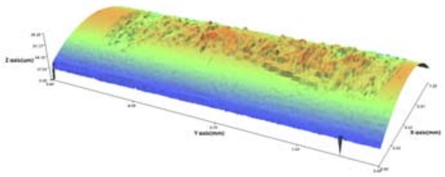


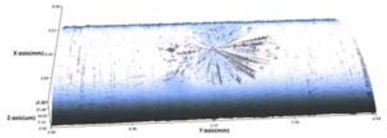
Fig. 1. Experimental facilities of nuclear fuel fretting; (a) pats unit (b) 1x1 cell unit: (c) F/A unit.

2.2 Analysis of worn surfaces

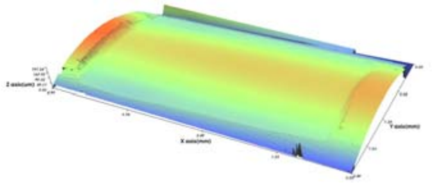
Fig. 2 shows typical results of worn surface examination at the partial and full scale fretting wear tests. It is apparent that the worn area of fuel rod at the partial spacer grid condition was covered with well-developed wear debris layers in an unlubricated condition and adhered to remained wear particles in water lubricated condition. At the full scale experiment, however, it is difficult to find the wear debris trace on the worn surface. This means that the flow field around the contact surfaces influenced generated wear debris behaviors to accelerate the fretting wear damages. Consequently, it is difficult to verify the effect of spacer grid spring shape on the fretting wear of nuclear fuel rod in the stagnant water condition regardless of temperature effects.



(a) Parts unit (unlubricated condition)



(b) 1x1 cell unit (unlubricated condition)



(c) F/A test (similar to PWR condtion)

Fig. 2. Typical results of worn surface measurement after the fretting wear tests at each test condition.

2.3 Definition of spring shape effect

Generally, wear debris is 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. In room temperature unlubricated condition, however, wear debris layer easily formed on the worn surface and shear traction due to relative slip amplitude between contact surfaces gradually decreased. So, it is possible to explain the spring shape effect with considering the wear debris removal path of each spring shape. As shown in Fig. 2, however, this debris effect hardly detects on the worn surface under the flow field. This means that, in the flow field condition, it is almost pointless explaining the spring shape effects by using wear debris behavior with different spring shape in the fretting wear tests of the partial spacer grid condition. So, spring shape effect of nuclear fuel fretting should be defined as the variation of flow field due to the spring shape.

3. Conclusions

Both rod vibration and debris removal behavior were affected by flow fields around the contact regions between fuel rod and spring/dimple. So, in the flow field condition, it is almost pointless explaining the spring shape effects by using the interaction between wear debris and contact shape due to different spring shape in the fretting wear tests of the partial spacer grid condition. So, spring shape effect of nuclear fuel fretting should be defined as the variation of flow field due to the spring shape.

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