The Wear Behavior between Zirconium Alloy and Inconel under Water Condition using Pin-on-disk Wear Tester

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1. Introduction

The spacer grid is one of the key component in the pressurized water reactor (PWR) fuel assembly. The most important function is to hold the fuel rods to maintain the distance between the fuel rods inside a fuel assembly. In the operating power plants, a fretting damage has been frequently reported between nuclear fuel rod and its supporting spring/dimple of the grid assemblies. Fretting damage is generally caused by fretting wear, which includes various wear mechanisms such as an oxidative, adhesive, abrasive wear etc. or fretting fatigue, including a surface or bulk fatigue. According to the previous researches, most of the studies have been performed with Zirconium to Zirconium alloy because the severe wear occurred at these contact area. Top and bottom grids are made from Inconel, thus, the specimens made of Inconel and Zirconium alloy were chosen in this study. Although any noticeable wear cannot be seen on the fuel rod surface supported by the Inconel grid, this study will be helpful to understand wear phenomenology.

2. Experimental procedure

2.1. Materials and specimen

The disk specimen was prepared with the dimensions of 56mm in diameter, and 0.45 mm in thickness by using a Zirconium alloy. And the pin specimen was prepared with the dimensions of 83 mm in length, 6 mm in diameter which is made of heat-treated Inconel. The schematic views of the disk, pin specimen and jig are illustrated in Fig. 1. The hardness value of the pin and disk specimens are summarized in Table 1

2.1 Test methods

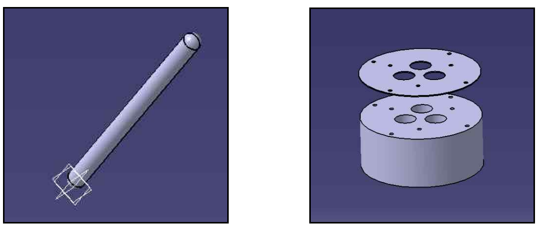

Fig. 1. Configuration of disk, pin specimen and jig (left : pin specimen; right : disk specimen and jig)

Table 1 Vickers hardness of pin and disk specimens

Vickers hardness value	
Disk specimen	Pin specimen
Zirconium alloy	Inconel alloy
* ~ 300	400 ~ *

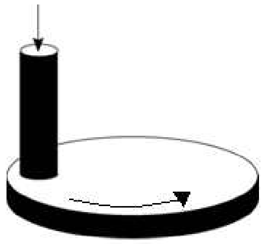

Fig. 2. Schematic sketch of a pin on disc apparatus

In the pin-on-disc test, a stationary pin is loaded axially in contact with a rotating disc, as shown in the schematic sketch. The friction force on the pin can be measured, thus making it easy to compute the friction coefficient. The weight of specimen before and after test is measured by electronic scale. Moreover, the friction coefficient and specific wear rate are calculated at each test. Physical meaning of the specific wear rate is a bulk loss of the materials considering random input energy. The definition can be expressed as Eq. (1).

$$\dot{\omega}_s = \frac{\Delta m}{\Delta t}\frac{1}{\upsilon \rho F_n} \quad (1)$$

Dimension of the specific wear rate is m^3/Nm. In this equation Δm is the mass loss, Δt is entire test time, υ is sliding velocity, ρ is density of the specimen, F_N is the axial force.

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3. Results and discussion

Fig. 3 shows the transition of the specific wear rate as a function of sliding speed. The wear rate decreased as the sliding speed increases. In addition, the decreased rate of specific wear rate saturated over 200 rpm. These phenomenon can be explained by the release rate of debris and effect of the friction force. At low speed range, 50 ~ 100 rpm, the friction force resulted from material deformation strongly affected to the Zirconium alloy rather than adhesive force. Moreover, the debris which were generated between pin and disc easily released at low speed since the adhesive force is low. Fig. 4 shows data as a function of axial load. The wear rate decreased until 11 N and increased again. As the increase of friction force resulted from material deformation and change of wear mechanism, the release rate of debris was decreased. Comparing to the other experimental parameters such as sliding velocity and number of cycles, it can be seen that the axial load is critical to wear. The micro-cutting is observed on the 5 N of axial load, and micro-cracking is observed at 10 N. The accumulation of the surface fatigue becomes delamination which observed at 15 N as shown in Fig. 6. The change of wear mechanism in this parameter can cause irregularity of real contact. As a result, the rebound of friction coefficient and wear rate occurred at high axial load. Furthermore, the increase of debris disturbs a release of debris from contact area. So that, one can measure the lowered wear rate at high axial load. Fig. 5 shows the data of cycle increase test. The specific wear rate rises linearly and wear volume non-linearly increased as was reported by Bowden and Tabor's research[5].

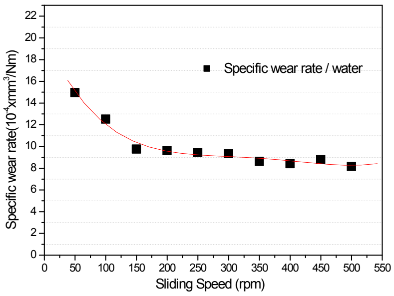

Fig. 3 Specific wear rate as function of sliding speed

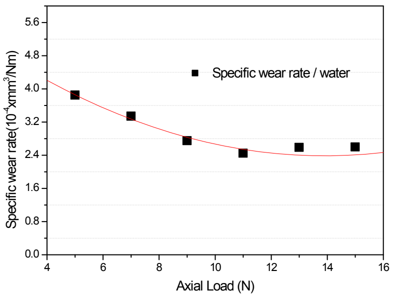

Fig. 4 Specific wear rate as function of axial load

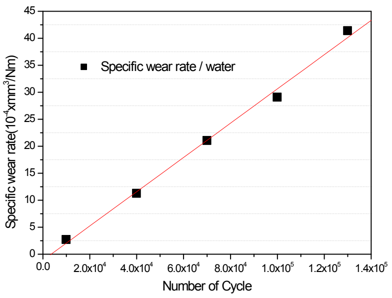

Fig. 5 Specific wear rate as function of no. of cycle

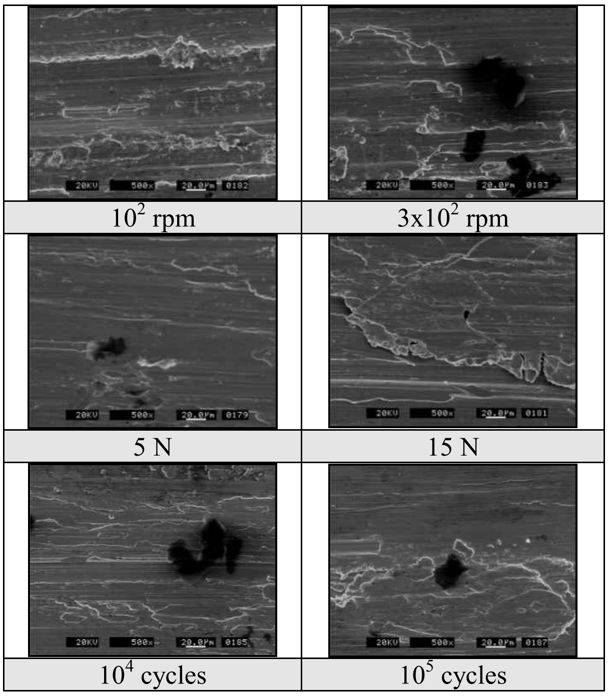

Fig. 6 SEM photographs of worn surface

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This means that there was no internal disturbance such as a change of wear mechanism. The micro-cutting and some of cracking were observed entire region of number of cycles. From the result of the test, the cycle does not affect to the change of wear mechanism or wear behavior in mechanical aspect in water lubricated environment.

3. Conclusions

The abrasive wear test performed under water environment to verify the frictional characteristic between fuel rod material and Inconel grid material. The control parameters were sliding speed, distance and axial load. The peculiar wear behavior and wear mechanisms was observed for each parameter.

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