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WEAR BEHAVIOUR OF STEAM GENERATOR TUBES IN ROOM TEMPERATURE WATER

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The wear behaviour of steam generator (SG) tubes (Inconel 600 and 690) against support materials (405 and 409 ferritic stainless steels) has been experimentally studied in room temperature water using reciprocating wear apparatus with tube-on-plate configuration. The results showed that the wear rate of Inconel 690 was lower than that of Inconel 600 with increasing normal loads and sliding amplitudes. Also, plastic deformation layers appear below the surface of both SG tubes, which have a specific thickness and are small compared with their grain size. This means that wear rate of SG tubes in water condition is closely related to the formation and fracture of plastic deformation layers.

Keywords : Steam generator, Inconel, Ferritic stainless steel, plastic deformation layer

1. INTRODUCTION

Recently, the fretting-related degradations in the SG tube materials are reported from many nuclear power plants. The main causes are both flow-induced vibration (FIV) between tube and support materials and the loose parts which randomly impact against the tube. Previous studies [1-2] have focused on the evaluation of the wear coefficient in a work-rate model to calculate the exact degradation rate for the estimation of residual lifetime. In spite of the widely recognized importance of wear coefficients in SG fretting wear, there has been relatively little effort made to understand wear mechanisms. The authors [3] have performed the wear test of SG tube materials in the room temperature air environment, in which the wear coefficients and the role of wear particle layers in the SG tube materials such as Inconel 600MA and 690TT were analysed.

In the present work, a fretting wear experiment was carried out with SG tube materials against ferritic stainless steels in room temperature water. The objective was to examine the possible wear mechanisms before high temperature and pressure experiments. The discussion focused on the relationship between the subsurface deformation and wear rate of SG tubes.

2. EXPERIMENTAL DETAILS

The test materials were Inconel 600MA and 690TT (abbreviated to 600MA and 690TT) used as SG tube materials in nuclear power plants. The counterpart materials were selected as 405 and 409 ferritic stainless steel (abbreviated to 405SS and 409SS) because those are used as tube support materials in the operating power plants.

A reciprocating wear apparatus with tube-on-plate configuration was utilized and the details of this test system are described in the previous studies [3]. The dimensions of the tube specimen were 19.05 mm diameter by 14 mm long and the counter specimens were prepared from the flat strip. The wear losses were determined from the weight measurements before and after the experiments using an analytical balance with an accuracy of the order of 0.1 mg. Prior to each test and weighing measurement, the specimens were acoustically cleaned in acetone for 5 min and dried in compressed air. The tube specimen oscillates with a peak-to-peak amplitude of 50~400μm at a frequency of 30Hz. The applied normal load was 10~40N. In the present study, distilled water was used for the environment and the wear experiments were performed at 25°C. To evaluate the wear mechanism in the water environment, the worn surfaces and cross-sections below the contact surface were examined using a Scanning Electron Microscopy (SEM) after tests. Also, nano-indentation tests were performed to assess the resistance to plastic deformation in the subsurface of the tube materials.

3. RESULTS AND DISCUSSION

3.1 Wear rate

Fig. 1 shows the effect of sliding distance on the mass loss of the tube materials at the same load. With increasing sliding distance, the wear rate, which is the slope of the tangent to the curve, is slowly decreased. Hence, the fretting wear rate does not linearly increase with sliding distance. If the generated wear particles are easily removed between contact surfaces in water environment during sliding, the wear transition phenomena is closely related with the change in hardness of surface or subsurface. From the previous study [4], when the subsurfaces were hardened to the same extent as the transfer particles and wear particles, the wear mode changed to the steady state wear. So, in water environment, wear rate of tube materials are determined by the variation of mechanical properties, such as work hardening, abilities of strain accommodation etc, between contact surfaces.

3.2 Correlation of friction coefficient

If the contact surface becomes harder due to severe plastic deformation, the contact area under the same load may decrease and consequently the friction coefficient will decrease. From the results, we deduced that 690TT experienced more work-hardening on its worn surface. Also, if wear particles were released from the worn surface after severe plastic deformation and fracture, the shear load, which was generated by friction force on worn surface, was dominantly related to deformation and fracture. Therefore, to identify the relationship between specific wear rate and shear load, we expressed wear rate against shear load, which was correlated with a friction coefficient in Fig. 2. In this figure, much of the scattering disappeared and specific wear rate is linearly increased with shear load. So, it is deduced that wear rate of tubes in water is determined by the abilities of strain accommodation on contact surfaces because this is closely related with the generation rate of wear particles.

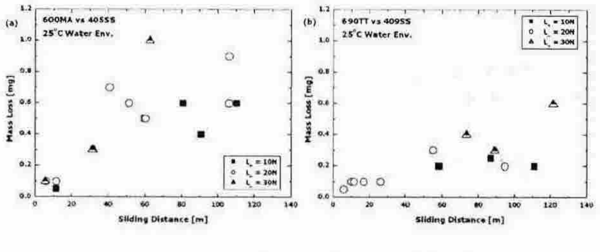
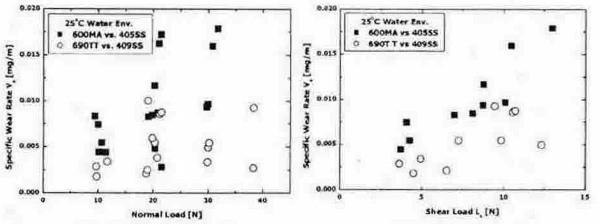


Fig. 1 The variation of mass loss of SG tube materials with sliding distance at the same load condition: (a) Inconel 600MA against 405 stainless steel; (b) Inconel 690TT against 409 stainless steel. Wear rate slowly decreases at both materials with increasing sliding distance.



(a) Normal load (b) Shear load

Fig. 2 The effect of normal and shear load on the specific wear rate of SG tube materials. Note the reduction of scattering in the plot of normal load (Fig. 2 (a)) when the friction coefficient was correlated to the wear rate (Fig. 2(b)).

3.3 Subsurface observation

Fig. 3 shows that almost all wear particles were removed and wear particle layer was not observable any more in water condition. So, they do not stay between contact surfaces for a long time and metal-to-metal contact is dominant. It seems apparent that the worn surfaces consisted of fractured thin plates, which were generated from the severe plastic deformation during wear. In 600MA, the thickness of those thin plates was about 2~3μm and cracks appeared under the worn surface in a perpendicular direction. But, in case of 690TT, the thickness of these plates and generated wear particles are relatively small. Fig. 4 shows cross-sections of worn surfaces in two tube materials. The plastic deformation layer apparently appears and they have specific thickness which is very small compared with their grain sizes (~30μm).

Besides, micro-cracks before wear particles propagate in deformed layer, not in grain boundaries. This means that if wear particles are generated by the fracture of these thin plates due to the hardness differences between upper and lower plates after severe plastic deformation, wear rate difference of two tube materials is, therefore, closely related with resistance to plastic deformation near worn surface during wear. Therefore, the wear rate of SG tube materials in room temperature water is determined by the balance between the rate of wear particle removal on the worn surface and the formation rate of plastic deformation layers in the subsurface.

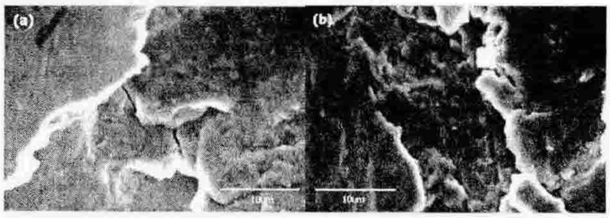


Fig. 3 SEM micrographs of the worn surfaces of SG tube materials after wear test: (a) Inconel 600MA; (b) Inconel 690TT.

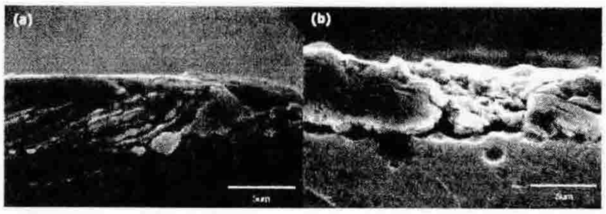


Fig. 4 The subsurface observation using SEM: (a) Inconel 600MA; (b) Inconel 690TT. Each tube materials have plastic deformation layers with specific thickness formed during wear.

4. CONCLUSIONS

Fretting wear behaviors of SG tube materials against ferritic stainless steels were investigated in room temperature water. The following conclusions are drawn;

(1) With increasing normal load and sliding distance, 690TT has low wear rate compared with 600MA in room temperature water. This result is mainly related to the changing mechanical properties of the tube materials during wear.

(2) The plastic deformation layers appear in the subsurface of both tube materials, which have specific thickness and are small compared with their grain sizes.

(3) In room temperature water, the wear rate of SG tube materials is determined by the balance between the removal rates of wear particles from the worn surface and the formation rate of plastic deformation layers in the subsurface.

5. REFERENCES

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