Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 10-11, 2007

Wear Progress and Mechanism of Alloy 600 SG Tube by Impact and Sliding Motion

Chi-Yong Park a, Jeong-Kun Lee a, and Tae-Ryong Kim a
a Korea Electric Power Research Institute, 103-16 Munji-dong, Yuseong-gu, Daejeon, Korea, cypark@kepri.re.kr

1. Introduction

Fretting wear is one of the important degradation mechanisms of SG tubes in the nuclear power plants. Especially, impact fretting wear occurred between SG tubes and tube support plates or anti-vibration bar[1]. Various tests have been carried out to investigate the wear mechanisms and to report the wear coefficients. Those are fruitful to get insight for the wear damage of SG tubes; however, most wear researches have concentrated on sliding wear of the SG tubes, which may not represent the wear loading modes in real plants. In the present work, impact fretting tests of SG tube were carried out. The wear coefficient has been investigated according to the work-rate model. A wear progression model for impact-fretting wear has been further investigated and proposed.

2. Experiments

Alloy 600 and SS 409 were used for the fretting wear test. Figure 1 is the schematic diagram of the impact fretting motion used in the present work. The fretting wear tests were performed with the impact frequency of 33 Hz and the oscillating slide frequency of 32Hz. The test temperature was 290°C. The sliding amplitude was chosen in the range of 30 to 120 μm. The impact normal force was set to be in the range of 20 to 50 N, which is known to be actual values existing between a SG tube and a tube support plate in operating plants. The test time was 40 hours. The wear rate was estimated by the weight change of the specimen before and after the test. To reduce the measurement error, the measurement was taken at least 10 times and averaged. The balance was calibrated using a reference specimen in each measurement. The worn surfaces and cross sections were observed through the scanning electron microscopy (SEM) equipped with energy dispersive spectroscopy (EDS).

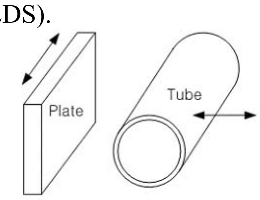


Figure 1. Schematic diagram of motion

3. Results and Discussions

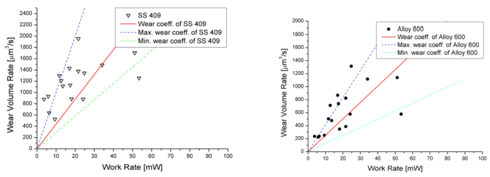
3.1. Wear volume by impact fretting wear

From the Archard formula, the volume wear rate is proportional to the normal work rate as below

$$\dot{V} = K\dot{W}_N \quad (1)$$

, where K is a wear coefficient.

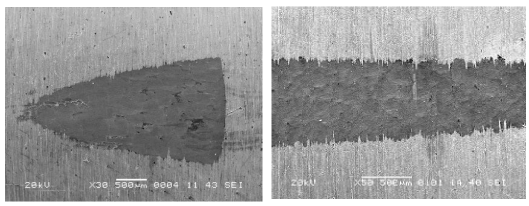
Figure 2(a) shows the wear volume rate vs. the work rate for alloy 600 tube material fretting against SS 409. The wear coefficient for alloy 600 is found to be in the range of 12.46E-15Pa^{-1} to 41.69E-15Pa^{-1}; the mean value is about 25.24E-15Pa^{-1}. The mean wear coefficient obtained from the present work is similar to that of the pure oscillating slide experiment, 26.88 E-15Pa^{-1} [2]. Figure 2(b) shows the relation of the wear volume rate with the work rate for SS 409 tube support. The wear coefficient for SS 409 against alloy 600 was found to be in the range of 28.99E-15Pa^{-1} to 100.01E-15Pa^{-1}. The mean wear coefficient is about 43.98E-15Pa^{-1}, which is about twice higher than that of alloy 600. The wear coefficient of the support material has never been reported yet due to less importance. The effect of the clearance between tube and its support should be considered in evaluating the wear damage and establishing the wear prediction model.



(a) Alloy 600 (b) SS 409
Figure 2. Wear volume rate vs. work rate

3.2 . Observation of Worn Surface

Figure 3 shows two cases of worn surfaces of alloy 600 at 290 °C. On both of the worn surfaces, the hammer-like imprint, known as the actual damaged wear pattern is observed. The case of the inclined impacting should contain the progressive wear marks from the initial stage to the fully developed stage although the wear rate data may be unreliable.



(a) Inclined Impacting (b) Normal Impacting
Figure 3. Worn surfaces by impact fretting in alloy 600

Figure 4 is the magnified photo of the left end area in Figure 3(a), which is thought to represent an initial wear mark. Crack-like pattern was observed on the surfaces.

It seemed that the rugged surface of oxide film was deformed and/or fractured by the abrasive wear mechanism.

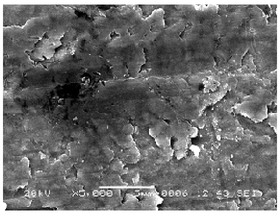
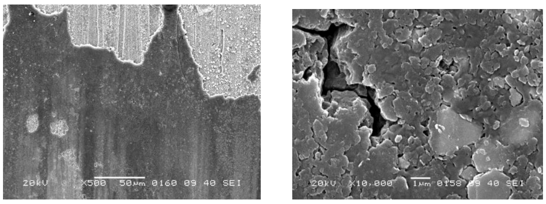


Figure 4. Surface at initial stage by impact fretting wear (The left end of Figure 3(a)).

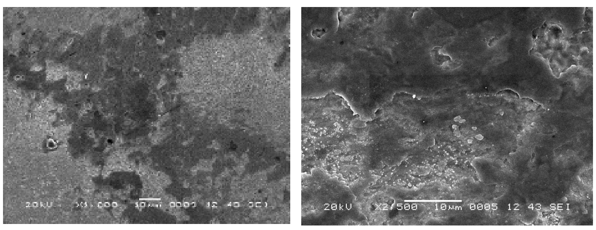
Figure 5 shows the boundary between the worn surface and the intact surface as-received and its spectrum results, which may represent the layer formation stage. Many wear particles were observed near the boundary without being damaged. Inside wear damaged area, the particles agglomerated to form a layer. Yet the particles showed polygonal characteristics



(a) x500 (b) x10,000

Figure 5. Worn surface observation at boundary i.e. the growing wear step(Second), by impact fretting wear

The magnified photos in the middle area of Figure 4(a) are shown in Figure 6, which were considered to be the worn surface at fully developed stage of wear. In Figure 6(a), the black colored region seemed to be the wear particles rammed by the impacting force, while the grey colored region to be new surface after the wear particles torn out. Microscopic view of the worn surface at fully developed stage is somewhat different from that at the initial stage of wear. Crack-like pattern at initial stage as seen in Figure 4 is not observed in this stage. From EDS examination, we can also infer the following wear process; the surface layer is hardened by impact load, crack is created and propagate at sub-surface under the wear layer, and the wear particles is torn out. Sectional view of worn surface was investigated to make sure of existence of TiC composition. Black belt seen in Figure 6 is thought to be a wear layer which will be torn out later.



(a) x500 (b) x2,500

Figure 6. Worn surface observation

3.3 Progress and Mechanism

From investigation of the macroscopic wear marks, microscopic SEM and EDS examination, a progressive mechanism of impact-fretting wear is proposed as followings;

(1) Oxide film breaking step : The initial start of wear mechanism is the abrasion process where the apices of rugged surface are removed. Then the cracking of the hard oxide film follows. Once the oxide film is torn out and stable impact fretting wear starts, this step is never reproduced in the controlled water chemistry condition, since oxide film is not formed due to the lack of dissolved oxygen.

(2) Layer formation step : As wear particles are stuck to surface and rammed by the impact force, a flat layer so called wear layer is formed on the surface. This is layer formation step.

(3) Energy accumulation step : The wear layer is being deformed by continuous hammering and the contact pressure. As energy is accumulated in the wear surface, micro-cracks, which could be observed in the sectional area, are formed in the sub-layer. The hammer imprints could be observed on the surfaces.

(4) Particle torn out step : The crack created at sub-surface under the wear layer propagates to the wear layer, and the wear particles are torn out. Then a new surface of deformed layer is exposed. This is particle torn out step. Then wear particles are stuck to the new surface again, which is the layer formation step in the stable impact fretting wear progress.

4. Conclusions

From the impact fretting wear tests of alloy 600 against SS 409 in SG operating condition, the following conclusions can be made.

1. The wear coefficient for the material of alloy 600 steam generator tube is about the half of that of SS 409 tube support plate materials, if the work-rate model is applicable

2. The proposed wear progression model of impact-fretting wear is as follows; oxide film breaking step at the initial stage, and layer formation step, energy accumulation step and finally particle torn out step which is followed by layer formation in the stable impact-fretting progress.

REFERENCES

[1] P. L. Ko, “Heat Exchanger Tube Fretting Wear: Review and Application to Design,” Journal of tribology, Vol. 107, pp. 149-156, 1985.

[2] Young-Ho Lee, In-Sup Kim, Sung-Sik Kang, Hae-dong Chung, “A study on wear coefficient and mechanisms of steam generator tube materials,” Wear, Vol. 250, pp.718-725, 2001.