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Impact Fretting Wear Characteristics of Tube Materials against Carbon Steel Support Structure in Steam Generator

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1. Introduction

Fretting wear generated by flow induced vibration is one of the important degradation mechanisms of steam generator (SG) tubes in the nuclear power plants. Understanding of tube wear characteristics is very important to keep the integrity of the steam generator tubes. Wear at tube support plates can result in damage to tubes in SG. Experimental examination has been performed for the purpose of investigating the impact fretting wear [1-2]. In this study, test material pairs were selected as alloy 690 and alloy 600 tubes against carbon steel support plate's material. Predicting future support wear requires experimental development of wear coefficients for tubes. Wear coefficients can be used in predicting potential anti-vibration bar or tube support plate wear damage or assessing wear damaged tube. Investigation of worn surfaces will also give insight for the worn tube in the plant fields.

2. Experiments and its Systems

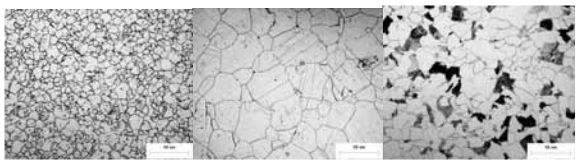
In this section, experimental method and test system used in performing fretting wear tests are described.

2.1 Wear Test System and Conditions

The test system for this experimental wear study consists of an environmental chamber, an actuator which is divided into a cyclic impact loading device and a reciprocating motion generator part, a water loop system simulating environments of secondary side of a SG in a nuclear power plant, and a control unit and program. In the high temperature and high pressure test, the temperature of the pure water is over 280°C in the chamber. To simulate and investigate impact fretting wear of SG tubes, test system as shown in Fig.1 have been used to control very small displacement of sliding motion and impact forces. Test system could be operated under plant operating conditions such as pressure of 15MPa, high temperature of 290°C and low dissolved oxygen under 5ppb.

Fig. 1 Wear test system

Alloy 690, which is a tube material of replaced SG and alloy 600, which is a tube material of original SG, were used for tube specimens. Tube support plate specimens, low alloy steel SA 508, were prepared from block. In some pressurized water reactor, carbon steel SA 508 was used as support material in old steam generator, which is one through steam generator. Since this steam generator has been served severe wear damages, this support material was selected for root cause analysis. Fig. 2 shows microstructures of tube and support materials



(a) Alloy 600 (b) Alloy 690 (c) SA 508
Fig. 2 Microstructures

Tests were performed in the water environment at the temperature of 290°C. Pressure is about 15MPa and N_2 gas was charged in distilled water. Reciprocating sliding distance is from 0.05mm to 0.2mm at a frequency of 11Hz. The applied normal load ranges from 20N to 50N at a frequency of 10Hz.

2.2 Reliability Check of Wear Test Process

The wear test process was inspected during the test period with 12 hours. The inspection included examination of the control monitor and the loop operation to monitor parameters such as the operating pressure, the operating temperature and the oxygen level. If abnormal operation of test facility would be detected, appropriate action such as process stop or discard of results data has to be done. For obtaining the sound wear test results, the process reliability has to be checked from the process information such as global peak force and work rate variation during the full test time.
The second checking method for sound wear test process is investigating the photo of the worn surface of tube and support specimen. Examination of the worn surface reflects the tightness of the fit between the jig and the test specimen and possible abnormal operation of the movement. In Figure 3, a worn surface is presented for a sound case with reliability for tube specimens. Figure 4 shows a photo for a worn plate.

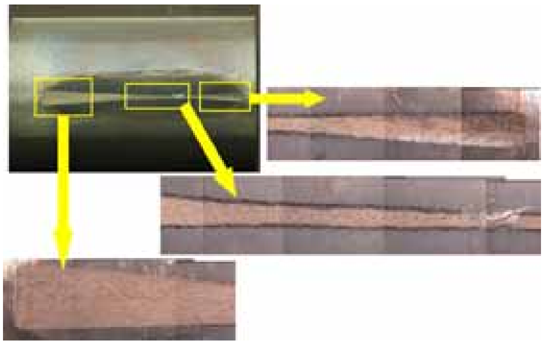


Fig. 3. Worn surfaces of alloy 600 tube

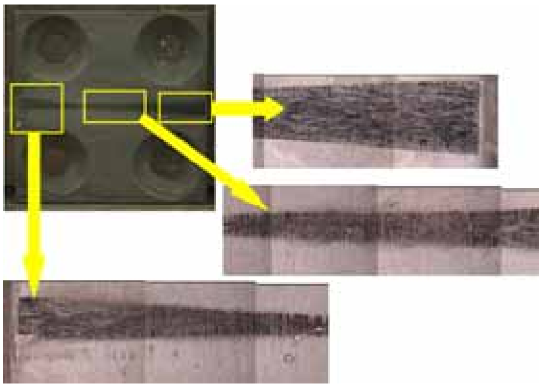


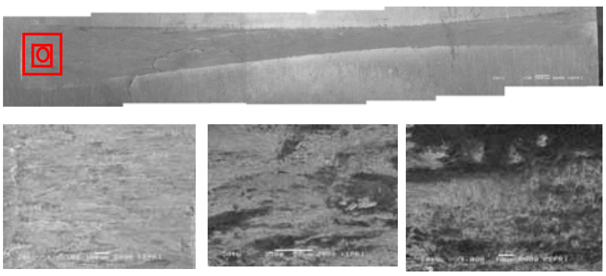
Fig. 4. Worn surfaces of carbon steel support plate

3. Results and Investigation

For obtaining insight into wear phenomenon through an investigation of the surface of the worn tube in the plant fields, photos of worn surfaces are presented. Wear coefficient of tubes were gained for evaluating the prediction of wear damage.

3.1 Worn Surfaces of Tube and Support

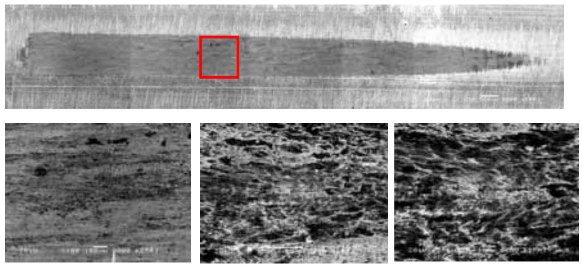
The worn surface was examined through a scanning electron microscope (SEM) for the purpose of obtaining insight about the general worn surfaces in the case of withdrawing a damaged tube from the steam generator. Figure 5 shows the worn surfaces of a piece of alloy 600 tubing (test with an impact force of 40 N and a sliding distance of 140 μm) and the enlarged photos. The large box, small box and small circles show the area with a magnification of 100, 500 and 1000, respectively.



(a) X100 (b) X500 (c) X1000

Fig. 5. Worn surface of alloy 600 against carbon steel

Figure 6 shows the worn surfaces of a piece of alloy 690 tubing (test with an impact force of 50 N and a sliding distance of 200 μm).



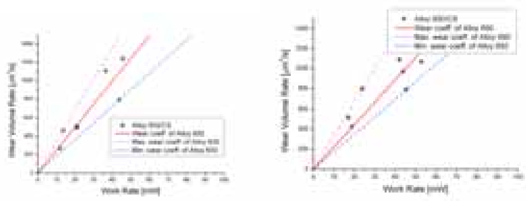
(a) X100 (b) X500 (c) X1000

Fig. 6. Worn surface of alloy 600 against carbon steel

3.2 Wear Coefficients

The wear coefficient will be used to estimate the remaining life of a worn SG tube using the wear rate model. Figure 7(a) shows the wear coefficient for alloy 600 against carbon steel support material based on the weight measurement. The wear coefficient ranged from $18.073\text{x}10^{-15}$ Pa^{-1} to $33.909\text{x}10^{-15}$ Pa^{-1}.

Figure 7(b) shows the wear coefficient for alloy 690 tube against the same material. The wear coefficient ranged from maximum $33.409\text{x}10^{-15}$ Pa^{-1} to minimum $17.367\text{x}10^{-15}$ Pa^{-1}. In the calculation of life prediction, selection of the average or maximum value may depend on the user option. For example, if a tube has severe wear, the maximum wear coefficient can be conservatively selected.



(a) Alloy 600 (b) Alloy 690

Fig. 7. Wear coefficient graph of alloy 600 and alloy 690 tube against carbon steel

3. Conclusions

The wear coefficients were obtained and some worn surfaces are presented from impact fretting wear test of SG tube against carbon steel.

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