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Fretting Wear Investigation of Alloy 690 against Flexible Material Remained inside Secondary Environment in Steam Generator

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1. Introduction

Tube's fretting wear generated by the remained material due to flow induced vibration is important on the maintenance and inspection fields of steam generator (SG) tubes in the nuclear power plants. Understanding of tube wear characteristics is also very important to keep the integrity of the steam generator tubes. And, it may give to insight the maintenance engineer for decision about reaching the plugging criteria. Experimental examination has been performed for the purpose of investigating the fretting wear[1-2]. In this study, test material pairs were selected as alloy 690 tubes against the flexible foreign object material such as gasket. Predicting tube wear requires experimental development of wear coefficients for tubes. Wear coefficients can be used in predicting life time and integrity for the 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.

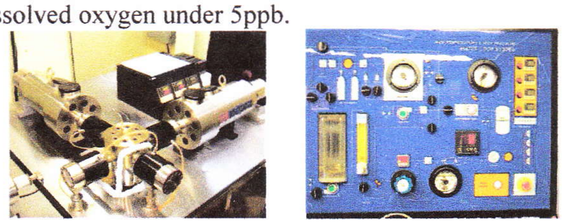
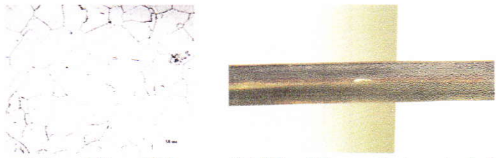


Fig. 1 Wear test system

Alloy 690, which is a tube material of replaced SG, was used for tube specimens. Foreign object material specimens, flexible gasket, were prepared with a fixing jig. Flexible gasket would be occasionally remained inside the secondary environment of steam generator after the overhaul. Fig. 2 shows microstructures of tube and flexible gasket material.



(a) Alloy 690 (b) Flexible gasket material
Fig. 2 Microstructures of Alloy 690 and gasket material

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 40N 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, which sample is shown Figure 3.

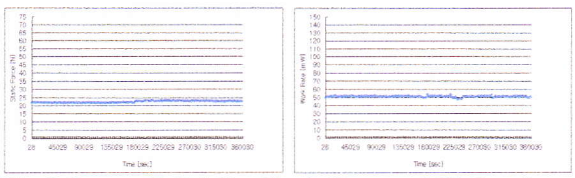


Fig. 3. Process Reliability Check (Force and Workrate)

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 4, a worn surface is presented for a sound case with reliability for tube specimens.

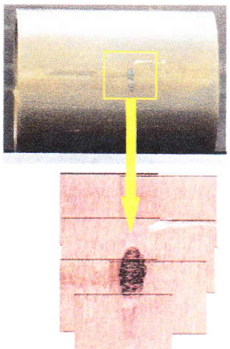


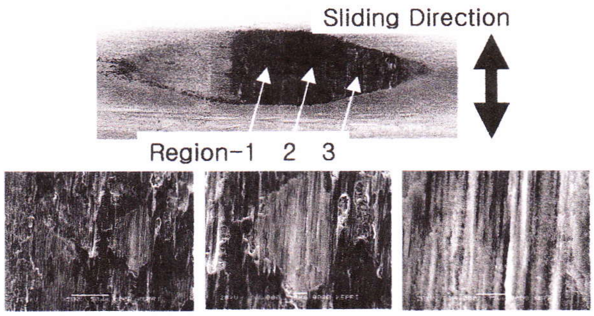
Fig. 4. Worn surfaces of alloy 690 tube

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, Figure 6 and Figure 7 show the worn surfaces of a piece of alloy 690 tubing (test with an impact force of 22 N and a sliding distance of 80 μm) and the enlarged photos at point 1, 2, and 3, respectively. The amplified photos show through a magnification of 500, 1000 and 4000, respectively.



(a) X500 (b) X1000 (c) X4000
Fig. 5. Worn surface of alloy 690 against flexible gasket (P-1)

(a) X500 (b) X1000 (c) X4000
Fig. 6. Worn surface of alloy 690 against flexible gasket (P-2)

(a) X500 (b) X1000 (c) X4000
Fig. 7. Worn surface of alloy 690 against flexible gasket (P-3)

From the metallurgical examination, the slide contacting interaction between tube and foreign object can be easily shown at almost surfaces. Abrasive wear mechanism is clearly observed at the Region-1, Region-2 and Region-3 of Figure 5. The delamination wear mechanism is shown in Figure 7, in which a work hardening lump of metal layer is removed from the surface. Dominant wear mechanism is known as the abrasive and the delamination wear.

3.2 Wear Coefficients

The wear coefficient will be used to estimate the remaining life of a worn SG tube by foreign objects using the wear rate model. Figure 8 shows the relation of work rate with wear rate for alloy 690 tubing against gasket. The wear rate was calculated from the wear volume which is conversed from the measured worn weight. From the relation between work rate and wear rate, the wear coefficient of alloy 690 tubing against gasket material is obtained as average 4.989x10-15 Pa^{-1}. The wear coefficient ranged from 10.915x10-15 Pa^{-1} to 3.741x10-15 Pa^{-1}. In calculation of tube life prediction, selection of the average or maximum value may depend on the user. For example, if a tube has severe wear, the maximum wear coefficient can be selected.

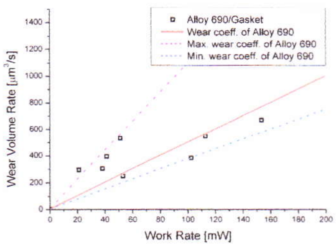


Fig. 8. Wear coefficient graph of alloy 690 tube

3. Conclusions

The wear coefficients were obtained and some worn surfaces are presented from fretting wear test of SG tube against gasket material.

REFERENCES

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[2] C. Y. Park, J. K. Lee and T. R. Kim, Wear Progress Model by Impact Fretting in SG Tube, KSME Transaction A, Vol.32, p.817, 2008.