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Wear Behavior of Anti-Vibration Structure Materials of Steam Generator in NPPs

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1. Introduction

It is well known that the wear of steam generator(SG) tubes in nuclear power plants is mainly caused by the repetitive impact and sliding motion between the tube surface and anti-vibration structure(AVS) under the flow-induced vibration. The wear of SG tube generally takes place at the contact points between tube and AVS within the upper bundle region of SG. A lot of information about the wear of SG tube has been provided through the operation experiences and the related studies [1, 2]. However, the wear behavior of AVS materials accompanied with wear process has not been evaluated widely in spite of the importance of their structural integrity in the viewpoint of the safety and the reliability of SG. This study was carried out to evaluate the wear behavior of AVS materials under the various test conditions taking into account the wear mode changes from fretting to sliding due to large-amplitude vibration. The sliding wear tests were performed with 403, 405, and 409 stainless steel(SS) used as AVS materials mated with steam generator tubes of Alloy 600 and 690 commonly used in OPR 1000.

2. Experimental Procedure

For the sliding wear test, 403, 405, and 409 SS AVS strips of 25×20×6 mm and Alloy 600 HTMA and 690 TT tubes of the size of 19.05 mm in diameter were used as fixed and moving specimens, respectively. A reciprocating sliding wear test apparatus as shown in Fig. 1 was used for simulating sliding wear between the AVS and the tube both at room temperature in air and in 300 ℃ water environment. At the conditions of the sliding amplitude of 0.1 to 10 mm and the frequency of 3 to 30 Hz, tests were performed up to 16 hrs under applied normal load from 10 to 40 N. Worn surface after test were examined to determined wear mechanism by using scanning electron microscopy(SEM).

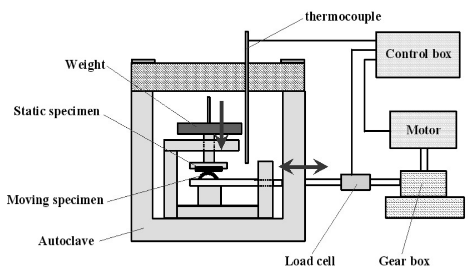


Figure 1. Schematic diagram of sliding wear test apparatus.

3. Results and Discussion

3.1 Wear behavior at room temperature in air

Fig. 2 shows the changes of total wear volume with the applied normal load for the various material combinations under the test conditions of the sliding amplitude of 4.5 mm, the frequency of 5 Hz for 16 hours in air. The wear volume increased linearly with the applied normal load regardless of the material combinations. The increase of normal load from 20 to 40 N resulted in two to three times increase in wear volume. These results are agreed well with Archard equation [3] predicting wear behavior.

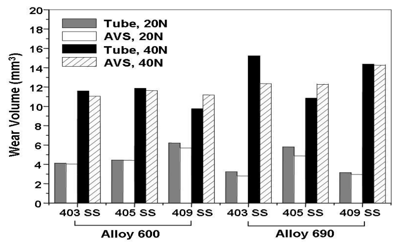
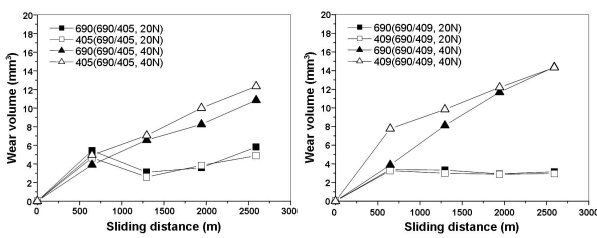


Figure 2. The change of wear volume under the normal load of 20 and 40 N at RT in air.

It is necessary to evaluate the changes of wear volume with increasing sliding distance as shown in Fig. 3. The wear volume increased parabolically with increasing sliding distance under the normal load of 20 N, while it increased linearly with sliding distance for the condition of 40 N. From SEM observation on the worn surface, it was revealed that this difference in wear rate was closely related to the wear surface condition as analyzed in the previous study [4]. That is, the decrease of wear rate under the lower load condition of 20 N was due to the formation of wear protecting layers such as glaze layer on the wear surface [5, 6], while a destruction of glaze layer under the higher load of 40 N resulted in the linear increase of wear volume.



(a) 405 SS/Alloy 690 (b) 409 SS/Alloy 690

Figure 3. The variation of wear volume with sliding distance at RT in air.

3.2 Wear behavior at 300 ℃ in water

Fig. 4 shows the results of total wear volume obtained from various material combinations and environments. It can be seen that there are some distinguishing differences in the amount of wear volume between in air and in water environment. A smaller wear volume of AVS and tube materials even in high temperature of water condition comparing to the result in air environment is mainly due to a lubricant action of water at contact areas between two materials in the sliding wear process [7]. It should be pointed out that the wear volume of all AVS materials is much larger than that of tube materials at high temperature in water. This wear behavior could be resulted from a reduction of strength and hardness of AVS materials, the fast formation of glaze layers, and the decrease of contact stress due to the lubrication role of water at high temperature.

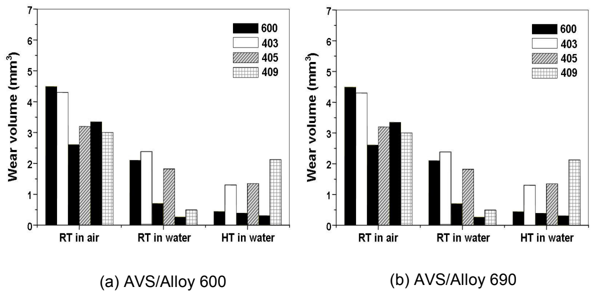


Figure 4. Wear behavior of AVS materials for different environments.

4. Summary

In various environments, it was found that the wear volume of AVS materials is always higher than that of tube materials except for the condition at room temperature in air. Compared with the results at room temperature in air, the differences in wear volume between AVS and tubes materials were increased significantly in high temperature water. It was shown that the increasing rate of wear volume for AVS materials was gradually decreased with increasing sliding distance for the normal load of 20N under both test conditions in air at room temperature and in water at high temperature, however, their wear volume increased linearly with increasing sliding distance under 40N. At room temperature in air, the wear behavior of AVS materials was affected by preventing the direct contact between metals due to material transfer and the formation of glaze layers. It can be drawn that a reduction of strength and hardness of AVS materials, the fast formation of glaze layers, and the decrease of contact stress due to the lubrication role of water were acted as important factors determining the wear behavior of AVS materials at high temperature in water. As a result, the effect of wear of AVS strip materials on the SG integrity at operation condition should be investigated intensively.

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