EFFECTS OF CONTACT LOAD ON FRETTING WEAR OF Al-Si ALLOY IMPREGNATED GRAPHITE COMPOSITE

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INTRODUCTION

An Al-Si alloy impregnated graphite composite (ALGR-MMC) containing a large amount of graphite (56 vol%) has been newly developed to improve the friction and wear characteristics of machine components such as clutches under dry sliding and journal bearings under lubricated sliding. The ALGR-MMC has the same self-lubricating performance as graphite in moist environments (1). It has good properties of thermal expansion, heat resistance and wear resistance.

The objective of this study is to investigate the friction and wear of the ALGR-MMC under fretting conditions (2). Ball-against-disk type fretting wear tests for the ALGR-MMC (flat) in contact with bearing steel (ball) were conducted at various contact loads in moist air under unlubricated conditions. The friction coefficient was monitored during the tests. The area and depth of wear scars were measured after the tests or in the interrupted tests. From the friction and wear data, the effects of contact load on the fretting wear characteristics of the ALGR-MMC were evaluated with SEM observations of wear scars and EPMA analyses of wear surfaces.

EXPERIMENTAL PROCEDURES

An Al-Si alloy impregnated graphite composite was used for disk specimens. The composite contained 56 vol% of graphite and 42 vol% of Al-Si alloy. Thus the porosity was 2 vol% and the apparent density 2.34×10³ Kg/m³. Steel balls of 12.7 mm (1/2 in.) in diameter were taken from commercially available thrust bearings and used for ball specimens. The composite was not heat-treated and machined to disks of 40 mm in diameter and 7 mm in thickness. The test surface of the disks was polished with #1500 emery paper and finally finished with #4000 (0.5 to 4 µm) diamond paste. Vickers hardness (Hv) and centerline average roughness (Ra) were 71 and 0.25 µm for the disk surface and 860 and 0.01 µm for the ball surface.

A ball-against-disk type fretting wear test rig was used. The ball was attached to a loading arm and the disk fitted to a fixation jig of the main drive shaft. The various loads from 5 to 100 N were applied to the contact point of the ball and disk by hanging a dead weight at a specified position of the loading arm. The disk in contact with the ball repeated a reciprocating motion for 2×10⁵ cycles at 6.66 Hz. This caused relative slip between the contact surfaces, resulting in fretting wear occurrence. The testing part of the rig was enclosed with a chamber, in which the temperature and relative humidity were kept at 24 °C and 70 %. The frictional force (F) between the contact surfaces was measured with strain gages bonded on the loading arm. The half amplitude of the reciprocating motion applied to the main shaft was measured with a laser-type displacement meter. From the recorded F waveforms, the kinetic friction coefficient (f_k) was obtained at the midpoint of the reciprocating motion stroke. The loading arm deflected slightly due to F during the tests. The half amplitude of the arm displacement in the sliding direction was obtained by using a pre-examined calibration straight-line between the output voltage due to F and the arm displacement. The half amplitude of relative slip was obtained by subtracting the arm displacement from the reciprocating motion. The desired value of the relative slip was 50 µm.

After each test, the ball and disk were disassembled from the rig and ultrasonically rinsed with acetone to remove wear debris. The wear scar size of the specimens, parallel and normal to the sliding direction, was measured by using a scale with ±0.5 µm precision attached to the microscope of a micro-Vickers hardness tester. Seven wear profile curves, parallel and normal to the sliding direction, were recorded near the center portion of the disk scars with a stylus-type surface profilometer, from which the maximum wear depth of the disk was obtained.

RESULTS AND DISCUSSION

Change in friction coefficient and slip amplitude with fretting cycles

Figure 1 shows a change in friction coefficient (f_k) and slip amplitude (S) with cycles at 40 and 75 N. Two types of fretting process are found. In Type A process, S increases drastically at a certain number of cycles (n_a) to the desired value of 50 µm at 40 N and uncontrollable values of about 60 µm. f_k decreases
corresponding to the change in $S$ at 40 and 75 N. $n_{cr}$ is defined as critical number of cycles. The first stage ranges from the start of test to $n_{cr}$ and the second stage from $n_{cr}$ to the end of test. Type B process is found at loads from 50 to 100 N. In Type B, $S$ keeps constant at low values without reaching the desired value throughout the test and $f_k$ exhibits high values approximately equal to the values at the first stage in Type A. At loads higher than 60 N, although $S$ cannot be controlled at approximately equal to the values at the first stage in Type A.

The mean critical number of cycles ($n_{crm}$) was obtained from the interrupted tests. Figure 3 shows $w$ as a function of load at the desired slip amplitude of 50 $\mu$m. The $w$ is the greatest in the first stage of Type A and the smallest for the total duration of the tests in Type B.

**Observations and EPMA analyses of ball sliding surface**

Figure 4 shows the SEM images of ball sliding surface at 60 N. The sliding surface in the first stage of Type A is sufficiently covered with adhered films as shown in Fig. 4 (a). The sliding surface after the tests of Type A (Fig. 4 (b)) is partly covered with the films so that the substrate of bearing steel is seen. The sliding surface after the tests of Type B (Fig. (c)) is covered with the films but the scar area is smaller than that in the first stage of Type A.

To investigate the material transfer from disk to ball, EPMA line analyses (1 mm) were performed three times at an interval of 50 $\mu$m along the middle portion of the scar on the ball sliding surface. Although adhered films of Al and C are formed over the whole area of the sliding surface in the first stage of Type A (Fig. 5 (a)), the carbon rich films flake off easily until the end of test (Fig. 5 (b)). On the contrary, the films are kept to form over the sliding surface throughout the test of Type B.

**CONCLUSION**

In Type A process, the ball tends to be in contact with the graphite portion of ALGR-MMC disk in the first stage so that the failure of brittle graphite occurs, resulting in an increase in wear rate of the MMC. In Type B process, the ball is in contact with the Al-Si alloy portion of the composite, leading to metal-to-metal contact. This causes less damage to the MMC.

**REFERENCES**