



Effect of surface film on sliding friction and wear of copper-impregnated metallized carbon against a Cu–Cr–Zr alloy

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ARTICLE INFO

Article history:

Received 26 May 2011

Received in revised form

13 September 2011

Accepted 8 October 2011

Available online 14 October 2011

Keywords:

Oxide layer

Electrical contacts

Friction

Wear

ABSTRACT

A block-on-ring wear test was performed between a copper-impregnated metallized carbon brush and a Cu–Cr–Zr alloy ring under ambient environment. After 50 km of rubbing at 20 A electrical current and 111 kPa normal pressure at a constant velocity of 25 km/h, a surface film, which was composed of Cu_2O , CuO , C and water, formed on the copper alloy ring due to graphite transfer from the brush to the copper alloy and oxidation of the copper. A second series of friction and wear tests was carried out both with and without this initial surface film and at different electrical currents. The friction coefficient and wear mass loss were compared. The results showed that the initial surface film could reduce the friction coefficient in the presence of an electrical current, but in the absence of an electrical current, the film's lubricating performance gradually degraded as the test progressed. Wear mass losses caused by the rubbing of the brushes against the rings having an initial surface film were lower when the electrical currents were 0 A, 10 A and 15 A, respectively, while the situation was reversed when the electrical current was 20 A, i.e., the wear mass loss of the brush specimen rubbing against a ring with an initial surface film was higher than that of a ring without it.

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1. Introduction

Copper-impregnated metallized carbon/copper or copper alloys have been widely used in sliding electrical contacts due to their excellent electrical conductivity and high mechanical strength [1–3]. To decrease the cost of maintenance and keep these systems running stably, a better understanding of the wear mechanisms encountered in electrical sliding contacts is needed. The wear of the materials and the formation of the surface films occur during the rubbing process. More than 90% of the energy from friction is concentrated within the surface films [4]. Therefore, surface films formed on the contact surfaces in sliding electrical contact systems are the key to understanding wear mechanisms.

The surface films are the result of complex physical and chemical processes, including material transfer, debris generation and oxidation. These films have unique lubrication and electrical properties [5–7]. With an electrical current present, the heat generated on the contact surface in wear processes is mainly attributed to friction heat q_f , arc heat q_a and Joule heat q_r [8]. The temperature rise caused by heating increase the wear of the material and favors oxidation [9–11]. Therefore, the film formed with an electrical current present is different from that formed without an electrical

current. Although much work has been done to study the tribological behavior of copper-impregnated metallized carbon, most research has been concerned with the effects of electrical current, normal pressure, velocity and so on. However, less work has focused on the effects of the surface film on the tribological behavior of these materials. The effects introduced by these surface films are not well understood, so it is worthwhile to study their characteristics. In this study, we demonstrate that the composition and lubricating performance of the surface films are different with and without an applied electrical current.

2. Experiment

Friction and wear tests were conducted on a UMT-2 tribometer with a block-on-ring configuration. The structure of the test machine is shown in Fig. 1. The brush specimen used for the test was fixed in an insulated upper sample holder. The ring sample was attached to the spindle of the rotary drive. Another electrical brush was mounted in the lower sample holder to conduct the electrical current, which was supplied by a DC power source. The test brush was connected to the negative terminal of the DC power, and the lower electrical brush was connected to the positive terminal. The upper brush specimen and lower electrical brush were aligned with an offset so they could run in different tracks of the rotor.

A commercial copper-impregnated metallized carbon contact strip was used in this study and was cut into brushes of

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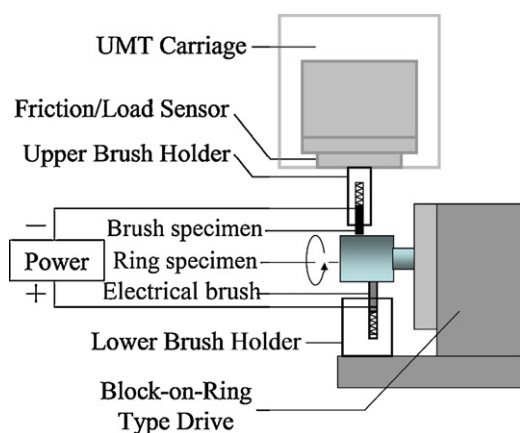


Fig. 1. Schematic of the test apparatus.

6 mm × 6 mm × 25 mm to fit into the upper brush holder. The chemical composition (wt%) of the brush specimen was 81.2% C, 15.4% Cu, and the balance S. The hardness of the brush was 99 HS. Its counterpart was a Cu–Cr–Zr alloy ring of 28.4 mm in diameter and 27 mm in length. The chemical composition (wt%) of the ring was 1.09% Cr, 0.2% Zr, and the balance Cu. The hardness of the ring was 75 HRB.

One type of ring sample was polished using sand paper, cleaned with alcohol before each test, and then rubbed against the brush specimen at a velocity of 25 km/h for 2 h at 20 A electrical current and 111 kPa normal pressure. After rubbing, a surface film was formed at the ring surface due to graphite transfer from the brush specimen and oxidation of the copper. This specimen is recorded in this paper as the ring with an initial surface film. The other type of ring specimen was also polished using sand paper and cleaned with alcohol before each test but was not rubbed against the brush under an applied electric current. This ring is described as being without the initial surface film. The brush specimens were also polished using sand paper and cleaned with alcohol before each test.

All experiments were conducted in a laboratory environment with a relative humidity of approximately 15%. In all tests, the normal pressure was 111 kPa. The ring samples were rotated at a velocity of 25 km/h for 2 h. The selected electrical currents were 0 A, 10 A, 15 A and 20 A. A series of tests were conducted with the brush sample rubbing against the ring sample, both with and without the initial surface film.

The morphologies of the rings were observed with an OLYMPUS BX60M optical microscope (OM). The composition of the surface films was analyzed by AXIS ULTRA X-ray photoelectron spectroscopy (XPS). The worn surfaces of the brush specimens were studied using JOEL JSM-6510A scanning electron microscopy

(SEM). Wear losses of the brush specimens were determined by weighing them using a balance with 0.1 mg precision.

3. Results

3.1. OM observation and XPS analysis of the initial surface film

The surfaces of rings without and with initial surface film are shown in Fig. 2. The darker initial surface film can be seen adhered to the surface of the ring sample.

Fig. 3a shows an XPS survey scan of the initial surface film. Three main elements (carbon, oxygen and copper) were observed. High resolution scans of the Cu 2p_{3/2} and O 1s features were examined in detail. The binding energies of the Cu 2p_{3/2} and O 1s peaks were calibrated with respect to position of the C 1s (284.8 eV) peak. Fig. 3b shows the different Cu 2p_{3/2} states of the initial surface film. Generally there were two peaks for Cu 2p_{3/2}. Peak 1 (932.7 eV) is attributed to Cu₂O, and peak 2 (934.7 eV) is attributed to CuO. Fig. 3c shows the different O 1s states. Peak 1 (531.3 eV) is attributed to CuO, peak 2 (532 eV) is attributed to Cu₂O, and peak 3 (533.4 eV) is attributed to adsorbed water from the atmosphere [12,13]. The XPS results confirmed that the initial surface film was composed of Cu₂O, CuO, C and water.

3.2. Effects of the initial surface film on the friction and wear of brush specimens

Fig. 4 shows the change in the friction coefficients over time under different electric currents. Without an electric current, the starting value of the friction coefficient for the ring with the initial surface film was about 0.3. Then the friction coefficient quickly increased. It surpassed 0.40 within 10 min and then increased more slowly, reaching approximately 0.45 after about 90 min of rubbing, a value equal to that of the ring samples without the initial surface film, as shown in Fig. 4a. With an applied electric current, the friction coefficients of the rings with the initial surface films were always lower than those of the rings without the initial surface film, as shown in Fig. 4b–d.

Furthermore, the friction coefficients of ring samples without initial surface films fluctuated more widely than those with initial surface films, as can be seen from the greater number of spikes in the measurements for those samples. This difference in the amount of variation was observed under all test conditions. The behavior confirms that the initial surface films can act as a solid lubricant.

Fig. 5 shows the variation in the wear mass losses of the brush specimens rubbed against the ring samples. Measurements are plotted for the brushes used against each type of ring, both those with and without the initial surface films, and under different electric currents. For either type, the wear mass losses increased with

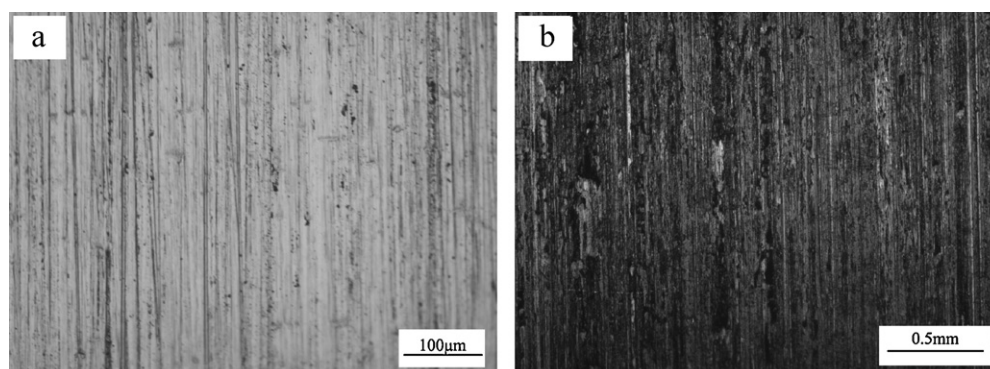


Fig. 2. OM micrographs of the surface of ring specimens (a) without and (b) with the initial surface film.

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