Tribology International 127 (2018) 372–378

Contents lists available at ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

Identification and evaluation of wear phenomena under electric current by using an acoustic emission technique

Alan Hase[a,*], Hiroshi Mishina[b]

[a] Department of Mechanical Engineering, Faculty of Engineering, Saitama Institute of Technology, 1690 Fusaiji, Fukaya-shi, Saitama, 369-0293, Japan
[b] Department of Artificial System Science (Tribology Laboratory), Graduate School of Engineering, Chiba University, 1-33, Yayoi-chō, Inage-ku, Chiba-shi, Chiba, 263-8522, Japan

ARTICLE INFO

Keywords:
Condition monitoring
Sliding contact
Wear measurement
Electric current

ABSTRACT

The use of acoustic emissions to evaluate the tribological characteristics of the collector friction system of an electric railway was investigated. Both mechanical wear and wear by arc discharge and melting occur at the sliding interface. When friction and wear experiments were performed with a pin-on-disk-type sliding-friction tester with an electric current flowing between the specimens, an analysis of the frequency of the resulting AE signal showed that each phenomenon produced a distinct AE frequency spectrum. The tribological characteristics of the materials in the presence of an electric current can therefore be evaluated from features of the AE frequency spectrum.

1. Introduction

Mechanical wear of electric-current-collection systems is inevitably accompanied by additional wear arising from arc discharge and melting. Consequently, the rate of wear of the materials of these devices in frictional contact in the presence of an electric current is significantly increased compared with the case in which no electric current is present. Heat generated from the contact resistance between surface asperities causes melting and fusion at the sliding interface. Subsequently, dielectric breakdown occurs in the gap resulting in arc discharge, which causes further abrasion of the surface when the arc discharge ends. The generation of arc discharge and the damage caused by the arc discharge and melting are expected to differ depending on the nature of the material from which the current collector is constructed. Evaluation of the tribological characteristics of current-collector materials in the presence of an electric current is therefore important for developing suitable materials for these applications. Because of the complexity of current-collector friction systems (e.g., trolley-wire conductors and pantograph contact strips on railroad wagons), many factors including the sliding conditions, the materials, the electric current, the atmosphere, and the quality of installation affect the rate of wear. Moreover, increased levels of wear might interfere with the control of railroad wagons as a result of faulty electrical connection and the resulting noise, etc. Therefore, adequate monitoring of the state of wear of the materials in the presence of an electric current and the evaluation and measurement of their tribological characteristics become indispensable.

The evaluation and the diagnosis of the tribological phenomena that occur on sliding surface can be performed by using the acoustic emissions (AEs) to detect the elastic stress waves that arise when materials are deformed and fractured. Various correlations between tribological characteristics (friction and wear characteristics) and AE parameters have been presented by several researches [1–5]. Because AE signals change in response to microscopic tribological phenomena [6], the AE technique can detect changes that cannot be detected by measuring frictional forces [7]. Also, it has been proved experimentally that the AE technique is superior to monitoring of vibration, stator currents, or shock pulses in the detection of grease contaminants in bearings [8].

We have paid particular attention to changes in the frequency spectrum of AE signal waveforms in response to the deformation and fracture of materials, and we have proposed a "correlation map of AE frequency spectra" for phenomena involving deformation and fracture as a means of identifying wear phenomena in buried interfaces by using an AE technique [9]. Moreover, if the AE frequency spectrum corresponding to a given phenomenon can be characterized, it should be possible to extract or discriminate an AE signal component corresponding to the phenomenon by means of band-pass filter processing of the recorded AE signals. AE-based techniques should therefore be very useful in evaluating tribological characteristics in the presence of an electric current, where several phenomena occur simultaneously in the contact area.

In this study, to examine the relationship between the wear state and AE signals under sliding friction in the presence of an electric

* Corresponding author.
E-mail address: alan_hase@sit.ac.jp (A. Hase).

https://doi.org/10.1016/j.triboint.2018.06.027
Received 14 April 2018; Received in revised form 19 June 2018; Accepted 24 June 2018
Available online 25 June 2018

current, the AE signals and the voltage drop between specimens were measured simultaneously, together with the light emitted at the interface and the wear state of the materials. Furthermore, because tribological phenomena can be identified from features of the AE frequency spectrum, the AE signal waveforms were measured and analyzed to identify and evaluate the tribological phenomena in the presence of an electric current. Therefore, to identify and evaluate wear phenomenon under sliding friction in the presence of an electric current (especially, where both arc discharge and melting phenomena occur) from the AE frequency spectrum, we performed a static experiment that artificially produced arc discharge and melting phenomena. From the changes in the frequency spectra of the AE signal waveforms measured in this experiment, we elucidated the wear phenomena under sliding friction with an electric current for various materials.

2. Experimental procedures

2.1. Experimental setup and the acoustic-emission measurement system

Friction and wear experiments were performed by using a pin-on-disk-type sliding friction tester with an imposed electric current, as shown in Fig. 1. A schematic diagram of the experimental setup, the superimposed voltage circuit, and the AE measurement system is shown in Fig. 2. A normal load was applied by placing a weight on the stationary part of the pin specimen. An electric current was applied between the specimens through a rotary electrical contact. The contact voltage drop between specimens was measured to evaluate the state of contact at the sliding interface.

A wideband-type AE sensor (frequency band: 500 kHz to 4 MHz) was mounted on the upper part of the pin specimen, as shown in Figs. 1 and 2. AE signal waveforms that for which the trigger voltage exceeded the selected background-noise level were detected with a fast-waveform digitizer (resolution: 12 bit; sampling frequency: 100 MHz). In addition, the amplitude of each AE signal was evaluated as an AE mean value (AE signal mean amplitude value). The AE mean value was evaluated by subtracting the mean amplitude of the background noise from the recorded value.

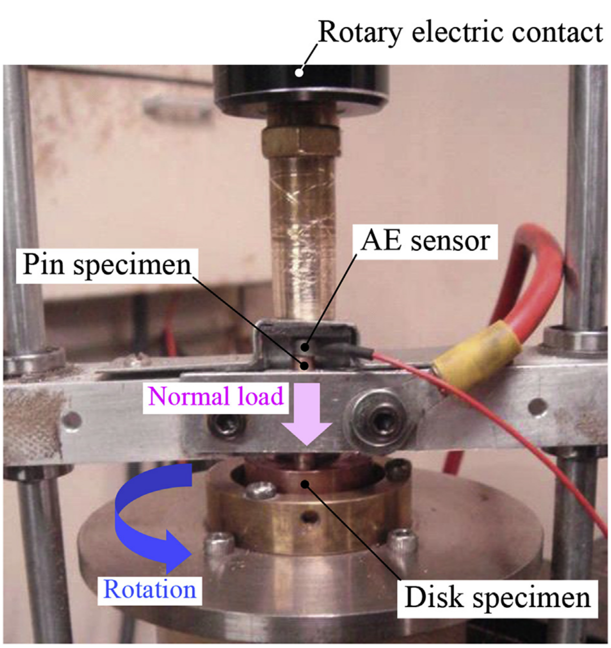

Fig. 1. Appearance of the pin-on-disk-type sliding friction tester.

2.2. Experimental conditions and specimens

A copper sintered alloy and ferrous sintered alloy were used as pin specimens as models for the contact strip. Each pin specimen was 4 mm in diameter and 20 mm long. Oxygen-free copper was used as the disk specimen to represent the trolley wire. The disk specimen was 25 mm in diameter and 6–10 mm thick. The properties of the specimens are summarized in Table 1. The surfaces of both the pin and disk specimens were finished by rubbing with emery paper with a grain size of #2000. Both specimens were degreased by washing in acetone before the experiment.

The experimental conditions are listed in Table 2. An electric current of 4 A (20 V dc) was applied between the specimens. The AE signal was passed through a 100-kHz high-pass filter to eliminate noise. All the experiments were carried out in air at room temperature (about 20 °C) and ambient relative humidity (about 40%).

3. Results and discussion

3.1. Observation of surface damage and wear curve

Fig. 3 shows micrographs of the friction surfaces of the pin and disk specimens for (a) before rubbing, (b) after rubbing without an electric current, and (c) after rubbing with an electric current (pin: Cu sintered alloy; disk: Cu). The arrows represent the direction of sliding. In the absence of an electric current, adhesion marks and transfer particles on the worn surface were observed and the surface almost retained its metallic color, meaning that typical mechanical wear had occurred, as shown in Fig. 3(b). On the other hand, in the presence of an electric current, the surface did not retain its metallic color, and the surface was much darker, showing damage caused by heat and flow of electricity, as shown in Fig. 3(c). These results show that the state of surface damage of the sliding surface in the presence of an electric current flow was markedly different to that in its absence. Both sintered copper and sintered iron showed very similar trends.

Fig. 4 shows the wear–sliding distance curves for the disk and the pin specimen in the presence and absence of an electric current. The wear rates for the pin and disk unit are summarized in Table 3. In the absence of a current, the amount of wear was relatively constant for both disk-and-pin specimens, whereas in the presence of an electric current condition, it increased continuously over time. Fig. 5 shows micrographs of the damage to the wear track caused by arc discharge and by melting caused by rubbing in the presence of an electric current for the copper sintered alloy. As indicated by the arrows in Fig. 5, both a mark of mechanical wear due to adhesion and a crater mark and spheroidal wear particles formed by impact and melting caused by arc discharge and heating were observed. It is therefore clear that the amount of wear in the presence of an electric current was larger than in its absence due to the influence of heat and abrasion caused by continuous arc discharge. We have therefore confirmed that both mechanical wear and electrical wear (arc discharge and melting) affect the degree of surface damage in the presence of an electric current.

3.2. Recognition of the generation of arc discharge by using an AE technique

Fig. 6 shows the fluctuations of the AE mean value and the drop in contact voltage with and without an electric current for the copper sintered alloy pin. In the absence of an electric current, the change in the AE mean value was small, whereas in its presence, the AE mean value changed markedly immediately after the contact voltage dropped. Up to a sliding distance of 0.17 km, the AE mean values were almost identical under both conditions, but after this point, the AE mean value in the presence of an electric current increased markedly, the voltage dropped, and arc discharge between the sliding surfaces was observed continuously. The arc discharge was caused by the momentary separation (pantograph bounce) of the specimens. It is assumed