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Correlation between features of acoustic emission signals and mechanical wear mechanisms

Alan Hase [a,*], Hiroshi Mishina [b], Masaki Wada [c]

[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
[c] Department of Precision Mechanical System Engineering, Polytechnic University, 4-1-1, Hashimotodai, Midori-ku, Sagamihara-shi, Kanagawa 252-5196, Japan

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ABSTRACT

The recognition of wear mechanisms is important for effective maintenance of dynamic machinery, because the selection of an appropriate maintenance solution is dependent on the particular mechanism of wear that occurs at the frictional interface. To permit the recognition of wear mechanisms by means of an acoustic emission (AE) monitoring technique, the features of AE signals generated during adhesive wear and during abrasive mechanical wear were examined. For adhesive wear, friction and wear experiments were conducted by using a micro-sliding friction tester of the pin-on-block type with various combinations of pure metals that showed different adhesion forces. For abrasive wear, the experiments were conducted by rubbing an iron pin on emery papers with various grain sizes. AE signal waveforms generated in each wear mechanism were recorded and a frequency analysis was performed. AE signals detected during adhesive wear showed a large peak in the high-frequency region, whereas AE signals detected during abrasive wear showed a few peaks in the low-frequency region. These results permit the recognition of wear mechanisms by the AE technique.

1. Introduction

Mechanical damage to sliding areas of machinery is chiefly caused by wear. The main types of mechanical wear produced by sliding friction are adhesive wear and abrasive wear. Adhesive wear is caused by sticking of the surfaces to one another and subsequent tearing off of surface material. Abrasive wear is caused by plowing and cutting of the surface. A change in the primary wear mechanism (wear mode) at a frictional interface can sometimes accelerate the progress of wear. Such a change in wear mechanism can occur, for example, when the surface layer becomes worn out or when hard particles become embedded in the surface. It is important to be able to recognize the wear mechanism that is occurring at a given time to permit appropriate maintenance of dynamic machinery, since the appropriate solution is dependent on the particular mechanism of wear taking place at the frictional interface. For instance, under sliding friction with imperfect fluid lubrication, lubricants can decrease the amount of adhesive wear but they can increase abrasive wear [1]. The mechanism of the wear that occurs is generally judged from observations of the worn surfaces and the particles generated by the wear; however, considerable time and experience are needed for accurate identification of the wear mechanism by this method.

Acoustic emission (AE) signals are produced when elastic stress waves are generated as a result of deformation and fracture of a material. AE signals are generated when friction and wear processes occur at a frictional interface. Application of AE monitoring permits in-process measurement to be made of the state of wear of materials, e.g. the prediction of seizing [2,3], oil rupture [4], the formation of wear particles [5,6], mild-to-severe wear transitions [7,8], or the failure of coatings [9,10]. Furthermore, quantitative relationships between AE signals and the state of wear have been examined for the individual mechanisms of adhesive wear [11,12] and abrasive wear [13]. Generally, adhesive-wear and abrasive-wear mechanisms tend to coexist and a detailed investigation of the features of AE signals generated in mechanical wear is necessary for practical applications, because the quantitative relationships between AE signals and wear vary depending on the nature of the wear mechanism.

Until now, there have been no reports of any studies on the differences in the AE signal waveforms produced by various wear mechanisms. In this study, to permit the recognition of the mechanism of wear that is operative under given conditions by using the AE technique, we examined the features of AE signals generated during wear by the two main mechanisms: adhesive wear and abrasive wear.

* Corresponding author. Tel/fax: +81 48 585 6827.
E-mail address: alan_hase@sit.ac.jp (A. Hase).

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2. Experimental procedure

Friction and wear experiments were performed by using a pin-on-block-type micro-sliding friction tester. Fig. 1 is a schematic showing the experimental setup. The pin specimen was slid once on a block specimen by using a one-axial piezoelectric actuator. A normal load was applied by placing a weight on the stationary part of the pin specimen. To determine the sliding distance, the displacement of the pin specimen was measured by a noncontact displacement sensor attached to the side of the stationary part of the specimen. To examine the relationship between wear phenomena and AE signals, the two main wear mechanisms, adhesive wear and abrasive wear, were reproduced as follows. For adhesive wear, the experiments were conducted with various combinations of three pure metals with different adhesion forces between the three materials: iron-to-iron, copper-to-iron, and silver-to-iron (pin-to-block). When the adhesive wear experiments were complete, the worn surface was examined by atomic-force microscopy (AFM) to compare the state of adhesion. For abrasive wear, the experiments were conducted by rubbing an iron pin on emery paper attached to the block specimen. Here, emery papers with grain sizes of #400 and #800 were used. The nose shape of the pin specimen was a hemisphere of diameter 4 mm and its length was about 10 mm. The surfaces of both the pin and block specimens were finished to $R_{max} < 50$ nm by mechanical polishing. Both specimens were degreased by washing in acetone before each experiment. The purity and hardness of the materials used as the pin and block specimens were as follows: iron (99.9%, 97 HV), copper (99.99%, 80 HV), and silver (99.99%, 90 HV). The experimental conditions are listed in Table 1. All the experiments were carried out in air at room temperature (about 20 °C) and ambient relative humidity (about 40%). No lubricant was used in the adhesive-wear experiments, whereas paraffin oil was used as a lubricant in the abrasive-wear experiments.

The AE signals generated by the friction and wear processes were detected by means of an AE sensor mounted on the upper surface of the pin specimen, as shown in Fig. 1. Fig. 2 shows a block diagram of the instrumentation used for the acquisition of the AE signals. The AE sensor used in the experiments was a wideband transducer (frequency band: 500 kHz to 4 MHz). Because the voltage of the signals detected using the AE sensor was quite low, the signals were amplified to a level of 90 dB by a preamplifier and main amplifier. The AE signals were then passed through a band-pass filter to eliminate noise signals. AE signals that exceeded a trigger voltage of 200–500 mV were detected with a fast waveform digitizer (resolution: 12 bit; sampling frequency: 100 MHz). A frequency analysis was then performed to identify the waveforms of the AE signal.

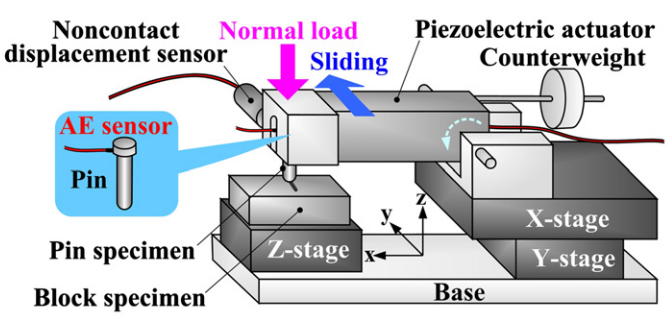

Fig. 1. Schematic showing the experimental setup.

Table 1
Summary of the experimental conditions.

Normal load *W*, N	0.49
Sliding velocity *v*, μm/s	100
Sliding distance *L*, μm	50–200
AE amplification factor, dB	90
AE band-pass filter, MHz	High-pass filter: 0.5 Low-pass filter: 3

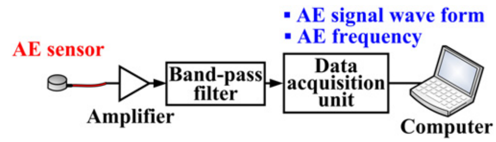

Fig. 2. Block diagram of the instrumentation used for the acquisition of the AE signal.

3. Results

3.1. Identification of wear mechanisms by observations of worn surfaces

Fig. 3 is a micrograph showing the wear track for the pin specimen. Fig. 3(a) and (b) was obtained from two experiments in which pin specimens were rubbed under dry conditions on an iron block polished to a mirror finish and on emery paper of grain size #400 under lubricated conditions, respectively. The mode of wear can be identified from the micrographs shown in Fig. 3. In Fig. 3(a), damage associated with adhesive wear, in which fine transfer particles adhere to the surface can be seen. Although the size of the particles generated by adhesive wear differed depending on the pair of materials involved, the type of damage was similar for all the pin materials used. On the other hand, the peculiar type of damage associated with abrasive wear, in which abrasive grains produce grooves on the surface of the pin specimen, can be seen in Fig. 3(b). Although the depth of the grooves produced by abrasion depended on the grain size of the emery paper, a similar type of damage was observed when coarser (#800) emery paper was used. Therefore, the results clearly show that the type of wear phenomenon (adhesive wear or abrasive wear) could be reproduced in the two experiments.

3.2. AE frequency characteristics of the experimental system

Before examining the experimental results for frequency analysis of AE signals, it was necessary to identify the effects of background noise and of the resonance point for the entire experimental system (not just the AE sensor). The frequency characteristics of the AE signals were examined by means of a pencil-lead breaking test. The resonance point in the experimental system can be evaluated by analyzing the AE signal that is produced when a pencil lead is broken at the tip of the pin specimen. A frequency analysis of the background noise signal was also performed. The frequency spectrum of the AE signals from the breaking pencil lead and the background noise signal in the experimental system are shown in Fig. 4(a) and (b), respectively. Fig. 4(a) shows that multiple frequency peaks in the signal from the breaking pencil lead were present in the region below 0.2 MHz. Here, only the signal from the breaking pencil lead signal was measured, with an amplification factor of 60 dB and without a band-pass filter. This is the resonance point for the experimental system, which shows a frequency distribution similar to the frequency characteristics of the AE sensor used. These frequency peaks need to be eliminated by processing with a band-pass filter. Also, it can be seen from Fig. 4(b) that a principal frequency peak in the background noise signal occurred at around