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Scanning electron microscope observation study for identification of wear mechanism using acoustic emission technique

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ABSTRACT

A non-destructive acoustic emission (AE) technique that detects elastic stress waves generated by deformation and fracture is proposed for evaluating friction and wear phenomena. Specimens in a scanning electron microscope (SEM) are subject to adhesive and abrasive wear, and the resulting AE signals were analyzed. We find that the peak frequency during adhesive wear occurs at around 1.1 MHz, while that during abrasive wear occurs at around 0.5 MHz. As a result, we demonstrate that the wear mechanism can be identified from the amplitude and position of the frequency peaks of the detected AE signals.

1. Introduction

Recognizing friction and wear phenomena is an important step in prolonging the lifetime of machinery. Tribological phenomena can be recognized, for example, by the coefficient of friction, the amount of wear, surface observations, surface analysis, and lubricating oil analysis. However, to observe the sliding surface the sliding must be stopped, which requires significant labor and time. Moreover, our knowledge of what happens at the friction interface does not exceed the region of study because the observations are made after sliding has stopped.

Real-time measurement of the amount of wear and identifying the wear mechanism is possible through an acoustic emission (AE) technique. This non-destructive technique detects elastic stress waves generated by the deformation and fracture of materials and is useful for evaluating friction and wear phenomena. However, to identify wear mechanisms more accurately, further study on the relationship between wear processes and AE signals is needed. We found in a previous study that features of the AE signals in the frequency spectrum differ according to the wear mechanisms [1]. Since this finding was obtained from a micro-sliding experiment after rubbing only once, it is necessary to clarify how the AE frequency spectrum changes after repeated rubbings over a long distance under different friction systems. Although we studied the relationship using in situ observations with an optical microscope [2], we still need studies of the relationship on a microscopic level because only the changes in the amplitude of the AE signals and not the AE frequency spectrum have been examined. A great deal of effort has been made to elucidate the wear mechanisms using a scanning electron microscope (SEM) [3–7], but as far as we know, no studies have succeeded in measuring AE signals with SEM observations of the friction and wear phenomena due to the background noise problems.

The aim of this study was to verify the relationship between the friction and wear processes and the AE signals using an SEM. Two main mechanical wear mechanisms (adhesive and abrasive) were reproduced and examined by measuring the AE signals. The results of the observations allow us to clearly explain the relationship between the AE frequency spectrum and the friction and wear phenomena.

2. Experiments

2.1. Friction and wear experimental setup and sliding conditions

Fig. 1 shows the small pin-on-disk-type friction and wear tester that was installed in the SEM vacuum chamber for this study. Fig. 2 shows a schematic diagram of the experimental setup. The tester components were mainly stainless steel and aluminum alloy parts that have low outgassing rates in vacuum. The friction system was placed on x–y and inclination stages to enable micro-positioning

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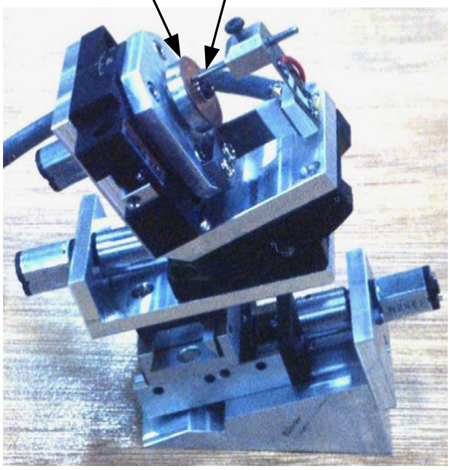


Fig. 1. The small pin-on-disk-type friction and wear tester used in this study.

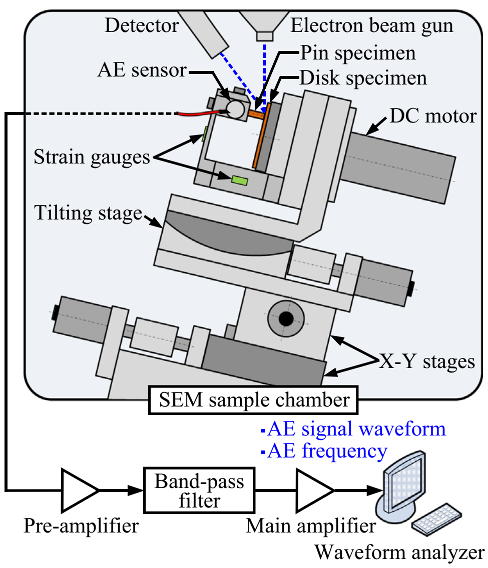


Fig. 2. Schematic diagram of the experimental setup.

and three-dimensional observation. The normal and friction forces were measured with two laminated springs that were attached to the supporting parts of the pin specimen.

The copper disk specimen had an outer diameter of 20 mm and was 0.5 mm thick. The mean friction diameter was 14 mm. The pin specimen was 2 mm in diameter and 12 mm in length. We reproduced two wear mechanisms, adhesive and abrasive, by using different pin-specimen tip shapes. To reproduce adhesive wear, the pin tip was shaped into a hemisphere with a diameter of 2 mm. Two pin specimens of copper and iron were fabricated. To reproduce abrasive wear, the pin tip was shaped to resemble a cutting tool with a rake angle of 20° and a relief angle of 3°. A ceramic pin of zirconia (ZrO_2), with a surface processed by metal deposition to maintain conductivity, was used. The angles were set to small values to minimize any digging into the disk specimen. The specimen specifications are summarized in Table 1. The sliding surface of both specimens was finished with a 2000-grade emery paper, and ultrasonic cleaning was performed in acetone before each experiment. The experiments were performed with a sliding velocity of 0.9 mm/s and normal loads of 1.5 and 10 N under dry conditions in a vacuum of 7×10^{-4} Pa. To observe moderate cutting, a light normal load was used in the abrasive wear experiments. The experimental conditions for each experiment are listed in Table 2.

Table 1
Specimen specifications.

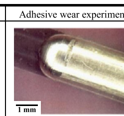
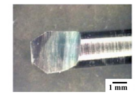
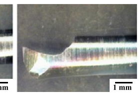
Specimen		Adhesive wear experiment	Abrasive wear experiment	
Pin	Shape	 Hemispherical (2 mm in dia.)		
			Cutting tool shape (rake angle: 20°, relief angle: 3°)	
	Material	Cu	ZrO_2 (metal deposited)	
Disk	Shape	ϕ20 mm × t0.5 mm		
	Material	Cu		

Table 2
The experimental conditions.

	Adhesive wear experiment	Abrasive wear experiment
Normal load, W (N)	10	1.5
Sliding velocity, υ (mm/s)	0.9	
Sliding distance, L (m)	1	
AE amplification factor (dB)	70	80
AE band-pass filter (kHz)	High-pass filter: 100 Low-pass filter: non-filter	
Trigger voltage (mV)	500	150

2.2. AE measuring system and conditions

The AE signals were detected using an AE sensor, which was braze mounted onto the side face of the stationary part of the pin specimen. The small AE sensor used in this study was a resonant type AE transducer (resonance frequency: 1.0 MHz). To minimize the influence of noise, the sensor cable was run out of the vacuum chamber, and an adhesive filler was inserted between the cable and the vacuum chamber lid to maintain the vacuum. The AE signals were amplified to 70 or 80 dB by a pre-amplifier and a main amplifier, before passing through a high-pass filter of 100 kHz to eliminate noise. In this study, in order to verify the relationship between friction and wear processes and features of AE signal waveforms, waveforms of AE signals in different wear mechanisms (adhesive and abrasive) were analyzed and examined. An AE signal waveform is a very fast wave which is generally measured in microseconds and monitoring it for a long period of time is unrealistic because it contains a huge amount of data points. For that reason, only waveforms that go over the trigger voltage were recorded. In the experiments, a fast waveform digitizer (resolution: 16 bit; sampling frequency: 50 MHz) was used to detect AE signal waveforms that exceeded a trigger voltage of 150 or 500 mV.

3. Results and discussion

3.1. Adhesive wear experiment

3.1.1. SEM observations and load fluctuations during adhesive wear

Fig. 3 shows the SEM observation images of the reproduced adhesive wear for stages I–III (as explained here). Fig. 4 shows the fluctuations in (a) the normal force and (b) the friction force, where the changes in a constant cycle were caused by a minute inclination of the disk specimen, which is unrelated to the load fluctuations that occur in friction and wear phenomena. From the SEM observations and the load fluctuations, the friction and wear