

Evaluation of Friction Phenomena of Brake Pads by Acoustic Emission Method

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ABSTRACT

Brake pads are composite materials made from dozens of ingredients intended to simultaneously satisfy various performances such as brake effectiveness, wear, noise and vibrations. For this reason, the friction phenomena that occur during braking are complicated. It is important to clarify the friction phenomena, but that is not easy because the associated complexities as mentioned above.

We looked to acoustic emission (AE) as an online evaluation method of friction phenomena. AE is a non-destructive testing method that measures elastic stress waves caused by the deformation and fracturing of materials. In fact, it has been reported that the difference between abrasive wear and adhesive wear of a metal can be identified from the change in the frequency spectrum of AE signals. In this study, we verify whether differences in the friction phenomena of brake pads are detectable by the AE method.

Three kinds of brake pads were used in the experiments. One of the specimens included an abrasive ingredient, one included an adhesive ingredient, and another included neither. As an analysis of the AE signals from the abrasive pad revealed harmonic signals, it is thought that those signals were caused by the detachment of the tribofilm, not abrasive wear. On the other hand, 600 kHz signals were detected in the adhesive pad. It is thought that those signals were caused by adhesive wear. And, the incidence of the AE signals was different depending on temperature.

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INTRODUCTION

Brake pads are intended to simultaneously satisfy various performances such as brake effectiveness, wear, noise and vibrations. For this reason brake pads are phenolic resin composites that contain several ingredients such as metal fibers, inorganic fillers, organic fillers, and so on. Therefore, various friction phenomena such as adhesive wear, abrasive wear, detachment of the ingredients and generation and detachment of the tribofilm are caused at the interface of a pad and disk, and these phenomena while braking is complicated [1]. This makes it difficult to clarify the relationship between the ingredients and brake performances. In the meantime, regulations on the use of raw materials (such as copper) are being strengthened, because those materials exert bad influences on the environment and health [2]. Therefore, the search for alternative materials is necessary. Given this information, it is important to clarify the friction phenomena, but that is not easy because friction phenomena are complicated as mentioned above.

Currently, there are several indexes for brake performance such as brake effectiveness and wear. But, they evaluate the performance that consists of various friction phenomena. Therefore, it is difficult to specify each friction phenomenon. On the other hand, analyses of brake performance, friction surfaces and wear debris have been carried out to hypothesize friction phenomena. However, these analyses are not applicable in real-time. Accordingly, it has been said that the development of a new analysis technique to evaluate individual friction phenomena in real-time is necessary.

We looked to acoustic emission (AE) as an online evaluation method of friction phenomena. AE is a non-destructive testing method that measures elastic stress waves caused by the deformation and fracturing of materials. Information like microscopic friction and wear phenomena that cannot be detected by changes in frictional force and vibration acceleration, can be detected by the AE method. In fact, it has been reported that the difference between abrasive wear and adhesive wear of a metal can be identified from the change in

the frequency spectrum of AE signals [3,4]. Specifically, several peaks are distributed in the region between 0.25 and 1 MHz during abrasive wear. On the other hand, it appears that the frequency peaks at around 1.1 MHz during adhesive wear. But, not a single reported case has been applied to brake pads as far as the authors know. So, we set out to verify whether differences in friction phenomena are detectable by the AE method.

In this paper, firstly, pad specimens and equipment are described. Secondly, characteristics of AE signals are explained. After that, relations between AE signals and friction phenomena are discussed. Finally, conclusions are stated.

MEASUREMENT METHOD

Pad Specimens

The friction phenomena of brake pads are complicated as mentioned above. Therefore, pads made with minimum ingredients that constitute a pad were used to simplify friction phenomena. Reference pad contained phenolic resin, aramid fiber, calcium hydroxide, graphite and barium sulfate. Abrasive pad added aluminum oxide powder as an abrasive ingredient to the reference pad. And, the adhesive pad added copper fiber as an adhesive ingredient to the reference pad. Table 1 shows the formulations of the test samples. Pad specimens were cut from those pads so that the contact surface was $20 \times 20 \text{ mm}^2$. In addition, we used only a lining to lower the damping of the AE signal inside the pad and at the interface between the lining and back plate. The distance from the friction interfaces to the AE sensor receptor was 3 mm.

Table 1. Formulations of test samples [Vol. %]

	Reference pad	Abrasive pad	Adhesive pad
Phenolic resin	20		
Aramid fiber	10		
Calcium hydroxide	5		
Graphite	2		
Barium sulfate	63	58	58
Aluminum oxide powder	-	5	-
Copper fiber	-	-	5

Friction Conditions / Experiment Equipment

Figure 1 outlines the equipment used in the experiment. Table 2 shows experimental conditions. The friction testing conditions were 110 rpm (sliding velocity: 1 m/s) and 400 N (applied pressure: 1 MPa).

AE signals generated by the friction and wear processes were measured by an AE sensor attached to the back of the specimen. The AE sensor used in the experiments was made of piezoelectric ceramic and it was a wideband transducer (frequency band: 100 kHz to 1 MHz). And, the diameter of

sensor receptor was 12 mm. Vaseline was applied between the pad specimen and AE sensor receptor to lower the damping of the AE signal.

The signals were amplified to a level of 40 dB by a preamplifier and a main amplifier, because the voltage of the signals detected using the AE sensor was quite low. The AE signals were then passed through a high-pass filter to eliminate noise signals. And, AE signals were recorded by a data logger.

We paid our attention to the AE mean value and AE frequency to evaluate the friction phenomena while braking. The AE mean value is the average value of an envelope waveform of AE signals. The AE mean value includes information of all friction phenomena at the interface between the pad and disk. And, we can measure for a long time, because information can be measured at a low sampling rate. In this research, measurements were done at a 10 Hz sampling frequency. On the other hand, friction phenomena are suspected to be distinguishable by AE frequency spectrum because the frequency of AE signals depends on the friction phenomena. But, long measurements are difficult, because measurement must be done at a high sampling rate. In this research, measurements were done at a 5 MHz sampling frequency.

In addition, the frictional surfaces were examined under laser-microscope and wear debris were examined under Field Emission - Scanning Electron Microscope (FE-SEM), to clarify friction phenomena.

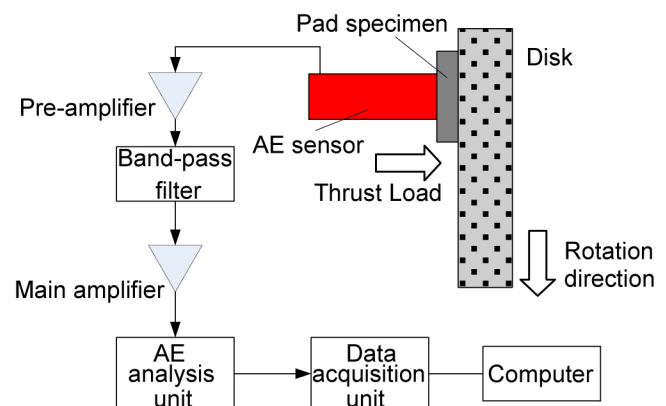
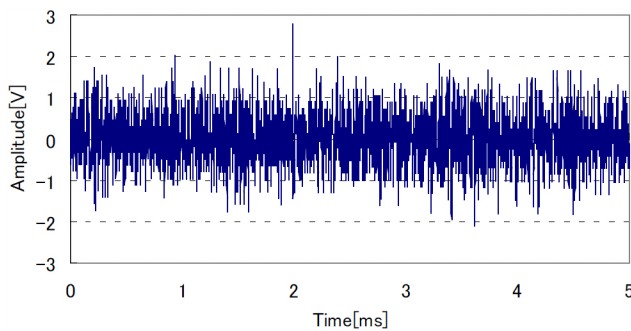


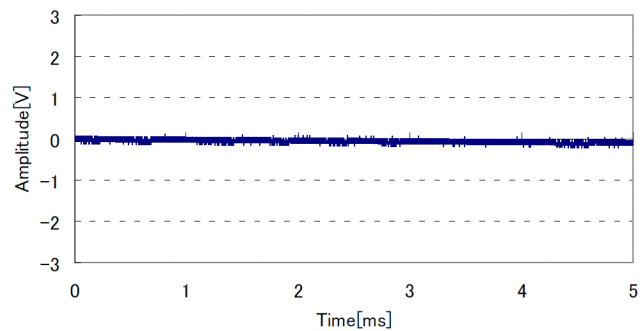
Figure 1. Outline of equipment used in experiments

Table 2. Experimental conditions

Pad size, mm	20×20
Disk material	Cast iron (FC250)
Disk size, mm	φ200×20 ^t
Normal load, N	400
Sliding velocity, m/s	1
Sliding distance, m	900
AE amplification factor, dB	40
AE band-pass filter, kHz	High-pass filter: 20 Low-pass filter: Thru



(a) Under 400 N thrust load



(b) Under no thrust load

Figure 2. Examples of AE signals during disk rotation

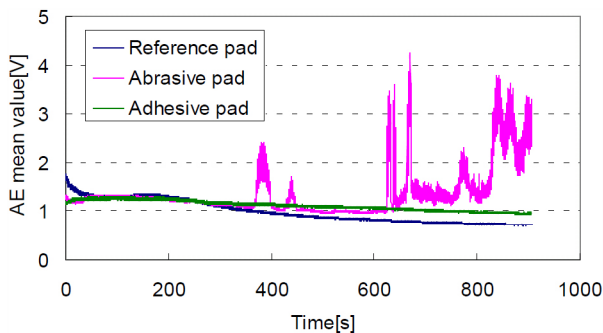


Figure 3. Change in AE mean value against sliding distance

MEASUREMENT RESULTS

Confirmation of Validity

Figure 2 shows two examples of AE signals during braking. Continuous AE signals occur during braking (thrust load: 400 N) as shown in Fig. 2(a). On the other hand, AE signals when thrust load is 0 N are very small in comparison with those during braking as shown in Fig. 2(b). These results show that influence of noise from equipment is negligible. So, it is thought that the detected signals are caused by the friction phenomena of the brake pad.

Characteristics of AE Signals

Figure 3 shows the change in AE mean value against sliding distance. Amongst the brake pads, the AE mean values of the reference pad and adhesive pad are stable. But, that of the abrasive pad is unstable.

Figure 4 shows the representative frequency spectrum that was analyzed for each brake pad by short-time Fourier transformation. As shown in Fig. 4(b), the frequency spectrum of the abrasive pad when the AE mean value was stable is similar to the spectrum of the reference pad. On the other hand, harmonic signals of an approximate 50 kHz fundamental frequency were detected when the AE mean value was unstable as shown in Fig. 4(c). The fundamental frequency

changes in the region between 45 and 100 kHz. But, several peaks in the region between 0.25 and 1 MHz that reportedly were caused by abrasive wear from metal-metal contact before were not detected [3,4].

On the other hand, approximately 600 kHz signals were detected in the adhesive pad as shown in Fig. 4(d). These signals have a lower frequency than the adhesive wear of metal. But, the frequency characteristics are similar to the signal produced during the adhesive wear of metal. Consequently, it is thought that 600 kHz signals were caused by adhesive wear.

Verification of Friction Phenomena

We verified what kind of friction phenomena caused the AE signals detected in the abrasive pad and adhesive pad.

Abrasive Pad

To clarify what kind of phenomenon harmonic signals are caused by, frictional surfaces and wear debris from AE mean value stability and instability were examined under microscope.

Figure 5 shows the surface appearance of the abrasive pad. Figure 6 shows the surface appearance of the disk. As shown in Figs. 5(a) and 6(a), a tribofilm, which looks black, was confirmed. But, the tribofilm decreased during AE mean value instability, as shown in Figs. 5(b) and 6(b).

To verify in detail, frictional surfaces were examined under laser-microscope and wear debris were examined under Field Emission - Scanning Electron Microscope (FE-SEM). Figure 7 shows micrographs of the abrasive pad. As shown in Fig. 7(b) and 7(c), there are many cracks in the tribofilm from AE mean value instability. Figure 8 shows micrographs of the abrasive pad wear debris. As shown in Figs. 8(b) and 8(c), large wear debris (particle diameter: more than 10 μm) of condensed smaller wear debris were confirmed during AE mean value instability. The characteristics were not confirmed for AE mean value stability as shown in Figs. 7(a) and 8(a). As a result of observation, it is thought that the AE signals were caused by the detachment of the tribofilm, not abrasive wear. And, it is thought that harmonic signals were caused by the nonlinearity at the time of the opening and closing of the crack.