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Short Communication

Automatic detection of scuffing using acoustic emission

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ABSTRACT

This study investigates the use of acoustic emission (AE) for *in situ* monitoring of surfaces sliding under starved conditions until failure due to scuffing mechanism. Reciprocal lubricated sliding tests having flat-on-flat set-up have been carried out for a cast iron–steel tribo-pair at a constant load of 600 N and a frequency of 6 Hz. According to the friction behavior, three regimes of events have been specified; steady-state, pre-scuffing, and scuffing. Acoustic signals for these regimes have been decomposed with wavelet packets, and sub-band energies have been chosen as features. The classification is performed using support vector machine. Experimental results reveal the feasibility of automatic detection of surface pre- and scuffing states using acoustic emission.

1. Introduction

The mechanism known as scuffing is one of the most problematic failure mechanisms in lubricated sliding surfaces working under extreme conditions of load and/or speed [1–5]. However, it still remains one of the least understood phenomena [6,7]. Various definitions have been used to describe scuffing [6,8,9] but a general definition is given by the Organization of Economic Cooperation and Development (OECD) as "*localized damage caused by the occurrence of solid-phase welding between sliding surfaces without local surface melting*" [10]. It is a sudden failure of the protecting lubricating films accompanied usually by an unexpected increase in friction force and temperature. This leads to the roughening of the surface and the loss of the component functionality [6,7]. Therefore, the performance and the lifetime of the machine components are strictly limited by the scuffing resistance in lubricated systems. It is generally accepted that the collapse or failure of the lubricant fluid film is necessary but not sufficient for the occurrence of scuffing [3,11]. The formation of the lubricant film prevents having metal–metal contact and the collapse of this film is due to a still unknown mechanism. Over the years, numerous scuffing models and theories have been investigated. Despite all the efforts by the scientific community, a large degree of uncertainty still exists, which is due to the lack of fundamental understanding of scuffing and its mechanisms [3,6]. Poor understanding of this phenomenon is mostly caused by the complex nature of contacting surfaces and the large number of effective factors envolved [3].

In order to increase the reliability of machine components, an *in situ* monitoring technique with the ability of scuffing recognition is essential. Numerous monitoring techniques have been recently developed with the capability of severe surface damage detection. However, the time between the first detection and seizure is extremely short, which often prevents being able to react before catastrophic failure [12]. The coefficient of friction (COF) and sample temperature rise are widely used as indicators of scuffing [13,14] but usually, a sharp increase in COF or temperature is observed when scuffing already happened. Accordingly, having a more precise technique able to detect the defects in an incipient stage is crucial.

Acoustic emission (AE) analysis is one of the most effective monitoring methods with high sensitivity and great ability of early and rapid detection of failures [15,16]. AE is defined as an elastic stress waves generated by a sudden release of elastically stored energy from micro- or macro-failures while applying a static or a dynamic stress [17,18]. AE signal has been reported to be more sensitive in sliding tests as compared to the friction force or wear rate [16]. Several attempts have been made to correlate different AE parameters such as AE root mean square (RMS) value and AE count rate with the tribological behavior of sliding surfaces [19–21]. Price et al. [12] applied Fourier transform (FT) to analyze AE signals detected during severe sliding and pitting process in a four-ball lubricant test. They found changes in frequency patterns especially before the pitting. There are also few studies on defect detections of bearings based on wavelet packet decomposition of AE signals [22,23]. The aim of this study is to investigate the use of acoustic emission for monitoring the reciprocating surfaces

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working under starved conditions, and detect incipient failure due to scuffing mechanism. Automatic acoustic characterization of the friction behavior is carried out using wavelet packet decomposition together with support vector machine (SVM) classifier.

2. Experimental details

2.1. Tribo-tests and characterization

Flat-on-flat tribo-tests were performed using a reciprocating tribometer (SRV® III, Optimol Instruments Prüftechnik GmbH, Germany), which is shown schematically in Fig. 1. The upper sample holder used in this study was designed to prevent inclination of the counter-body and provide flat-on-flat conditions. The counter-body used for all tests was a hardened steel (42CrMo4) loaded against an oil lubricated gray cast iron (EN-GJL-300) with the hardness value of 600 and 201 HV, respectively. The chemical composition of the counter-body (hardened steel) and the bottom sample (cast iron) are presented in Table 1. Both the counter-body and the bottom sample were polished to reach the roughness values (R_a) of about 0.4 µm and 0.8 µm, respectively. The counter-body was oscillating with a stroke of 4 mm at a frequency of 6 Hz (12 strokes per second). The sliding duration for each stroke, considering the holding time for direction variation and overcoming the static COF, was 54 ms/stroke. Tests were carried out in a chamber with controlled temperature and humidity (35 °C, 30% RH). The variation in sample temperature due to friction was continuously monitored using a thermocouple, which was placed at the bottom of the cast iron sample. Prior to each tribo-test, 0.4 µl/cm^2 of pure poly-alpha-olefin oil (PAO) was homogeneously sprayed on the cast iron surface using a high precision spraying machine (AutoJet®, Model 2250, USA). To minimize the spraying errors, the weight of the lubricant was measured for each test before and after spraying by an electric balance (± 0.1 mg precision). The limited and controlled volume of the lubricant present in the contact was to force the tribo-system to starved lubrication conditions and eventually provoke scuffing failure. All tests were conducted by applying a constant normal load of 600 N (giving an apparent contact pressure ≈ 24 MPa) and continued until scuffing took place. Scuffing was considered to happen when a sharp increase in COF was observed and consequently traces of failure could be detected on the cast iron surface. Specific tests were stopped at different stages before scuffing for surface analysis. To characterize surfaces before and after failure, pictures were taken using scanning electron microscope (SEM) (Hitachi, S-4800, Japan).

2.2. AE acquisition system

In order to collect the AE signals generated by the sliding process, during each tribo-test, a PAC WD sensor (PAC Group Inc., USA) with a broadband response range of 100 kHz to 1 MHz was mounted close to the bottom sample with a thin layer of grease. The signal amplification was 34 dB with the record trigger threshold set at 29 dB to avoid recording the machines' noises. The sampling rate was 1 MHz with a record duration of 65 ms to cover a complete stroke. Fig. 2 shows a typical AE signal (waveform) collected by the system.

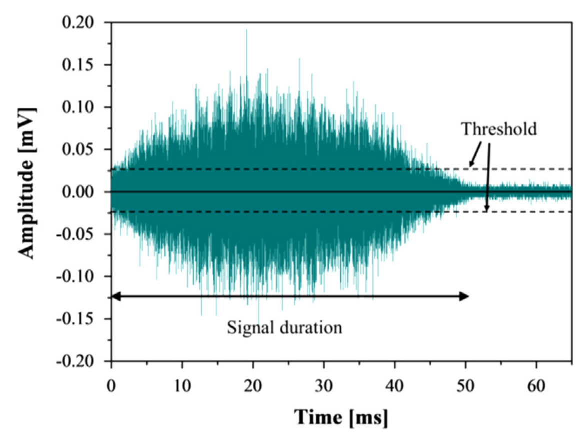

Fig. 2. Typical acoustic emission (AE) signal for one stroke of the reciprocal movement of cast iron against steel under starved lubrication conditions.

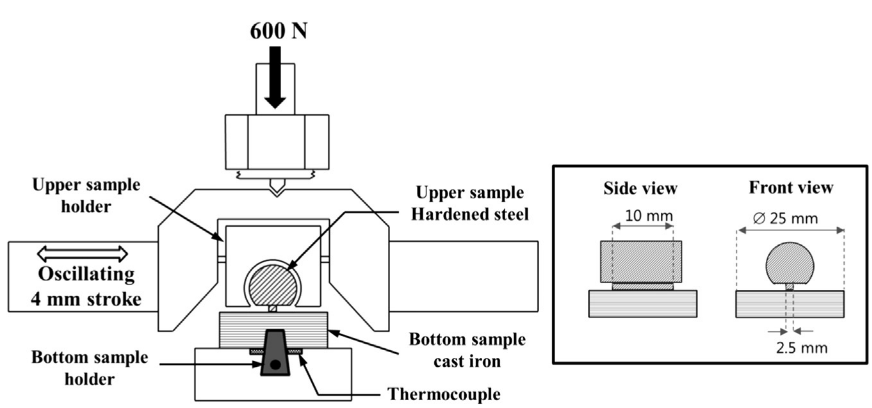

Fig. 1. Schematic of the reciprocating tribometer including the geometry of the bottom sample and the counter-body.

Table 1
Chemical composition of the bottom sample (cast iron) and the counter-body (hardened steel) (wt%).

	C	Mn	Si	P	S	Cu	Cr	Mo	Fe
Gray cast iron	2.890	0.940	1.470	0.036	0.059	1.000	–	–	Balance
42CrMo4 steel	0.400	0.750	0.330	0.035	0.028	–	1.010	0.160	Balance