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Acoustic emission monitoring of a mechanochemical surface finishing process

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ABSTRACT

Acoustic emission monitoring of cutting machining operations is an established researched area, though monitoring non-removal finishing processes is less studied.

This work presents an initial investigation on Acoustic emissions potential of an mechanochemical superfinishing process. Conclusions are drawn from the monitoring signal regarding the resulting surface friction characteristics, composition and possible runnability issues.

Monitoring data was collected from tests performed at Applied Nano Surfaces' testing laboratory. Test series with varying parameters enabled a correlation analysis between the monitoring data, surface friction characteristics and tribofilm formation. Increasing tool wear tests were monitored to find early runnability warning.

Results shows Acoustic emissions indication potential when the finishing process has achieved the intended friction reduction, tribofilm deposition as well as runnability issues identification.

1. Introduction

The phenomenon often referred to acoustic emission (AE) occurs when a component is subjected to stress, be it dislocation movements, deformation, fracture or crack propagation [1]. These generated high frequency elastic energy waves can be detected and converted into electric signals for condition monitoring purposes.

AE has been used in process monitoring research on a wide span of industrial machining operations for over 25 years, where Tönshoff et. al. [2] compiled the field developments and trends in 1988. From that time the vast majority of research concerns cutting operations and methods to quantify wear or material build up on the cutting tools. Literature covering e.g. cutting [3–6], grinding [7], and tool wear [8–10] shows how AE is mainly used in the broad area.

The use of AE from a tribological perspective applied in rolling element bearings has been covered by Tandon & Choudhury in 1999 [11]. A lot of AE research has been done on bearing applications due to its potential as a condition monitoring tool of such machine elements. Further, more recent research covers acoustic emissions correlation to wear modes [12,13], scuffing [14] and coating failure [15].

The use of AE on the non-removal finishing processes has not, however, been as widely researched yet, especially regarding its feasibility as a process monitoring tool on finishing processes. Investigations of AE used to monitor different material removal finishing processes include grinding [16] and polishing of semiconductors by chemical-mechanical planarization [17]. In 2003 it was also discussed by Dornfeld et. al. [18] the application of AE monitoring on a number of ultraprecision machining operations.

10 years earlier Dornfeld and Liu [19] performed a monitoring investigation on a tape burnishing process, which to the authors knowledge is the only specific example of AE being used on a burnishing finishing operation in literature. The results of the investigation, performed by burnishing a rotated disk with Al substrate and Ni-P undercoat with a lapping tape, showed that AE can be a good tool to obtain information about friction behaviour.

Research on mechanochemical superfinishing processes on metal components is a narrow field where Applied Nano Surfaces (ANS) has researched tribological properties of steel or cast iron machine elements with a deposited tungsten disulphide based tribofilm since 2008 [20–23]. Sliding friction reduction and increased wear resistance on ferrous machine elements has been achieved by burnishing and with the contact pressure initiate a deposition of tungsten disulphide tribofilm.

The rapid progress of mechanochemical superfinishing, together with the knowledge gap regarding AE monitoring applied on mechanochemical finishing of ferrous materials, initiated the work presented in this paper. In this paper monitoring tests have been performed on process evaluation test series to investigate an AE systems feasibility to monitor sliding friction reduction and tribofilm composition of the mechanochemical superfinishing process.

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2. Experimental equipment and procedure

2.1. Acoustic emission equipment

The measurement system, provided by SKF Development and Production Center in Luleå, consisted of a Multilog IMx-W Windcon system. The Windcon is commonly used in vibration condition monitoring of wind turbines, and has the capacity to log signals from 16 accelerometers simultaneously.

To enable the Windcon to handle acoustic emission measurements, the SKF CMON 2504 interface card was used together with the SKF CMSS 786 M dual accelerometer and acoustic emission sensor with a frequency broadband response range of 100–500 kHz. The signal emitted from the sensor was by the interface card enveloped by applying a bandpass filter at 100–500 kHz and rectified, after this the Windcon measured the enveloped signal with a sampling rate of 102.4 kHz.

The data was managed in the SKF @ptitude Observer software, where the stored time waveform data values go through multiple post processes and analysis tools. To get a visible trend an FFT is applied on the time waveform and the maximum amplitude value is stored as trend data at that specific sample time point, in our investigation the AE trend values change over time has been analysed.

2.2. Process test rig and evaluation methods

Mechanochemical treatments were performed using a laboratory process test rig at ANS, Uppsala Sweden, which has previously been used in research of evaluating the improvements and develop this kind of process [20,21,23], the rig consists of a lathe with an internally developed and built tool package to perform the burnishing and a lubrication system feeding lubricant directly to the contact from above. A representation of the tool set up and an overview of the test rig can be seen in Fig. 1. Note that tools are mounted on both sides of the sample to eliminate bending, though these are missing in the overview.

ø22×100 mm samples of SS0727 ductile iron produced by turning and finally polished to a surface roughness R_a of 0.1 µm, are rotated in the lathe. Meanwhile mirror polished ø10 mm carbide tools are pressed against and oscillated axially over the sample and it is these combined two movements together with the contact load which creates the burnishing operation. A synthetic process fluid with tungsten containing additives react to form the deposited tungsten disulphide tribofilm on the component surface, with the reaction initiated by the contact pressure and flash temperatures between the test component and the carbide tools [23].

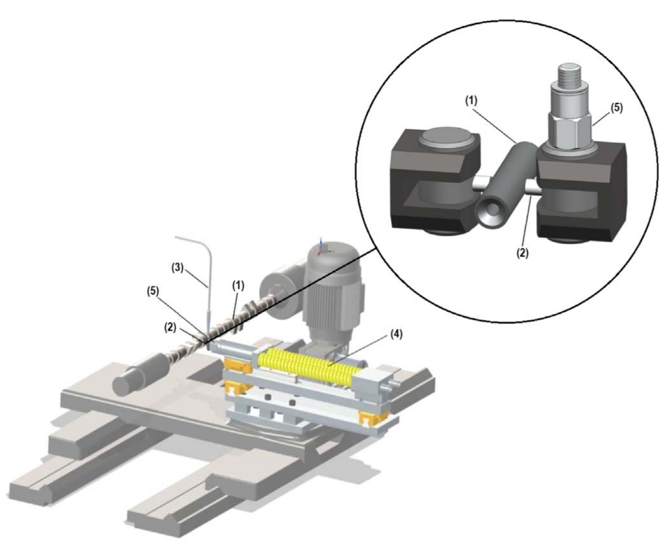
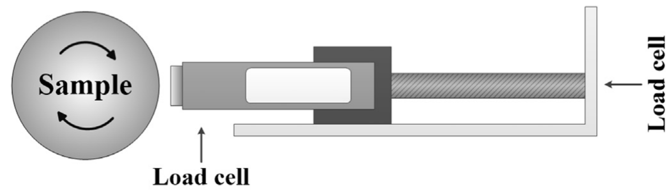
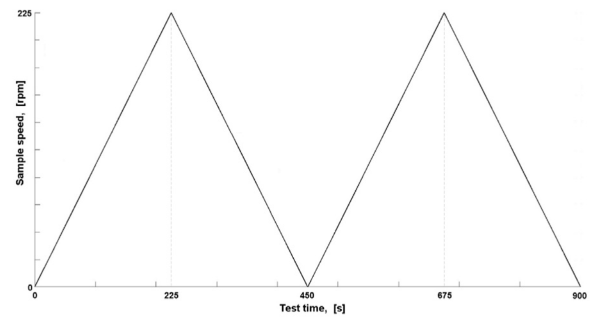


Fig. 1. The test rig and tool set up. (1) Test component, (2) carbide tool/component contact, (3) lubrication fluid feed, (4) springs through which the tools are loaded against the component, (5) sensor and mounting position on tool holder (modified from [20]).



(a) Visualized friction test rig



(b) Test procedure

Fig. 2. Illustrations of the test rig and procedure.

Table 1
Investigated test series.

Varied load			Varied time		
Load [kN]	Contact pressure [GPa]	Time [min]	Load [kN]	Time [min]	Sliding dist. [m]
REF.	REF.	REF.	REF.	REF.	REF.
0.5	0.47	5	3	0.5	5.52
1	0.66	5	3	1	11.06
1.5	0.81	5	3	2	22.12
2	0.94	5	3	3	33.18
3	1.15	5	3	4	44.23
			3	5	55.29

To reduce AE signal damping, caused by distance and material interfaces between the AE sensor and the operation, a mounting stud to the sensor was placed directly on the tool insert. A second mounting position was placed further back on the tool holder, but initial start-up tests found that the extra 80 mm distance from operation and extra three material interfaces dampened the signal making an analysis difficult.

The two main evaluation methods previously used of the improvements and composition results is to look at comparison values of sliding coefficient of friction (C.O.F) reduction and the tungsten percentage in the tribofilm. The results are only comparative within the specific set-up of materials and test objects, and cannot be directly transferred from a ductile iron test sample as above to other components with different geometry and material.

To evaluate the sliding C.O.F reduction a second lathe at the ANS test laboratory was used to rotate the sample at different speeds, meanwhile a bearing roller was spring loaded against the sample surface. With loading cells in the tool package logging both the applied radial load and the resulting peripheral load (i.e. the friction force), the sliding C.O.F could be sampled. The friction measurement test procedure consisted of:

1. 3 N constant radial load
2. Rotational acceleration from 0 to 225 rpm during 225 s
3. Deceleration to 0 rpm during 225 s
4. Acceleration and deceleration repeated once