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Detection of the onset of galling in strip reduction testing using acoustic emission

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Abstract

Galling is an important issue in metal forming of tribologically severe materials such as high strength steel, stainless steel, Al- or Ti-alloys, since it leads to poor surface quality of the formed components, production stops and possibly deterioration of tools. The onset of galling is difficult to detect, since it is either based on the operator's personal judgement or indirect measuring techniques. The application of acoustic emission measuring technique for characterization of onset of galling in sheet metal forming is discussed in the presented paper. The strip reduction test, which emulates the ironing process, has been examined in order to evaluate onset of galling and how this is related to the generated acoustic emission parameters. Preliminary investigations have shown that differences can be found in the acoustic emission signal parameters depending on the frictional conditions between the tool and the workpiece surfaces. A correlation to the severity of galling is found. This is inspected through observations of tested workpiece surfaces in SEM and measurements of the surface roughness. The acoustic emission measuring technique is found to possess promising aspects for online monitoring of galling in metal forming processes.

Keywords: Acoustic emission; Strip reduction testing; Galling; Surface roughness; Online monitoring;

1. Introduction

Acoustic emission (AE) testing is a non-destructive testing method based upon measurement of dynamic surface motion induced due to a rapid release of elastic stress waves [1-3].

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Elastic waves may be generated suddenly in solids in the ultrasonic frequency regime (typically reported to be in the range 100 kHz - 300 kHz) [4-6] due to
different failure mechanisms caused by static or dynamic loading. Such failure mechanisms are e.g. crack propagation or debonding of corrosion products etc. The occurrence of such events in the solids are experienced as dispersed elastic energy propagating as elastic waves, which can be detected using piezoelectric sensors.
The ability to detect abnormalities non-destructively has caused extensive use of AE testing as a tool for monitoring structural health and processing. The AE testing method has thus been implemented in a variety of different fields, e.g. evaluation of resistance spot welding processes, structural health monitoring of wind turbine systems, detection of defects in bearings etc.

As regards to sheet metal forming the prevented access to the sheet/tool contact interface requires indirect measuring to detect the onset of galling. Conventional techniques, e.g. measurement of the friction force, have typically been found to have too limited sensitivity. AE measuring has, on the other hand, been successfully applied as an online monitoring technique for evaluation of different tribological characteristics in metal forming operations [7-12]. Behrens et al. [13] have concluded that acquisition and analysis of AE signals allows for online assessment of production conditions and deviations in production processes. Skåre [14] similarly noted that energy analysis of the AE signals allows for an evaluation of the quality of lubrication and detection of process defects in sheet forming such as the stick-slip effect, cracking etc. Mostafavi and Pashmforoush [7] successfully applied the AE technique for detecting the onset of galling, noting a direct relation between the wear mechanism and AE peak amplitudes. However further investigations are needed in order to correlate the AE signals with the experienced failure mechanisms. The current study therefore aims at exploring the possibility to apply the AE testing methodology for detection of the threshold sliding length for lubrication breakdown and the subsequent onset of galling.

1.1. Acoustic emission parameters and signal characterization

AE signals generally occur in the two distinguishable forms; namely as burst signals or continuous signals. Burst-type emissions are characterized by being individual emission events of very short duration and large amplitudes. A continuous AE signal is on the other hand defined as having a sustained signal level, which is produced by rapidly occurring AE events. Common waveform parameters are defined in ISO 12716: 2001 for characterization of AE signals. The common purpose of AE testing is to characterize AE events and parametrize these in order to adequately describe the occurring event. For such analysis, the following characteristics are commonly applied:

- AE event counts above a voltage threshold.
- Averaged signal intensity (root mean square of the voltage signal).
- Peak amplitudes
- AE energy
- Duration and rise time of AE events
- Frequency spectral analysis.

Assessment of the listed parameters is commonly applied for analysis of the time domain for real time monitoring applications.

2. Experimental procedure

2.1 Strip reduction testing

The strip reduction test in figure 1 is a testing method used to emulate the ironing process [15]. A strip is placed on a supporting plate and both are fixed in a pair of jaws, while a circular cylindrical tool pin is loading the top of the strip with a defined height reduction. The strip is subsequently pulled with constant speed. The test is developed as a simulative test, which emulates the tribological conditions in the interface between a die and a can wall during ironing. Evaluation of the tribological conditions of the process can be performed by measurement of 1) the horizontal drawing force, 2) the surface roughness of the strip after reduction [16] and 3) AE events.

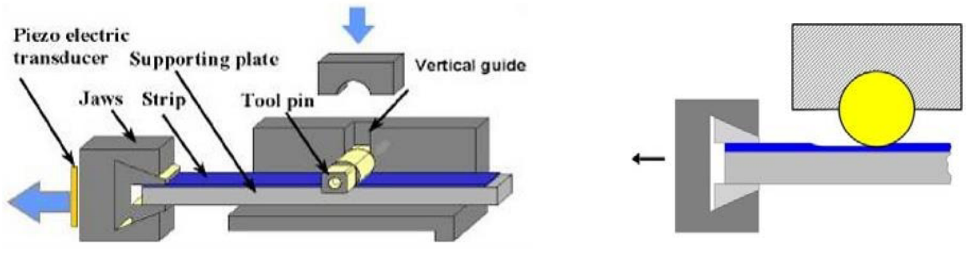

Figure 1: Schematic of the experimental test set-up [15].

The strip reduction test was performed with a reduction of 20% using a Ø15 mm tool pin of DIN W. no.1.3344 PM, polished to a surface roughness of Ra = 0.02 µm, on a 1 mm thick strip of 304L stainless steel. The drawing length was 300 mm and the drawing speed was 70-100 mm/s. Two different lubricants, CR5/Sun60 and Pn226, were investigated. A description of the lubricants is given in table 1.

Tabel 1: Description of the applied lubricants.

Code	Name	Description	Viscosity at 40°C (cSt)
CR5/Sun60	Houghton Plunger CR5, Sunoco Sun 60	Mixture of 50 wt.% Sunoco Sun 60 plain low viscosity naphthenic mineral oil and 50 wt.% Houghton Plunger CR5 high viscosity mineral oil.	60
Pn226	Castrol Iloform PN 226	Medium additive mineral oil with chlorine based EP additives	66

Lubrication is applied manually on the entire length of the strip. In one of the two test series with Pn226, however, lubrication is only applied to the first half of the strip length in order to induce galling after an initial period of good lubrication.

2.2 Acoustic emission data acquisition

The AE signals were measured with a National Instruments 9223 analog to digital converter with a sampling rate of 1MHz at a 16-bit resolution, connected through a National Instrument 9146 4-slot expansion chassis. Simultaneous data acquisition was carried out using a preprogrammed setup in LabView, with a data segmenting function in order to avoid buffer overflow. An R15α general purpose AE sensor from Physical Acoustics was attached with a clamp to the outer guide of the strip reduction tool, with a thin layer of applied grease-paste to improve acoustic coupling [17]. The sensor has an operating frequency range of 50 kHz - 400 kHz and a resonant frequency of 75 kHz. The sensor was connected to a Physical Acoustics 2/4/6 analogue signal preamplifier with a 60 dB signal gain. Upon measurement of the AE, signal drift was compensated by comparison of the levels of background noise within the different test series.

After the strip reduction test the surface roughness of the strip was measured across the strip with 30 mm interval on a Surtronic 4+ roughness tester with a cut-off filter of 0.8 mm. The surface quality was furthermore inspected visually by scanning electron microscopy.

3. Experimental results

3.1 Surface structure upon strip reduction testing

Figure 2 shows the surface structure of the strips, after the strip reduction test with the different lubricants. The surfaces are further inspected with a higher magnification using SEM imaging, seen in figure 3.

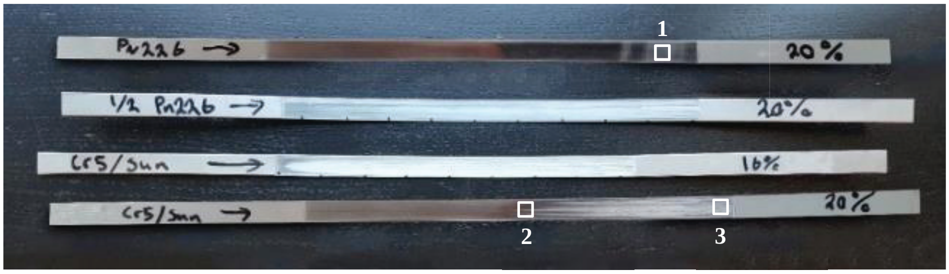

Figure 2: Overview of the surface structure of the strips upon reduction of the thickness.

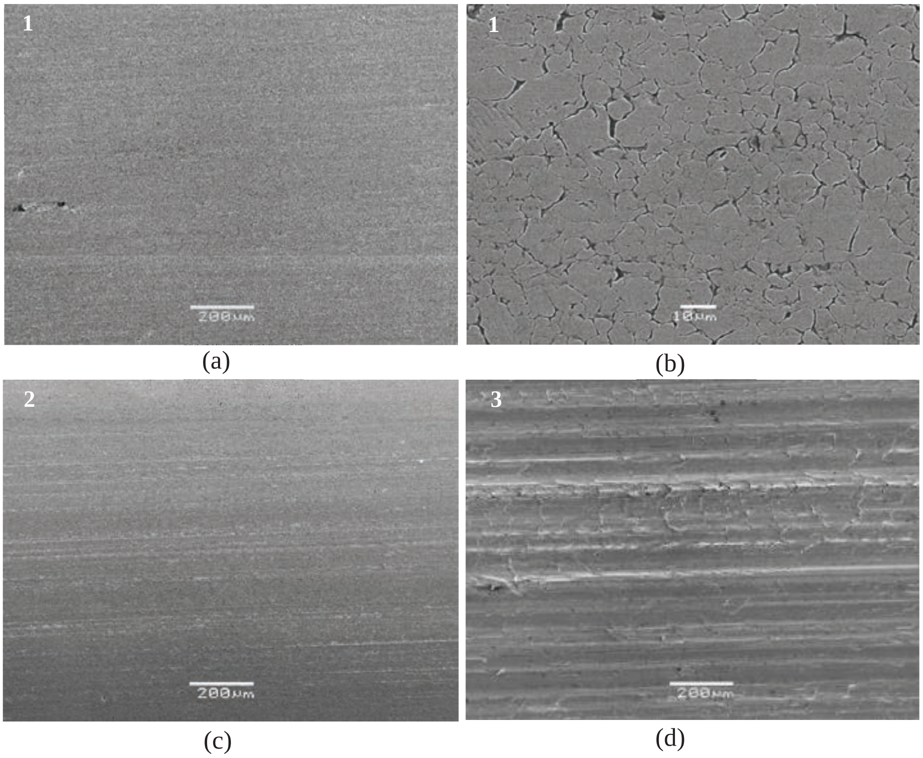

Figure 3: SEM imaging of different regions of the strips after reduction of the thickness.
(a),(b) Smooth surface finish using Pn226. (c) Slight scoring using CR5/Sun60. (d) Severe scoring using CR5/Sun60.

Visual inspection of the surface quality of the strips after reduction of the thickness indicates that boundary lubrication with Pn226 inhibits galling. The CR5/Sun60 lubricant, however, shows very poor performance. In figure 2d severe galling appears leading to heavy scoring of the strip surface. The SEM images furthermore shows that a very smooth surface structure is achieved with the Pn226 lubricant, where the strip reduction process has flattened the surface asperities as seen in figure 3b. Figure 3c on the other hand represents the initial stage of galling with CR5/Sun 60 leading to slight scratches of the strip surface. Figure 3d shows the result of severe galling with heavy scoring of the workpiece surface due to breakdown of the lubricant film and pick-up on the tool surface.

3.2 Roughness measurements

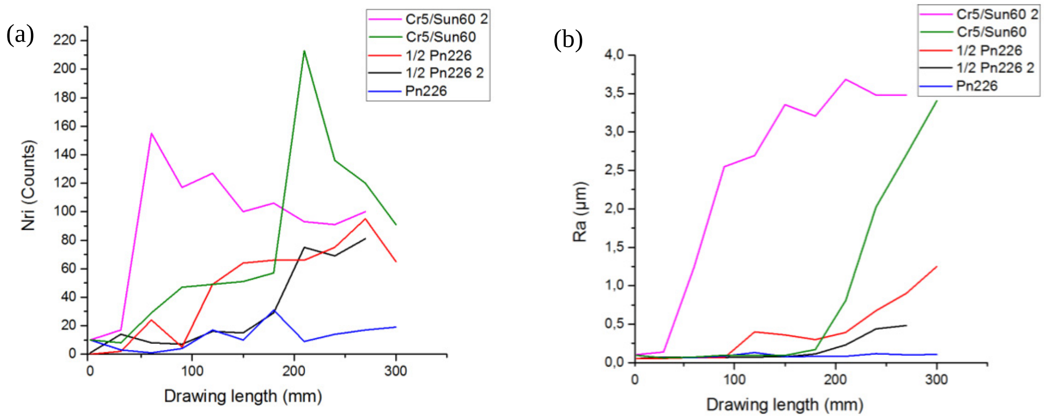

Figure 4: (a) Number of valleys deeper than 1 μm at different sliding lengths. (b) Arithmetic average surface roughness at different sliding lengths.

Two test series were carried out with CR5/Sun60 and with partial lubrication with Pn226. The roughness development with the drawing length confirms the SEM images of the surface structure. Pn226 generally results in a very smooth surface structure, while the strip lubricated with CR5/Sun60 experience severe galling. The sudden increase in the roughness parameters indicates the threshold sliding length for lubricant breakdown and a subsequent initiation of galling. The test series with a partly lubricated strip (marked with ½Pn226) is noticed to run smoothly during the lubricated part of the test with a subsequent increase in roughness when lubrication ends.

3.3 Acoustic emission measurements

Initial assessment is made of the AE signal from the strip fully lubricated with the Pn226 lubricant, which resulted in a smooth surface structure. This is taken as a reference signal for a strip reduction without the occurrence of galling. Based on the acquired signal from the reference strip reduction, a threshold limit of 0,5 V is selected in order to distinguish between an AE event and background noise. With a selected threshold limit for the signal strength, an accumulation of the AE hits can be made for the different data series, as seen in figure 5.

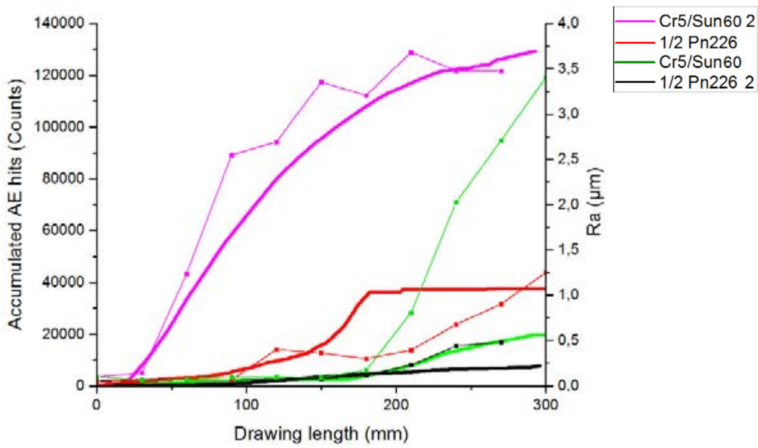

Figure 5: Accumulated AE hits as a function of the drawing length, compared to the developed surface roughness (marked with dots).

It can be gathered from figure 5, that the second test trial with CR5/Sun60 lubricant has a high level of AE activity, which initiates almost immediately. This is in good agreement with the developed surface roughness, which indicates immediate scoring. The other test with the same lubricant indicates a lower wear rate with increased severity approximately at half the drawing length. This corresponds well with the surface roughness measured, which shows a significant increase after a drawing length of approximately 150 mm. The strips which are partly lubricated with Pn226 indicate a minor increase in wear after drawing 150 mm, in accordance with a small increase in the average roughness values. This indicates that the AE method can have sufficient sensitivity to measure the occurrence of minor levels of galling. The presented methodology thus allows for an initial estimation of the onset of galling through assessment of the AE signal developed. By comparison with a reference signal, the overall deviations in the AE signal in the strip reduction test can be correlated to the adhesive and abrasive wear mechanisms associated with galling. The current investigation indicates a few discrepancies between the generated AE signal and the observed roughening of the test pieces especially at lower rates of galling. This is possibly due to an increased influence of mechanical and electrical noise sources. The strip reduction test is, however, a tribologically severe test, which due to the large normal pressures, surface expansion and increase in temperature during testing results in severe galling in case of insufficient lubrication. For such cases the AE technique proves sound. In case of milder tribological tests e.g. strip drawing and bending under tension testing, where minor levels of galling may appear, further investigations are required for characterization of the correlation between the frictional conditions and the generated AE signals.

4. Conclusion

Based on the presented study it can be concluded that AE can be applied as an indirect, non-destructive measuring technique for assessment of galling in strip reduction testing. Based on preliminary testing, it was noted that testing, which resulted in severely scored surfaces, generated a high number of AE events, while the creation of smooth surfaces had a significantly lower level of activity. This indicates a direct correlation between the contact conditions and the generated AE events. The AE methodology is therefore found to be suitable for initial assessment of lubricant performance and can possibly be expanded to online monitoring of galling in sheet forming production.

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