Technical University of Denmark

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Moghadam, Marcel; Nielsen, Chris Valentin; Christiansen, Peter; Bay, Niels Oluf

Publication date:
2018

Document Version
Peer reviewed version

TOOL CONDITION MONITORING IN STRIP REDUCTION TESTING USING ACOUSTIC EMISSION

Marcel Moghadam[1], Chris V. Nielsen[1], Peter Christiansen[1], Niels Bay[1]
[1]*Department of Mechanical Engineering, Technical University of Denmark, Kongens Lyngby, Denmark*

Summary

The usage of diamond-like-carbon (DLC) tool coatings has previously been found to prolong the tool life of forming tools, while reducing the demands of the lubricants used for different metal forming operations. This allows for a more environmentally friendly production without the use of hazardous lubricants, which were previously deemed necessary due to their unique lubricating ability. While facilitating production without the use of hazardous lubricants, the occurrence of coating deterioration can cause damage to the forming tools and produce components with diminished surface quality. The present study outlines the possibility to employ measurements of acoustic emission for online tool condition monitoring in a strip reduction test, which emulates industrial production conditions for ironing.

1. Introduction

Galling is a wear phenomenon commonly encountered in various sheet metal forming processes, often occurring when working with tribologically difficult materials such as stainless steel, Al- or Ti-alloys. The galling mechanism is characterized as a localized macroscopic transfer of metallic material between contacting surfaces where surface damage progressively increases in severity. The occurrence of galling is a major concern in sheet stamping industry, since it leads to poor surface quality, production stops and tool damage. It is similarly reported that galling wear accounts for up to 71% of the cost of die maintenance in the sheet metal forming industry [1][2]. A significant amount of work has therefore been carried out on development of new lubricants, anti-seizure tool materials and tool coatings in order to facilitate a stable production and minimize the costs related to die maintenance [3]. In this context, several promising tool coatings [4][5] have been found to be able to protect against galling, for several thousand strokes, when forming tribologically difficult materials under dry conditions. While being able to support a forming operation under dry condition, the gradual deterioration of tool coatings can introduce diminished surface quality on the formed components. Online process monitoring of the forming operation is therefore of significant interest in order to actively minimize the occurring wear in production. Since the wear mechanism occurs in the contacting interface between the sheet metal and the forming die, the requirement for online process monitoring for sheet metal forming calls for an indirect measuring technique with sufficiently high sensitivity to detect any minute differences in the process. Measurement of conventional process parameters, such as the drawing force, might give a good indication of the tribological conditions in simulative laboratory tests, however these parameters are often found to have too limited sensitivity to evaluate lubricant film breakdown or tool condition in complex, industrial forming dies [6]. Measurement of acoustic emission (AE) has, on the other hand, been successfully applied as an online monitoring technique for evaluation of different tribological characteristics in different metal forming operations [7],[8]. Behrens et al. [9] concluded that acquisition and analysis of AE signals allow for online assessment of production conditions and deviations in production processes. Skåre [10] 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 and cracking. Mostafavi and Pashmforoush [6] successfully applied the AE technique for detecting the onset of galling in a slider-on-sheet test, noting a direct relation between the wear mechanism and AE peak amplitudes. Preliminary investigations by the present authors on detection of the onset of galling in strip reduction testing [11] have similarly shown a correlation between the development of the signal and the generated surface roughness, allowing for an assessment of the severity of the wear mechanism by comparing the developed AE signal with a reference threshold value. The present study therefore aims at investigating the applicability of AE measurements for tool condition monitoring and detection of coating failure in strip reduction tests with coated tools.

2. Experimental procedure

2.1 Strip reduction test

The strip reduction test was performed on the universal sheet tribo-tester developed at the Technical University of Denmark in 2012, as initially described by Bay and Ceron [12]. The test was conducted with two cylindrical tools of Vanadis 4 with a diameter of Ø15mm, which were polished to a surface roughness of Ra = 0.02μm prior to deposition of a surface coating of 3μm DLC upon a base coating of Hyperlox® [13]. The workpiece material used for the strip reduction test is EN 1.4307 stainless steel, with dimensions of 30x1mm, where a 20% reduction in the sheet thickness was performed during testing. For the test, a draw sequence was performed with a 40mm stroke length and a sliding speed of 50mm/s with an idle time of 0,5s between each stroke. A schematic illustration of the tool setup is shown in figure 1.

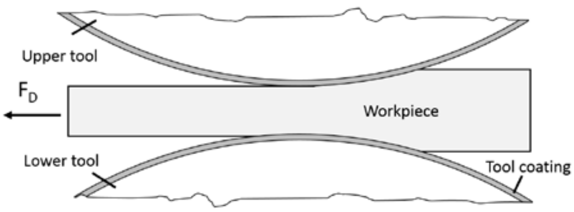

Figure 1: Schematic illustration of the strip reduction test.

The surface structure of the ironed workpiece material was examined with light optical microscopy upon testing.

2.2 AE Measurement

Data acquisition of the generated AE signals during testing were made with a R15α piezoelectric sensor connected to a 2/4/6 analog preamplifier with a built-in bandpass filter of 10-900 kHz. The piezoelectric AE sensor was fixed to the tool housing with a screw clamp and the contact area between sensor and tool housing was provided with grease paste as an acoustic couplant. The preamplifier was connected to a NI 9223 multipurpose data acquisition unit which was connected to a NI 9146 4-slot expansion chassis. The data acquisition was furthermore conducted with a sampling rate of 1 MHz.

3. Experimental results

3.1 Surface structure

The generated surface structure of the workpiece material, which was in contact with the upper tool, is shown in figure 2.

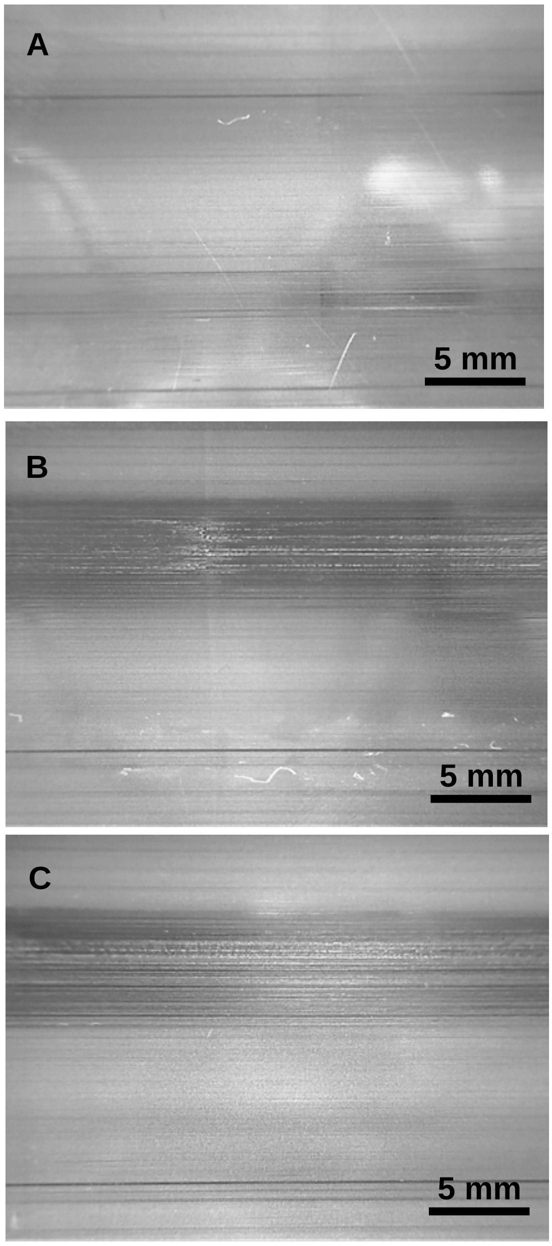

Figure 2: Surface structure of the ironed strip after (A) 38 strokes (B) 495 strokes (C) 722 strokes. The drawing direction is from right to left.

Figure 2A shows a smooth surface structure of the workpiece material after 38 strokes. This represents the initial test conditions, where the tool coating allows for a strip reduction under dry conditions without the occurrence of visible wear. At a drawing length corresponding to approximately 495 strokes, see figure 2B, a noticeable deterioration of the wear protecting ability of the surface coating is seen, as a minor development of scoring on the surface of the workpiece material initiates. This indicates that the surface coating has gradually been eroded and local pickup of workpiece material has been accumulated on the tool pin. At an increased sliding length, see figure 2C, corresponding to 722 strokes, a significant increase in severity of the galling mechanism is noted, prior to fracturing of the strip at stroke number 726.

3.2 Force and acoustic emission measurements

The drawing force and the generated acoustic emission during testing are shown in figure 3 and 4, respectively.

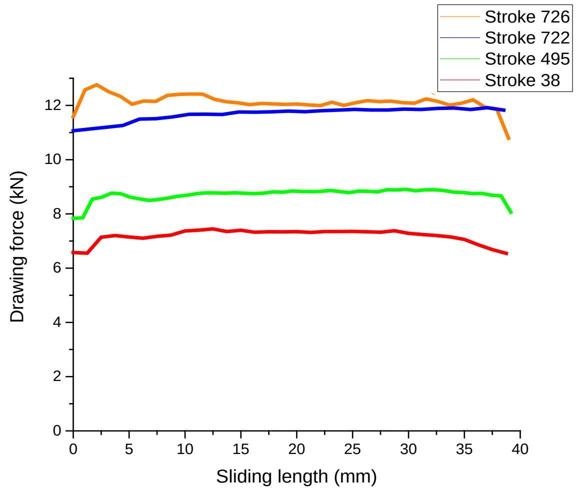

Figure 3: Force measurements during the strip reduction test.

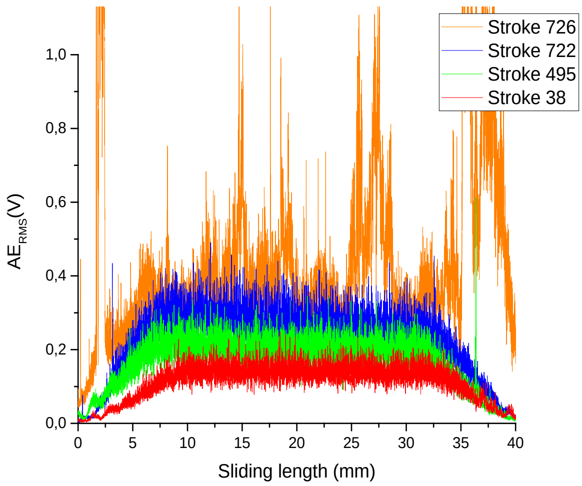

Figure 4: Measurement of the generated AE during the strip reduction test.

From the force measurements, seen in figure 3, a stable force is seen at stroke number 38, corresponding to the smooth surface structure in figure 2A. At the onset of deterioration of the tool coating an increase of the drawing force was experienced. As the surface damage progressively increases in severity in the subsequent strokes, an increase in the drawing force was similarly measured. Evaluation of the development of the drawing force is thus found to give a good basis for monitoring the occurring surface damage during testing. The generated AE during testing reveals a similar tendency, with a very low signal level at the initial strokes, while a significant increase in the signal level is noted after stroke 495, where surface damage is apparent on the workpiece material as shown in figure 2B. The generated acoustic emission during testing is therefore found to be highly correlated to the tribological conditions during testing. Assessment of simple time domain parameters such as the RMS level can therefore give detailed information about the process conditions during forming.

4. Conclusion

The AE measuring technique has been found to be a powerful tool for online process monitoring of the strip reduction test. By measuring the generated AE, assessment of the tool condition can be made, where the generated AE was found to be correlated to the severity of the experienced wear mechanism. This was evaluated by visual inspection of the generated surface structure as well as by assessment of the drawing force measured during testing. Assessment of the development of the captured AE signal therefore allows for an online evaluation of process conditions in sheet metal forming operations. This can prove valuable for process monitoring e.g. in complex forming dies, where other indirect measuring techniques cannot be applied.

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