

Experimental Analysis of Die Wear in Sheet Metal Forming

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ABSTRACT

Advanced high strength steels (AHSS) are particularly attractive to automotive industry. Stamping AHSS parts, however, results in accelerated die wear problems which could emerge after few thousands of stampings. The existing wear testing methods are either not suitable for charactering die wear in stamping or requires significant capital investment. The first generation of strip-on-cylinder wear test apparatus which can efficiently and economically characterize die wear is introduced in this paper. Different measurement methods were compared and white light interferometer with nanoscale accuracy was chosen to determine the wear volume due to its overall advantages. Based on the strip-on-cylinder wear test apparatus, a design of experiments study analyzing the effects of contact pressure, sliding speed and hardness of the die material on die wear was conducted and the results were discussed.

INTRODUCTION

Advanced high strength steels (AHSS) have been in use in the automotive industry since the 1990's. AHSS include dual phase (DP) steels and transformation induced plasticity (TRIP) steels. The minimum tensile strengths of AHSS range from 500 to 800 MPa¹. They are easier to form than high strength steels with similar initial yield strengths due to their higher hardening behavior. AHSS are particularly attractive to the automotive industry due to their favorable properties, such as: weight reduction, cost reduction, improvement

of fuel economy and excellent crash performance. Recently, more research work has been focusing on improving the initial yield strength beyond 1 GPa. Stamping such a hard material, however, results in severe die wear problems which could emerge after only few thousands of stampings. These severe die wear problems usually happen at the corner radius of the deep drawing die or at drawbeads. Excessive die wear can result in inferior surface finish and geometrical deviations of final products. Due to a combination of the high manufacturing cost of die, and the ever increasing demand of high-quality parts, die wear has become a vital interest to manufacturers.

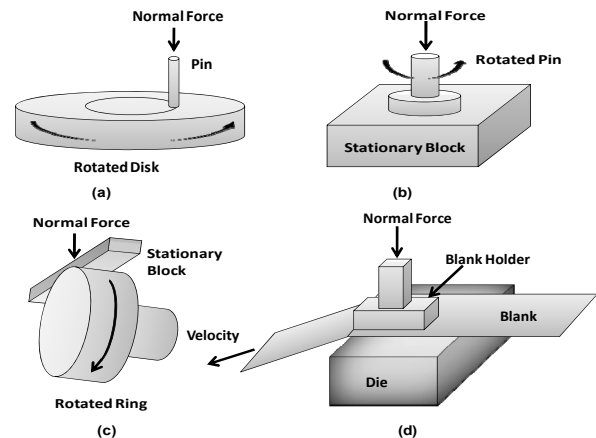


Figure 1: (a) pin-on-disk test method, (b) twist compression test, (c) block-on-ring test method and (d) Strip pulling test method

Wear has been intensively studied in the past and various wear test methods have been developed for different applications and wear conditions. Figure 1 shows the schematics of four most widely used methods for charactering die wear: pin-on-disk method, galling test method, block-on-ring method and strip pulling method. In the pin-on-disk test (Figure 1a) [2- 4], a small flat-ended pin is pressed in contact with a rotating disk. Damage to the disk and the pin was measured by stylus profiling and converted to wear volume. This device is compact and robust. However, the contact surfaces of pin and disk remain the same through the test, which is totally different from the actual stamping operation. In metal forming, the die material gets in contact with new metal surfaces at every stroke. Similarly, the twist compression method [4, 5] involves rotation of a flat-ended pin under a predetermined normal force on a flat counter face (Figure 1b). This method is used to determine the threshold galling pressure which is the apparent contact pressure at the highest load before galling starts. Another similar one is the block-on-ring test method [6, 7] in which a stationary block is brought into contact with a metal ring under controlled contact pressure and relative velocity (Figure 1c). This method is usually used to rank materials according to their sliding wear characteristics. Figure 2 shows that as the surface in contact wears out, the contact area increases gradually. This causes the contact pressure to be inconsistent across the sample. During the test, like the pin-on-disk method, twist compression and block-on-ring methods repeat the contact track on the same sheet metal surface. This limitation determines that they are not suitable for charactering die wear in stamping.

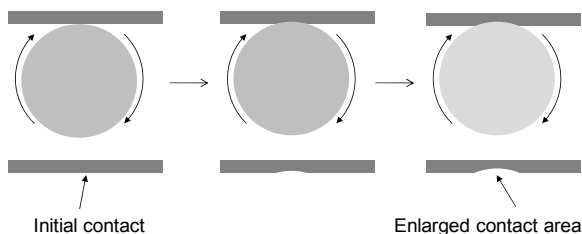


Figure 2: Enlargement of contact area

More recently, with the aim of studying the die wear problem in sheet metal forming, the strip pulling method was introduced. In the strip pulling method (Figure 1d), a metal strip, unrolled directly from a coil, was pulled by a motor and pressed in contact with a portion of the radius tool by a blank holder. The contact surface keeps changing during the test, making it more representative of the actual stamping conditions [8, 9]. However, it is not quite suitable for the study of the effect of contact pressure on die wear. As known, the typical contact pressure is only around 1-10 MPa for the flat blank holder region but on the order of 100 MPa at the corner radius of the deep drawing die or at the drawbeads radius. These corners experience the most severe

operating condition where the wear rate for the die material is the highest. In the strip pulling method, the contact pressure of the blank holder region is controllable, whereas the contact pressure at the corner of the die, the most important part of the die, is not directly controlled. It may vary depending on the pulling angle, applied blank holder pressure, etc. The lack of direct control of contact condition makes it difficult to study the relationship between contact pressure and die wear. In addition, the strip pulling method requires a suitable motor to provide a decent sliding speed which is comparable to the sliding speed in real stamping. A new wear test method which can closely represent the real sheet metal forming process is needed.

In this paper, a new desktop apparatus was designed to efficiently and economically characterize die wear. The strip-on-cylinder wear test concept and experimental setup will be introduced in the next section. In the same section, different wear measurement methods will be compared and the most suitable wear measurement method will be determined. Next, a design of experiments (DOE) study will be conducted to analyze the effects of contact pressure, sliding speed and hardness of the die material on die wear. The results of the study can help to establish a die wear prediction model which can be used to redesign manufacturing processes to reduce the overall operation cost.

EXPERIMENTAL SETUP

CONCEPT AND APPARATUS:

The objective of this work is to design a new testing method to accurately quantify the amount of wear as a function of relative sliding speed, contact pressure and contact material pairs. Meanwhile, the test apparatus should be as accurate and as economic as possible.

A schematic of the strip-on-cylinder concept is illustrated in Figure 3. The cylinder is made of die material, representing the tooling. The strip is made of sheet metal, and being pressed against the cylinder by an adjustable normal load. The die cylinder and the strip move in opposite directions, the relative sliding speed is the sum of the speed of strip (V_s) and the rotation speed of the cylinder ($r \cdot \omega$).

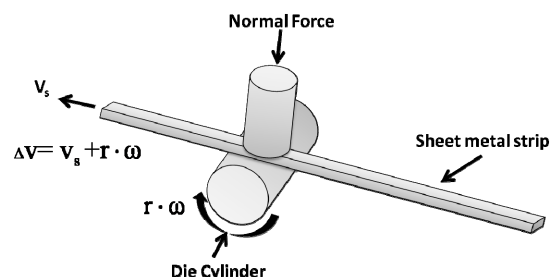


Figure 3: Strip-on-cylinder wear testing concept

This strip-on-cylinder design has following advantages:

- Contact surface of the sheet metal keeps changing
- Critical contact pressure can be directly controlled
- Save material and therefore, reduces the cost
- Compact, efficient and continuous

The apparatus fabricated based on this concept is shown in Figure 4. The die cylinder is driven by a three phase electric induction motor which is controlled by an AC inverter. The sheet metal strip is pressed against the cylinder by the force provided through an adjustable counterweight and pulled by a small motor through a control box. The high rotation speed of die cylinder makes it possible to reach a desired sliding speed with a much smaller workspace compared to the strip pulling test method.

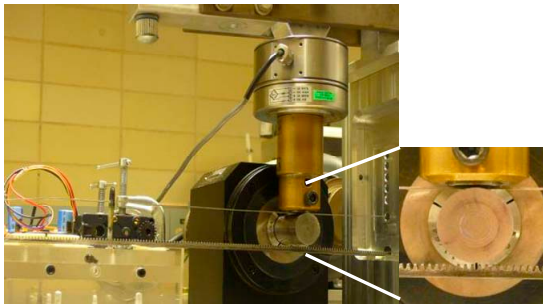


Figure 4: Strip-on-cylinder die wear test apparatus

MEASUREMENT METHOD:

In the following paragraphs, the design of die cylinder and sheet metal strip will be discussed. Before this, the method of measuring the wear volume has to be determined first. There are three common methods to determine wear volume: weighing method, mechanical gauging method and optical method. The pros and cons of these methods will be discussed and the most suitable method will be chosen.

Weighing is the simplest way to measure the wear amount. It can get the wear volume indirectly by weighing the mass difference before and after the wear test. Weighing is a relatively rough measurement method. Since the weight of the worn out material is on the order of 1 mg, the debris left on the surface of the sample and the moisture in the air have significant impacts on the final result. Another limitation is that the weighing method cannot distinguish between abrasive wear and adhesive wear. Abrasive wear occurs when hard asperities on the sheet scratch through the softer tool material. Adhesive wear occurs in a contact when the friction generates heat and causes the asperities or high points to weld together. Abrasive wear has a negative effect on the weight, while the adhesive wear has a positive effect on the weight, which will counterbalance the lost weight.

The mechanical gauging method, such as atomic force microscope (AFM), takes a profile of the wear track and then estimates the wear volume. Compared with the weighing method, the mechanical gauging method is much more accurate. However, it is more difficult to operate, slower and much more sensitive to ambient conditions. To obtain a reasonable estimate of overall wear volume, many repeating tests at different locations are needed, therefore, the mechanical gauging method is more time consuming.

The optical method, such as white light interferometer (WLI), bounces light off of a surface, and analyzes the interference fringes resulting from the reflected light combining with the emitted light. By measuring the shift in wavelengths the surface of a specimen is measured to nanometer precision. Compared with AFM, WLI can measure much larger areas, without a loss in precision at the nano-scale. The use of light instead of a physical entity also simplifies the system, and allows measurement of deep, narrow features as long as light can be reflected.

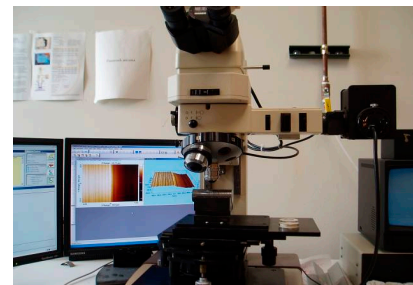


Figure 5: White Light Interferometer (WLI)

Based on the above discussion of three different measurement methods, the optical method using WLI has been selected due to its accuracy, stability and good repeatability. The ADE Phase Shift MicroXAM-100HR WLI used in the research (Figure 5) has the ability to scan to a depth of about $100\text{ }\mu\text{m}$ with a minimum resolvable depth of 5 nm . The maximum view area with this resolution is $1.38\text{ mm} \times 1.03\text{ mm}$.

SAMPLE PREPARATION:

Multiple tracks were machined in one die cylinder to represent independent dies (Figure 6). This multi-track design can save material and reduce the total cost of the experiments. In addition, it is much easier to control the hardness and surface roughness of all the wear tracks by machining and grinding them under the same process. The wear results obtained from the multiple wear tracks of one cylinder will be much more comparable than those from different cylinders. To make sure the experiment represents the actual sheet metal forming process, the surface roughness of the wear tracks was set to be $1\text{ }\mu\text{m}$.