TRIBOLOGY IN SHEET METAL FORMING: A MODIFICATION OF TRIBOMETER FOR STRIP DRAWING TEST

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Abstract

In the pursuit to produce the best product at the lowest cost, much can be done to reduce the cost of production. One of these methods, which is nowadays inseparable from the development part of production, is numerical simulation. However, the real world cannot be accurately modelled. The use of simplified models for numerical simulation can lead to different results between reality and simulation. One of these models is a coefficient of friction used in sheet metal forming simulations. Nowadays modern simulation software used for simulating the sheet metal forming process uses simplified model of friction coefficient using variables including surface roughness, topography, lubrication, and others. One of the variables not included in these models is temperature. In deep drawing, temperatures of sheet metal can be over 120 °C. Temperature can greatly change tribological properties, thus changing the friction between the tool and the sheet metal. The aim of this paper is to review a method of measurement of tribological properties in sheet metal forming and to design a modified tribometer for strip drawing test, focusing on the effect of temperature on tribological properties, predominantly for materials used in the automotive industry.

Keywords: Sheet metal forming, tribology, strip drawing test, coefficient of friction

1. INTRODUCTION

In recent years, trends in the automotive industry have been towards the production of lighter components to reduce emissions and production costs while maintaining product quality. Achieving these conditions can be achieved by research into materials and production technologies, etc. One of the important parameters in the context of surface forming is the discipline of tribology, which influences several properties in forming processes.

Modern simulation software uses formulas based on Amontons laws of friction to calculate simulations of tribological conditions in forming processes, describing the relationship between friction force and coefficient of friction, where friction force is directly proportional to compressive force. The ratio between these forces is expressed as the coefficient of friction. The coefficient of friction used in the numerical simulations is determined under ideal conditions. During forming processes, deformation of the material occurs, which causes a change in parameters that affects the tribological properties of the material (temperature, surface topography, oil viscosity, etc.). Following the change in tribological properties, the parameters of the forming operation, in particular the forming force, also change. [1-3]

This article focuses on the search for a tribometer for use in testing tribological properties at various temperatures. The data from this research would be used in numerical simulations to further increase the accuracy of the sheet metal forming simulations.

2. TRIBOLOGICAL TESTS IN THE SHEET METAL FORMING PROCESS

Coefficient of friction in sheet metal forming is measured by myriad of ways. Tribological test methods can be distinguished into six categories as shown in **Figure 1**. Categories 1-3 are from the perspective of testing forming processes during production of an actual product. Major advantages of this approach is relative accuracy of results, since the real forming operation is used during trial. Main disadvantage is limitations to change the parameters of the trial, mainly load and the implicit measurement of variables like coefficient of friction. Furthermore, these tests require special dies and are therefore quite expensive. [1]

On the other end of the spectrum, we have the general tribometers described in **Figure 1** as category 6. Main advantages of general tribometers are their standardisation (DIN 51350, DIN 51834, ASTM D5707, ASTM D1894, ASTM G99) these standards assure, the repeatability of the tests. Disadvantage, with regard to sheet metal forming, are different contact conditions therefore low applicability to forming processes (relatively small contact area, lubricated condition, etc.). [1]. Category 4 are mainly used for study of tribological systems, particularly lubricants. Model tests performed by drawing a cylindrical cup often lack systems for direct measurement of force or friction coefficients. Therefore, these tests are mainly used in studies focused on qualitative comparisons and proof of feasibility [1]

Tests of category 5 utilize strip of sheet metal as a test sample. Methodology behind model tests of category 5 is to simulate conditions that occur in sheet metal forming operations by simulating frictional behaviour under specific conditions (contact pressure, sliding velocity, temperature, topography, etc.). Such tests mainly aim at quantitative results in form of friction coefficients.[1]

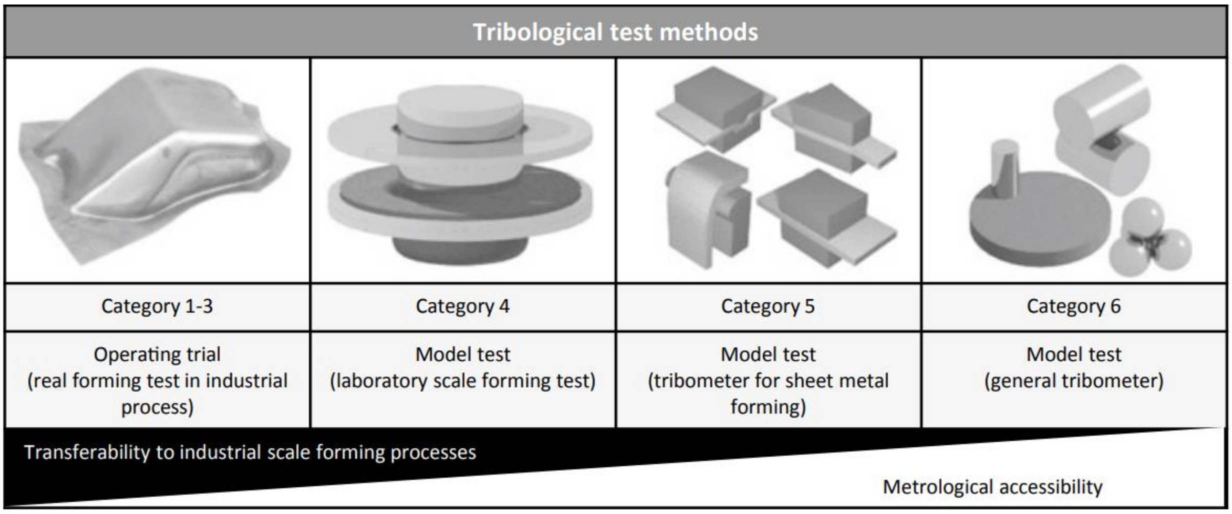

Figure 1 Types of tribological test methods [1]

The most common methods of measuring the friction coefficient during different sheet metal processes are shown in **Figure 2**. These model tests consist mainly of category 5 and one from category 6.

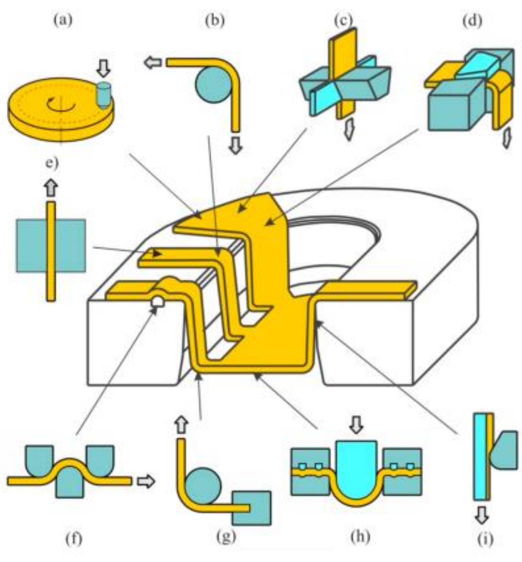

Figure 2 Tribological tests representing different conditions in sheet metal forming process: (a) pin-on-disc tribometer, (b) bending under tension, (c) drawing with tangential compression, (d) bending with Tangential compression, (e) strip drawing test, (f) draw-bead test, (g) strip-tension test, (h) hemispherical stretching, (i) strip reduction testing [2]

From methods mentioned in **Figure 2,** the strip drawing is most suitable for the purpose of measuring the difference of tribological properties, in this case changes dependant on temperature. Device for strip drawing test is relatively simple to build in an already established laboratory. Universal testing machine can be easily modified for this purpose. Therefore, this paper is focused on strip drawing test.

2.1 STRIP DRAWING TEST

Strip drawing test (**Figure 2a**) is one of the methods used for measuring coefficient of friction in sheet metal forming due to its relative simplicity and adaptability for various universal testing machines. Main principle of strip drawing test is to use one or two dies, that apply pressure on strip of sheet metal. In case of using two flat dies the equation of coefficient of friction is described in (1) and pictured in **Figure 3**. [2]

$$\mu = \frac{F_T}{2\,.\,F_N}\ [-] \qquad \text{...(1)}$$

where:

μ - the coefficient of friction (-)

F_N – the normal force (N)

F_T - the pulling force (N)

The jaws can be flat, but it is also possible to use a cylindrical or other shape. It is important to note that the resulting coefficient of friction is influenced by the tribological conditions (contact pressure, relative velocity of the friction bodies, temperature, amount and type of lubricant, topography of the surface of the jaws and sheet metal), as well as the shape of the jaws and the orientation of the sheet metal between the jaws. For consistent results, it is important that the tribometer design is as rigid as possible. [1-3]

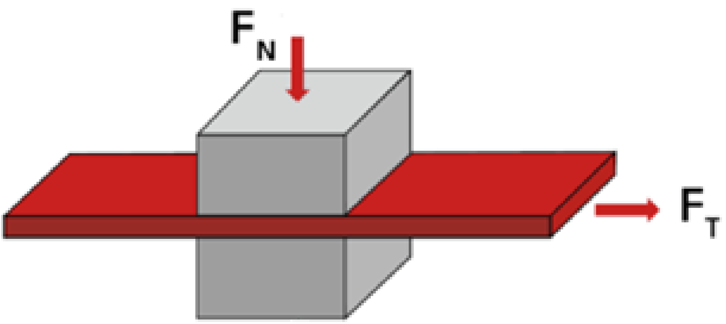

Figure 3 Schematic of strip drawing test with flat dies [1]

3. STRIP DRAWING TRIBOMETER:

Design incorporates the universal testing machine LabTest 5.100SP1 as a source of the pulling force with real-time monitoring, shown in **Figure 4**. Parameters of the universal testing machine are shown in **Table 1**.

Table 1 Technical parameters of universal testing machine LabTest 5.100SP1

Technical data	**Units**	**5.1002P1**
Rated load	kN	100
Max. Testing Speed	mm/min	600
Working Space Height	mm	1130
Working space width	mm	400
Frame rigidity	mm/N	1.6E1-06
Machine Dimensions W x D x H	mm	2373x920x880

Figure 4 Universal testing machine LabTest 5.100SP1

In the design of the tribometer following criteria were established:

- Changeable dies
- Heating of the dies
- Temperature measurement
- Quick insert of a test sample

Main frame of a tribometer consist of a base plate and two side plates which are welded together at the base. Top of the frame is linked by 4 guide rods, which are threaded to front plate and pas through back plate where they are secured by nuts. Tribometer is designed with two dies in mind, one stationary, with adjustable position for incorporating dies of various length and shape. The second die is exerting normal force by means of linear springs. Springs are compressed between two plates held in place by guide rods and a movement screw. Guide rods are placed inside precision bronze bushings to ensure smooth movement of operation and accuracy of die alignment. The compression length is adjustable by two screws located on the sides of the plates, but main movement is done by trapezoidal screw located in the middle of the plate. Trapezoidal screw is mounted inside of the front frame in a bronze bushing and kept in place by nut, which is held in place by a pin. Adjustment of clearance is done in such a way to assure a smooth operation. Movement screw ensures quick clamping of the test sample, due to springs being preloaded, the distance that needs to be cleared is minimal. 3D model of the tribometer is shown in **Figure 5**

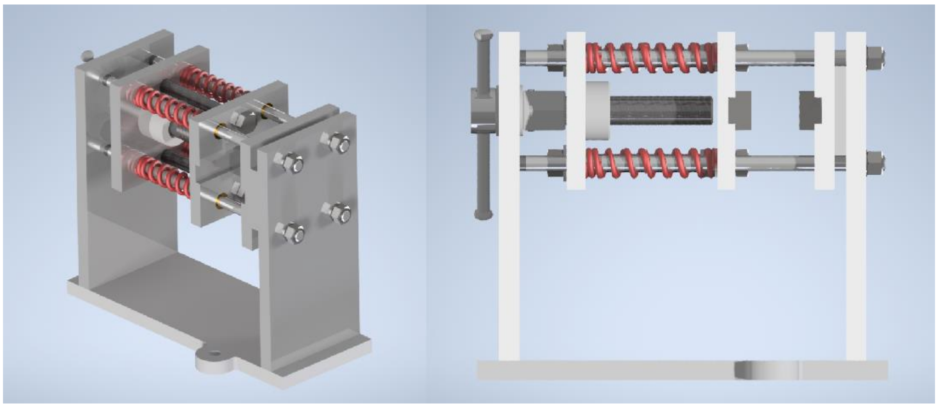

Figure 5 3D model of the proposed tribometer

Heating of the dies is done by a heating element embedded in a square aluminium rod which is clamped between the jaws. Temperature reading will be carried out by thermocouples located on the back of the jaws. The desired temperature will be reached when the jaws are heated to the desired temperature. The expected temperature range is from 20 °C to 120 °C.

Test sample is a strip of sheet metal 0.8 mm thick, 30mm wide and 300mm long. Sliding length of the sample is 200mm. Maximum normal force is determined by size of linear springs used, assumed maximum normal force is 10kN. Material of the test sample will be from commonly used steels in automotive industry such as: HCT490X, DX57D. [4,5]

The methodology of the test is as follows. Firstly, test samples are cleaned and degreased, same applies to the dies. Springs are preloaded to the given amount of normal force by tightening of screws, at this step all other parameters of the test are set (temperature reading, speed, etc.). Then heating device is inserted into the jaws and clamped (**Figure 6a**). When goal temperature is reached heating device is removed from tribometer and set aside. Test sample is then clamped in the jaws of the universal testing machine and dies of the tribometer clamp the test sample (**Figure 6b**). Universal testing machine is then turned on and sample is pulled through the dies of a tribometer. Test is done when sample is pulled through (**Figure 6c**). Then steps are repeated for the next test.

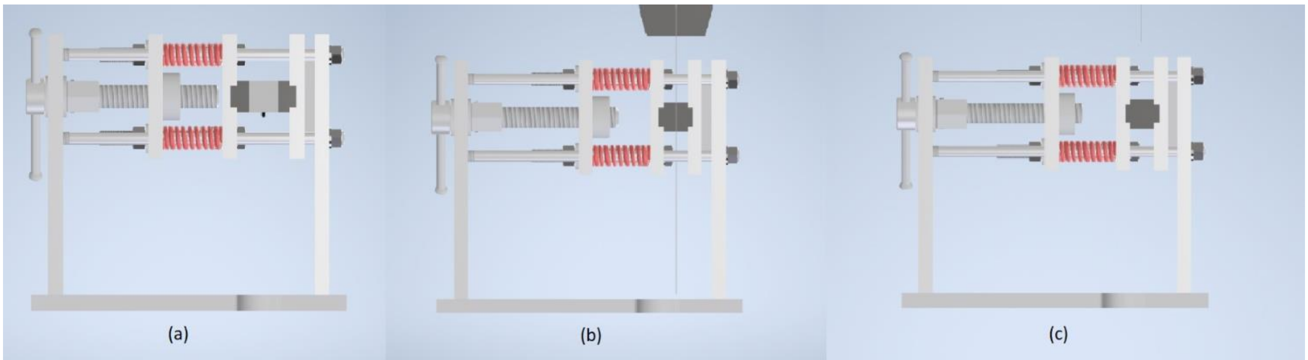

Figure 6 Test methodology: (a) Tribometer with heating device, (b) tribometer with clamped test sample, (c) Tribometer after the test

4. CONCLUSION

This article deals with the issue of measuring coefficient of friction in sheet metal forming. The methods of measuring tribological properties in the field of sheet metal forming are described in chapter 2: Tribological tests in sheet metal forming process. Proposed tribometer was designed with purpose of measuring the change of coefficient of friction depending on the surface temperature of the metal. Tribometer is designed to slot into the universal measuring machine LabTest 5.100SP1. Design of the tribometer is described in Chapter 3: Strip drawing tribometer. Further research into this topic will include production of designed tribometer and carrying out the test according to the mentioned methodology.

Further research activities into tribological properties under realistic forming temperature conditions would contribute to the refinement of simulation software results, resulting in cost reduction in the pre-production phase of sheet metal forming manufacturing.

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