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# Improved Tribotesting for Sheet Metal Forming

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## Abstract

A new tribotester has been developed to characterize the friction conditions in sheet metal forming applications. The basic principle for the tribotester is parallel strip drawing. This apparatus is an improvement on conventional test setups in that it offers controllable speed and normal load during experimenting, a tool size that is variable over a wide range, and direct force measurement to allow the calculation of friction coefficients without using internal material deformation. These features increase the efficiency of the testing procedure when developing new tooling concepts within the sheet metal forming industry.

*Keywords:* Tribotester; Friction; Sheet metal forming

## 1. Introduction

In sheet metal forming a blank of sheet metal is formed into a product between a punch and a die. The process is based on sheet deformation caused by the relative movement between the tool and the sheet, an interaction that generates friction forces. It is important to understand and be able to control the friction conditions generated in the forming process in order to produce top quality sheet metal products. Errors like crack formation, shrinkage, surface defects and severe tool wear can be reduced by controlling the tribological conditions in the process.

It is generally believed that the friction between two surfaces in contact varies with velocity, applied load and type of lubricant, according to the Stribeck curve. However, in a sheet stamping operation the friction cannot be considered as a static parameter due to the varying process conditions during the forming operation. In reality, the friction fluctuates widely in the forming tool depending on the actual forming condition.

It is a massive undertaking to completely map the friction conditions between two surfaces in contact considering parameters such as different materials, textures and roughness, amount and type of lubricant, and different process conditions. Much work has been devoted to developing various tribotesters, both commercial and non-commercial, to explore the world of friction. A common shortcoming for most of them is an inability to effectively cope with multi-dimensional parameter studies. In addition the testers have narrow ranges of application, forcing you to use several tribotesters to cover the complete tool, see Bay et al.[1]. The results from laboratory friction tests are very important for reducing time and costs in the pre-industrial testing phase. The friction data must be as accurate and comprehensive as possible. Using several friction test setups to cover the actual working area takes time and increases the source of errors due to the vague correlation between different setups.

Today, there are a number of standard methods for friction and wear measurement, such as pin on disc, block on ring, pin on V-block [2-7] and a number of variants [8] [9].These methods are often poorly correlated to true friction or wear conditions. Parameters such as contact area, applied load and geometry in these test devices are often not comparable to manufacturing processes like sheet metal forming, resulting in rough estimates of the friction coefficients. Several tribological test apparatuses have been developed to specifically imitate the load conditions in different sheet forming

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processes. Methods such as bending under tension (BUT) [10-13], TNO test [13], strip drawing [14], draw-bead-simulation (DBS test) [15] [16], and strip reduction test (STR test) [17] are often used to estimate the friction and wear behavior between surfaces.

However, these methods have some drawbacks. Many of them can only take a few parameters into consideration, such as fixed or limited tool size, instead of real contact situations such as a line or point contact. In addition they rely on a static test procedure with fixed parameters like load and speed to calculate the friction. These properties reduce the possibility of effective screening.

This paper presents a newly developed tribotester based on strip drawing with flat dies. The tribotester is capable of evaluating the friction between two surfaces in contact under a number of different static and dynamic conditions. Parameters such as applied normal force, contact area, lubricant, temperature, surface texture, and sliding velocity are fully controllable.

## 2. Experimental setup

The actuator generating the movement between the tool and sheet and the controllable normal load are the main differences between this device and other tribotesters based on parallel strip drawing. This device utilizes a linear motor. This option makes it possible to combine very accurate control of the relative movement between the sheet and the tool with outstanding dynamic properties. Figure 1 illustrates the principles of the tribotester.

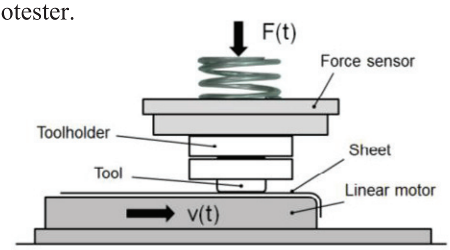

Fig. 1. Schematic illustration of the experimental setup.

### 2.1. Linear actuator

The basic functioning of the tribotester is illustrated in figure 1. The linear motor as the actuation unit in the shearing direction is essential to obtain the required controllability for force and speed control. The specification for the linear drive in terms of velocity, distance, force, and load is primarily based on estimates from sheet forming processes. The specifications for the linear motor are:

- Maximum normal load: 12 kN
- Maximum drag load (shear load): 6 kN
- Maximum velocity: 6 m/s
- Maximum acceleration: Limited by the variable frequency drive performance and current setup.
- Travel distance: 600 mm

### 2.2. Measurement system

The forces are measured with a 3-axis Kistler piezo-electric transducer (9275B). A sample rate of 100 kSample/s was used. A linear encoder measures the position of the strip synchronously with the force signals. The position data were processed and the velocity was calculated. Both electrical and mechanical sources generate unwanted interference with the acquired measurements. The eigenfrequencies of the complete test rig as well as the spring-loaded normal forces varies depending on the actual process condition. Other major sources of noise are the drive unit for the linear motor and the drive system for the normal load. A low-pass filter, using a cut-off frequency of 60 Hz, was used to reduce the noise and disturbances in order to analyze the collected data.

### 2.3. Tool material

The tool material used in all the experiments in this work has the commercial name Sleipner. It is manufactured by Uddeholm and there is no applicable standard specification. The material is commonly used in cold working tools, such as blanking and stamping tools in the sheet metal forming industry, due to its high resistance to wear and chipping. The chemical composition of the tool material can be seen in table 1.

Table 1. Chemical composition (wt. %) of Sleipner

| C | Si | Mn | Cr | Mo | V |
|---|---|---|---|---|---|
| 0.9 | 0.9 | 0.5 | 7.8 | 2.5 | 0.5 |

The tools were produced with three different active sizes of the tool surface, 10*10 mm, 20*20 mm and 30*30 mm, as shown in figure 2. A radius of 1.5 mm was initially created at the edges to prevent and reduce boundary effects from the edges of the tool during experiments. All tools were hardened to 62 HRC. The surface topography was generated by surface grinding to a surface roughness of Ra 0.1. To further reduce effects like scratching and galling, which originate from sharp edges during testing, the edge between the active surface and the radius was smoothly chamfered, see figure 2.

Fig. 2. Different tool sizes and edge preparation.

### 2.4. Sheet material

The sheet material used in this first experimental study was Docol 600DP. It is an uncoated high-strength steel (HSS) widely used in the car body industry, from SSAB. The mechanical properties and chemical composition are shown in table 2.

Table 2. Properties for Docol 600DP

| Mechanical Properties | | |
|---|---|---|
| Yield strength | Tensile strength | Elong. $A_{80}$ |
| 350-450 N/mm$^2$ | 600-700 N/mm$^2$ | 16 % |

| Chemical composition (wt. %) | | | | | |
|---|---|---|---|---|---|
| C | Si | Mn | P | S | Al |
| 0.11 | 0.40 | 0.90 | 0.015 | 0.005 | 0.04 |

The sheets were cut in strips of 510*40 mm. The strips were cut so the friction tests could be performed in the rolling direction. To minimize irregularities during testing, the strips were carefully deburred and visually inspected to remove test pieces with errors like scratches or imprints of any kind.

## 3. Experimental conditions

The range of applied loads and velocities used for these experiments was mainly based on real process conditions in sheet stamping. The major advantage of this system is the controllability of these input parameters. The present measurement platform limits the applied normal load to 10 kN, but the normal pressure can easily be altered by using different tool sizes. The range for the initial experiments varied from 1 MPa to 15 MPa for the normal pressure and from 0.1m/s to 1.4 m/s for speed. The majority of the tests were performed using tools sizes of 20*20 mm in order to cover the test area (1 to 15 MPa in pressure) without changing tool size. The length of each stroke was between 300 mm and 410 mm depending on the situation. High-load tests required shorter distances to stabilize compared to the low-load tests. During the ramped experiments the maximum travel distance was used.

Two different lubricants were used during the experiments, Fuchs Anticorit 3802-39S and Sellcleaner 1350. Both are commonly used in the sheet forming industry. The Fuchs oil is a delivery oil acting as corrosive protection but has some additives so it can be used as a press oil. Table 3 summarizes the properties for the two lubricants.

Table 3. Properties of lubricants.

| Anticorit 3802-39S | Sellcleaner 1350 |
|---|---|
| Density 20°C 0.91 g/cm$^3$ | Density 20°C 1.07g/cm$^3$ |
| Viscosity 40°C 60mm$^2$/s | Viscosity 20°C 100mm$^2$/s |

Different amounts of lubricant were used during the tests ranging from totally dry to 4g/m$^2$. Each strip was thoroughly cleaned with ethanol before applying the lubricant. A precision scale (resolution 0.0001 g) was used to apply the correct amount of lubricant to each sheet. 1 g/m$^2$ on a sheet corresponds to 0.02 g on a strip. The accuracy for the amount of applied lubricant was ± 5%. The oil was applied with a cloth and the oil film thickness and distribution were not checked.

Figure 3 shows a successfully drawn strip with an even mark from the tool (20*20 mm). Sheet preparation such as deburring and removing irregularities in the form of indents of any kind appeared to be very important to obtain valid results.

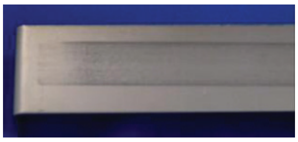

Fig. 3. Tested Sheet

## 4. Results

Three main types of experiments were performed to illustrate the versatility of the newly developed tribotester. The friction force was acquired and the friction coefficient was calculated for, constant speed and constant normal force, varying speed with constant load during the tests and varying load with constant speed during the tests. Additional studies with lubricants, amount of lubricant, and varying sizes of the tool were also performed.

### 4.1. Constant speed and normal force

The filtered friction results from basic strip drawing experiments at constant speed are shown in figure 4. Data acquisition was started and stopped manually. The friction coefficient for the tests using constant speed was calculated by taking the mean value of the filtered friction function at 40–80% of the travel distance.

Experiments were repeated to check the distribution between deterministic experiments for different applied loads. Five tests were performed for each load. The test conditions are shown in table 4.

Table 4. Test conditions, constant speed

| | |
|---|---|
| Tool size | 20*20 mm |
| Lubricant | Fuchs 1.2 g/m$^2$ |
| Speed | 0.3 m/s |
| Pressure | 1MPa, 2.5MPa, 5 MPa, 10 MPa, 15 MPa |

The graphs in figure 4 indicate some deviation between the individual tests. The variability and instability of the measured load functions seems to increase with decreased applied load, generating deviations in the calculated friction values.

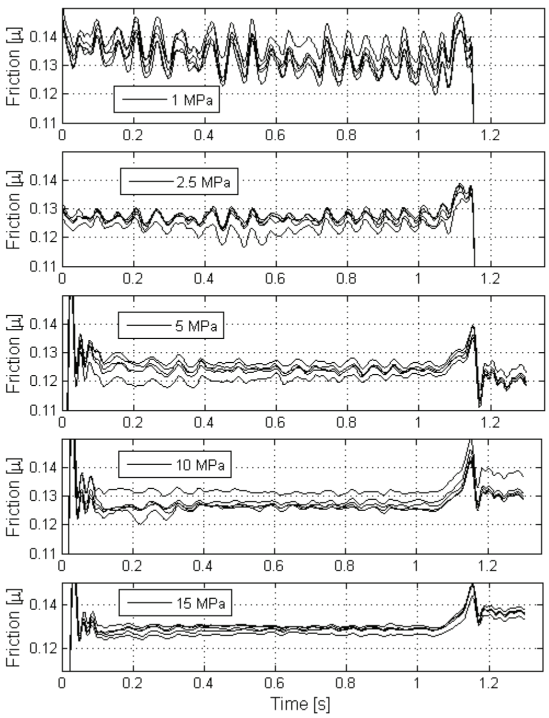

Fig. 4. Coefficient of friction as a function of time and applied normal pressure.

Figure 5 shows the calculated mean friction values as a function of pressure for the different experiments in figure 4.

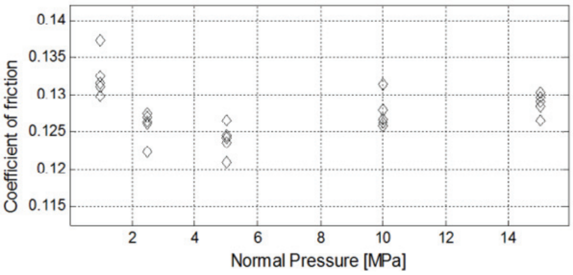

Fig. 5. Coefficient of friction as a function of normal pressure.

Experiments were also performed to evaluate how friction correlates with speed. A single experiment was performed for each load case. The test conditions in table 5 were used.

Table 5. Test conditions, constant speed

| | |
|---|---|
| Tool size | 20*20 mm |
| Lubricant | Sellcleaner 2 g/m$^2$ |
| Speed | 0.05 m/s 0.1 m/s 0.3 m/s 0.6 m/s 1.0m/s |
| Pressure | 1 MPa, 5 MPa, 10 MPa, 15 MPa |

Figure 6 shows the coefficient of friction as a function of speed for different applied normal pressures.

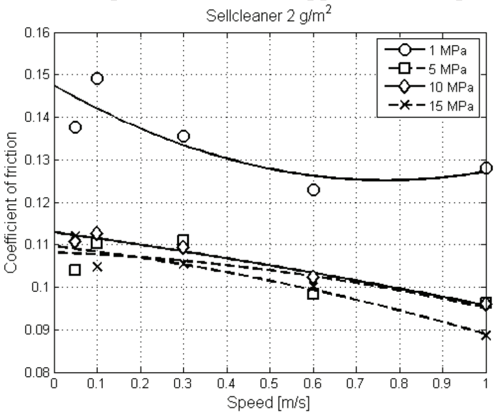

Fig. 6. Coefficient of friction as a function of speed.

### 4.2. Ramped speed

Ramped speed is an effective way of reducing the number of experiments during screening and friction characterization. By controlling the speed-function along the stroke, it is possible to directly calculate the friction as a function of speed, as shown in figure 7. The example in the figure confirms Stribeck's statement of decreased friction with increased speed. However, this is for this specific load and parameter setup.

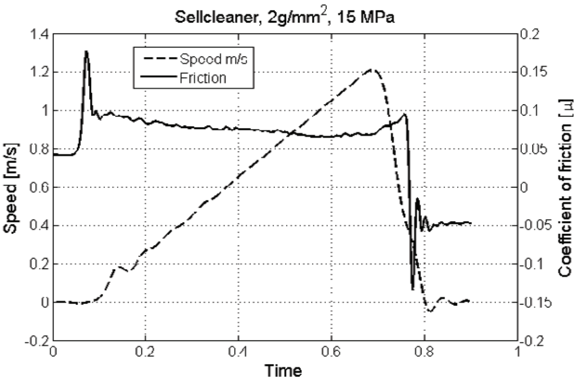

Fig. 7. Coefficient of friction as a function of speed.

Figure 8 illustrates the difference between three different stresses during experiments with ramped speed. Table 6 shows the conditions tested.

Table 6. Test conditions, ramped speed

| | |
|---|---|
| Tool size | 20*20 mm |
| Lubricant | Sellcleaner 0.1 g/m$^2$ |
| Speed | 0 to 1.4 m/s, ramped |
| Pressure | 1 MPa, 5 MPa, 10 MPa |

Four tests were conducted for each load step. As in the constant speed tests in figure 4, the results show a larger variation at low normal forces.

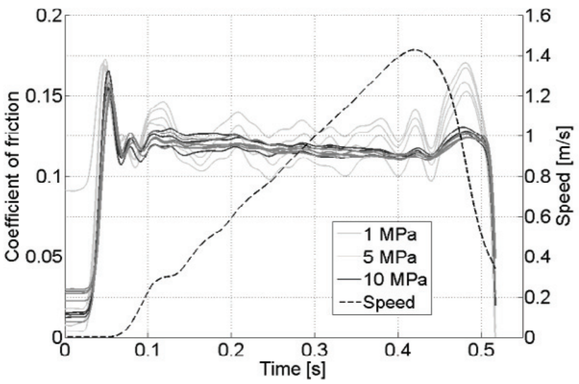

Fig. 8. Coefficient of friction as a function of time, speed and surface pressure.

A number of tests (table 7) were performed using increased speed (0–1.4 m/s) and different amounts of lubricant. Figure 9 shows an example of mapping the friction versus lubricant and speed. Here it is clear that the friction is strongly correlated to the speed and amount of lubricant.

Table 7. Test conditions, ramped speed

| Tool size | 20*20 mm |
|---|---|
| Lubricant | Sellcleaner<br>0 0.1 0.4 0.8 1 2 3 4 g/$m^2$ |
| Speed | 0 to 1.4 m/s, ramped |
| Pressure | 5 MPa |

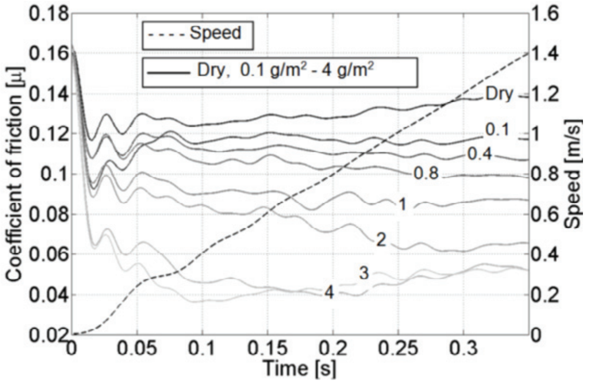

Fig. 9. Coefficient of friction as a function of speed and different amount of lubricants.

### 4.3. Ramped normal force

Experiments were performed using a ramped normal force. The filtered measured data can be seen in figure 10. The calculated friction and measured filtered ramped normal force are plotted in figure 11. Test conditions for the ramped normal force tests are shown in table 8.

Table 8. Test conditions, ramped force

| Tool size | 20*20 mm |
|---|---|
| Lubricant | Fuchs 1.2 g/$m^2$ |
| Speed | 0.3 m/s |
| Pressure | 2.5 MPa - 10 MPa Ramped |

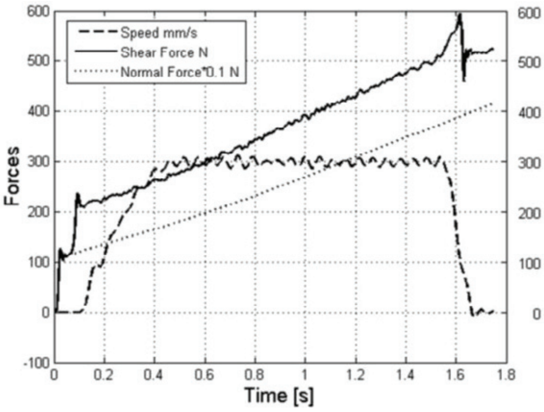

Fig. 10. Collected filtered force data for a ramped normal force test.

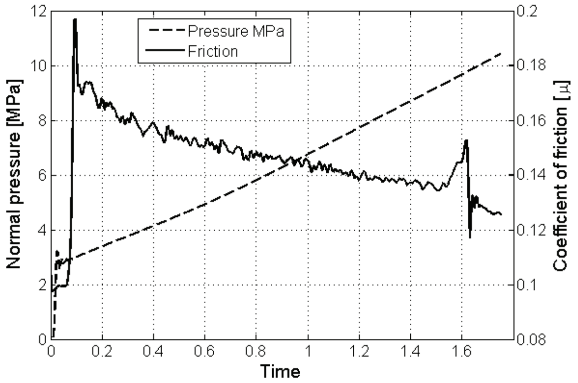

Fig. 11. Calculated friction as a function of normal pressure.

### 4.4. Tool size

Experiments at low loads seemed to generate larger test-to-test variation than high-load experiments in both the constant and ramped speed experiments. Tests with different tool sizes were performed to determine whether the variation depended on load or tool size. The test conditions are shown in Table 9.

Table 9. Test conditions, different tool size

| Tool size | 10*10 mm 20*20mm 30*30 mm |
|---|---|
| Lubricant | Fuchs 1.2 g/$m^2$ |
| Speed | 0.3 m/s |
| Pressure | 1 MPa 2.5 MPa |

Figure 12 shows the calculated friction coefficient for the three different tool sizes. The graphs clearly indicate that there is better correlation between individual experiments and improved repeatability when the normal pressure increases or when the tool size increases. Both cases imply increased normal force.

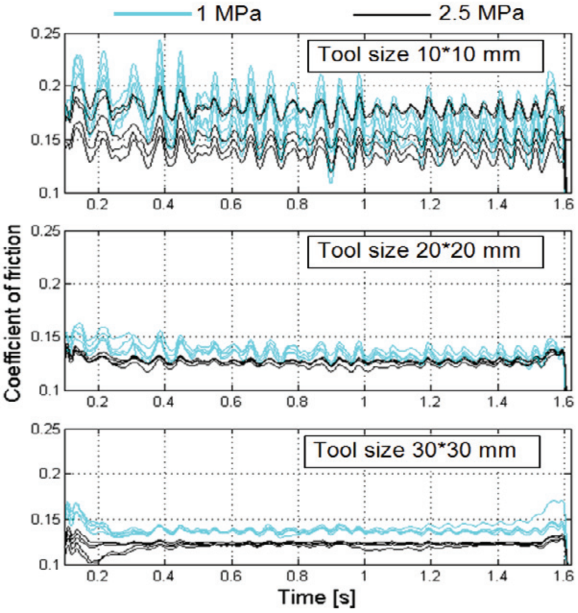

Fig. 12. Calculated friction as a function of tool size.

## 5. Summary

The objective was to develop a more versatile and efficient tribotester for the sheet metal industry than the existing devices used for friction studies. The tribotester is based on strip drawing with flat dies. It is capable of evaluating the friction between two surfaces in contact under a number of different static and dynamic conditions.

Initial experiments showed that test preparation is crucial for the accuracy and repeatability of the experiments. Small differences in the preparation or imperfections in the specimens result in large discrepancies in the calculated results.

Friction studies were performed to evaluate the experimental setup. Different experiments were carried out with constant load, constant pressure, and constant speed, with different types and amount of lubricants.

Results from the different static friction tests (constant parameter tests) showed promising results, particularly at high normal loads. However, greater test-to-test variation appeared at low pressures. Experiments with constant normal pressure and altered tool sizes verified the results. The normal force is applied using a spring buffer and this may interfere with the sheet/tool interaction during testing with low normal force.

Experiments were carried out with varying load and speed during the tests. The ability to control the applied normal load and speed as a function of time creates great opportunities to improve tribotesting by reducing the number of tests. The dynamic speed and load tests were repeatable and stable. The friction data was not fully correlated with the static tests, but future work will be devoted to resolving the correlation issue. Lower applied loads generated more variation in results, as was found in the static tests.

## Acknowledgments

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