In-situ-measurement of the friction coefficient in the deep drawing process

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Abstract. The surface texture plays an important role in the tribological behaviour of deep drawn components. It influences both the process of sheet metal forming as well as the properties for post processing, such as paint appearance, bonding, or corrosion tendency. During the forming process, the texture of the sheet metal and therefore its friction coefficient, changes due to process related strains. This contribution focuses on the development and validation of a tool to investigate the friction coefficient of the flange region of deep drawn components. The influence of biaxial strain on the friction coefficient will be quantified through a comparison of the experimental results with a conventional friction test (stand). The presented method will be applied on a cup drawing test, using a segmented and sensor-monitored blankholder. This setup allows the measurement of the friction coefficient in-situ without simplification of the real process. The experiments were carried out using DX 56D+Z as sheet metal and PL61 as lubricant. The results show a characteristic change in the friction coefficient over the displacement of the punch, which is assumed to be caused by strain induced change of the surface texture.

1. Introduction

Sheet metal forming and especially deep drawing operations are widely used in manufacturing process chains and industrial applications. The process is characterized by high efficiency and excellent surface quality of the deep drawn part. Due to the high competition in the industrial field of sheet metal forming and the increasing demand for more challenging product geometries, the process limits are narrowed. Therefore the tribological behaviour in the forming process has to be fully understood.

Friction is a key parameter to control the deep drawing process. Especially in the regions of the blankholder and drawing radius, a reduced friction coefficient can lead to increasing drawing ratios and thus enabling the production of more complex parts without using multiple operations. For a better examination of the ongoing interactions in a tribological system, the individual components such as opposing body, main body, intermediate material and the surrounding medium have to be fully investigated [1].

Over the past years the effect of the tool geometry and surface as well as the lubrication have been investigated in several publications [2, 3, 4], leaving potential open field regarding the influence of the blank topography and especially its evolution during the deep drawing process. Recent publications show a high influence of the prestraining on the blank surface topography [5, 6]. For example, uniaxial strained specimens showed a linear increase of surface roughness over the technical strain (see Figure 1).
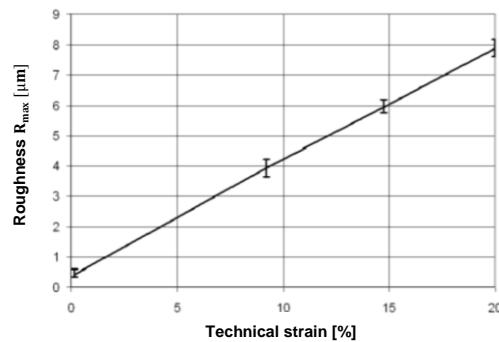
Figure 1. Evolution of the surface roughness as a function of the technical strain [5].

Since the total process forces in deep drawing are a sum of several single force components, such as ideal forming force, bending forces and friction forces, a change in the surface topography influences both the friction coefficient between blank and tool and the deep drawing process. Nowadays several tests are used to investigate the friction coefficient of a tribological system in dependence of sliding velocity, contact pressure and temperature. Hol et al. analyzed the different approaches in a round robin test [7], coming to the conclusion, that the VDA standardized test stand at the PtU showed the most realistic results for the implementation in a numerical simulation. However, all tests were carried out with the initial tool surface. This approach is only valid for the first time increments of the forming process. For the rest of the process it is a simplification of the real conditions, which are influenced by a surface evolution of the blank. Therefore, the focus of this paper will be to analyze the influence of an in-situ friction coefficient measurement compared to a conventional strip drawing test stand. This in-situ measurement will gain a clearer understanding of the ongoing effects during deep drawing and is a first approach to account for the influence of the surface evolution on the friction coefficient.

2. Experimental setup
The design of the experimental setup is based on a conventional cup drawing test, consisting of a punch, die and a blankholder. During the forming process the normal force in the flange region is applied by the press ram and the gas pressure springs at the blankholder (see Figure 2).
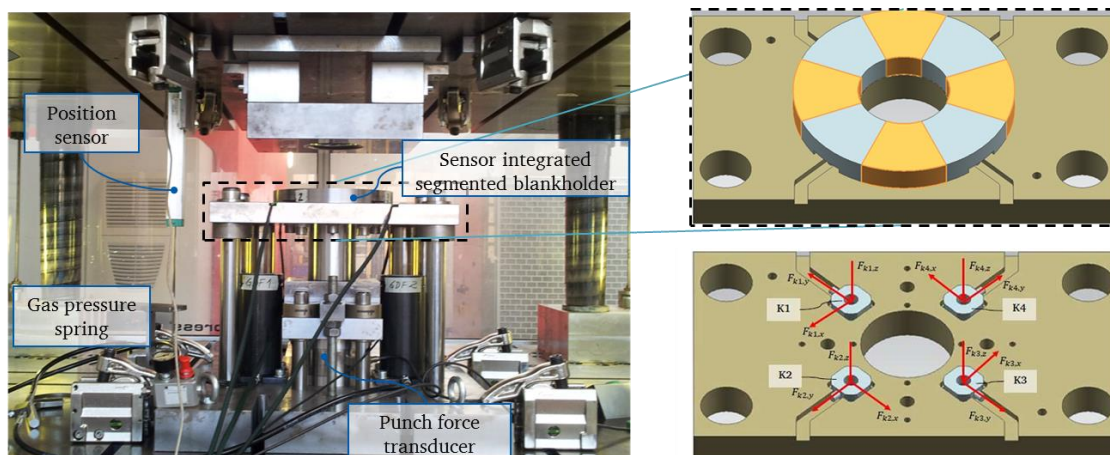

Figure 2. Experimental setup with a detailed visualisation of the sensor integrated blankholder.

The main improvement of this test stand are the sensors integrated in the blankholder, which allow to measure the radial, tangential and normal component of the applied force.

Therefore the friction coefficient can be calculated with temporal and spatial resolution during the deep drawing process. In total the blankholder of the cup drawing test is equi**p**ped with four force transducers (Kistler 9047C). Although the deep drawn part is symmetric, one force transducer is not sufficient to characterize the entire flange region. The reason for this is the anisotropy of the blank and the concentrated force transmission of the gas pressure springs, which cause a nonuniform distribution of the contact pressure over the flange.

Two different specimen geometries (i.e. circular blank, strip blank) will be compared. The experiments using a strip as a specimen can be compared to a conventional strip drawing test, since no biaxial strains are applied in the flange region (see Figure 3). In the strip drawing test the friction coefficient is calculated by deviding of friction and normal force. Therefore the strip is positioned between the upper and the lower tool. After applying a defined normal contact pressure the strip is getting drawn by a gripper. During the process the friction forces are recorded by force transducers.
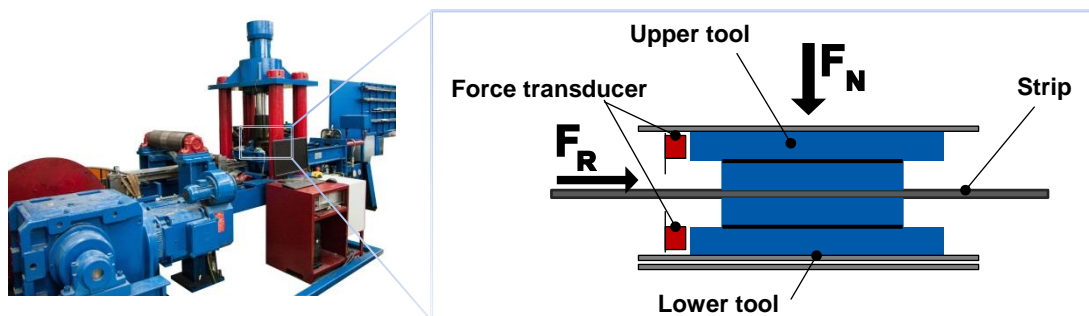
Figure 3. Left: Strip drawing test according to VDA 230-213; Right: Schematic diagram of the test stand;

The new setup shows a first approach to evaluate the surface evolution, which is considered very minor in the state of the art. Through the comparison of the strip with the circular specimen, under same tribological conditions, the effect of biaxial strain is quantifieable.

Table 1 shows the parameter which have been varried in the experiments.

**Table 1**. Parameters and their variation in the experiments.

Parameter	Variation	
Experimental setup	Modified cup drawing test	Strip drawing test
Specimen	Circular (diameter=200mm)	Strip (width= 39 mm)
Material (thickness)	DX 56 D+Z (0.8 mm)	
Lubricant (amount)	PL 61 (1.2-1.5 g/m^2)	
Blank orientation in reference to force transducers	0°	45°

3. Experimental results

The experiments have been conducted at constant gas spring pressure (60 bar). Aside from the specimen geometry, the influence of the rolling direction on the restraining and normal forces was investigated for the circular specimen.[1]

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[1] Here and in the following the orientation of the blank is defined relative to the transverse axis of the blankholder. For example, the orientation in 0° means that the rolling direction is aligned to the transverse axis of the blankholder

As can be seen in Figure 4, all sensor signals for the friction force (FR1-FR4) as well as the normal force (FN1-FN4) for the specified rolling direction deviate only slightly from eachother. Moreover, the normal and friction force are increasing over the punch displacement, due to the increasing blankholder force, caused by the characteristic of the gas pressure springs. The statistical security of the experiments has been guaranteed by at least two repetitions of the experiments.
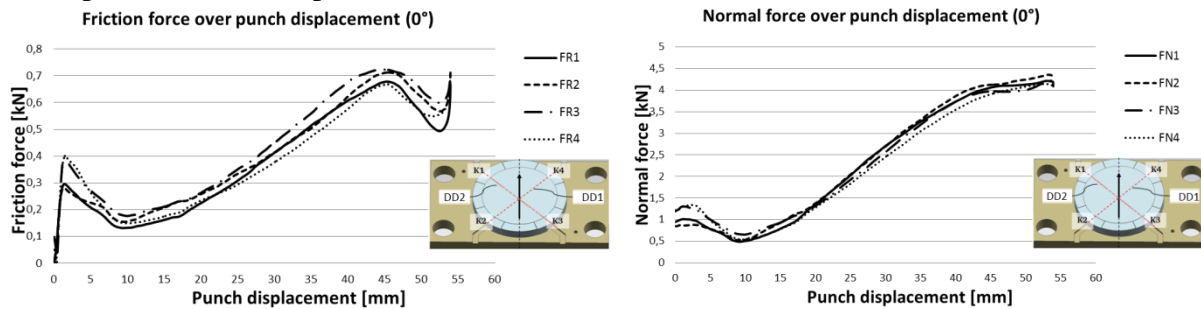
Figure 4. Friction force (radial) and normal force (axial) over punch displacement for rolling direction perpendicular to long side of blankholder (0°).

By changing the rolling direction of the specimen the sensor signals show a high deviation between the signals of force transducer one/three and two/four (see Figure 5). The deviation between the sensors one and three, respectively two and four is low since they are both aligned in rolling respectively transversal to rolling direction. The deviation between the two directions is caused by the anisotropy of the blank material. The blank thickness varies over the flange region, the same applies for the contact pressure in the blankholder region and therefore for the friction force.
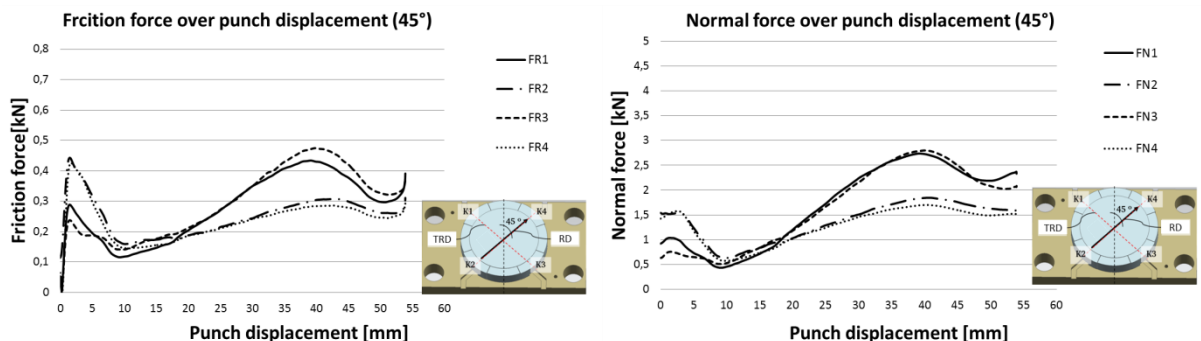

Figure 5. Friction force (radial) and normal force (axial) over punch displacement for rolling direction in direction K2-K4 (45°).

The calculated friction coefficient shows a distinctive curve for all investigated specimen sizes. The curve is characterized by two peaks (static friction), one at the beginning and one at the end of the process. In between those peaks dynamic friction is present. In general, both curves show highly nonlinear behavior. This could be caused by the change in the surface topography and the surface evolution during the deep drawing process.

Figure 6 shows the calculated friction coefficient for both rolling directions. Therefore, the average values for the friction and normal force for each test setup are calculated. As a result, two curves for the friction coefficient over the displacement are generated. The first curve (0°) represents the diagonal direction, whereas the second curve (45°) represents the average values for the rolling and transversal to rolling direction. Comparing the friction values of both curves shows a small increase for the second case, where the rolling direction is aligned in the direction of K4-K2. This can be explained by the increased contact normal pressure,

compared to the orientation in 0°. The maximum of the normal force for 45° orientation is at 4.2 kN approximately (see Figure 4, right), whereas the maximum for the other direction is at 2.7 kN (see Figure 5, right). Since the friction coefficient is highly dependent of the contact pressure, an increase in normal force leads to a reduced friction coefficient [8].
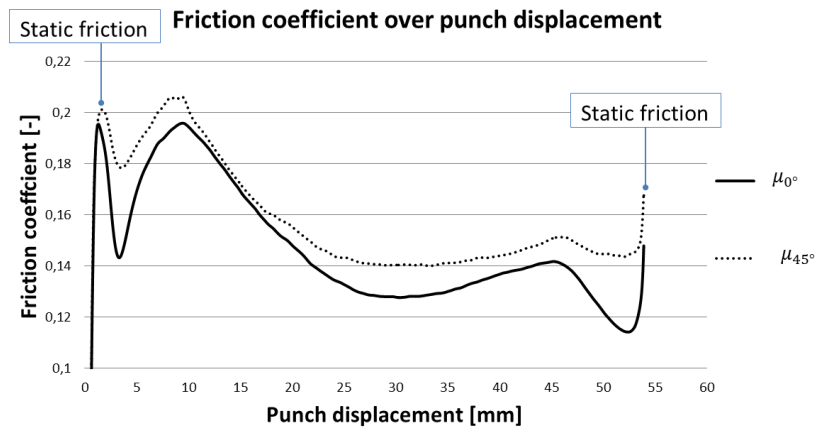
Figure 6. Friction coefficient over punch displacement for two different rolling directions.

4. Experimental validation

To validate the results of the adopted cup drawing test a conventional strip drawing test according to VDA 230-213 was used[2].
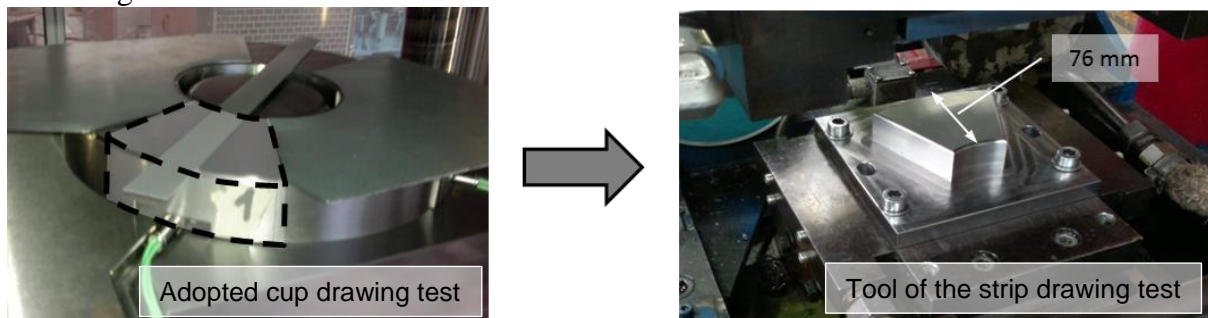
**Figure 7**. Left: Experimental setup for the segmented blankholder; Right: Tool of the strip drawing test.

Therefore a strip was placed on segment one and three. During the test additional assisting blanks guaranteed a homogeneous contact pressure distribution in the region to be investigated (see Figure 7, left). For both experiments the same tribological system has been used. The comparison of the two tribological test stands shows that the values of the segmented cup drawing test are within an acceptable range (see Figure 8, right). Moreover an almost linear course between the peaks of the static friction is an indication for reliable results (see Figure 8, left).

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[2] The area of the tool was adjusted to the area of a single segment in the blankholder of the cup drawing test.
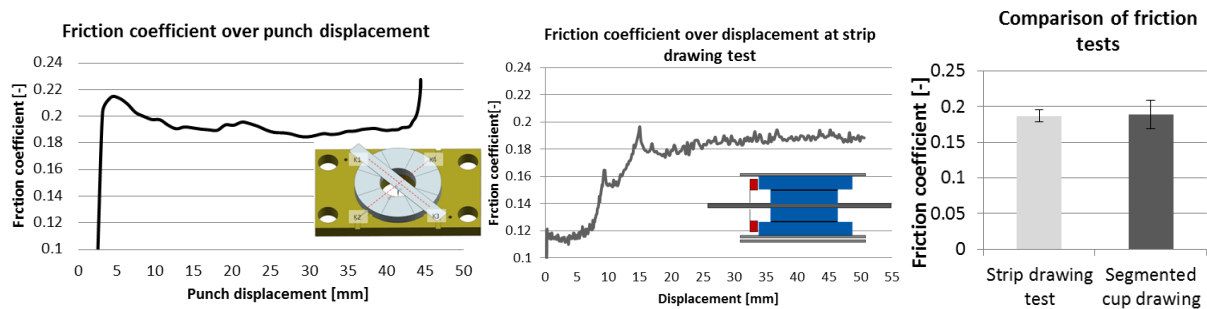
Figure 8. Left: Friction coefficient over punch displacement for a strip analysed with the segmented cup drawing test; Middle: Friction coefficient of a strip analysed by a conventional strip drawing test; Right: Comparison between both friction test stands.

One possible explanation for the highly nonlinear course of the friction coefficient curve for the circular specimen could be the strain induced surface evolution. To investigate this effect the surface of the deep drawn cup was analyzed by means of confocal microscopy. Therefore the area which was used for the evaluation of the friction coefficient were examined at nine measuring points (see Figure 9).
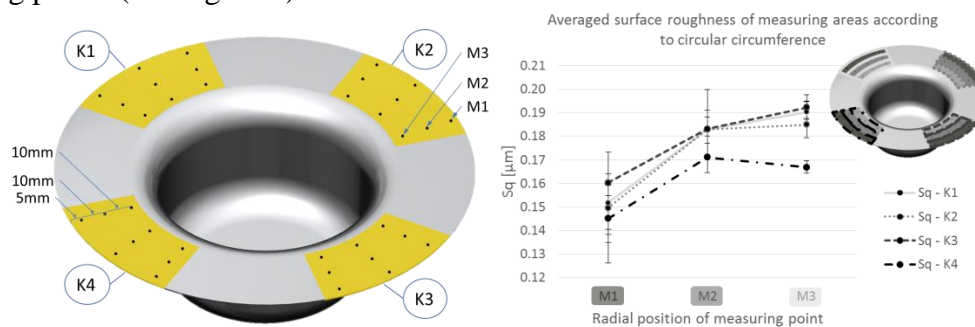
Figure 9. Left: Measuring points for the evaluation of the surface evolution; Right: Evaluation of the radial surface roughness for segments K1-K4.

The results show that the roughness, expressed through the Sq value, increases towards the center of the cup (see Figure 9, middle). This is caused by the higher contact normal pressure at the edge of the flange, induced by a higher blank thickness. The results show that the investigation with a single strip drawing test is not sufficient to characterize the complete behavior of a sheet metal during the forming process.

5. Conclusion

In this paper a new method was presented to evaluate the friction coefficient in the deep drawing process. Therefore the blankholder of a cup drawing tool was equipped with force transducers, which are capable of evaluating the friction in the flange region. Several deep drawing operations have been carried out to investigate the friction coefficient over the punch displacement. The measured forces are highly nonlinear and also strongly dependent of the specimen's rolling direction.

To validate the setup, a conventional strip drawing test was used. The validation shows that the friction coefficients of both test stands are in good agreement. Moreover the surface evolution was analyzed, with the results showing a change of surface topography over the flange region.

In contrast to the state of the art, where the friction coefficient is mostly described as a factor of relative velocity, contact normal pressure, and temperature, the results presented in this publication show a more complex correlation. The authors assume that the ongoing

surface evolution caused by straining and contact-bounded flattening of the surface asperities is responsible for the nonlinear characteristic of the friction curve. However, this effect will be examined in further investigations, to isolate the impact of the surface evolution on the friction coefficient.

6. References

[1] H. Czichos; K. Habig, Tribologie-Handbuch - Reibung und Verschleiß. 3. edition, Vieweg + Teubner Verlag, Wiesbaden, 2010.

[2] A. Peter, Entwicklung eines Modells zur Abbildung der Reibverhältnisse beim Innenhochdruck-Umformen, Berichte aus Produktion und Umformtechnik, Nr. 61, Shaker Verlag, 2004.

[3] V. Schulze, Modern mechanical surface treatment, WILEY-VCH Verlag, Weinheim, 2006.

[4] M. Steitz, J. Scheil, C. Müller, P. Groche, Effect of Process Parameters on Surface Roughness in Hammer Peening and Deep Rolling, 16th ESAFORM Conference, Key Engineering Materials, Switzerland, 2013.

[5] R. Schäfer, Kontaktgebundene Oberflächenwandlung polykristalliner Blechoberflächen; Berichte aus Produktion und Umformtechnik, Nr 76; Shaker Verlag, 2008.

[6] M. Ludwig, J. Stahlmann, P. Groche, Advanced Friction Model for Cold Forging Processes, in: Steel research journal, pp. 1003-1006, 2012.

[7] J. Hol, J. H. Wiebenga, M. Hörning, F. Dietrich, C. Dane, Advanced friction simulation of standardized friction tests: a numerical and experimental demonstrator, Numisheet Journal of Physics: Conference Series 734, 2016.

[8] Filzek, J.; Ludwig, M.; Groche, P., Improved FEM Simulation of Sheet Metal Forming with Friction Modelling using Laboratory Tests, Proceedings of the IDDRG, Bilbao, Spain, 2011.