Advanced friction simulation of standardized friction tests: a numerical and experimental demonstrator

J. Hol[1], J.H. Wiebenga[1], M. Hörning[2], F. Dietrich[2,3], and C. Dane[4]

[1] TriboForm Engineering, Hengelosestraat 500, 7500 AM Enschede, the Netherlands
[2] Adam Opel AG, Bahnhofsplatz, 65423 Rüsselsheim am Main, Germany
[3] PtU TU Darmstadt, Otto-Berndt-Straße 2, 64287 Darmstadt, Germany
[4] Tata Steel, P.O. Box 10.000, 1970 CA IJmuiden, the Netherlands

E-mail: j.hol@triboform.com

Abstract. For the characterization of friction conditions under sheet metal forming process conditions, different friction test set-ups are being used in industry. However, different friction tests and test set-ups are known to result in scattering friction results. In this work, the TriboForm software is utilized to numerically model the frictional behavior. The simulated coefficients of friction are experimentally validated using friction results from a standardized strip drawing friction test set-up. The experimental and simulation results of the friction behavior show a good overall agreement. This demonstrates that the TriboForm software enables simulating friction conditions for varying tribology conditions, i.e. resulting in a generally applicable approach for friction characterization under industrial sheet metal forming process conditions.

1. Introduction

The quality of sheet metal formed parts is strongly dependent on the tribology and friction conditions that are acting in the production process. These friction conditions are dependent on the utilized sheet material, tooling material and lubricant. This combination of factors is known as the tribological system [1]. Choosing the optimal tribological system in an early stage of the design process enables Adam Opel AG to design products with optimal quality at minimal time and cost investment.

To analyze the effect of the tribological system on the final part quality, there is a need to quantify the corresponding frictional behavior and include an accurate description of this behavior in Finite Element Method (FEM) simulations. One way to determine the frictional behavior for a specific tribological system is to execute friction tests. Varying experimental set-ups are available in industry to determine the frictional behavior. The question is which friction test set-up to use to determine the frictional behavior acting in the actual production process.

To answer this question, a study has been performed by the German Deep Drawing Research Group (GDDRG) [2]. In this study, a round robin test was performed by comparing the outcome of seven different friction test set-ups. In this round robin test, only the type of test set-up was altered. That is, the analyzed tribology system and test conditions were kept identical, i.e. an identical combination of sheet material, tooling material, and lubricant was used per test set-up. The outcome of the round robin test is summarized in Figure 1, showing the experimentally determined friction coefficients (μ) as a function of nominal contact pressure (P_{nom}) resulting from the seven friction test set-ups. The friction test set-up relevant for this work is the flat-bed strip draw test from the PtU Darmstadt, Germany.

Figure 1 shows that despite using an identical tribological system and identical test conditions in all seven test series, the friction coefficients range between μ = 0.03 and μ = 0.26. Also note that even the trend of the frictional behavior differs between the test set-ups. To summarize, the results from the round robin test clearly show a strong scattering in magnitude and trend of the friction results. Although not further analyzed in detail in [2], the scatter in the results can likely be related to differences in the tooling geometry and dimensions used [4,5], but also on e.g. the overall design and stiffness of the test set-ups. All these aspects differ per test set-up and hence no conclusion can be drawn on the correct magnitude and trend of the frictional behavior for this tribological system.
The ultimate goal in the design of sheet metal formed parts with A-class quality is to determine an accurate description of the frictional behavior which is acting in the real production process. This description should be generally applicable, i.e. independent of the experimental test set-up used. In this work, this is achieved by using an advanced friction modeling approach instead of an experimental approach. For this purpose, the TriboForm software is used. As a first stepping stone towards industrial application at Adam Opel AG, the outcomes of the TriboForm software are experimentally validated using the standardized strip draw friction test from the PtU Darmstadt. This will be done for different sheet surface textures and lubrication amounts, all leading to a difference in the frictional behavior.

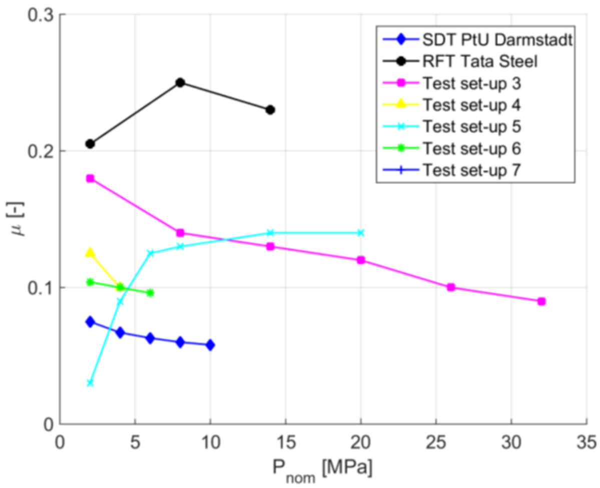

Figure 1. Experimentally determined friction coefficients resulting from seven different friction test set-ups showing a large scatter of results [2].

2. Friction modeling using the TriboForm software

Tribological conditions in metal forming processes are dependent on local process and lubrication conditions, loading and local strain state of the sheet material. The TriboForm software allows for multi-scale modelling of a time and locally varying friction coefficient under a wide range of process conditions. Information of the tribology system is required as an user input, i.e. the applied sheet material, coating and tooling material, lubrication type, lubrication amount and process conditions. This information can either be entered by the user or extracted from a database, i.e. the TriboForm Library. The friction models simulated and generated by the TriboForm software can be readily imported in FEM simulations of forming processes using the TriboForm FEM Plug-In.

3. Friction experiments

In this study, friction tests have been performed using a flat-bed strip draw test, see Figure 2. The tests have been performed at the PtU Darmstadt in Darmstadt, Germany. This friction test set-up and conditions are specified according to the VDA norm 230-213 [3]. In this study, strips of VDA239 CR4 GI sheet material with a thickness of 0.8 mm are drawn through a set of GGG70L tools at a constant relative sliding velocity of 50 mm/s while recording the friction forces. Varying sheet surface textures were considered, referred to as ‘T1’ and ‘T2’, see Figure 3. A Fuchs Anticorit PL3802 39S lubricant

was used in two different lubrication amounts, i.e. 0.5 g/m^2 ('pre-applied') and 1.2 g/m^2. The sheet material is loaded from two sides with a relatively large tooling area, which limits the maximum nominal contact pressure that can be achieved with this test set-up. In this study, a maximum pressure of 10 MPa could be achieved after which the strip of sheet material breaks.
As an input for the friction simulations, the real 3D surface topographies of the tooling and sheet surfaces are utilized. The surface topographies can be imported by the user or extracted from the TriboForm Library. The virgin sheet surface topographies of texture T1 and T2 are measured by 3D confocal microscopy and utilized in the TriboForm software for the friction simulations. Figure 3 shows a hot-dip galvanized zinc coating with a specially designed surface texture (T1) and a hot-dip galvanized zinc coating with an Electro Discharge Textured (EDT) surface finish (T2). The sheet surface textures have comparable roughness values of s_a = 1.35 µm for T1 and s_a = 1.41 µm for T2.

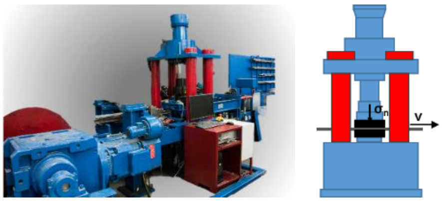

Figure 2. Flat-bed strip draw test, PtU Darmstadt, Darmstadt, Germany [3]

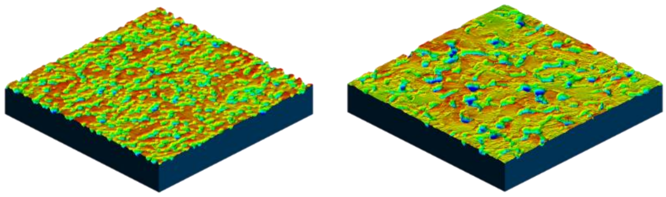

Figure 3. Sheet surface topographies: Texture 1 (T1, left) and Texture 2 (T2, right)

4. Results

4.1. Friction modelling
The basis of a TriboForm simulation model to calculate friction conditions is the projection of the tool surface topography on to the sheet surface topography. In this way, simulation models are generated in the TriboForm software for both the T1 and T2 sheet surface topography. Using the resulting two simulation models, the friction conditions are calculated by loading and sliding the tool surface over the sheet surface. The amount of lubricant on the sheet surface can be entered in the TriboForm software, i.e. 0.5 g/m^2 and 1.2 g/m^2. The friction conditions are calculated for pre-defined ranges of process conditions, i.e. nominal contact pressure, plastic strain in the sheet material, relative sliding velocity and interface temperature. In this paper, only the friction results as a function of nominal contact pressure will be discussed and experimentally validated.

4.2. Friction test results
Figures 4 and 5 display the friction test results up to a contact pressure of 10 MPa for a lubrication amount of 0.5 g/m^2 and 1.2 g/m^2 respectively. Each marker represents an average friction coefficient resulting from 5 experimental repetitions. The test results show a decreasing friction coefficient for increasing contact pressure for both the sheet surface texture T1 and T2. The hot-dip galvanized zinc coating with an EDT surface finish (T2) shows a lower overall frictional behavior compared to the hot-dip galvanized zinc coating with the specially designed surface texture (T1). Comparing Figure 4 and Figure 5, a slight reduction in the measured friction coefficient magnitude is observed for an increasing lubrication amount. Moreover, an increasing difference in frictional behavior between sheet surface texture T1 and T2 is observed for increasing lubrication amounts. This demonstrates the interaction between lubrication amount and sheet surface texture on the resulting frictional behavior.

4.3. Friction simulation results and experimental validation
TriboForm friction simulations have been performed per tribological system. The TriboForm simulation results are shown in Figures 4 and 5 up to a contact pressure of 15 MPa. Note however, that TriboForm enables the calculation of the friction behavior for much higher contact pressures as well, i.e. up to 500 MPa. The results demonstrate that the TriboForm software enables an accurate prediction of friction

coefficients for varying lubrication amounts and sheet surface textures, both in terms of the magnitude and trend of the friction results. The lower frictional behavior for the T2 sheet surface texture compared to the T1 texture is correctly predicted. For the friction results using a lubrication amount of 0.5 g/m^2 shown in Figure 4, an difference in frictional behavior for the T2 surface texture can be observed whereas the frictional behavior for the T1 texture is in good agreement. The friction results using a lubrication amount of 1.2 g/m^2 show a good agreement between simulation and experimental results for both sheet surface topographies.

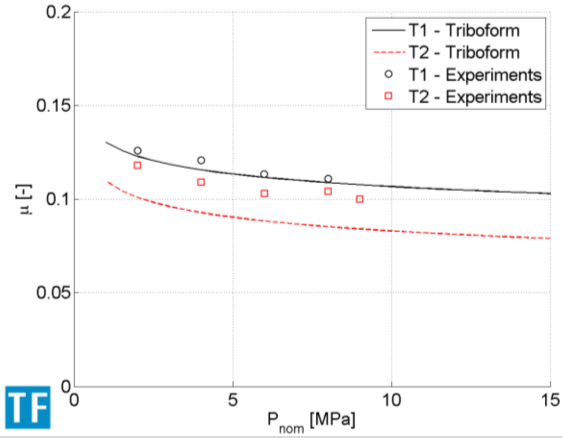

Figure 4. Experimental and simulation results for CR4 GI - T1 and T2 with 0.5 g/m^2 lubricant

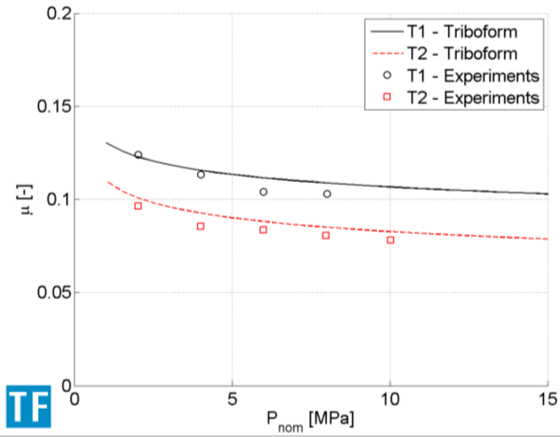

Figure 5. Experimental and simulation results for CR4 GI - T1 and T2 with 1.2 g/m^2 lubricant

5. Conclusions

The TriboForm software enables the simulation of friction coefficients resulting from standardized friction tests. Both the magnitude and the overall trend of the experimentally obtained friction results from the standardized flat-bed strip draw friction test are in good agreement. This is demonstrated for varying lubrication amounts and sheet surface topographies.

Benefits of the presented friction modelling approach are the following. First of all, the TriboForm software provides a generally applicable approach for friction characterization under industrial sheet metal forming process conditions. Secondly, it reduces the demand for experimental friction testing. Determining the same amount of information using friction tests would require a significant time and cost investment. Finally, the TriboForm simulations can be performed early in the design process and the results can be readily imported in FEM simulations of forming processes. This enables Adam Opel AG to perform more accurate metal forming simulations including the friction model corresponding to the tribological system as applied in stamping production, and design A-class quality sheet metal formed parts at minimal time and cost investment.

6. References

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Acknowledgments

The authors are grateful for the financial support from Adam Opel AG for this project.