Friction modelling in sheet metal forming simulations for aluminium body parts at Daimler AG

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Abstract. Tribology plays a key role in the production of high-quality car body parts. In forming simulations, often a constant value for the friction coefficient is used, which limits the overall simulation accuracy. In reality, friction depends on the pressure distribution, forming velocity, interface temperature, plastic strain, type/amount of lubrication and the surface topography of both the sheet and the tooling. The simulation accuracy, and therefore the prediction of the formability of complex geometries, can be improved significantly by taking all these parameters into account. This paper presents a selection of results for 2 aluminium cases: 1 scientific part conducted at the IFU Stuttgart and 1 complex body part from Daimler AG. Simulation results have been validated by experimental results to show the influence of friction on e.g. part quality, draw-in and spring-back. Results show that friction modelling becomes increasingly important in the stamping process of aluminium parts, and that the overall simulation accuracy increases when accounting for the actual tribological conditions in stamping.

1. Introduction

The tribological conditions in the forming tools determine to a large extent the material flow and, therefore, the parts dimensional accuracy and surface quality. Corresponding to the complexity of the part, the material flow is controlled in the process by means of bearing areas and drawbeads in the blankholder region. Different tribological conditions are acting due to the relative movements and restraining of the sheet material. Furthermore, the tribological conditions are dependent on the tribology system, i.e. the applied sheet material, coating, tooling material, lubrication- and process conditions. Although friction is of key importance, it is currently not considered in detail in stamping simulations. The current industrial standard is to use a constant (Coulomb) coefficient of friction. This limits the overall simulation accuracy as also demonstrated in earlier work of the authors for a square cup product and body side panel in [1] and a door-outer in [2].

This paper presents a selection of results of a cooperation between Daimler AG, AutoForm and TriboForm. Two cases will be presented to discuss the importance of friction in Aluminium forming, with a focus on areas with sharp radii like e.g. the draw-bead areas. The simulation approach will be described in Section 2. The first application case (Section 3) concerns an Aluminium U-Bend part, whereas the second application case (Section 4) concerns an Aluminium front fender from a Mercedes-

Benz passenger car. Both application sections include a description of the simulation set-up and a comparison with experimental results. The conclusions of the results and outlook are given in Section 5.

2. Approach
This section describes the simulation approach followed to obtain the results as discussed in this paper. The sheet metal forming simulations are performed by using AutoForm^{plus} R7.0.3 in conjunction with the TriboForm FEM Plug-In for AutoForm.

2.1. Simulation of friction and lubrication conditions
The TriboForm software allows for multi-scale modelling of a time and locally varying friction coefficient under a wide range of process conditions. The tribology system information as described in Section 2.2, combined with the viscosity data of the lubricant used, enables the generation of a TriboForm Library. The TriboForm Library includes the friction conditions for the considered tribology system. The required input information of the tribology system and procedure to generate TriboForm Libraries is described in [3,4]. The resulting TriboForm friction models can be imported in the AutoForm software using a the TriboForm FEM Plug-In (Figure 1), replacing the constant coefficient of friction. A more detailed description of the simulation approach can be found in [5].

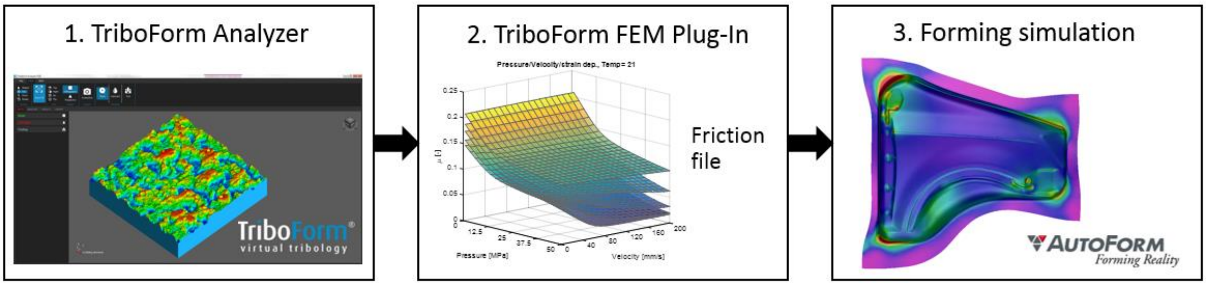

Figure 1. Simulation approach for friction and lubrication modelling in sheet metal forming simulations.

2.2. Tribology system: Sheet material, Tool material and lubrication
The sheet material used for both applications presented in this paper is an AL6-OUT Aluminium sheet material with a sheet thickness of 1mm and an EDT surface texture. The blanks have a Titanium Zirconium surface coating and are lubricated with 1 g/m^2 Oest Platinol B804/3 COW-1. Tools are made of EN-JS-2070 material. The surface roughness of the sheets was measured at different locations and had an average S_a roughness value of 1.1 µm. The forming tools of the U-Bend and front fender part had an average S_a roughness value of 0.5 µm and 0.6 µm, respectively. The U-Bend parts were pressed using an Aida servo press at the Institut für Umformtechnik (IFU) in Stuttgart, Germany, with 6 strokes/min. The front fender part was produced on a Schuler Servo try-out press at Daimler AG in Sindelfingen, Germany, with a stroke rate of 15 strokes/min.

2.3. Simulation set-up
To account for material properties the measured stress-strain data was used together with the Barlat 89 material model to describe the yield surface. Friction conditions are described by a Coulomb friction coefficient of 0.12, a pressure-velocity friction model and the TriboForm friction model (Section 2.2). As input for the TriboForm friction model the S_a roughness value for the different parts of the forming tools are taken equal to the average roughness value as mentioned in Section 2.2. For both parts the measured press motion curves are used in AutoForm. The drawbeads are modelled in 3D using the real 3D CAD surfaces to obtain the most accurate forming results as also presented by the authors in [1].

Special focus was given to the pressure distribution at the bearing zones using pressure foils. The U-Bend part is modelled using symmetry conditions including two pins for positioning of the blank.

3. Application 1: U-Bend product

In the first set of tests the following tools have been used to analyze different U-Bend geometries:

1. Round beads with contact gap of 0.2 mm and no bearing zone of 8 mm (drawing depth 28 mm)
2. Round beads with bearing zone 20 mm (drawing depth 28 mm)
3. Lock beads with bearing zone 20 mm (drawing depth 15 mm)
4. Lock beads with bearing zone 20 mm and bearing angle 25° (drawing depth 20 mm)

In the middle of the punch two pins are used to ensure the reproducibility of the blank position during blankholder closing, especially for the 25° U-Bend part. The pins also ensure that the blank does not move crosswise during drawing. The disadvantage of the pins is a reduction of drawing depth using lock beads due to higher strains caused by the reduced sheet profile in that area. The sheet contour including the positioning-holes were produced by laser cutting.

The pressure in the bearing zone has been analyzed by using blue spotting paint and Fuji Prescale films. Figure 2 show the pressure results for the U-Bend with lock beads. A uniform pressure distribution would be 20 MPa and 15 MPa for the lock beads and round beads, respectively. In the forming process however, the pressure is reduced by the uplift force of the beads and the pressure distribution is changed due to the strain in the sheet material. In the simulation results shown in this paper, the distribution at the beginning of drawing is used, leading to changes in the pressure distribution from the draw-start to the draw-end as shown in Figure 2 (middle and right).

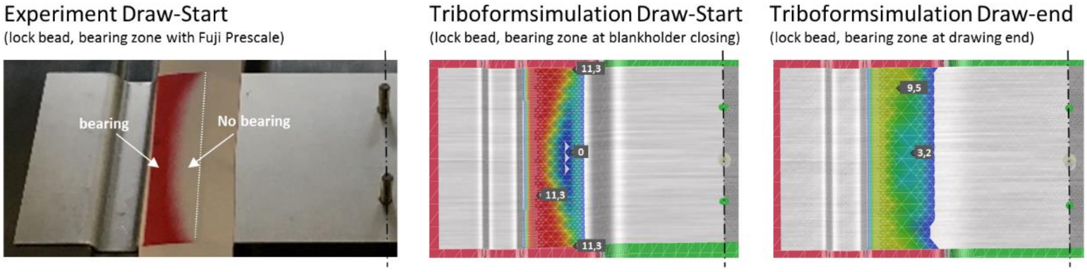

Figure 2. Pressure distribution [MPa] in the bearing zone of the U-Bend with lock beads

Figure 3 to 6 shows the draw-in, the major strain in the cross-section of the sheet between the two pins and the amount of spring-back corresponding to the four different tools. The draw-in and the spring-back were measured using the GOM Atos Scanner. The alignment of the different spring-back geometries have been done in GOM Inspect using the punch area as a reference. A grid was printed on the aluminum sheets to enable strain measurements using the GOM Argus system. Due to high contact pressures in the bead areas the quality of the strain measurements in these areas is limited.

The results show that the draw-in prediction using the TriboForm friction model shows the highest correspondence with real measurements. The major strain in the bottom of the part and the punch radius are improved significantly by making use of TriboForm. This area is crucial for class A outer panels. Using lock beads the difference between the TriboForm friction model and the Coulomb friction model in major strain is minor. The gap controlled round beads and 25° lock beads depict the best correspondence with experiments using TriboForm. The highest improvement of spring-back is achieved for the gap controlled setup using the TriboForm friction model.

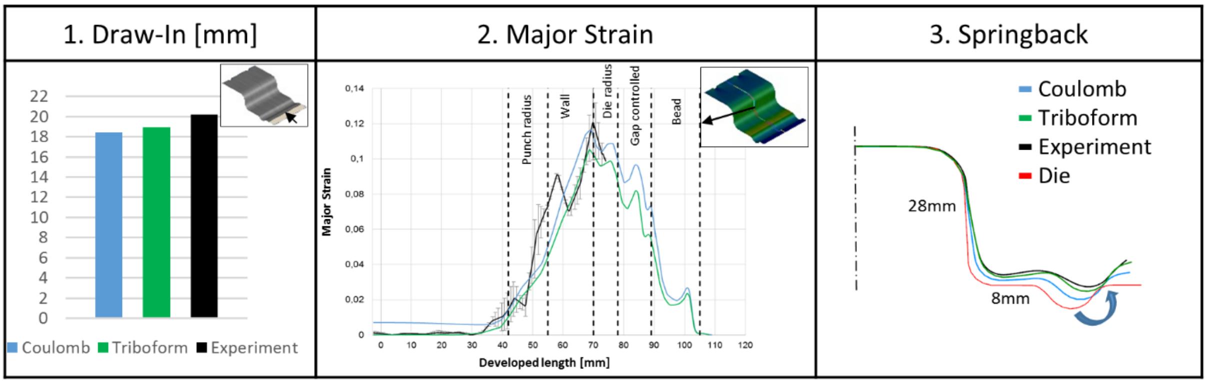

Figure 3. U-Bend with gap controlled round bead (no bearing zone)

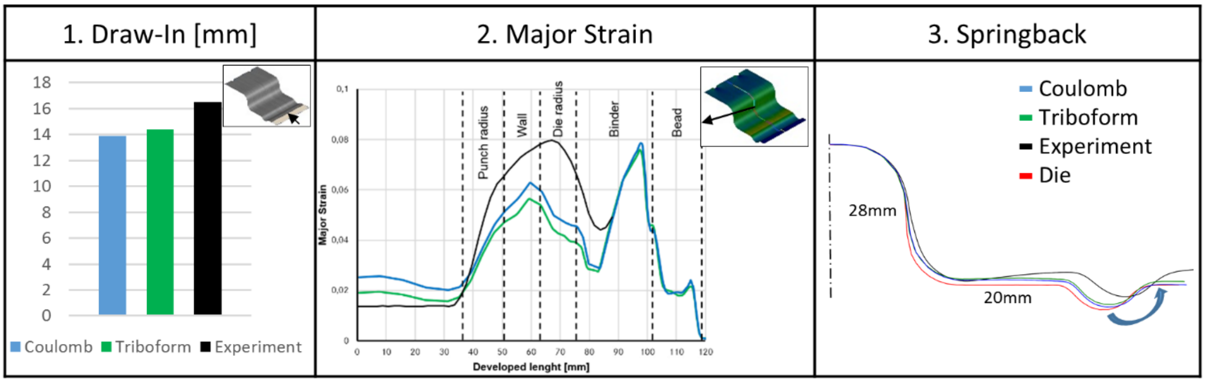

Figure 4. U-Bend with bearing zone and round bead

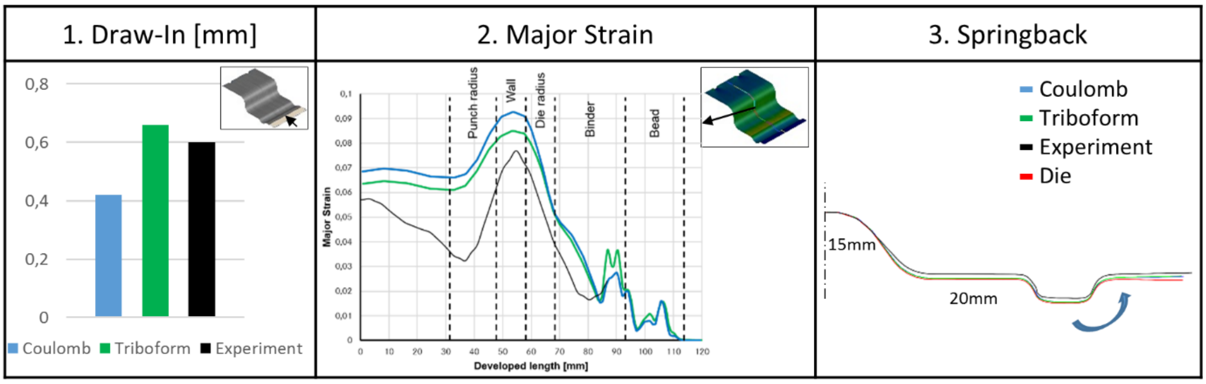

Figure 5. U-Bend with bearing zone and lock bead

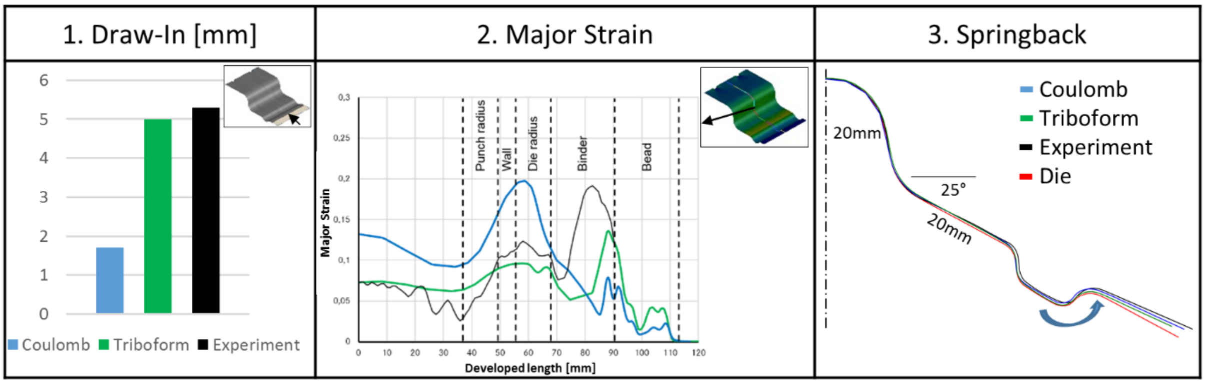

Figure 6. U-Bend with bearing zone and lock beads under 25°

4. Application 2: Front fender product

Figure 7 shows the simulation results of a Mercedes-Benz passenger car front fender part using different friction models. The forming tools have been designed by making use of AutoForm in conjunction with the TriboForm software. Figure 7 (right) shows the amount of draw-in after the first try-out. Originally, the tools of the front fender product were designed by using a fixed value of the friction coefficient (μ=0.12). The design of the tools included round beads, which have been changed to lock beads at some areas as the restraining forces were not enough based on the simulations performed by using the TriboForm friction model. As a result, the simulation with the Coulomb friction model (see Figure 7, left) shows a high risk of failure. The enhanced Coulomb friction model (including pressure dependency) increases the material flow resulting the blank passing the drawing beads at the blue areas (Figure 7, middle), leading to insufficient stretch in the front fender geometry. The draw-in predictions by using the TriboForm friction model matches best with the try-out results, as shown in Figure 7 (middle). With a small change in draw-bead geometries the single area of insufficient stretch has been eliminated by making use of the TriboForm friction model.

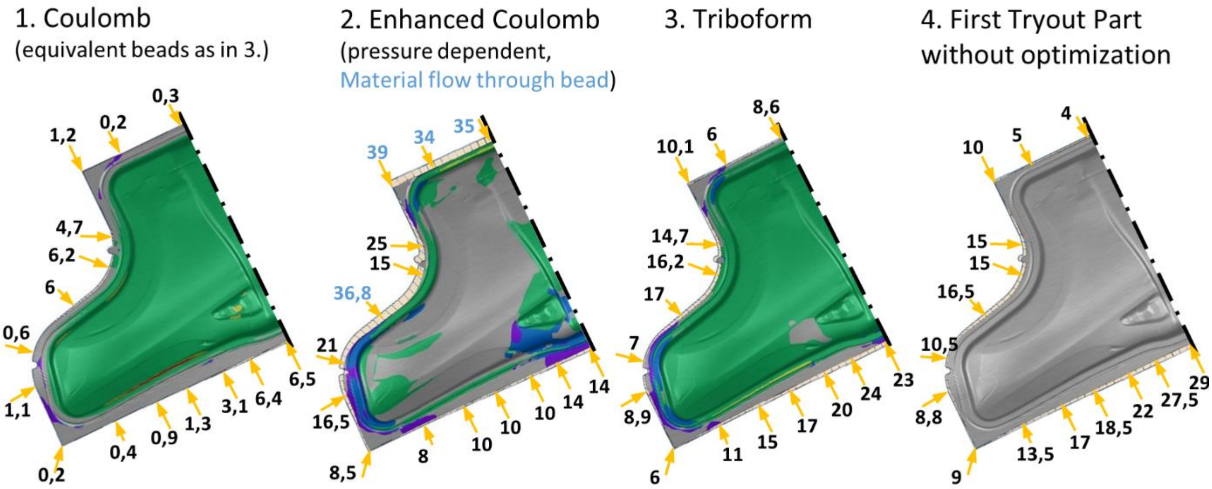

Figure 7. Draw-in and formability results of forming simulations of an Aluminum Mercedes Benz passenger car front fender part

Figure 8 (right) shows the amount of spring-back after the first try-out part without any specific optimization. The amount of spring-back is measured and compared with simulation results as discussed in Section 3. Spring-back predictions are shown by making use of the Coulomb friction model (Figure 8, left) and the TriboForm friction model (Figure 8, middle). Results of the Enhanced Coulomb friction model are not shown as the part showed insufficient stretch in the parts geometry. It is clearly visible that the simulations performed by making use of the TriboForm friction model improves the spring-back prediction in several areas significantly compared to simulations performed by making use of the Coulomb friction model.

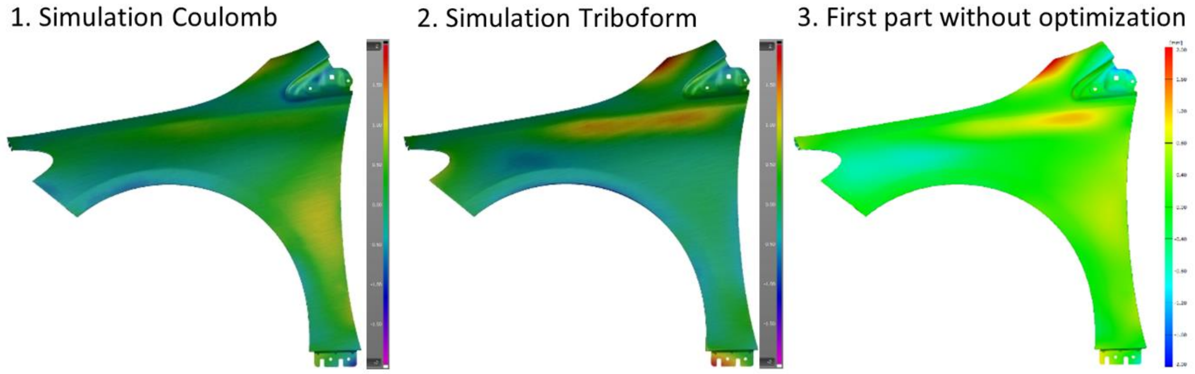

Figure 8. Springback simulation and real part measurement of the aluminum Mercedes Benz passenger car Fender

5. Conclusions and outlook

In this paper 2 aluminum application cases are discussed and simulation results are compared with experimental results. Simulations have been performed by making use of different friction models, demonstrating that the TriboForm friction model enables a detailed description of the tribological conditions during forming and that draw-in predictions and strain predictions are improved. As a result, also spring-back predictions of complex automotive parts, like the front fender part as discussed in this paper, gets closer to the real formed part. The premise is that the finishing of the forming tools should match with the tribological conditions as simulated before.

The experiments on the U-Bend part showed that areas with applied bearing pressure requires additional attention. To account for the bearing area properly the stiffness of the tools and forming press needs to be taken into account. Also including the influence of reloading effects in the TriboForm friction model and applying separate roughness values for the different parts of the forming tools might further increase the accuracy of the forming simulations.

Future possibilities with AutoForm Sigma and TriboForm will help to further understand the effects by running specific parameter analysis. The ultimate goal is to enable a complete digital process chain with reduced manual finish to produce robust part dimensions with high quality surfaces. In addition, accurate spring-back predictions between operations is crucial to achieve a proper positioning of the formed part into the cutting dies.

References

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