Improving stamping simulation accuracy by accounting for realistic friction and lubrication conditions: Application to the door-outer of the Mercedes-Benz C-class Coupé

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Abstract. In the stamping of automotive parts, friction and lubrication play a key role in achieving high quality products. In the development process of new automotive parts, it is therefore crucial to accurately account for these effects in sheet metal forming simulations. Only then, one can obtain reliable and realistic simulation results that correspond to the actual try-out and mass production conditions. In this work, the TriboForm software is used to accurately account for tribology-, friction-, and lubrication conditions in stamping simulations. The enhanced stamping simulations are applied and validated for the door-outer of the Mercedes-Benz C-Class Coupé. The project results demonstrate the improved prediction accuracy of stamping simulations with respect to both part quality and actual stamping process conditions.

1. Introduction

The quality of sheet metal formed parts is strongly dependent on the tribology, friction and lubrication conditions that are acting in the actual production process. 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 [1].

Figure 1 demonstrates the profound influence of friction and lubrication on the accuracy of stamping simulation results. It shows the outcome of a sensitivity analysis performed using AutoForm Sigma for a uniside panel, demonstrating the influence of multiple parameters on the sheet thinning. Of most interest in the evaluation of these results are the areas that are sensitive for splits, which are located near the B-pillar and roof top (see Figure 1). In these critical zones, it is observed that friction and lubrication dominates the sheet thinning by up to 70%. This demonstrates the necessity of an accurate description of friction and lubrication conditions in stamping simulations.

This paper presents a selection of results considering friction and lubrication modeling in stamping simulations of the door-outer of the Mercedes-Benz C-class Coupé. First the overall project approach will be outlined. Next, the stamping process of the door-outer part will be introduced. A description of the project results including validation of the simulation results based on door-outer parts from a press trial is provided. Finally, the conclusions and points of future work are described.
Figure 1. Friction dominates sheet thinning in encircled critical areas up to 70% for a uniside panel

2. Approach
The approach followed in this work is visualized in Figure 2 whereby the TriboForm software is used in combination with the AutoForm software.

2.1. Simulation of friction and lubrication conditions
The TriboForm software allows for modeling the friction and lubrication behavior under a wide range of process conditions. The physically-based models included in the TriboForm software enable multi-scale modeling of friction conditions in the mixed lubrication regime [2, 3]. As a user input, information of the tribological system is required, 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.

Figure 2. Approach for friction and lubrication modeling in stamping simulations

2.2. Friction model
Using the TriboForm Analyzer R1.0, a friction model is created per tribological system. The resulting friction model describes the frictional behavior as a function of the local contact pressure, relative sliding velocity, plastic strain in the sheet material and interface temperature. The resulting four dimensional friction model can be saved and exported from the TriboForm Analyzer in a friction file, see Figure 2.

2.3. Stamping simulations
Next, the friction file is imported into AutoForm\textsuperscript{plus} R5.2 using the TriboForm FEM Plug-In and incorporated in the door-outer simulation model. As a result, the constant coefficient of friction in AutoForm is replaced by the four dimensional friction model. Friction coefficients are computed for each node and each time increment of the FEM simulation. The local- and time-dependent friction coefficients describe the sheet, tooling and lubricant used in actual production of the door-outer part.

3. Door-outer trial and simulation results
An impression of the door-outer part is shown in Figure 3. In this work, the drawing operation OP20 is considered. The door-outer part is produced using a CR210BH-EG sheet material with a thickness of
0.7 mm and an EDT surface finish. Blanks with a dimension of 1600 mm x 1600 mm are used. The blanks are lubricated with Oest Platinol B804/3 COW-1 in varying lubrication amounts, i.e. 2.0 g/m$^2$, 1.2 g/m$^2$ and 0.5 g/m$^2$. A prototype tooling is used made of GG25 material. The parts are pressed using a hydraulic try-out press at Daimler AG in Sindelfingen, Germany, with a maximum stroke rate of 2 strokes/min. The drawing velocity is varied between 49 mm/s, 35 mm/s and 15 mm/s. For a decreasing drawing velocity and lubrication amount, the door-outer part shows splits in the areas as indicated and enlarged in Figure 3. This demonstrates the dependence of the door-outer part quality on the friction and lubrication conditions in the stamping process as further discussed below.

![Figure 3. Critical and gridded areas of the door-outer part of the C-class Coupé](image)

Figure 3. Critical and gridded areas of the door-outer part of the C-class Coupé

Figure 4 shows a comparison of the Forming Limit Diagram (FLD) resulting from strain measurements performed on a pressed part (see the gridded and evaluated areas in Figure 3) and resulting from AutoForm simulations. The part shows a critical strain distribution exceeding the FLC. The simulation using a Coulomb coefficient of friction of $\mu = 0.15$ underestimates the strains in the part. Next a TriboForm friction file is used describing the actual tribological system of the door-outer part and corresponding lubrication amount of 2.0 g/m$^2$. AutoForm simulation results using this friction file are included in Figure 4, and show an improved prediction accuracy of the critical strain distribution with respect to the pressed part.

![Figure 4. Comparison of the FLD results from the press trial and stamping simulations](image)

Figure 4. Comparison of the FLD results from the press trial and stamping simulations

![Figure 5. Comparison between press trial and simulation results: Influence of drawing velocity](image)

Figure 5. Comparison between press trial and simulation results: Influence of drawing velocity
A comparison between press trial parts and simulation results for decreasing drawing velocities is shown in Figure 5. The parts are pressed, and TriboForm simulations are performed, using a lubrication amount of 2.0 g/m$^2$. The door-outer part shows splits when the drawing velocity is reduced. This behaviour is not captured by the simulations using a constant coefficient of friction. The simulation results using the TriboForm friction file, including the friction dependency on sliding velocity, show an improved prediction accuracy of the critical strain distribution and splits with respect to the pressed parts.

A comparison between press trial and simulation results for decreasing lubrication amounts is shown in Figure 5. All parts are pressed at a drawing velocity of 49 mm/s. The door-outer part shows splits when the lubrication amount is reduced. This is not captured by the simulations using a constant coefficient of friction. The simulation results using a TriboForm friction file per lubrication amount again show an improved prediction accuracy of the critical strain distribution and splits with respect to the pressed parts.

![Figure 6](image.png)

**Figure 6.** Comparison between press trial and simulation results: Influence of lubrication amount

4. **Conclusions and future work**

The results presented in this paper demonstrate the strong influence of friction and lubrication conditions on the quality of the door-outer part. Moreover, it demonstrates that accounting for realistic and accurate friction and lubrication conditions bring metal forming simulations to a higher level and improve the prediction accuracy of stamping simulations, both qualitatively and quantitatively. Future work will include further applications in series production, which should lead to the broad application of advanced friction and lubrication models in stamping simulations at Daimler AG.

**References**

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