The effect of friction and lubrication modelling in stamping simulations of the Ford Transit hood inner panel: a numerical and experimental study

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Abstract. Reducing weight of Body in white (BIW) is a well-known solution to tackle environmental issues in automotive industry. Replacing steel by lighter aluminium sheet material is an accepted alternative. However, this trend brings challenges like the forming of Aluminium into complex car body parts. These challenges signify the necessity of more advanced tools to obtain defect-free parts. Nowadays, it is a common practice to implement forming simulations at the early stage of part design in order to identify critical features and to optimize the production process. Although, it is known that friction and lubrication conditions are one of the most influential sources affecting product quality in aluminium sheet metal forming, it is currently not considered in detail in stamping simulations. The current application case focuses on the role of friction and lubrication modelling in stamping simulations of an aluminium hood inner part of the new Ford Transit. A comparison was made between different friction models to identify and resolve split issues in the forming simulations. Simulation results were used to guide try-out towards efficient and successful elimination of these issues on the physical panels. Finally, different possible scenarios corresponding to production conditions were investigated to define a robust process window.

1. Introduction
At present, the automotive industry is facing several trends, particularly the increased use of aluminium and thinner sheet materials. The trends are geared towards light weighting, and they bring challenges, including the fact that forming thinner sheet materials and aluminium is difficult. These challenges signify the necessity for more advanced tools to obtain defect-free parts. Nowadays, it is a common practice to implement forming simulations at the early stage of part design before try-out to identify critical features in the design and to optimize the forming process. Simulations are used to support and get through the try-out phase without issues. Series production will be initiated only if the try-out phase is successful.

Although it is known [1] that friction and lubrication conditions are two of the most influential sources affecting product quality in aluminium sheet metal forming, it is not considered in detail in stamping simulations. The current industrial standard is to use a constant coefficient of friction.
limits the overall accuracy of the forming-process simulation. It is also known that the friction conditions are not only affected by the properties of the sheet metal and tooling, but also by the process conditions, such as sliding velocity, contact pressure, temperature and lubrication type and amount.

This paper describes a selection of results of an application case by Ford Otosan examining split issues observed in the try-out phase of the Ford Otosan Transit hood inner panel. Figure 1 shows the all new Ford Transit. The respective part and stamping process is described in detail in Section 2. The simulation approach followed to predict the split issues is described in Section 3, followed by a sensitivity study to identify a robust process window in reality. In Section 4, it is explained how split issues were tackled in simulations and subsequently in try-out together with a summary of the sensitivity analysis. Finally, a conclusion and points of future work are given in Section 5.

Figure 1. The all new Ford Transit

2. Stamping process of the Ford Transit hood inner panel

2.1. Tribology system: sheet material, lubricant and die material

The combination of the utilized sheet material, lubricant type and die material is referred to as the tribology system. The hood inner part used for this study is shown in Figure 2. The sheet material used is an Aluminum 6xxx series. The sheet material is pre-lubricated with a hotmelt lubrication. An average pre-applied lubrication amount of 1.2 g/m² was considered. The utilized tooling material is GGG70L. The die surfaces are polished and hardened. It is assumed that the surface properties of the blank resemble a commonly used AA6xxx series. The surface topography of the sheet was captured using 3D confocal microscopy measurements and was seen to have a surface roughness of 1.0 µm. An average tooling roughness of Sa = 0.4 µm was assumed using a common surface topography from the same tooling family.

Figure 2. Hood inner part with critical regions showing splits (red boxes)
2.2. **Stamping process and observed try-out issues**

This highly complex part was stamped using a single action process in the Ford Otosan press shop in Kocaeli, Turkey. The formed hood inner part is shown in Figure 2, whereby the critical regions are indicated in the red boxes. At first it was assumed that these splits must be a tryout issue, and that the problems had arisen from the die spotting level etc. However, after several trials to solve the issue by checking the dies at the press, the same result continued over a couple of weeks period.

3. **Stamping simulations**

3.1. **Sheet metal forming simulation approach**

This section describes the simulation approach followed in this work, as visualized in Figure 3. The sheet metal forming simulations in this study were all performed with AutoForm plus R7.0.3. After observing the split issues, Ford performed a full investigation to detect the reason of discrepancy. In their evaluation, material properties, blank size, punch force, and die spotting level were compared with reality, and were confirmed to show good agreement between reality and simulation. When additional oil was applied to the sheet some sensitivity was observed which highlighted the influence of tribological behavior on the aluminum part quality.

3.2. **Simulation of friction and lubrication conditions**

Initial simulations were performed with a constant Coulomb coefficient of friction of $\mu = 0.12$, which is commonly used in industry to describe frictional behavior of parts from Aluminum. In the second step, a pressure-velocity dependent friction model, referred to as P-V dependent friction model, was adopted. It was out of scope of this study to develop a P-V dependent friction model based on the experimental data so the settings of the P-V dependent friction model were based on the default settings provided by AutoForm with a base friction coefficient of 0.12 [2]. The model takes into account the decrease of friction coefficient due to an increase in contact pressure and increase in relative sliding velocity between the sheet and the contacting tools. The effective coefficient of friction $\mu_{\text{eff}}$ is calculated according to the formula:

$$\mu_{\text{eff}} = \mu \left( \frac{p}{p_{\text{ref}}} \right)^{e-1} - a \ln \left( \frac{\max(v_{\text{rel}}, v_{\text{ref}})}{v_{\text{ref}}} \right)$$

Where

- $\mu$ - base friction coefficient; in this case 0.12
- $p$ - contact pressure
- $p_{\text{ref}}$ - reference pressure (Default value of 4.0 MPa)
- $e$ - pressure exponent (Default value of 0.9)
- $a$ - velocity factor (Default value of 0.015)
- $v_{\text{rel}}$ - velocity of the sheet relative to the tool in contact
- $v_{\text{ref}}$ - reference velocity (Default value of 10 mm/s)

Finally, to more accurately account for friction and lubrication conditions in sheet metal forming simulations, the TriboForm software was used. See Figure 3.

The TriboForm software allows for multi-scale modeling of a time and spatially varying friction coefficient under a wide range of process conditions [3, 4]. The tribology system specification as described in the Section 2.1 (sheet material: Aluminum 6xxx series; hotmelt lubrication; tooling material: Cast iron, GGG70L), combined with hardening behavior of AA6xxx and viscosity data of the lubricant, enables the creation of a TriboForm Library which includes the friction conditions for the considered tribology system according to the procedure described in [5]. The resulting TriboForm friction models are a function of local contact pressure, straining of the sheet material, relative sliding velocity and interface temperature. The friction model can be imported into the AutoForm software.
using the TriboForm FEM Plug-In, replacing the constant coefficient of friction. A more detailed description of this simulation approach can be found in [3, 4, 5].

3.3. Parameter variations as encountered in press-shop reality

A sensitivity analysis was performed on the final part, whereby the part has been simulated with different levels of lubrication amounts and tool roughness values. By setting these different tribological conditions in TriboForm, and performing AutoForm simulations with the resulting friction models, it is possible to simulate the forming process including variations that can occur in press-shop reality. The first TriboForm model was defined to simulate low friction conditions, i.e. generating a friction model with a high lubrication amount (2 g/m²) and a low tool roughness (Sa = 0.2 µm), see Figure 4. Also, a TriboForm friction model with a low lubrication amount (0.5 g/m²) and a high tool roughness (Sa = 0.6 µm) was generated, corresponding to a friction model with high friction conditions (see Figure 4).

4. Results and discussion

In this section, a comparison is made between simulation and try-out results. AutoForm simulations were performed using a Coulomb coefficient of friction of µ = 0.12, the P-V dependent friction model and the TriboForm friction model respectively. In addition, it is described how split issues were resolved in simulations and subsequently in try-out. Finally, the results of the sensitivity study are discussed.

4.1. Try-out vs. simulation results: formability
Figure 5 shows the formability results using Coulomb friction which fails in predicting the critical regions in the product. The corresponding region with high risk of splits from try-out is also indicated in the forming limit diagram (FLD). It can be seen that these points are far below the forming limit curve, and therefore “safe”. In the next step, the P-V dependent friction model was used. The P-V dependent friction model is an enhanced version of the Coulomb friction model, however, also with this model the splits were not predicted in the part (see Figure 6). In the third simulation, the results using the TriboForm friction model are shown which predicts the splits in the exact same location as they occurred during try-out (Figure 7).

**Figure 5.** Initial simulation results using coulomb 0.12 showing no risk of splits

**Figure 6.** Simulation results using P-V friction model also showing no risk of splits
4.2. Reverse engineering to resolve the split issue
Using the improved stamping simulation that included the TriboForm friction model, Ford started to change the simulation model to solve the split issues in try-out. After varying different parameters, it was found that modifying the 2nd drawbead in the simulation, as shown in Figure 7-left, resulted in a green simulation with no risk of splits. Subsequently, Ford verified this solution by die modification in reality. Figure 8-right shows that indeed the split issues were solved in the part according to the modified drawbead geometry.

4.3. Sensitivity study
Evaluating the effect of lubrication amount and tool roughness on the formability of the part shows that the part is not affected when friction conditions are decreased (lower friction, see Figure 9-left). However, increasing friction conditions (higher friction) can result in critical regions which are located at different locations compared to the default simulation (medium friction conditions, see Figure 9-right). These results demonstrate the robustness of the part with respect to tribological conditions in terms of formability. It is important to understand that lowering the tool roughness, compared to an average roughness value of 0.4µm, means additional polishing of the tools which is a costly procedure in terms of both man power and time. At the other hand, the tools should not exceed the average tool roughness of 0.4µm too much, as this can result again to split issues. Therefore, based on this study, additional polishing of the tools is not necessary, but it may increase the safety margin to possible account for other variations encountered in reality such as blank holder force and press velocity.
Figure 9. Low friction conditions (left) resulted in part with no forming issues while the high friction conditions (right) caused splits in the part.

5. Conclusions and future work
This work clearly demonstrates the strong influence of friction and lubrication on part quality of the Ford Otosan Transit hood inner panel. More importantly, it was demonstrated that the observed try-out issues could be simulated accurately by accounting for an advanced friction model in sheet metal forming simulations. This subsequently enabled Ford to first virtually predict production issues and subsequently improve the forming process to produce a defect free product. This can now be done by controlling, adjusting and optimizing the tribological conditions both in simulations and production. Future work of Ford Otosan will focus on continuing the implementation of TriboForm’s advanced friction and lubrication modeling technology into AutoForm’s sheet metal forming simulations. The ultimate goal is to further enhance the prediction accuracy of forming processes to improve the prediction of part quality. Specifically, the use of such advanced tribological models for aluminum parts will be considered, as this is considered as indispensable for virtual design of lightweight car bodies.

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