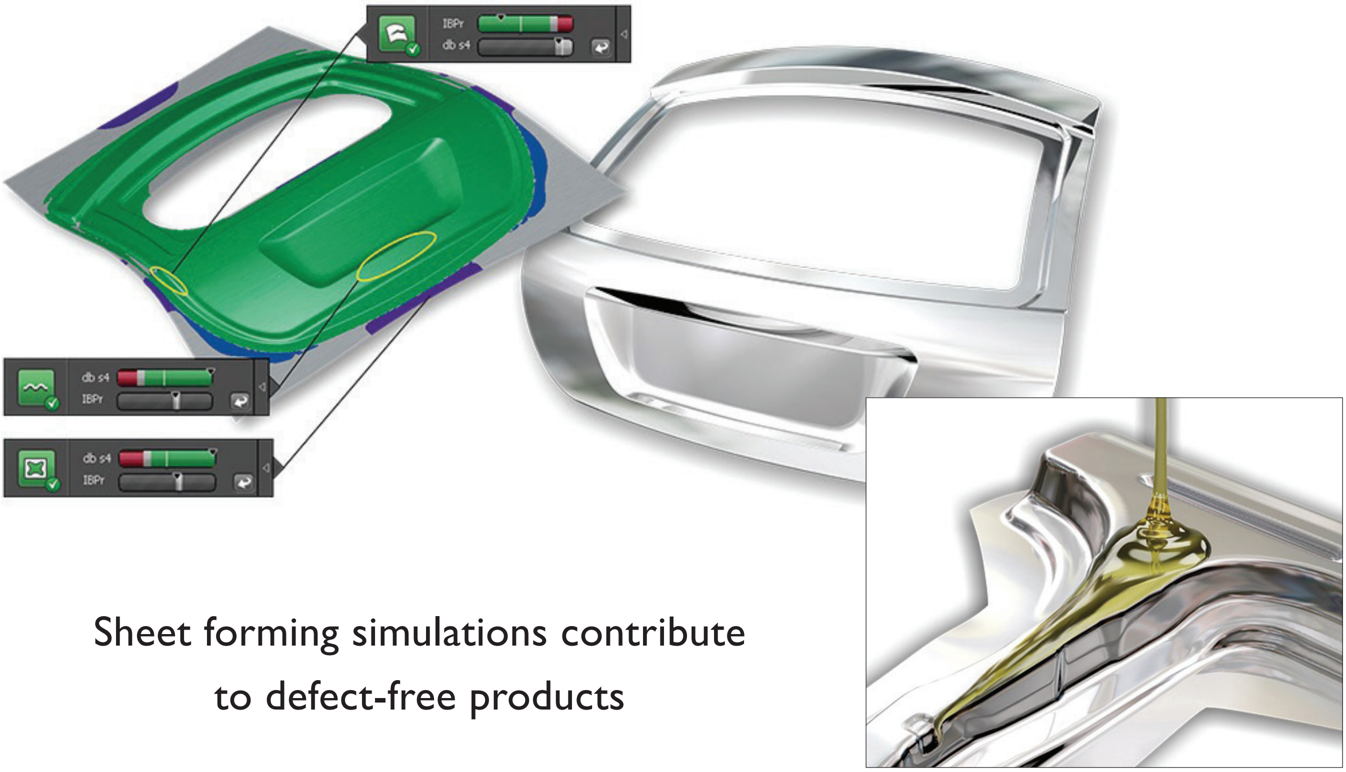
*By Sanaz Berahmani and Michael Stippak*

# BRIDGING THE GAP BETWEEN TRYOUT & MASS PRODUCTION



### Sheet forming simulations contribute to defect-free products

At present, the automotive industry is facing several trends, particularly the increased use of aluminium and thinner sheet materials. The trends are geared toward lightweighting, 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 products.

Nowadays, it is a common practice to implement forming simulations at the early stage of part design before tryout to identify potential risky features in the design and also to optimize the tryout phase. Simulations are used to support and get through the tryout phase without issues. Series production will be initiated only if the tryout was successful.

Although it is known 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 (coulomb) coefficient of friction. This limits the overall accuracy of the tryout's forming-process simulation. It is also known that the friction

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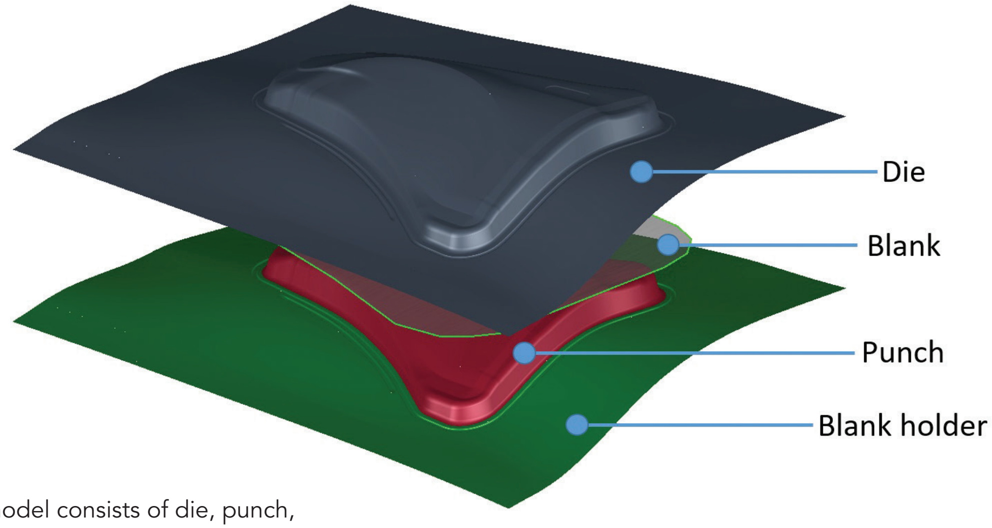

FIGURE [1] / The fender model consists of die, punch, sheet and blank holder

conditions are not only affected by the properties of the sheet metal and tooling, but also by the process conditions, such as sliding velocity, temperature and lubrication amount.

## Robust Process Window

However, there are several discrepancies in the process setup between tryout and production. Therefore, it is important to define a robust process window that results in a defect-free product under both tryout and production conditions. Having a robust process window is even more essential during the forming of critical sheet metals such as aluminium and thin sheet materials, which show a higher sensitivity to friction and consequently, to the process parameters.

The sensitivity study described in this article aims to bridge the gap between tryout and full-scale production with a focus on the effect of frictional conditions on the aluminium-forming process under both conditions. For this purpose, TriboForm software is used in combination with AutoForm-Sigma®plus. TriboForm enables the simulation of friction and lubrication conditions.

The results can be directly integrated in sheet-metal forming simulation software like AutoForm's. AutoForm-Sigmaplus is a strong tool for achieving a robust process window. It lets engineers assess part quality as a function of several parameters and their variation.

## Aluminium Front Fender in Simulation

In this article, an aluminium deep drawn front fender is considered. (See Figure 1.) Blank material was from AA6016 with a thickness of 1.15 mm. Profile-based 3-D beads during closing and adaptive line beads after closing were applied to simulate the drawbeads. TriboForm is used to simulate the frictional behavior between sheet and tools as realistically as possible. The software lets the user select a friction model that corresponds to the actual tribology system used in the forming process, i.e., the combination of sheet material, tool material and lubrication type.

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For the front fender part, properties of the sheet, lubricant and tooling material were defined in the software. First, the type of sheet material and its surface properties were selected based on the blank material type (AA6016). The software provides the option for the user to either choose a material from the build-in TriboForm Library or import real 3-D surface measurements. For the current application case, the build-in default library for AA6xxx series aluminium was selected.

Next, the lubrication type, Hotmelt, which is commonly applied when metal forming aluminium parts, was entered into the software. Finally, the type of tooling material and its surface

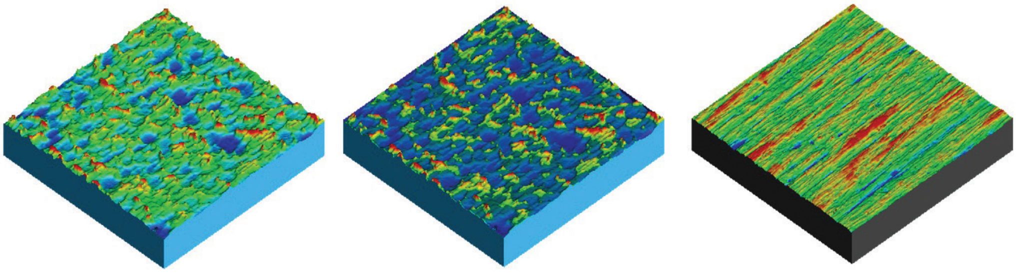

FIGURE [2] / (Left) Surface properties of aluminium sheet, (middle) hotmelt lubrication is applied to the surface, which is visualized by a transparent blue layer and (right) surface properties of cast iron (GGG70).

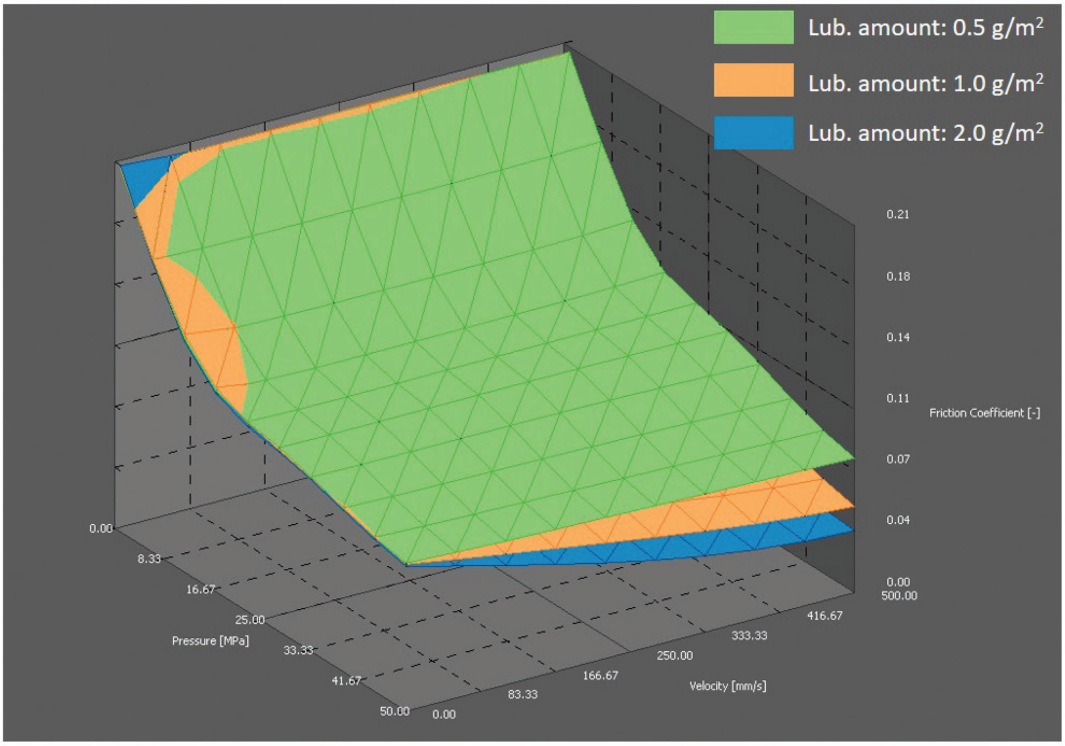

FIGURE [3] / The advanced friction model, demonstrating the dependency of friction to pressure and sliding velocity for three different lubrication (lub.) amounts

conditions were added. For the front fender part, cast-iron tool (GGG70) with a surface roughness of 0.4 µm was selected. Next, the TriboForm Analyzer enables the calculation and visualization of the friction conditions for the considered sheet material, lubricant and tooling material. (See Figure 2.)

The software generates a four-dimensional friction model that accounts for the effect of contact pressure, plastic strain, sliding velocity and interface temperature on the frictional behavior. Figure 3 shows the relation between friction with pressure and velocity for the temperature of 20 degrees Celsius and strain of zero.

## Frictional Behavior

A strong pressure dependency with lower friction for higher range of pressure is observed for all lubrication amounts. In addition, it can be seen that the frictional behavior decreases with increasing lubrication. Finally, there is a minor velocity dependency for the higher range of lubrication amounts (1.0 and 2.0 $g/m^2$) compared to a lower amount of 0.5 $g/m^2$. This results in a lower range of friction by increasing velocity from 1 mm/sec to 500 mm/sec. Finally, it was observed that increasing temperature has a direct relation with friction, which means a higher coefficient of friction is obtained for a higher range of temperature.

Using TriboForm in combination with AutoForm R7, the so-called systematic process-improvement approach using AutoForm Sigma was performed. Three design variables that play an important role in the frictional behavior during forming have been investigated, i.e., the forming velocity, the lubrication amount and the temperature. (See Table 1.)

Two temperature settings were considered, namely a blank/tool temperature of 20 degrees Celsius to describe tryout conditions based on the low-velocity stamping process with several breaks in-between the stamping operations. A tool/blank temperature of 30 degrees Celsius was set to describe production conditions with a high stroke rate and with less/no breaks in-between stamping operations. This leads to the tools heating and finally, the blanks, too.

TABLE [1] / Investigated design parameters with their applied ranges

| Design Parameters | Minimum | Maximum |
|---|---|---|
| Forming velocity (mm/sec) | 10 | 500 |
| Lubrication amount (g/m$^2$) | 0.5 | 2 |
| Temperature (°C) | 20 | 30 |

## How Much Lubrication to Use?

The objective was to determine a proper amount of lubrication while achieving a safe process window for the forming velocity under both production scenarios. For this purpose, three standard lubrication amounts have been investigated, i.e., 0.5, 1 and 2 g/m$^2$.

The process window is defined by the risk of splits (more specifically the limit of thinning and max failure), while at the same time achieving adequate stretching defined by the limit of 3-percent plastic straining. In other words, the goal was to obtain a defect-free product (no splits and adequate stretching) for an acceptable range of stroke velocity (100-250 mm/sec) under tryout and production conditions.

Figures 4 and 5 display the distribution of maximum failure and plastic strain on the front fender after the deep-drawing step. The highest range of maximum failure was on the fender side wall, while the minimum plastic strain occurred on the vertical wall. In addition, the relation between these two outcome parameters with stroke velocity is shown for three lubrication amounts and two temperatures.

## Maximum Failure and Plastic Strain

A clear decline in maximum failure and plastic strain by increasing the lubrication amount was observed. (The curves are shifting downward in both figures for higher lubrication amounts.) This observation can be explained by having a lower coefficient of friction for higher lubrication amounts, which results in increased material flow.

In addition, there is a clear decreasing trend between maximum failure and plastic strain (y-axis) with stroke velocity (x-axis). A higher velocity results in a lower coefficient of friction, which in turn, results in lower maximum failure and plastic strains in all cases. One important difference between the two outcome parameters (max failure and stretching limit) is that the safe (green) and critical (red) regions have an opposing effect with respect to each other. That is, a lower maximum failure is desirable, but the plastic strain should not drop below the stretching limit.

Finally, to answer the main goal of this sensitivity study, it can be seen that the lubrication amount has a significant influence on the defined quality issues and that only a lubrication amount of 1.0 g/m$^2$ leads to a safe process window. For this lubrication amount, a safe product is obtained for a defined range of velocities (~100-250 mm/sec) for both scenarios.

A lubrication amount of 0.5 g/m$^2$ satisfies the stretching limit, but splits would occur independent of the forming velocity under production settings. That is, due to the higher temperature of 30 degrees Celsius, higher friction coefficients are observed, resulting in a more critical product. On the contrary, a higher lubrication amount has an opposing effect with a safe process window for splits, but with inadequate stretching at certain locations.

Due to the complex nature of frictional behavior during the forming process, more advanced simulation tools are required to incorporate these effects into forming simulations. In this sensitivity study, not only a realistic frictional model based on the specification of a tribology system was applied to an aluminium front fender, but also the effect of process parameters on the forming behavior was studied using simulations.

## Role of Frictional Conditions

These advanced approaches highlight the important role of frictional conditions to achieve a robust forming

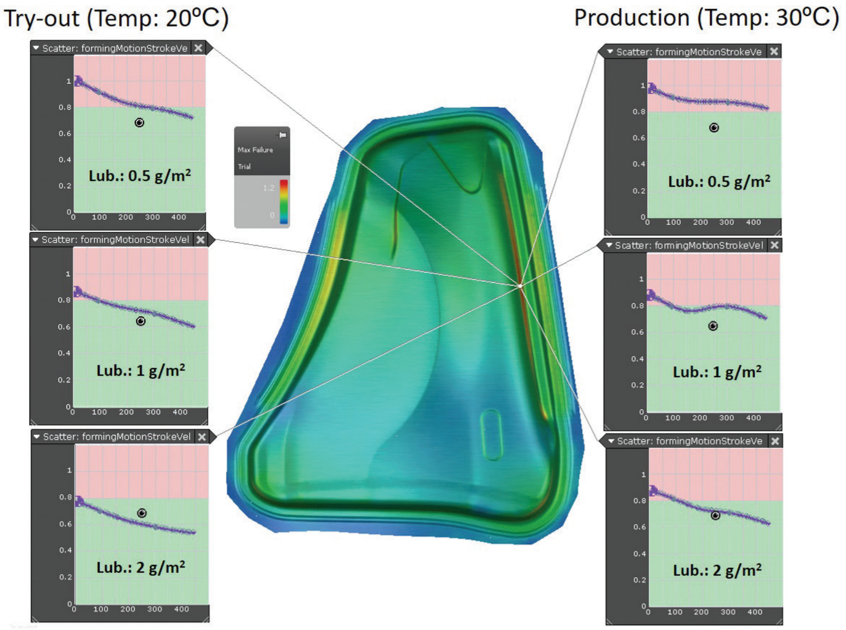

FIGURE [4] / The relation between maximum failure and velocity for different lubrication amounts, and both production and tryout settings. Red means critical, and green means safe region. X-axis represents the stroke velocity, and y-axis is maximum failure.

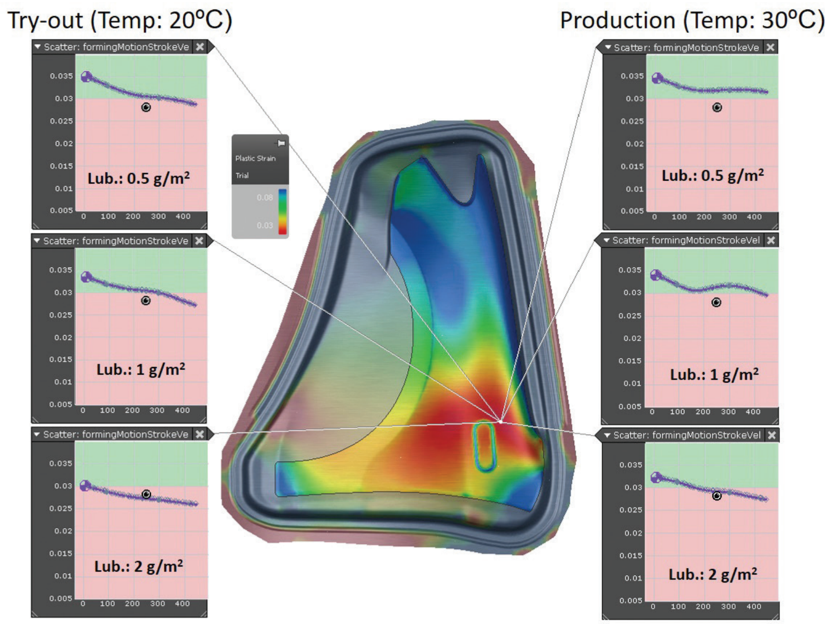

FIGURE [5] / The relation between plastic strain and velocity for different lubrication amounts, and both production and tryout settings. Red means critical and green means safe region. X-axis represents the stroke velocity, and y-axis is plastic strain.

process of an industrial aluminium part by using AutoForm-Sigma in combination with the TriboForm software. A safe product under tryout and production settings can only be achieved by using a specific range of forming velocities under specific lubrication conditions. It is important to realize that these process parameters are interacting with each other, making it almost impossible to study the effects independently.

In addition, it should be emphasized that the found range of lubrications are highly dependent on the studied part and its specification. Therefore, this study can be used as a reference to perform similar types of analysis on other parts. LW

## ABOUT THE AUTHORS:

**Sanaz Berahmani** obtained her Ph.D. in bio-mechanics from Radboud University Nijmegen in the Netherlands. Her main technical expertise is simulation using finite element software, tribology and experimental testing.

After joining AutoForm-TriboForm in 2017 as an application and sales engineer, she became responsible for technical and sales-related activities with a focus on Asian and American markets.

**Michael Stippak** graduated with a mechanical engineering degree from the University Darmstadt, Germany. He began working as a simulation engineer for sheet-metal forming parts with AutoForm software at Schuler Cartec (part of the Schuler Group).

Mr. Stippak joined AutoForm Engineering Deutschland GmbH (Germany) in 2005 as an application engineer and became technical product manager in 2008. He is responsible for the technical aspects of the AutoForm products, AutoForm-Sigma and AutoForm-TryoutAssistant.