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# INFLUENCE OF ENHANCED COULOMB'S MODEL ON THE DRAW-IN OF THE HOOD INNER PANEL

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***Abstract***
*A constant coefficient of friction (Coulomb) is commonly used as the current industry standard to describe friction on the sheet metal forming simulation software. The use of constant Coulomb's friction may reduce precision and so the effectiveness of the simulation to represent real-world processes. This paper presents an approach using a physical measurement of friction combined with pressure dependent friction model as an input for the metal forming simulation of a hood inner part on AutoForm. The input variable parameters are the constant Coulomb and the enhanced pressure-dependent model. For the output this study analyses the Forming Limit Diagram (FLD) and blank's draw-in in a real problem provided by a car manufacturer.*

***Keywords:*** *enhanced Coulomb, metal forming, friction, physical measurement*

## 1. Introduction

The automotive industry has been playing a major role in the development of sheet-metal forming technologies. The development of cost-effective production processes requires accurate sheet metal forming simulations. For that, advanced friction models are added in order to increase the accuracy in finite element simulations. One of the most popular FEM tools for sheet metal forming is the software AutoForm.

The tribological properties have a significant impact on the forming processes. Tribology is used for examining how various components interact with the surface of sheet metal. Friction and wear are important factors to be considered for this study together with the lubrication. Despite its significance, friction is commonly neglected in metal forming simulations. A constant coefficient of friction (Coulomb) is commonly used as the current industry standard (Lee et al., 2002; Sigvant et al., 2018; Tisza, 2001).

The use of constant Coulomb's friction may reduce precision and so the effectiveness of the simulation to represent real-world processes. The Coulomb friction law is only substantial if a direct proportionality can be made between the real contact area and the normal force. This relationship can only be noticed for low normal forces. Simply stated, the Coulomb model can only be used as an approximation to the actual world. In reality, a variety of variables might affect the coefficient of friction, which is not always constant. The latest solutions rely on enhanced models and virtual tribology. Even considering that virtual tribology is a leading technology for metal forming simulation, employing enhanced Coulomb models still has benefits related to cost savings and readiness (Figueiredo et al., 2011; Sigvant et al., 2018; Tisza, 2001).

This paper presents an approach using a physical measurement of friction combined with pressure dependent friction model as an input for the metal forming simulation of a hood inner part on AutoForm. The input variable parameters are the constant Coulomb and the enhanced pressure dependent model. For the output this study analyses the Forming Limit Diagram (FLD) and blank's draw-in in a real problem of a part provided by a car manufacturer.

### 1.1. Physical Measurement

Currently, there are no universal methods for determining the coefficient of friction to be applied to metal forming simulation. This comes from a variety of geometries of contact area between tool and sheet, as well as the different stress and strain states in different areas of the drawing piece that can change in different moments of the forming process.

In the strip drawing test, a metal strip is forced between a tool and a stage while being simultaneously drawn by the motion of the stage fuse. Continuous measurements are made of the normal load that is being delivered as well as the tangential force that opposes movement. The measurement may be performed using a load cell, which enables the computation of friction coefficient values (Tavares et al., 2021).

Using the base of the Strip Drawing test the friction measurement device built at the Institute of Material Science and Technology at the University of Miskolc is shown in Figure 1.

***Figure 1.*** *New tribometer available at the University of Miskolc*

The tribometer is previously presented in the Institute of Physics (IOP) Conference Series: Materials Science and Engineering (Carvalho and Lukács, 2022) where the functionality of the device is well illustrated.

### 1.2. Enhanced Coulomb Model

One of the most significant variables that affect the coefficient of friction is the contact pressure. The influence of pressure shall be evaluated on both macro and micro scales. The topography of the in-contact surface flattens as the contact pressure increases. As a result of these elements, the contact geometry varies, which has an influence on the coefficient of friction. On the other hand, the contact pressure exerted on the sheet rises as the flange area reduces as the material flows to the cavity of the die. In sheet metal forming, it is crucial to take this influence into account. A heterogeneous contact pressure distribution can be discovered because the thickness of the sheet may alter differently in various regions of the sheet during the flow of the material.

Based on the part's geometry, the tooling, and the forming operation, the pressure-dependent friction model was selected for the current analysis. The equation for the Pressure Dependent Friction Model is shown in Equation 1

$$\mu_{eff} = \mu\left(\frac{p}{p_{ref}}\right)^{(e-1)} . \qquad (1)$$

On Equation 1 $\mu$ is the base friction coefficient, $p_{ref}$ is the reference pressure and $e$ is the pressure exponent. Both mathematical variables ($p_{ref}$ and $e$) describe the true influence of pressure on the friction behaviour.

## 2. Methods

### 2.1. Physical measurements

The first step consisted in analysing the material provided by the partner. The material of the metal strip (35x300mm) and the tool (21x46mm of contact area) are respectively a high-strength-steel and heat-treated carbon steel. The coefficient of friction was calculated using the new tribometer previously presented in Figure 1. Considering a constant contact pressure and the friction force measured with the MTS the friction coefficient was calculated using Equation 2

$$\mu = \frac{2F_R}{F_N} . \qquad (2)$$

$F_R$ is the friction force considering the contact with both sides of the metal strip and both tools. $F_N$ is the nosmal force calculated by the pressure applied to the tools in contact with the metal strip sample.

### 2.2. Simulation on Auto-Form

The application of the enhanced coulomb model on AutoForm was made for the simulation of a hood inner panel provided by the automotive partner. The analysis was made on the first drawing operation of the blank. The final step of the drawing operation is shown in Figure 2. The tools are shown in Figure 3 where it can be seen the die, the blank holder and the punch.

***Figure 2.*** *Hood inner panel. Final step of first drawing operation*

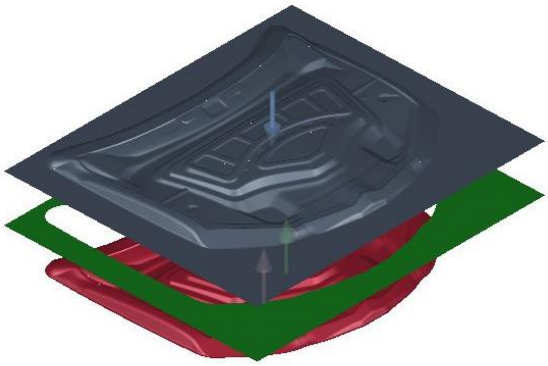

***Figure 3.*** *Drawing tools*

The software requirements for the material behaviour on AutoForm are: basic properties, hardening curve, Yield surface and the forming limit curve. The basic proprieties are: Young's modulus ($E = 7 \cdot 10^4$ MPa), Poisson's ratio ($\nu = 0.33$), specific weight ($\rho = 2.7 \cdot 10^5$ MPa/mm). The hardening curve, Yield surface and the forming limit curve are shown in Figure 4.

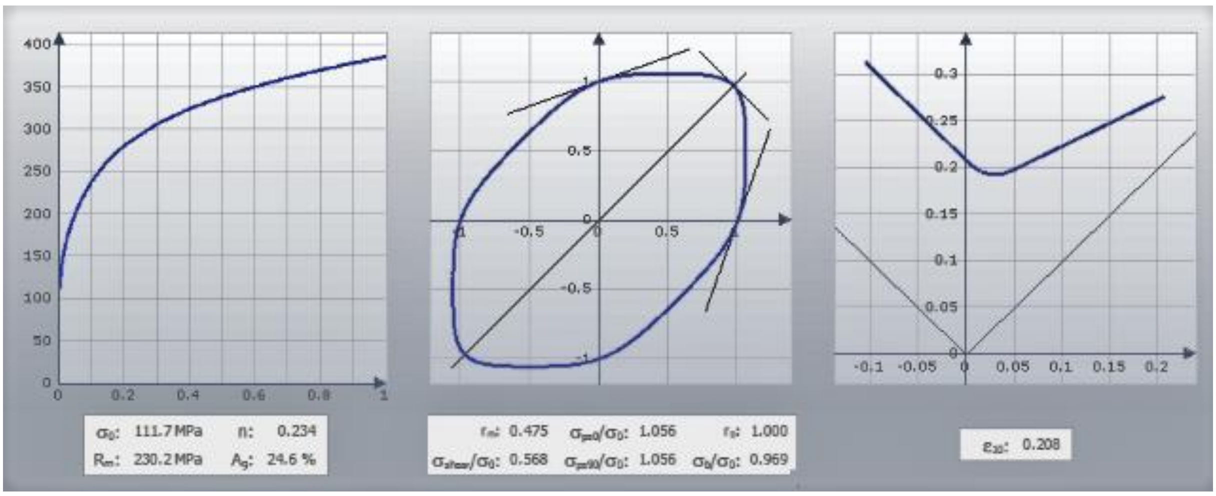


***Figure 4.*** *Hardening curve, Yield surface and the forming limit curve*

For the FEM simulation of the Hood inner part on AutoForm two different friction models were used. At first it was considered a constant friction (Coulomb) equal to 0.15. For the second analysis it was applied the pressure dependent friction model. The input parameters for the enhanced Coulomb's model (Equation 1) are shown on Table 1.

***Table 1.*** *Input parameters for the Pressure Dependent Friction Model*

| **Input Parameter** | **Value** | **Unity** |
|---|---|---|
| Base friction coefficient ($\mu$) | 0.15 | - |
| Reference Pressure ($P_{ref}$) | 4 | MPa |
| Pressure Exponent ($e$) | 0.5 | - |

Since this paper is focused on the comparison between the constant of Coulomb and the pressure dependent friction model the higher influence of pressure was considered. For that, the results of a previous study published by the authors (Carvalho et al., 2021) was used to define the pressure parameters of equation 1 ( $p_{ref}$ and $e$) together with the physical measurement of friction to define $\mu$.

The drawn in measurements were made in the 3 different regions of the part. The locations of the measurements are shown on Figure 5.

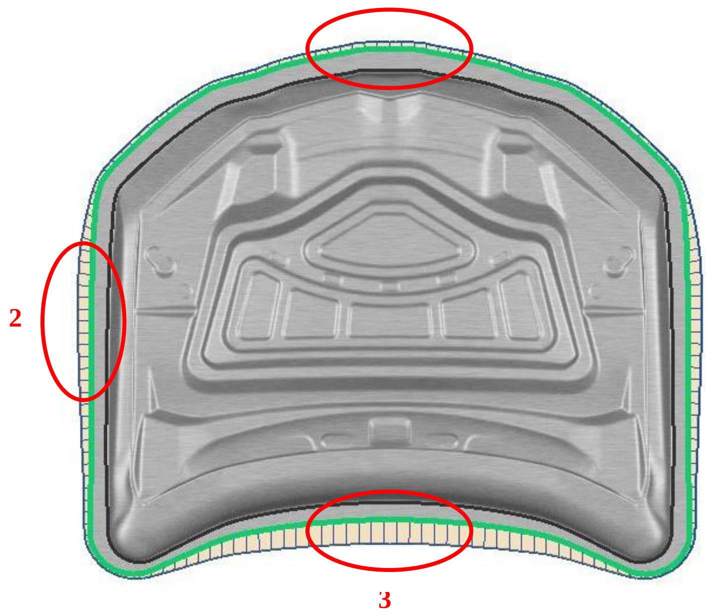


***Figure 5.*** *Measurement location for draw-in analyzes*

## 3. Results and Discussions

The Forming Limit Diagram (FLD) curves of the two experiments clearly show a difference between the two friction models. The curves are presented in the Figures 6 and 7.

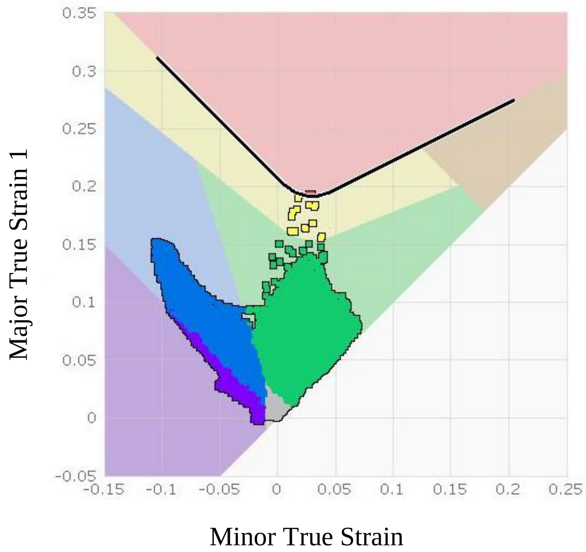


***Figure 6.*** *Forming Limit Diagram for constant friction model*

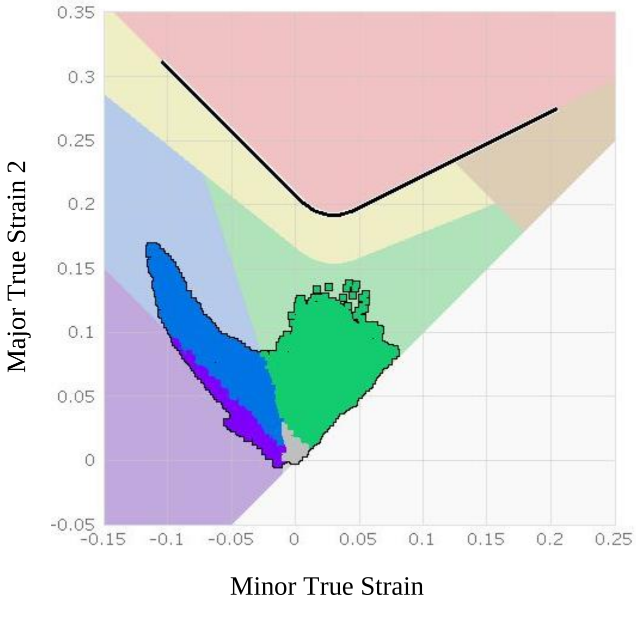


***Figure 7.*** *Forming Limit Diagram for pressure dependent friction model*

It can be seen that when using the constant coefficient of friction (Figure 6) the analysed part has a risk of splits (yellow region) and splits (red region). In the second analysis when choosing the pressure-dependent friction model there are no risks of splits. The application of enhanced coulomb models has the intention to approximate the simulation results to real-life processes. Previous studies (Lacues et al., 2019; Sigvant et al., 2018) have concluded that the use of the constant Coulomb model tends to bring the simulation to failure when manufacturing the part with the same conditions will not cause failures in real life.

The results of the draw-in measurements are shown in Table 2. It can be seen that for the same position for different friction models the draw-in has reached a difference of around 2.5 mm at the region 1, 1.5 at the region 2, and almost 9 mm at the region 3 of the part.

***Table 2.*** *Draw-in measurements*

| **Friction Model** | **Measurement position** | **Measurement (mm)** |
|---|---|---|
| Constant Coulomb | 1 | 23.97 |
| | | 24.28 |
| | | 23.99 |
| | 2 | 44.41 |
| | | 45.05 |
| | | 43.88 |
| | 3 | 79.31 |
| | | 79.90 |
| | | 79.67 |
| Pressure Dependent | 1 | 21.45 |
| | | 21.73 |
| | | 21.48 |
| | 2 | 44.97 |
| | | 45.70 |
| | | 44.65 |
| | 3 | 70.59 |
| | | 71.04 |
| | | 70.86 |

The comparison of the draw-in results is summarized in Figure 7. It can be noticed that the major influence happened on region 3 of the hood inner panel where the draw-in length is bigger (illustrated in Figure 4). The same behaviour has been noticed in region 1 on the panel, therefore, for on the measurement of region 2 a small influence and a slight increase could be noticed.

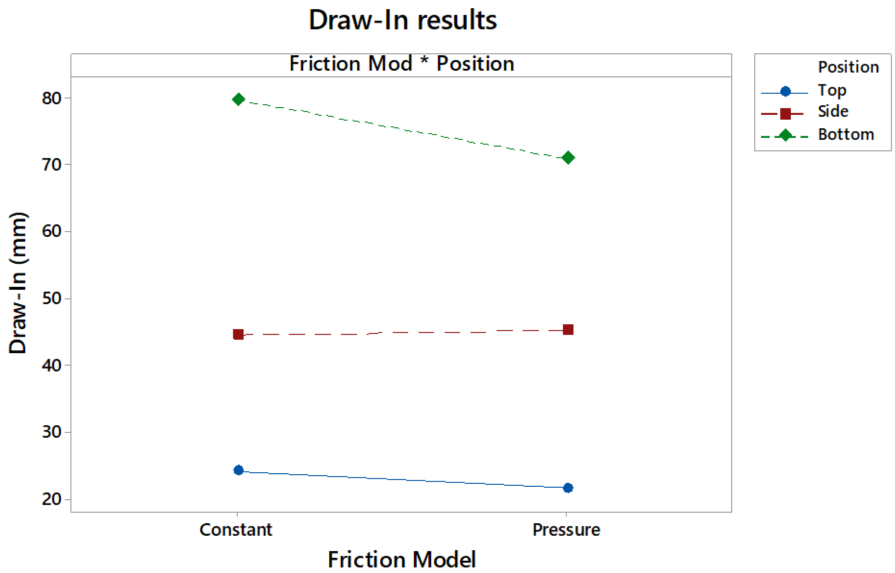


***Figure 7.*** *Influence of friction model on the draw-in.*

## 4. Conclusions

The current study has the goal to develop a methodology combining a physical measurement with an enhanced coulomb equation as a solution for the improvement of metal forming simulation on AutoForm. Previous studies together with the current one have shown the potential of the physical measurement designed at the Institute of Material Science and Technology of the Faculty of Mechanical Engineering and Informatics of the University of Miskolc. The current study achieved a safer simulation result for the pressure dependent friction model when analysing the FLDs. These are the desired results for the improvement of friction description as previously stated on chapter 3. In addition, the draw-in results have shown a higher draw-in measure for the constant of Coulomb. This result reinforces the conclusions obtained by the analysis of the FLDs. For the future steps of this research further investigations and validations of the current method will be conducted.

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