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Application of enhanced coulomb models and virtual tribology in a practical study

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Pollack Periodica • An International Journal for Engineering and Information Sciences

17 (2022) 3, 19–23

DOI:
10.1556/606.2022.00582

Received: December 31, 2021 • Revised manuscript received: May 20, 2022 • Accepted: May 25, 2022

ORIGINAL RESEARCH PAPER

ABSTRACT

For the final quality of the part, metal forming trends are depending on improvements of friction and tribology. As a consequence, there is a trend in which tribology and friction are becoming increasingly important for correctly replicating the forming simulation of those parts. The objective of this work was to improve the forming simulation of an automotive shell part on AutoForm. The part was provided by a vehicle industry supplier. Enhanced Coulomb models consider a change on friction coefficient due to different factors, better approximating the description of friction to reality. For the current study, pressure and velocity dependent friction models were chosen as long as the combination of both. The virtual tribology was simulated using the software TriboForm. Velocity dependent friction model and the virtual tribology have shown similar results with expected lower coefficients of friction.

KEYWORDS

metal forming, tribology, friction, enhanced coulomb, virtual friction

1. INTRODUCTION

When the tool shop notifies a simulation engineer that a component that was safe in the forming simulations was really problematic in the try-out, it may be a nightmare. Finding the reasons of divergence between simulation and try-out is essential. In the tool shop, trial and error is impracticable, time-consuming, and expensive. As a result, during the simulation stage, the issues must be addressed and corrected.

In the practice of mass manufacture using metal sheets the metal forming process is the most often applied method. Stamping and deep drawing are the most extensively used methods in industrial sectors to create sheet metal components today. Both need a high initial investment and unique dies for each item, making them restrictive and only economical for mass production [1].

The forming results are heavily influenced by tribological characteristics and frictional processes. Tribology has a critical function to play: it investigates how numerous factors interact with the sheet metal surface. Friction and wear are two major elements that have an impact on energy consumption. Tribology studies also include the lubrication method. Experiments are required for the development of new lubricants that fulfill both environmental and tribological standards. As a result, it is critical to predict lubricant qualities by modeling and the use of computer models in order to speed up the design process [2].

Despite the importance of friction, it is frequently overlooked in metal forming simulations. The current industry standard employs a constant coefficient of friction (Coulomb). This strategy may reduce simulation precision in order to better represent real-world processes. In order to get more realistic simulations with higher accuracy, tribology effects in metal forming simulations must be taken into account. Some examples of approaches for simulating friction and lubrication in metal forming processes include pressure and velocity dependent friction models and the software TriboForm [3–5].

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Many manufactures are demanding for a more accurate description of tribology. TriboForm was successfully applied to the inner trunk component of the Renaut Talisman. To better characterize the tribology aspects, Groupe Renault, Tata Steel, AutoForm, and TriboForm collaborated to solve the problem. For the stamping simulations, the constant Coulomb coefficient of friction of 0.15 was employed as a baseline. They evaluated the TriboForm model using AutoForm simulation to achieve a more accurate simulation in terms of friction and lubrication, taking into accounts the variation of friction conditions locally and over time. Friction is dependent on local factors including pressure, velocity, strain, and interface temperature, in addition to not being constant in different locations and phases of the process. In the draw bead area, where local contact pressures are very high, friction has shown results as low as $\mu = 0.03$. In the blank holder region, on the other hand, friction coefficients have shown values closer to $\mu = 0.13$ [6].

All models used to analyze forming processes must account for friction, since the material flows over the tool's surface at the contact areas. It is assumed that the contact occurs only at the peak asperities including both surfaces during the sheet metal forming. For this application, friction models are typically based on the Amontons-Coulomb model [7].

Time, position on the surface, and geometry all influence the relevance of friction in three-dimensional deformations like sheet metal forging. The contact between the tool and the working piece, the surface condition, the presence of lubrication, as well as the rate of deformation and the local temperature, all have an impact [8]. As stated in Eq. (1), the Coulomb friction law states a proportional relation between the friction shear stress R and the effective normal stresses N in the contact area, with μ as the friction coefficient,

$$\tau_R = \mu \cdot \sigma_N. \tag{1}$$

The friction coefficient is calculated using Eq. (2),

$$\mu = \frac{F_R}{F_N}. \tag{2}$$

The Coulomb friction law is only valid when the increase in real contact area is proportional to the normal force. Beyond that, this relationship can only be seen for low normal forces. The Coulomb model is simply a rough approximation of real-world friction. In reality, the coefficient of friction is not constant, but it can be impacted by a range of factors. Enhanced models and virtual tribology are the current solution. Although virtual tribology is a very important technology for the metal forming simulation there are still same advantages of using the enhanced Coulomb models, related to cost reduction and readiness.

The objective of this work is to improve the forming simulation of an automotive shell part provided by a vehicle industry supplier. The problem faced by the company is related to the unbending process on the edge of the shell part, which will be the focus of the current analyses. The geometry of the part was provided by the partner company and the software AutoForm was used for the simulation of the process.

2. MATERIALS AND METHODS

In Fig. 1 ther is shown the initial and final shape of the unbending process discussed on this paper. The key attention should be paid on the edge of the shell part, highlighted on both Fig. 1a and b all overs the part's diameter. All the consecutive analyzes will be made considering the same region.

Figure 2, display the processes tooling and meshing. The tooling includes two supports for the part and the unbending tool itself.

Material parameters of 304 stainless steel are shown in Table 1.

A combination of the Swift and Hockett-Sherby approximations is used to define the hardening curve, Eq. (3). The weighting of the functions is determined by the combination factor a. σ is the true stress, C and ε_0 are parameters for Swift hardening curve, ε_{pl} is the plastic part of the total strain, m is the rate of evolution of the bounding surface. The parameters for the hardening curve are shown on Table 2.

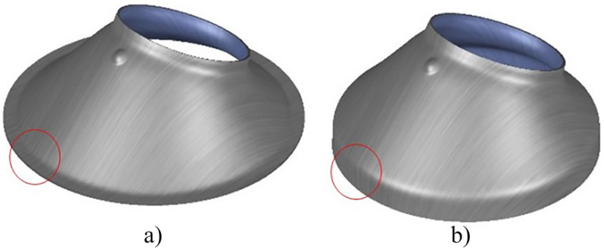

Fig. 1. Workpiece, a) initial shape; b) final shape

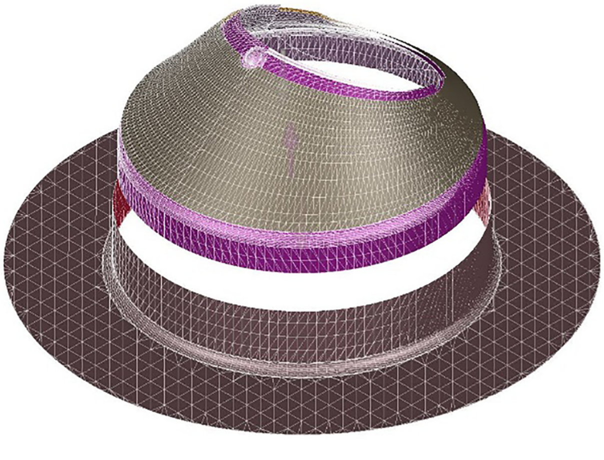

Fig. 2. Forming tools

Table 1. Material parameters

Propriety	Value
Specific Weight (MPa mm^{-1})	$7.68 \cdot 10^{-5}$
Young's Modulus MPa	$2.1 \cdot 10^{5}$
Poisson's Ratio	0.3

Table 2. Swift and Hockett-Sherby hardening curve parameters

ε_0 (-)	m (-)	C (MPa)	σ_i (MPa)	σ_{sat} (MPa)	a (-)	p (-)	a (-)
0.05	0.529	1,637	342.3	3,836	0.526	0.85	0

$$\sigma = (1-\alpha)\left\{C^{*}\left(\varepsilon_{pl}+\varepsilon_0\right)^{m}\right\} + \alpha\left\{\sigma_{sat} - (\sigma_{sat}-\sigma_i)e^{a\varepsilon_{pl}^{p}}\right\} \quad (3)$$

Available friction models for the simulation on AutoForm includes: constant Coulomb friction; directional dependent friction; pressure dependent friction; velocity dependent friction; and the TriboForm friction model. For the current study both enhanced coulomb models, Pressure and Velocity Dependent, were chosen as long as the combination of both and the virtual tribology by the software TriboForm.

2.1. Pressure dependent friction

The contact pressure is one of the most important factors that influences the coefficient of friction, and it may be measured at both macro and micro scales. As the contact pressure increases, the topography of the in-contact surface flattens out. The contact geometry changes as a consequence of these factors, resulting in a change in the coefficient of friction. When the material flows to the cavity of the die, the contact pressure applied to the sheet increases as the flange area decreases. This is an important impact to consider in sheet metal forming. Since the thickness of the sheet might change differently in different locations of the sheet during the flow of the material, a heterogeneous contact pressure distribution can be found [9, 10].

The effective coefficient of friction can then be expressed as a function of pressure in Eq. (4), where the p_{ref} is the reference pressure, e is pressure exponent,

$$\mu_{eff} = \mu\left(\frac{p}{p_{ref}}\right)^{(e-1)}. \quad (4)$$

2.2. Velocity dependent friction

The velocity dependent friction model accounts for the decrease in friction coefficient as the relative velocity between the tool and the sheet increases. Equation (5) is an enhanced Coulomb model to calculate the effective coefficient of friction, μ_{eff},

$$\mu_{eff} = \mu - a\ln\left(\frac{\max v_{rel}, v_{ref}}{v_{ref}}\right). \quad (5)$$

For this approach it is considered that if the relative velocity is smaller than the reference velocity, the effective friction coefficient is equal to the base friction coefficient μ.

A combination of both enhanced models is stated in Eq. (6).

$$\mu_{eff} = \mu\left(\frac{p}{p_{ref}}\right)^{(e-1)} - a\ln\left(\frac{\max v_{rel}, v_{ref}}{v_{ref}}\right). \quad (6)$$

2.3. TriboForm

The parameters of the virtual tribology file are shown in Table 3.

Pressure dependent friction model, velocity dependent friction model, pressure plus velocity friction model and virtual tribology were used for the simulation of the unbending operation on the studied shell part using the software AutoForm. Tree different analyses were made: friction coefficient; friction shear stress and max shear stress (on the tool).

3. RESULTS AND DISCUSSIONS

3.1. Friction coefficient

The friction results are shown in Fig. 3. The analyses are focused on the edge of the shell part where the unbending process was made, as previously mentioned.

Table 3. TriboForm input parameters

Parameters	Values
Lubrication Amount	1.2 g m^{-2}
Average Friction Coefficient	0.113
Sheet group	Steel (coated)
Sheet type	Mild Steel (+EG)
Sheet roughness	1.50
Lubricant group	Drawing oil
Lubricant min	0.60
Lubricant max	2.00
Tooling type	Cast Iron
Tooling roughness	0.40

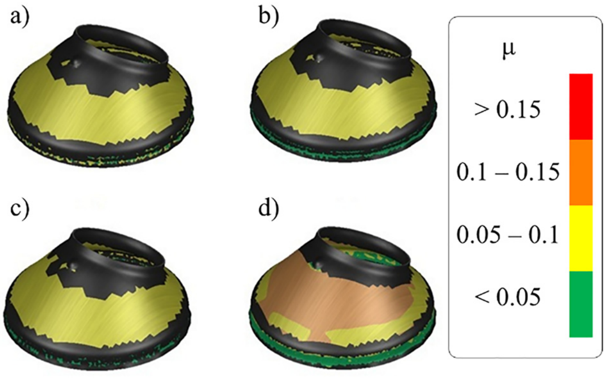

Fig. 3. Friction coefficient, a) pressure dependent friction; b) velocity dependent friction; c) pressure plus velocity dependent friction; d) virtual tribology

The state-of-the-art discussions related to friction description have come to a conclusion that the standard constant of Coulomb results in higher values of friction when compared to real processes. Parts that fail on the simulation stage can came without any failure on the workshop due to a mistaken friction description. Due to this scenario and the proven efficacy of TriboForm, the current study is taken lower friction values as a target. In Fig. 3a the worse results with higher values for the friction can be seen. On the other hand, in Fig. 3d TriboForm has shown the best results followed by the velocity dependent model in Fig. 3b.

3.2. Friction shear stress

The *x*-*z* shear stress induced by friction is known as friction shear stress (*z* is the direction normal to the sheet; *x* is the flow direction of the sheet). It is μ times the reaction pressure if the sheet slides, but it might be lower if it sticks. Below the binder, both friction shear stress at the upper and lower contact are added. Figure 4 shows the results for the friction shear stress.

The friction shear stress values are used to detect the places on the sheet that are exposed to tangential stress caused by contact with the tools, to verify the draw-beads, to identify areas of tool tear and wear, and to inspect the surface quality. Since AutoForm converts the draw-bead forces of the draw-bead model to friction forces, the draw-bead effects are also included in the friction shear stress. Analyzing the results, in Fig. 4a it can be noticed that the pressure dependent friction model has resulted on higher values for friction shear stress. Both, velocity dependent model and the virtual tribology have provided similar results.

3.3. Tool results

The maximum absolute value of the contacted element's friction shear stress that has occurred up to the current time is indicated within every tool node. The results for the friction max stress are shown in Fig. 5.

Apart from the absence of draw-bead contributions and the fact that the contact search for wear post-variables is performed from tool point to sheet, the maximum shear stress values must match the values observed for the result variable friction shear stress, which is provided for all layers. If the friction shear stress is specified for all layers, the maximum value of the tool variable maximum shear stress for each tool must be less than or equal to the friction shear stress at the contacting surface throughout the entire simulation.

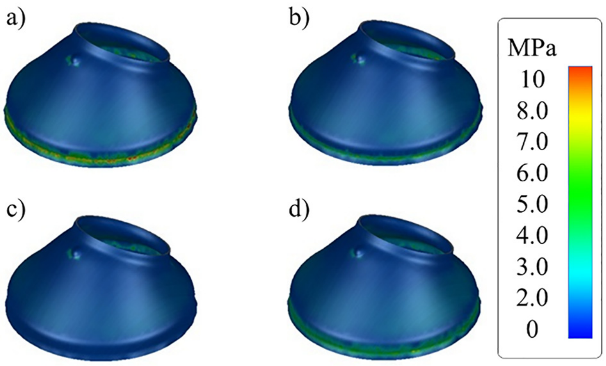

Fig. 4. Friction shear stress, a) pressure dependent friction; b) velocity dependent friction; c) pressure plus velocity dependent friction; d) virtual tribology

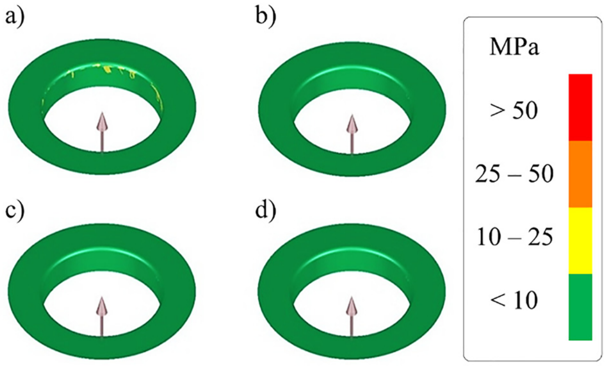

Fig. 5. Max shear stress, a) pressure dependent friction; b) velocity dependent friction; c) pressure plus velocity dependent friction; d) virtual tribology

However, in Fig. 5 the results indicate that only pressure dependent friction model has resulted in higher values. It can also be noted that both, only velocity and velocity plus pressure dependent models, resulted in lower stress together with the virtual tribology. These findings support the conclusion that there is an importance of velocity for describing friction for the unbending process on the studied region.

4. CONCLUSION

Simulation results have shown a smaller coefficient of friction when using virtual tribology. Therefore, for friction shear stress the results were similar for the velocity dependent friction model and the virtual tribology, with values close to 4 MPa. On the analyses of the tool, max shear stress was higher for pressure dependent friction model and no differences were found for the other models. For the analyzed region submitted to the unbending process the velocity dependent enhanced coulomb model seems to be more relevant than pressure dependent model to describe friction together with the simulation results using virtual tribology.

ACKNOWLEDGEMENTS

This research was conducted at the Institute of Material Science and Technology, the Faculty of Mechanical Engineering and Informatics at University of Miskolc.

REFERENCES

[1] I. Paniti, “CAD API based tool path control for novel incremental sheet forming,” *Pollack Period.*, vol. 5, no. 2, pp. 81–90, 2010.

[2] B. H. Lee, Y. T. Keum, and R. H. Wagoner, “Modeling of the friction caused by lubrication and surface roughness in sheet metal forming,” *J. Mater. Process. Technol.*, vols 130–131, pp. 60–63, 2002.

[3] M Sigvant, J. Pilthammar, J. Hol, J. H. Wiebenga, T. Chezan, B. Carleer, and A H van den Boogaard, “Friction in sheet metal forming simulations: Modeling of new sheet metal coatings and lubricants,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 418, 2018, Paper no. 012093.

[4] M. Tisza and T. Fülöp, “A general overview of tribology of sheet metal forming,” *J. Technol. Plast.*, vol. 6, pp. 11–25, 2001.

[5] I. M. Berezin, A. A. Petunin, D. I. Kryuchkov, and G. L. Kovács, “Finite-element simulation of the cold stamping process of spherical vessels,” *Pollack Period.*, vol. 12, no. 1, pp. 81–92, 2017.

[6] J. Lacues, C. Pan, J. C. Franconville, P. Guillot, M. Capellaere, T. Chezan, J. Hol, J. H. Wiebenga, A. Souchet, and V. Ferragu, “Friction and lubrication in sheet metal forming simulations: Application to the Renault Talisman trunk lid inner part”, *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 651, 2019, Paper no. 012001.

[7] L. Figueiredo, A. Ramalho, M. C. Oliveira, and L. F. Menezes, “Experimental study of friction in sheet metal forming,” *Wear*, vol. 271, nos 9–10, pp. 1651–1657, 2011.

[8] Y. Y. Wu, W. C. Tsui, and T. C. Liu, “Experimental analysis of tribological properties of lubricating oils with nanoparticle additives,” *Wear*, vol. 262, nos 7–8, pp. 819–825, 2007.

[9] I. Gil, J. Mendiguren, L. Galdos, E. Mugarra, and E. S. de Argandoña, “Influence of the pressure dependent coefficient of friction on deep drawing spring back predictions,” *Tribol. Int.*, vol. 103, pp. 266–273, 2016.

[10] Y. S. Kim, M. K. Jain, and D. R. Metzger, “Determination of pressure-dependent friction coefficient from draw-bend test and its application to cup drawing,” *Int. J. Mach. Tools Manuf.*, vol. 56, pp. 69–78, 2012.
