# Friction and lubrication modelling in sheet metal forming simulations of the Volvo XC90 inner door

**M Sigvant[1,2,7], J Pilthammar[1,2], J Hol[3], J H Wiebenga[3], T Chezan[4], B Carleer[5] and A H van den Boogaard[6]**

[1] Volvo Cars, Dept. 81153 Stamping CAE & Die Development, Olofström, Sweden.
[2] Blekinge Institute of Technology, Valhallavägen, 371 41 Karlskrona, Sweden.
[3] TriboForm Engineering, Hengelosestraat 500, 7500 AM Enschede, The Netherlands.
[4] Tata Steel, P.O. Box 10.000, 1970 CA IJmuiden, The Netherlands.
[5] AutoForm Engineering, Emil-Figge-Str. 76-80, D-44227 Dortmund, Germany.
[6] University of Twente, P.O. Box 217, 7500 AE, Enschede, The Netherlands.
[7] Author to whom any correspondence should be addressed

E-mail address: mats.sigvant@volvocars.som

**Abstract**. The quality of sheet metal formed parts is strongly dependent on the 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. This paper presents project results considering friction and lubrication modelling in stamping simulations of the Volvo XC90 inner door. For this purpose, the TriboForm software is used in combination with the AutoForm software. Validation of the simulation results is performed based on door-inner parts taken from the press line in a full-scale production run. The project results demonstrate the improved prediction accuracy of stamping simulations.

## 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. These friction conditions are dependent on the tribology system, i.e. the applied sheet material, coating, tooling material, lubrication- and process conditions. 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. At the Stamping CAE & Die Development Department at Volvo Cars, it is concluded that friction and lubrication modelling is the way forward for further improving stamping simulation accuracy. Since the results in [1] were very promising, the next step was to apply the method to stamping simulation of parts of car bodies.

## 2. Production Set-up

The part used in this study is the rear door inner of the right hand side of the Volvo XC90. The part is stamped with a single action die in a mechanical 3D-transfer press line at Volvo Cars Body Components, Olofström, Sweden. The die material is GGG70L and the die and the punch is chrome plated. The blankholder is only polished and then laser hardened. The blank is contour cut from a 0.7 mm thick VDA239-CR4 GI (hot-dip galvanized) sheet material with Fuchs 4107 applied as a pre-lube.

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

At the end of the production run, also 100 blanks of VDA239-CR4 ZM (Zinc-Magnesium coating) with the same lubricant and ordered amount were stamped. More information about the production set-up and the results from the trial are described in [2-3].

## 3. Numerical Models

### *3.1. Sheet Metal Forming Simulations*

The rear door inner forming process is simulated with AutoForm$^{plus}$ R6.0. The die, punch and blank holder surfaces have been scanned and thus also include geometrical draw-beads. The resulting deformations of the blank holder in the die structure analysis are incorporated into the sheet metal forming model by AutoForm's morphing functionality, see [4] for more details. The BBC2005 material model, see [9], is used for all simulations, using four initial yield stress, four R-values and the exponent M as input. The blank holder force is modelled with columns and the load on each column is taken from a die structural analysis. The ram speed in the simulation is taken identical to the ram speed of the mechanical press-line. The different friction models are included in the simulations using the TriboForm FEM Plug-In for AutoForm.

### *3.2. Friction Models*

Tribological conditions in metal forming processes are dependent on local process and lubrication conditions, loading and local strain state of the sheet material as demonstrated in [5-6]. The TriboForm software allows for multi-scale modelling of a time and locally varying friction coefficient under a wide range of process conditions. The physically-based models included in TriboForm enable friction modelling in the mixed lubrication regime. This is achieved by coupling a boundary lubrication friction model [7] and a hydrodynamic friction model [8]. Information of the tribology system is required as an user input, 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. The friction models for GI and ZM lubrication systems assumes the following: tool surfaces are chrome plated GGG70L die material with a Ra of 0.35 and the amount of the lubricant Fuchs 4107 is 2.0 g/m$^2$. The lubrication amount is based on the lubrication amount measurements on the blanks and the observation that there was oil present on the forming surfaces in the die.

## 4. Results

### *4.1. Friction models*

A comparison of the two lubrication systems reveals that they have a different tribological behaviour. The friction coefficient in the GI lubrication system varies more with contact pressure and relative velocity of the sheet than the ZM lubrication system. Another difference is that the friction coefficients at low contact pressures are almost twice as large for GI than for ZM. Generally, the ZM lubrication system is rather stable, i.e. similar friction coefficient independently of contact pressure and relative velocity, which is a good property of a lubrication system. More information about the two lubrication systems can be found in [3].

### *4.2. Draw-in predictions*

The predicted draw-in values for the GI system are from a stamping simulation using a constant friction coefficient μ equal to 0.15 and a stamping simulation using the TriboForm friction model. On the top and bottom edges of the part, the predicted values are close to each other and also to measured ones. On the other two edges the difference is larger between the μ=0.15 and the TriboForm model. Also on these two edges, the predicted draw-in with the TriboForm model is very close to the measured one. The general impression is that the TriboForm model predicts the draw-in more accurately than the model using μ=0.15.

The prediction of the draw-in of the sheet edges with a TriboForm ZM lubrication model is less accurate than the GI model prediction. The ZM prediction is only accurate at front edge of the part, on all other edges the draw-in is overpredicted. On the other hand, the prediction of the size of the pre-cut holes are better for ZM lubrication system than for the GI lubrication system. Another interesting observation is that draw-in predictions with μ=0.15 is more accurate than TriboForm model on all edges, except at the front edge where μ=0.15 underpredicts the draw-in. These results indicate on one hand that the TriboForm ZM model predicts the friction coefficient on the part accurately, while it is underpredicting it on the addendum and on the other hand that μ=0.15 is a more accurate model for ZM. More information about the draw-in predictions can be found in [3].

### *4.3. Major strain predictions*

Figure 1 presents comparisons made between predicted and measured major strains. In areas with red colours the simulations are overpredicting the strains and in blue areas the simulations are underpredicting the strains. In black and white areas, the overestimation or underestimation is more than 0.05.

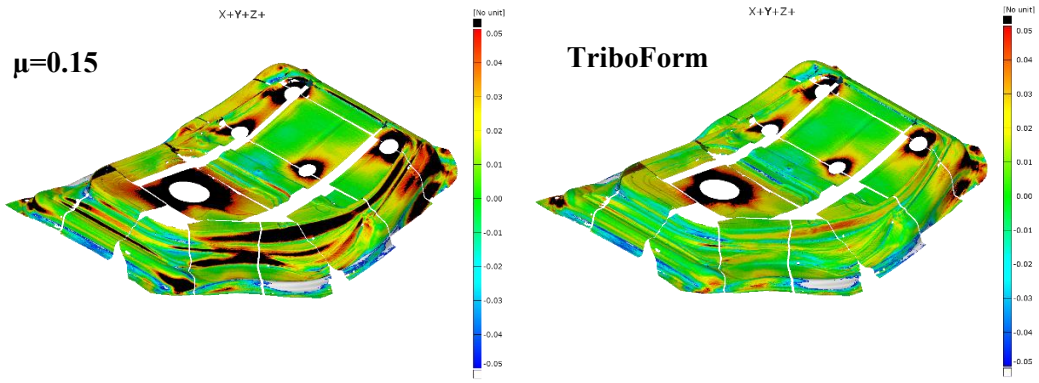


Figure 1. Difference in true major strain between simulations and experimental measurements for the GI system.

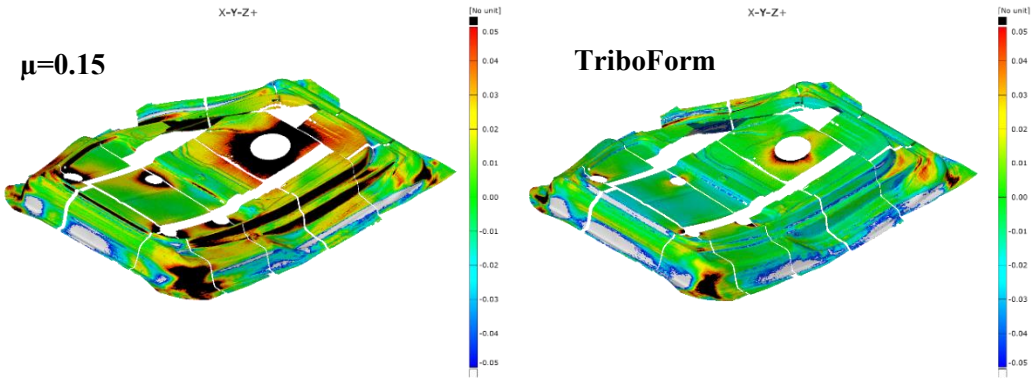


Figure 2. Difference in true major strain between simulations and experimental measurements for the ZM system.

Using a constant friction coefficient of μ = 0.15 results in too large major strains in several areas, especially in vertical walls. Using the TriboForm friction model will result in lower friction coefficients in areas with high contact pressures, e.g. in radii and draw beads, and also in areas with high relative velocity between the sheet and the die surfaces. This results in a better agreement between simulated

and measured major strains. The comparison for the minor strains show the same trend, i.e. that the accuracy of the sheet metal forming simulation results increases using the Triboform GI friction model.

Figure 2 shows the comparison between predicted major strains and measured strains for the ZM lubrication system. Once again the TriboForm model is predicting the strains more accurately than the $\mu = 0.15$ model. This is a very encouraging result since the draw-in was overpredicted for ZM system with the TriboForm model, which then could indicate that the TriboForm friction model for this lubrication system was less accurate.

## 5. Conclusions and future work

The results presented in this paper demonstrate 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.

There are several benefits of the presented approach. First of all, the TriboForm software is based on physical models with input parameters that can be efficiently collected from a database or measured with minimal effort. This enables to accurately predict the results of sheet metal forming operations before manufacturing the dies. Secondly, it enables the simulation of friction conditions for the materials and lubricants used in actual production of automotive parts and reduces the demand for experimental testing and try out. Overall, it enables Volvo Cars to further reduce lead time and development cost through the use of more accurate stamping simulations.

Although very encouraging results, there is still room for further improvements of the modelling techniques. Using the real ram velocity of the press results in strain rates in the simulation that are substantially higher than the strain rate material testing normally is performed at. Therefore, the strain rate effects of sheet material will be included in future studies and it will probably increase the accuracy even more. It is also important to have accurate models for each lubrication system used in the real die. Therefore, future implementations of the TriboForm FEM Plug-In will have the possibility to use multiple friction models.

References

[1] Sigvant M, Hol J, Chezan T and van den Boogaard A H, 2015, Friction modeling in sheet metal forming simulations: Application and validation on an U-bend product, *Proc. of FTF 2015 (Zürich, Switserland).*

[2] Sigvant M, Pilthammar J, Hol J, Wiebenga J H, Chezan T, Carleer B and van den Boogaard A H, 2016, Friction and lubrication modeling in sheet metal forming simulations of a Volvo XC90 inner door, *Proc. of IDDRG 2016* (*Linz, Austria*).

[3] Sigvant M, Pilthammar J, Hol J, Wiebenga J H, Chezan T, Carleer B and van den Boogaard A H, 2016, Friction in sheet metal forming: Simulation of the Volvo XC90 inner door, *Proc.of FTF 2016 (Ohlstadt, Germany).*

[4] Pilthammar J, Sigvant M and Walter S.K., Including die and press deformations in sheet metal forming simulations, *Proc.of NUMISHEET 2016 (Bristol, UK).*

[5] Grueebler R and Hora P, 2009, Temperature dependent friction modeling for sheet metal forming. *International Journal of Material Forming, **2**:251–254*.

[6] Ludwig M, Müller C and Groche P, 2010, Simulation of dynamic lubricant effects in sheet metal forming processes, *Key Engineering Materials, **438**: 171–178*.

[7] Hol J, Meinders V T, de Rooij M B and van den Boogaard A H, 2014, Multi-scale friction modeling for sheet metal forming: The boundary lubrication regime, *Tribology Int., **81**: 112–128.*

[8] Hol J, Meinders V T, Geijselaers H J M, and van den Boogaard A H, 2015, Multi-scale friction modeling for sheet metal forming: the mixed lubrication regime. *Tribology Int., **85**: 10–25*.

[9] Banabic D, Carleer B, Comsa D S, Kam E, Krasivskyv A, Mattiasson K, Sester M, Sigvant M and Zhang X, 2010, Sheet Metal Forming Processes, Constitutive Modelling and Numerical Simulation, *Springer*.