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# Friction in Sheet Metal Forming: Forming Simulations of Dies in Try-Out

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**Abstract.** The quality of sheet metal formed parts is strongly dependent on the tribology and friction conditions that are acting in the actual forming process. This paper focuses on the tribology conditions during early try-out of dies for new car models. The motivation for the study is that the majority of the forming simulations at Volvo Cars are performed to secure the die try-out, i.e. solve as many problems as possible in forming simulations before the final design of the die and milling of the casting. In the current study, three closure parts for the new Volvo V60 model have been analysed with both Coulomb and TriboForm friction models. The simulation results from the different friction models are compared using thickness measurements of real parts, and 3D geometry scanning data of the parts. Results show the improved prediction capability of forming simulations when using the TriboForm friction model, demonstrating the ability to accurately describe try-out conditions in sheet metal forming simulations.

## 1. Introduction

The quality of sheet metal formed parts is strongly dependent on the tribology and friction conditions that are acting in the production process [1,2]. These friction conditions are dependent on the utilized sheet material, tooling material and lubricant. This combination of factors is known as the tribological system or tribology system. 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. This limits the overall simulation accuracy as also demonstrated in earlier work of the authors, both for a U-bend application [3] and the Volvo XC90 right rear door inner [4,5].

This paper presents a selection of results considering friction and lubrication modeling in stamping simulations of dies for the new Volvo V60, demonstrating the strong influence of tribology and friction conditions on predictions of draw-in and sheet thickness. First the overall project approach will be outlined with details on the sheet materials, lubricants and die materials. Next, a description of the project results including a comparison between results from forming simulations using TriboForm friction models, forming simulations using a constant Coulomb friction and measurements on real parts is presented. Finally, the conclusions and points of future work are described.

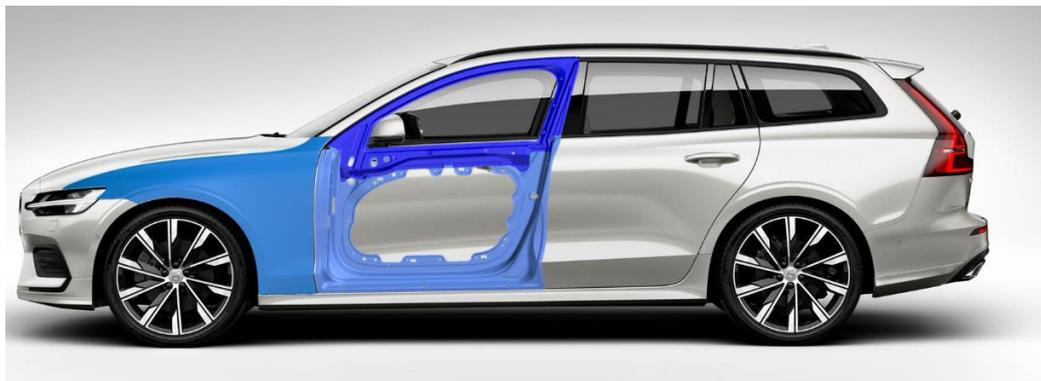


## 2. Approach

The goal of the current study is twofold. First of all, the goal is to apply TriboForm friction models at Volvo Cars on dies in early try-out. The motivation for the study is that the majority of the forming simulations at Volvo Cars are performed to secure the die try-out, i.e. solve as many problems as possible in forming simulations before the final design of the die and milling of the casting. Secondly, the goal is to study the effects on stamping results of new lubricants and sheet metal coatings. The current study includes three different parts for the new Volvo V60, see Table 1 and Figure 1. The stamping dies for these parts are all manufactured at Volvo Cars tool shop in Olofström.

**Table 1.** Parts included in the current study

Part	Material	Coating	Pre-lube	Process
Fender	CR3	ZM 50/50+E	PLS100T	Single action
Front Door Inner	CR4	GI 50/50+U	3802	Double action
Front Door Ringframe	CR4	GI 50/50+U	PLS100T	Single action



**Figure 1.** The new Volvo V60 and the parts included in the study.

### 2.1. Sheet materials, lubrications and die materials

The sheet materials used are two mild steels, VDA239 CR3 ZM50/50-E (abbreviated CR3-ZM) and VDA239 CR4 GI50/50-U (abbreviated CR4-GI). The pre-applied lubricants used for these parts are Fuchs Anticorit PL3802-39S (abbreviated 3802) and Fuchs Anticorit PLS100T (abbreviated PLS100T). The Fender is the first exterior part with ZM coating in Volvo Cars tool shop and main driver for ZM is increased corrosion protection. In addition, a previous study on the Rear Side Door Inner of XC90, presented in [5], revealed that the ZM coatings also improves the stamping performance. The friction conditions for the three different tribology systems have been determined according to the procedure described in [6,7]. The die material for all cases is GGG70L. The surface properties of the blanks were determined using sheet samples from Tata Steel. With this information and viscosity data of the lubricants, three TriboForm Libraries were created which include the friction conditions for the considered tribology systems.

### 2.2. Forming simulations

The sheet metal forming simulations in this study were performed with AutoForm<sup>plus</sup> R7.0.3. The material model used was BBC2005, with material parameters determined according to the method described in [8]. The used material data is presented in Table 2. The ram velocity for the single action processes was set to 50 mm/s and for the double action process it was set to 100 mm/s. This is due to the fact that the single action process was performed using a hydraulic press, while the double action one was tested using a mechanical press.

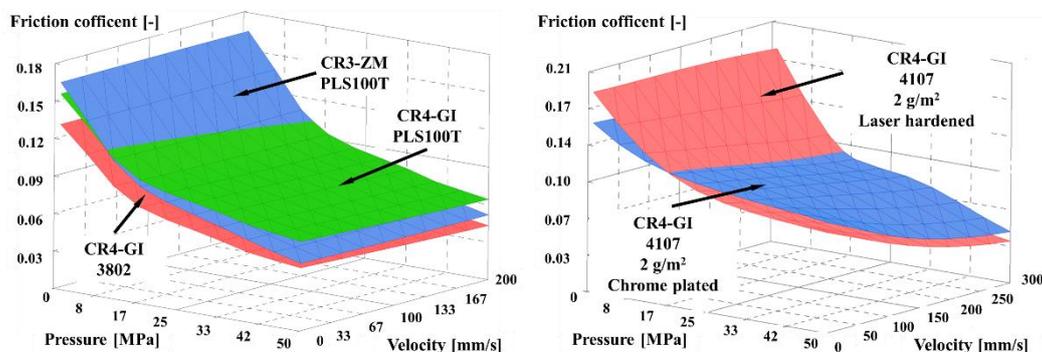
**Table 2.** Material data for the BBC2005 model.

	$\sigma_0$ [MPa]	$\sigma_{45}$ [MPa]	$\sigma_{90}$ [MPa]	$\sigma_b$ [MPa]	$R_0$	$R_{45}$	$R_{90}$	$R_b$	$M$
CR3	189.8	190.0	185.0	223.0	1.88	1.71	2.40	0.95	5.2
CR4	156.6	160.0	156.0	187.0	1.81	1.34	1.88	0.98	4.5

### 3. Results and discussion

#### 3.1. Tribology systems

The left plot in Figure 2 displays the three tribology systems used in this study and the corresponding friction models as a function of contact pressure and sliding velocity. As a comparison, the models from the study presented in [4,5] are displayed in the right plot in Figure 2. The three different systems used in this study are very similar and furthermore, the friction coefficients for each model is much lower than 0.15 which is today's standard value for Coloumb friction at Volvo Cars. Only at low contact pressures, the CR3-ZM model and the CR4-GI model with PLS100T has a higher friction coefficient than 0.15. Another interesting observation is that both models for CR4-GI in the current study have similar or slightly lower friction behavior than the models used in the study presented in [4,5]. Since the die surfaces in [4,5] are either hardened or chrome plated, with a lower surface roughness and a higher lubrication amount of 2 g/m<sup>2</sup>, one should expect lower friction coefficients for these models than the models used in this study. However in [4,5], the pre lubricant is only a rust protection oil which has less or no positive effects on the tribological conditions. Other positive effects of the first and second generation pre-lubricants are less migration and sagging over time compared to rust protective oils.



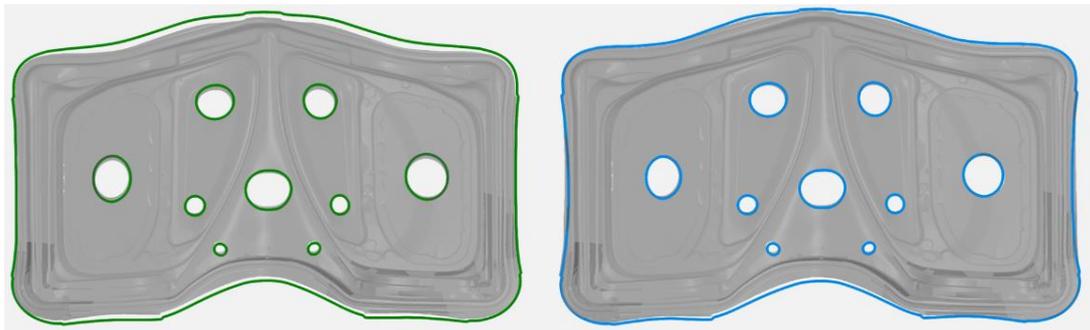
**Figure 2.** The three tribology models used in this study (left) and the tribology models from [4,5] (right) for a strain of 0% and a temperature of 21°C.

The varying friction conditions will have an impact on almost all results of a sheet metal forming simulation, i.e. draw-in, major and minor strains, spring-back and stamping forces. By comparing simulation results using the tribology models as presented in the left part of Figure 2, with simulations using a constant friction coefficient of 0.15 and measurements on real parts from die try-out, the impact on each stamping process result can be quantified.

#### 3.2. Draw-in

In this section the final position of the blank edge and pre-cut holes are compared with scanned data of parts from die try-out. This comparison reveals that the predicted blank edge position for the Fender and the Front Door Ringframe, is very similar, regardless if the TriboForm models are used or a constant friction coefficient of 0.15 is used. Furthermore, the accuracy of these predictions is generally very good, i.e. a small difference between measured and predicted edges are observed.

The results for the door inner is completely different. The CR4-GI with 3802 friction model has a much larger draw-in compared to the same simulation using a constant friction coefficient of 0.15. The maximum difference is almost 30 mm in some areas. The accuracy of the predictions is different in different areas of the part, see Figure 3. Along the lower edge of the two doors, the constant friction model has a higher accuracy of the draw in prediction. In these areas, the TriboForm model are overestimating the draw-in with up to 20 mm. The draw-in of the other edges, i.e. the front and rear edges of the doors, is underestimated by both friction models, but the TriboForm model is closer to the scanned data. Finally, the final edge of the pre-cut holes in blank is predicted with higher accuracy with the TriboForm friction model compared to using a constant friction.



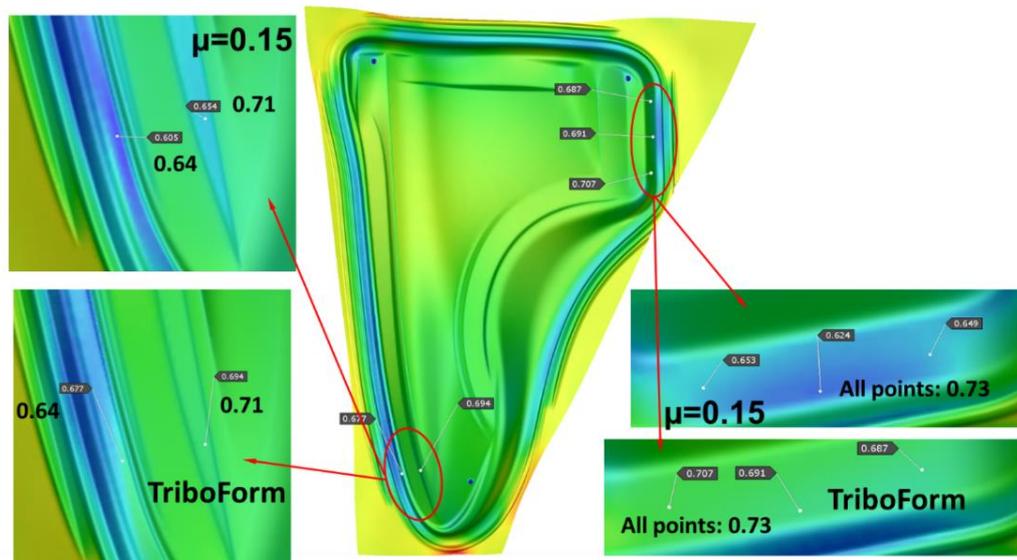
**Figure 3.** Scan data (grey) compared with predicted edges using  $\mu=0.15$  (left) and the TriboForm model for CR4-GI and 3802 (right).

This last conclusion indicates that the friction conditions for the parts of the blank that are in contact with the punch are more accurately modelled with the TriboForm model than using constant friction. The draw-in of the edges is also influenced by the pressure distribution under the blank holder which in turn is influenced by elastic deformations of the blankholder. Since this a double action forming process, the deformation of the blankholder varies quite a lot between different areas of the blankholder. It is reasonable to assume that the deformation is smaller and thereby yielding higher contact pressures along the lower edges of the door. This is due to the fact that these edges are closer to the outer ram than the other two edges. This argument will also lead to larger deformations along the front and rear edges and thereby a lower contact pressure.

### 3.3. Sheet thickness after forming

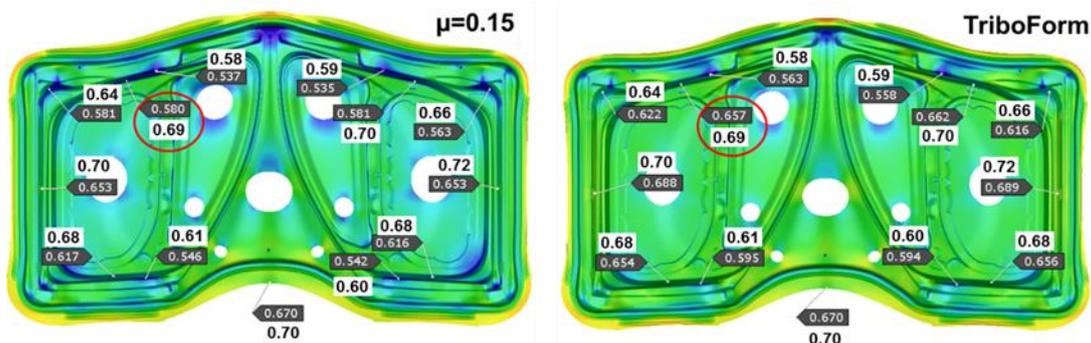
Since no strain measurements were available, the second best option was to compare sheet thickness measured in the final parts with the prediction from simulations using different friction models. The thickness measurements on the parts were made with an ultrasonic device. For the Ringframe part, both simulation models predict almost identical sheet thickness and these values agreed well with the measurements on the real part.

The predicted sheet thickness for the Fender is also generally very similar using the TriboForm model or using a constant friction coefficient. However, a closer inspection reveals that there are two areas of the part where the two simulation models predict quite different thicknesses, see Figure 4. In both these areas, the values predicted using the TriboForm model are closer to the measurements made on the real part than the results using a constant friction. In one point, the difference in sheet thickness between measurements and predicted values using a constant friction coefficient is 0.1 mm which is a large deviation. Worth mentioning is the fact that the predicted thickness in that point is smaller than the measured one, i.e. the part is closer to failure limit in the simulation than in try-out if one uses a constant coefficient of friction of 0.15. These results are encouraging and interesting since the draw-in for the two different friction models were very similar.



**Figure 4.** Predicted and measured sheet thickness for the Front Fender part. Measured values plotted next to AutoForm values.

The difference in predicted sheet thickness for the Front Door Inner is slightly larger than for the Fender. For this part, the values predicted using the TriboForm model are closer to the measured ones than the values predicted using a constant friction coefficient, see Figure 5. Also in this comparison, there is one point where the difference between the measurements and predicted values using a constant friction coefficient of 0.15 is more than 0.1 mm. This point is marked with a red circle in Figure 5. However, one should keep in mind that this part has the least accurate prediction of the draw-in, which also influences accuracy of the sheet thickness prediction. However, in the area where the marked point is located, the TriboForm of the sheet thickness prediction. However, in the area where the marked point is located, the TriboForm results predict the draw-in more accurately. For this point, it is therefore safe to claim that the TriboForm prediction is more accurate.



**Figure 5.** Predicted and measured sheet thickness for the Front Door Inner part. Measured values plotted next to AutoForm values.

#### 4. Conclusions

There are a number of interesting conclusions that can be drawn from this study. First of all, the TriboForm results indicate that the lubricants of the first and second generation used in this study will improve stamping robustness. Comparing the data for the TriboForm models in this study with data from previous studies with hardened and smoother die surfaces but only with a rust protective lubricant, the friction coefficients are similar or slightly lower. In addition, other positive effects of the new pre-lubricants that have not been analysed in this study are e.g. less migration and sagging.

Another interesting observation is that, using the TriboForm models in stamping simulations, results in predictions of draw-in and sheet thickness are at least as accurate as using a constant friction coefficient of 0.15. In fact, in the majority of the comparisons between simulation and measured data made in the study, the simulation accuracy is higher using the TriboForm models than using a constant coefficient of friction. This is the same conclusion as the authors have made previously in studies of both lab scale tests and parts in running production [3-5]. From the combined results of these studies, it can be concluded that the TriboForm software and resulting friction models are applicable on all different types of parts, tribology systems and scenarios present in sheet metal forming.

Finally, a constant coefficient of friction can be seen as an average value that can be used to approximate friction conditions for different tribology systems and forming processes in a good way and thereby resulting in a good simulation accuracy. An implication of this statement is that in order to achieve a higher simulation accuracy, you can try to determine an optimal constant friction coefficient for each tribology system and forming process. This is an almost impossible task since values are needed in the engineering phase that ideally can't be determined until after die try-out. The solution instead is to determine and use advanced friction models, like the TriboForm models, that accurately predict friction conditions of the actual tribology systems used.

## 5. Future work

The next step at Volvo Cars is to apply the TriboForm model in sheet metal forming simulations of all parts manufactured in the Volvo Cars tool shop. This must be done in a controlled manner and will be done gradually over a number of future car projects. A parallel track for future investigation is to include the variation of oil amount over the sheet in the simulations, e.g. as measured in production, and study the effects of this variation on part quality. The influence to different blank holder models and numerical setting in AutoForm should also be evaluated.

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