Strategies for increasing the accuracy of sheet metal forming finite element models

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Abstract. Accurate modelling of sheet metal forming can contribute significantly to reduction of lead time and development costs in manufacturing industries. The current way to improve the finite element model accuracy is to combine advanced constitutive material models and advanced tribological models. For model validation purposes the geometry of the forming tools needs to be updated and the most relevant parameters of the forming press needs to be incorporated. The addition of a simple and easier to control model test can offer additional information on difficult to characterize parameters of the industrial process. The industrial validation case presented in this paper demonstrates that the Tata Steel constitutive material model has similar prediction capability as the state of the art material model used at Volvo Cars for regular process development for automotive parts production. In both industrial and model tests the tribological system appears to affect significantly the overall model accuracy. The model tests suggest that further work is needed in order to improve the tribological model description at high contact pressure and high strain levels.

1. Introduction
Accurate modelling of sheet metal forming can contribute significantly to reduction of lead time and development costs in manufacturing industries. In addition, accurate models can be used for further optimization of sheet metal material selection and for maximization of blank utilization in order to keep the material costs at a minimum and to reduce scrap.

The overall accuracy increase can be obtained by combining models capable of describing the complex behavior during sheet metal stamping of both material plastic deformation and the corresponding tribological system describing the interaction between the metal sheet and the forming tools.

Significant advances in developing accurate sheet metal plastic deformation behavior achieved at Tata Steel R&D were reported by Abspoel et al in [1] and [2]. This new approach that allows accurate prediction of anisotropic yielding, strain rate sensitivity and material forming limit is currently available in commercial finite element codes used for sheet metal forming process development like AutoForm® plus R7.0.

The current state of the art tribological system model is offered by TriboForm [3] and [4]. This model predicts the dependence of the friction coefficient on contact pressure, sliding velocity, plastic strain and temperature, specific for a tribological system defined by lubricant type and quantity, material surface...
type and roughness and tool surface material and roughness. The accuracy increase offered by the TriboForm model as compared to the common Coulomb constant coefficient of friction model was demonstrated in the case of model tests and industrial forming processes in [5], [6] and [7]. The approach was proven to be successful especially in predicting forming speed effects.

Typically the stamping model accuracy can be estimated by comparing the model prediction with draw in and strain measurements on the formed parts. Usually such an exercise requires an update in the model of the geometry of the stamping tools due to the fact that the current geometry can be significantly altered during setting up series production processes. The update is done by tool surface digitization techniques using either optical 3D measuring systems or laser scanning and incorporation of elastic deformation of the tools like described in [7]. Further, in order to take advantage of the material deformation rate and sliding speed dependence of the friction coefficient the actual ram velocity is usually considered in the simulation.

Still there are various experimental parameters difficult to characterize and implement that might affect significantly the model accuracy like for instance actual contact pressure distribution on flat areas and draw beads, tool temperature and/or lubricant quantity. The validation exercises presented in this paper indicate that the differences between the model prediction and the experiments are measurable and significant suggesting that either process parameters update or the models accuracy can be further improved. The complexity of the industrial experiments makes difficult to identify and quantify the contributions of the industrial process parameters on accuracy limitations. The strategy we propose in this paper is to use a complementary model test like the cross-die described [8], [9] and [10]. Such a test offers better experimental control and possibility to isolate particular effects experimentally and consequently makes easier to distinguish between various contributions to the overall model accuracy.

2. Experimental

2.1. Materials

Four coated low carbon steel grades were used for this study. The industrial validation was performed on blanks of VDA239-CR4-GI and respectively VDA239-CR4-ZM [6], [7]. The model tests were performed on VDA239-CR5-GI and VDA239-CR4-ZM [9]. GI stands for a conventional hot-dip galvanized coating with Zn as the main constituent. ZM is an advanced hot-dip zinc coating alloyed with magnesium and aluminium. It reduces tool pollution for improved press shop efficiency whilst delivering superior corrosion protection and scope for weight reduction. Fuchs RP4107S was used in all cases as the lubricant.

The industrial validation experiments were performed on the right hand side rear door inner of the XC90 pressed at Volvo Cars Body Components, Olofström, Sweden [6] and [7].

The model tests were performed using a cross-die tooling in a hydraulic press at Tata Steel R&D, IJmuiden, The Netherlands [9].

For both industrial and model test blanks were electrochemically etch grided with a polka dot grid pattern and the formed parts were used for optical full-field strain measurements.

2.2. Numerical models

Specific material cards were built from tensile tests for the four materials according to Tata Steel procedure described in [1] and [2]. The corresponding hardening curves are presented in Figure. 1 and the yield locus parameters are summarized in Table 1. For the VDA239-CR4-GI also the Volvo Cars material model [6] was used for the industrial validation case. Tribocards [4] were generated for the GI and ZM systems. Examples of the calculated coefficients of friction as a function of sliding velocity, contact pressure and strains are presented in Figure. 2. The geometry of the industrial tools and the corresponding process parameters were incorporated in the finite element model as describe in [6] and [7]. A similar procedure was used to generate the finite element model of the cross-die test.
Figure 1. The hardening curves of the materials.

Table 1. Parameters of the yield locus of the materials.

| Parameters            | Industrial validation | Model test |
|-----------------------|-----------------------|------------|
| r-values              | CR4-GI                | CR4-GI-Volvo| CR4-ZM | CR5-GI | CR4-ZM |
| r0                    | 2.15                  | 1.81       | 2.10   | 2.43   | 2.24   |
| r45                   | 1.66                  | 1.34       | 1.72   | 2.05   | 1.75   |
| r90                   | 2.49                  | 1.88       | 2.56   | 2.97   | 2.58   |
| Uniaxial stresses     |                       |            |        |        |        |
| σ₀/σ₀                 | 1.00                  | 1.00       | 1.00   | 1.00   | 1.00   |
| σ₄₅/σ₀                | 1.03                  | 1.02       | 1.02   | 1.03   | 1.03   |
| σ₉₀/σ₀                | 0.99                  | 1.00       | 0.99   | 1.00   | 1.00   |
| Biaxial parameters    |                       |            |        |        |        |
| rb (r-value)          | 0.89                  | 0.98       | 0.85   | 0.82   | 0.87   |
| σb/σ₀ (stress)        | 1.13                  | 1.19       | 1.13   | 1.15   | 1.15   |
| Yield locus model     | Vegter                | BBC        | Vegter | Vegter | Vegter |
3. Results and discussions

3.1. Industrial validation

In Figure 3 the differences between the predicted and measured major strains for the industrial validation case are presented. For all simulations the TriboForm friction model was used. The areas in red indicate an overprediction while the areas in blue indicate an underprediction of the major strain as compared to the strain measurements. If the over prediction or under prediction is more than 0.1 the areas are respectively coloured black or magenta. For the GI system the Volvo Cars (a) and the Tata Steel material model (b) give similar results. The ZM system (c) is better predicted as compared to the GI system (b) particularly at the pre-cut holes and the rest of the punch area. All models appear to have difficulties in predicting the areas close to the draw beads. In these areas the local geometry of the tools creates concentrated areas of high contact pressure. The extreme case is the line contact in the draw bead areas where the material is bended and un-bended.

Figure 3. Differences in major strain between simulations and measurements for (a) Volvo material model – GI system, (b) Tata Steel material model – GI system, (c) Tata Steel material model – ZM system.
3.2. Model test
The prediction capability of the TriboForm friction model was further assessed in model tests at higher contact pressure conditions and at different plastic deformation levels. While the initial nominal pressure in the blank holder area for the door inner is of the order of 2 MPa, the cross die experiments allow the increase of the initial contact pressure to 6 MPa for a blank holder force of 250 kN and to 10 MPa for a blank holder force of 400 kN. The maximum contact pressure estimated in the cross-die experiments using a pressure sensitive foil was 40 MPa for 60 mm drawing depth for the ZM system and 20 MPa for 40 mm drawing depth for the GI system.

The differences between the predicted and the measured major strains for the model tests are presented in Figure 4. The colour scheme is similar to that in Figure 1. The ZM system appears to be very well predicted for tests performed at a blank holder force of 250 kN (Figure 4a, b and c). A more difficult to predict situation was found during testing the GI system at a blank holder pressure of 400 kN (Figure 4, e and f). In this case the simulations predicts much more stretching on the punch nose and less draw in suggesting a relative higher coefficient of friction of the TriboForm model as compared to the experimental behaviour.

The difference between the model prediction and measurements is already seen at 20 mm draw depth for the GI system. At this depth, in the experiments, the draw in of approx. 5 mm and the plastic deformation is approx. 0.2 major true strain in the punch nose area. The model predicts more stretching on the punch nose (yellow areas) and less draw in suggesting a higher model friction in the blank holder area as compared to the experiments. While the mechanical properties of the two materials are similar the friction models predict significantly higher coefficient of friction for the GI system as compared to the ZM system as illustrated in Figure 2. This can explain the observed difference between the model and measurements in the GI case.

Figure 4. Differences in major strain between simulations and strain measurements for the ZM system (250 kN blank holder force) for draw depths of (a) 20 mm, (b) 40 mm, (c) 60 mm and for the GI system (400 kN blank holder force) for draw depths of (d) 20 mm and (e) 40 mm.
4. Conclusions
The industrial validation case demonstrates that the Tata Steel material model has similar prediction capability as the state of the art material model used at Volvo Cars for regular process development for automotive parts production.

In both industrial and model tests the ZM system appears to be easier to predict as compared to the GI system. This is probably caused by the lower friction coefficient of ZM. The complementary information offered by model testing can be used to distinguish between different contributions to the accuracy of the finite element modelling used in stamping processes. The model tests suggest that further work is needed in order to improve the model description for high contact pressure and high strain levels.

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References
[1] M. Abspoel, M. E. Scholting, M. Lansbergen, Y. An and H. Vegter, "A new method for predicting advanced yield criteria input parameters from mechanical properties," Journal of Materials Processing Technology, vol. 248, pp. 161-177, 2017.
[2] M. Abspoel, M. E. Scholting and J. M. M. Droog, "A new method for predicting Forming Limit Curves from mechanical properties," Journal of Materials Processing Technology Vol 213, Issue 5, pp. 759-769, 2013.
[3] J. Hol, Multi-scale friction modeling for sheet metal forming PhD Thesis, 2013.
[4] "www.triboform.com," 2017. [Online].
[5] Sigvant M., Hol J., Chezan T., Boogaard T. van den: Friction modeling in sheet metal forming simulations: Application and validation on an U-bend product, FTF 2015, Zurich, Switzerland.
[6] M. Sigvant, J. Pilthammar, J. Hol, J. H. Wiebenga, T. Chezan, B. Carleer and A. H. van den Boogaard, "Friction and lubrication modelling in sheet metal forming simulations of the Volvo XC90 inner door," in Numisheet Journal of Physics: Conference Series 734, 2016.
[7] Sigvant M., Pilthammar J., Hol J., Wiebenga J.H., Chezan T., Carleer B., Boogaard T. van den: Friction in sheet metal forming: simulations of the Volvo XC90 inner door, FTF 2016, Ohlstadt, Germany
[8] J. van Beeck, T. Khandeparkar, T. Chezan, C. Dane and M. Sigvant, "Novel methods in tribomechanical modelling of automotive sheet steel forming," in Steels in Cars and Trucks, Noordwijkhout, 2017.
[9] T. Khandeparkar, T. Chezan, and J. van Beeck, "New developments in tribomechanical modeling of automotive sheet steel forming", Proc. ESAFORM 2018.
[10] J. van Beeck, T. Chezan and T. Khandeparkar, "Advanced tribomechanical modelling of sheet metal forming for the automotive industry", IDDRG 2018.