SMART STAMPING:
IMPROVED QUALITY IN STAMPING BY
MODEL DRIVEN CONTROL

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ABSTRACT: Sheet Metal Forming is a very complex manufacturing process with a number of non-linearities, e.g. large deformations, localisation, elastic-plastic materials, pressure and velocity dependant friction conditions and structural deficiencies in the die and press, present and interacting simultaneously. This leads to disturbances in running production that results in production waste, e.g. down time for the press line and cost for rework and scrapping of parts. These production problems are also hard to understand and solve based on experience and analytical models due to the presence of several non-linearities. An alternative is to try to solve these problems proactively before they occur. This could be done with model based control by creating a digital twin of the die-set and the press line. Therefore, a virtual production process is developed to be able to use as knowledge building and as engineering tool during development, manufacturing, issue resolution and optimization. In this paper presents the authors ideas and plans for research and other activities within the area of model based control of sheet metal forming.

KEYWORDS: Industry 4.0, Model Driven Control, Sheet Metal Forming Simulations, Material modelling, Friction Modelling, Elastic stamping dies.

1 INTRODUCTION

Figure 1 presents the cushion force as a function of the number of parts produced for two press batches of the left-hand side Front Door Inner of Volvo XC90. The ground for these alternations of the cushion force are various quality problems with the parts, e.g. if there are wrinkles the cushion force is increased, if there are local events occurring for instance necking or fracture, the cushion force is decreased. In addition, a change to another batch of raw material, i.e. steel coil, with slightly different mechanical properties and oil amount can influence the applied cushion force.

The changes of the cushion forces are done manually at the press line and are always triggered by inspections of produced parts by the press line operators. It is a hard and challenging task for them to find all disturbances and the operators are usually acting reactively, i.e. after a problem has occurred. It also interesting to observe that the two batches are produced using quite different setting of the press line.

This scenario is quite common and illustrates the potential benefits that can be achieved if the operators could act actively, i.e. change the settings of the press line before quality issues occur. One way to do that is to create a digital twin of the die set and press line and then let that digital model to iterate and decide the optimal press line setting for each batch based on the input parameters for that particular batch.
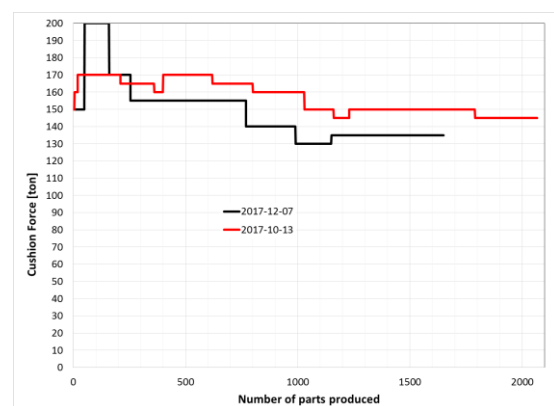

Fig. 1 *Cushion force as a function of number of parts produced for two batches.*

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2   MODEL BASED CONTROL

The first step is to create a digital twin of each combination of die set and press line used. One important demand on this digital model is that it must respond to changes in the input to the digital model in the exact same way as the real die set and press line responds to variation in input to the process, see Figure 2.
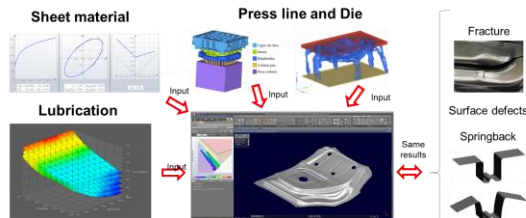

Fig. 2   *A schematic view of a digital twin of a die and a press line.*

Due to the number of non-linearities present in sheet metal forming, the digital model will be very complex and must include several features that are not included in sheet metal forming simulations today. This results in very long simulation times and therefore, in the second step, the results from the digital twin must be transformed into some kind of meta model that can be quickly evaluated by the operators at the press line, see Figure 3. Some results will be presented in the following sub-chapters that shows which effects that must be included in the digital twin and what choices that must be made when it comes to material and friction modelling.
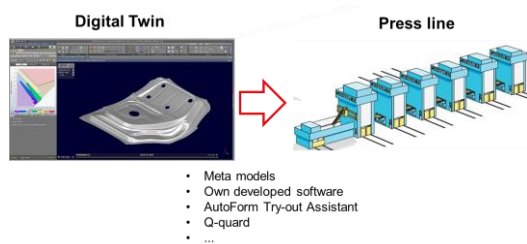

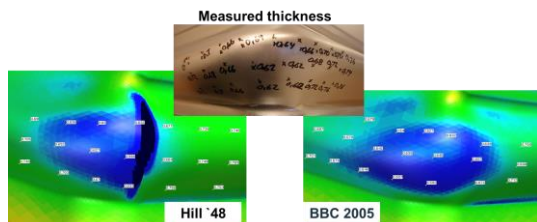**Fig. 3**   *A schematic view of the link between the digital twin and the press line.*

Fig. 4   *Predicted sheet thickness with Hill´48 (left) and BBC 2005 (right) together with measured thickness (middle).*

2.1   ACCURATE MATERIAL MODELLING

Volvo Cars has been using the BBC2005 material model in AutoForm since more than a decade. The benefits are improved accuracy of the predictions, see Figure 4. An important remark is that the defined input parameters must be checked with inverse modelling of some experiment, e.g. LDH with friction between punch and blank that Volvo Cars uses. For example, the exponent M is by many people, both in the industry and academia, assumed to be either 6 or 8. According to Volvo Cars experience, the exponent M is very different for different type of materials and for some grades even different from supplier to supplier.

In the future will also kinematic hardening, Young's modulus degradation with increasing plastic strain and strain rate dependency be included in the material modelling.

2.2   ACCURATE FAILURE PREDICTION

Of equal importance is the ability to predict part failure accurately. According to Volvo Cars standards, the part has failed when it has fractures and/or necking. This means that digital twins should first of all be able to detect the onset of necking accurately. This is normally done using Forming Limit Curve (FLC) and a safety margin and the prediction is done with high accuracy today at least for linear strain paths.

However, there are other failure modes that may not include localisation. Edge fracture of DP-steels is one example of such a failure mode. The trimming conditions influences the quality of the sheared edge and if this quality is low, the edge fractures when the part is flanged. This is normally detected today by comparing the edge strain with different limit values.

Another failure mode is surface fractures due to bending and stretching. Volvo Cars has developed test set-up for this failure mode but not yet found a robust way of determining the risk for failure due to this failure mode in the simulations. Figure 5 shows two test set-ups designed by Volvo Cars for edge fracture and combined bending and stretching.
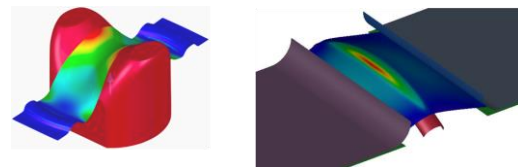

Fig. 5   *Volvo Cars test set-ups for edge fracture (left) and combined stretching and bending (right).*

2.3 ACCURATE FRICTION MODELLING

Friction and tribology in sheet metal forming has been a research area for a long time. Many models have been presented over the years but they often lack the general applicability aspect, i.e. a single model that is suited both for lab scale examples as well as simulation of production parts. This changed recently with the introduction of the TriboForm friction model. Volvo Cars has evaluated this model since 2014 with numerous examples of promising results, see Figure 6. One aspect that must be included in sheet metal forming simulation is that the process must be simulated with the same ram speed profile as the real process in order to get the correct velocity dependency of the friction model. This will also increase the need for strain rate dependency in the material data, se Section 2.1. At the moment, the implementation of TriboForm into simulations of parts in the simultaneous engineering phase in car project is ongoing at Volvo Cars.
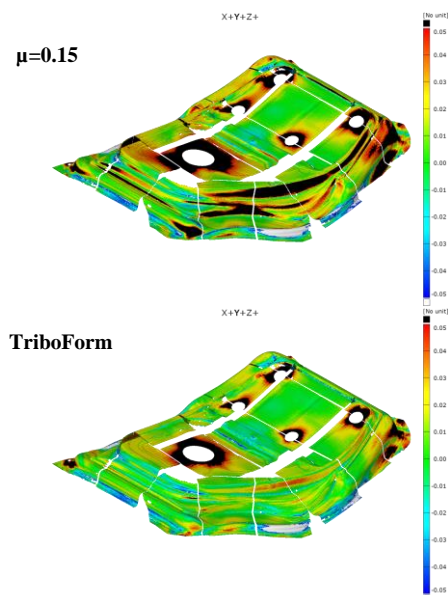

Fig. 6 *Difference in true major strain between simulations and experimental measurements for a GI coating.*

2.4 ELASTIC DIES AND PRESSES

It is a well known phenomenon in the sheet metal forming business that transferring a die from one press to another, e.g. from a try-out press in the tool room to the production press, can change the outcome of the forming process tremendously. One explanation for this effect could be that elastic deformation of the dies and/or the press influences the forming process. Since a few years back, Volvo Cars is running a PhD-project at Blekinge Institute of Technology on this topic. A few studies has been presented so far that shows that including elastic deformations of the dies in sheet metal

forming simulations has a major impact on the accuracy, especially when dies that are used in car production are studied, see Figure 7.
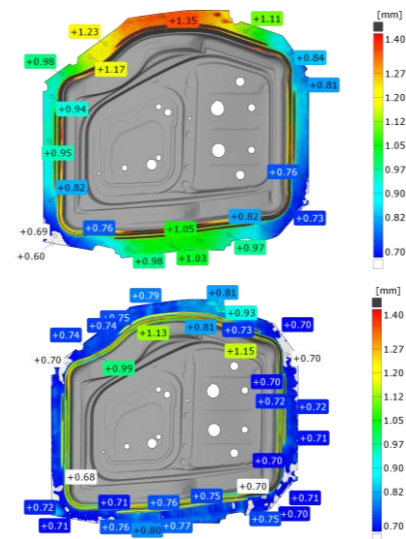

Fig. 7 *Gap between die and blank holder, unloaded (top) and loaded (bottom).*

2.5 IN-LINE MEASUREMENTS

Model driven control and the use of digital twins can be encompassed in what is called Industry 4.0. Another aspect of Industry 4.0 is to improve the manufacturing process by measuring a lot of data in the production during the process and later try to make effective use of these data. In sheet metal forming this can be done at the sheet material supplier, in the blanking line and in the press line.

Volvo Cars has installed an oil film thickness measurement system in one of its blanking lines. The measured data so far is very interesting and has resulted in a few improvements already in the production. Paralelly, another ongoing PhD-project at Blekinge Institute of Technology aims to develop methods for incorporating the measurement data into the sheet metal forming simulations. Initial studies have already shown that the distribution of lubricant over the sheet is influencing the simulation results and the response of the digital model when input parameters are changed, e.g. cushion force. See also Figure 8.
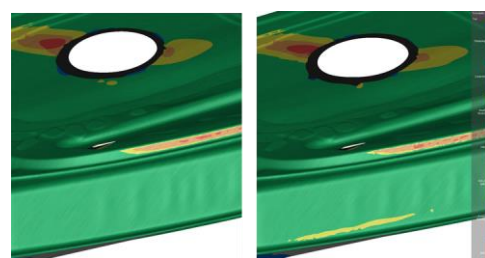

Fig. 8 *Formability plot for uniform oil film thickness (left) and varying oil film thickness (right).*

CONCLUSIONS

The creation of a digital twin of a die set and a press line offers the possibly to start to control the production process based on the measured input to the process and the response of the digital twin. For example, based on the input data of the two batches in Figure 1, the digital twin should have been able to define the optimal cushion force for each part in the batch so that every part fulfils the specifications and the quality is therefore much more consistent and robust.

Achieving this goal would be a major mile stone in sheet metal forming. However, one should be aware that a huge amount of work and research is needed to reach this ultimate goal. Another benefit of this work is the improved knowledge and understanding of sheet metal forming process and constituents. This could then in turn generate continuous improvements for the production even before the development of the final digital twin is completed.

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