Including die and press deformations in sheet metal forming simulations

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Abstract. Structural analysis, in Abaqus, of a stamping die and subsequent morphing of the tool surfaces in AutoForm were performed to improve a sheet metal forming simulation. First, the tool surfaces of the XC90 rear door inner were scanned. They were not matching when the die was unloaded and could therefore not give any satisfying results in sheet metal forming simulations. Scanned surface geometries were then added to a structural FE-model of the complete stamping die and some influential parts of the production press. The structural FE-model was analysed with Abaqus to obtain the structural deformations of the die. The calculated surface shapes were then transferred to AutoForm where a forming simulation was performed. Results from the different sheet metal forming simulations were compared to measured draw in curves and showed a substantial increase in accuracy and ability to analyse dies in running production when the morphed surfaces were used.

1. Introduction
A correct representation of the forming surfaces is of great importance when sheet metal forming simulations are performed for stamping dies in running production. Scanning of the tool surfaces is one way of getting data for the forming simulations. However, it is well known that the tool surfaces deforms during the drawing of the blank. This will influence the process conditions and final part geometry. These deformations are hard to predict in standard forming simulations where the tool surfaces are represented as rigid 2D surfaces. AutoForm, which is used for sheet metal forming simulations in this paper, has some capabilities for modelling of the blankholder deformations through its different binder models.

Previous works have been done regarding elastic tool deformations and its influence on the forming process and simulations. One example and one of the most extensive works [1], by R A Lingbeek describes different methods for analysis and virtual rework of tool structures and surfaces. Another example is [2] where a method for compensation against elastic tool deformations is outlined and demonstrated by simulations. Most of the previous work in the area is performed on small industrial tools or experimental tools. It is noted in several of the works that more work is required, especially simulations and validations for dies on an industrial scale. Many suggested methods combines the structural analysis and the sheet metal in the same FE-model. The focus of this work is instead two separate models where information is transferred between them.

Volvo Cars has also performed previous work on structural analysis and optimization of stamping dies. There seems to be a large potential in this area. One thesis was performed at Volvo Cars in 2007...
[3]. The other one is running during the spring 2016 and is about stress analysis and subsequent optimization steps for reducing stress levels and increasing stiffness of a blankholder.

2. Initial simulations

A production run with a die, XC90 rear door inner, was followed under real conditions. The die was initially of interest in a project regarding friction between Volvo Cars and Triboform [4-7]. It was expected and verified that the surfaces in contact with the sheet deviated from the original CAD model. The tool surfaces that deviated the most was the shape of the blankholder. It was also concluded that the surfaces needed to be deformed virtually to be able to run the forming simulation. No settings in AutoForm for the binder models were able to compensate for the difference in surface shapes. The best result obtained with the scanned surfaces can be seen in figure 1.

The die material is GGG70L with a chrome plated die and punch. The blankholder is polished and laser hardened. The blank material is VDA239-CR4 GI with a thickness of 0.7 mm and Fuchs 4107 as prelube (1.0 g/m²). The simulations are done in AutoFormR6.0 with friction models from the TriboForm FEM Plug-In based on measurements of the die and sheet material. The BBC2005 material model is used for all sheet metal forming simulations [8].

Figure 1. (a) XC90 rear door inner. (b) Blank shape compared to draw-in, red curve, after forming simulation with scanned surfaces.

3. Structural analysis and Sheet metal forming simulation

To be able to virtually deform the tool surfaces, a structural FE-model was created in Hypermesh 13.0 and solved with Abaqus 6.14. The entire tool was modelled as elastic bodies and solved with a dynamic quasi-static method. The ram was assumed to be rigid and an elastic model of the cushion was included in the model. The model was created from the original CAD model. The scanned surfaces were imported into Hypermesh in stl-format and the nodes on the blankholder and die surfaces were morphed with the scanned surfaces as target. This enabled solving of the structural model with the scanned tool surfaces.

The purpose of this structural simulation was to obtain the correct surface geometries for the loaded blankholder. The calculated shapes of the surfaces were then used during a new forming simulation. This will be valid under the assumption that the change in tool deformations are relatively small after the blankholder has been closed. The punch was not included in the structural FE-analysis since no forming was done in that simulation. In order to further reduce the model size the steel sheet was replaced with a contact surface between the blankholder and the die. The contact surface was given the same thickness as the sheet, 0.7 mm.

The resulting surfaces from the Abaqus simulation have the correct global shape of the loaded die. However, the mesh is way too coarse to be used in the sheet metal forming simulations. This was solved in AutoForm by morphing the already imported scanned surfaces of the blankholder and the die. In AutoForm morphing is done by using guide curves. They describe from where and where to the surfaces should be morphed. Catia V5 was used to create guide curves on the original scan surfaces and on the
deformed surfaces from the structural FE-simulation. The curves have exactly the same shape if they are projected onto the xy-plane. The difference can only be seen in the levels and shape in the z-direction. Position of the guide curves and difference between morphed and unmorphed surfaces can be seen in figure 2.

![Figure 2](image_url)

**Figure 2.** (a) Blankholder surface with position of guide curves for morphing. (b) Difference between scanned and morphed blankholder surface.

For the proposed method to work the blankholder shape must be kept constant during the forming simulation. This is obtained by setting a high value for the tool stiffness in a binder model with support type Force Controlled. Exactly what level that should be used is not certain but this simulation shows good results when the tool stiffness is in the interval 5000 – 30000 MPa/mm. The best value has to be determined by analysing more models.

4. Results
The result from the structural FE-simulation showed that the blankholder deformed up to 0.7 mm in Z direction which can be seen in figure 3. The surfaces of the die and blankholder that are in contact with the sheet was exported as stl-files from Hyperview. Other parts of the die and the cushion in the press also showed deformations but they are much smaller than the deformations of the blankholder.

The sheet metal forming simulations with the morphed surfaces shows a very large improvement compared to the initial simulation with scanned surfaces. The results can be seen in figure 4. The draw-in is now matching the measured curved very well except for minor deviations in some areas. The deformed surfaces together with TriboForm’s advanced friction model are shown to be of great importance if final part properties, e.g. shape, strains, wrinkles etc. should be predicted with high accuracy. This paper has focused on the importance of tool surface shapes and how to incorporate them into sheet metal forming simulations. The importance of an accurate friction model and the influence on other results such as strains and wrinkles for this die are described and discussed in [5-7].

![Figure 3](image_url)

**Figure 3.** (a) Complete structural FE-model of stamping die. (b) Deformations of the blankholder in z-direction. The red area represents the largest deformations with a magnitude of 0.7 mm.
5. Discussion and future work

The ability to virtually deform a die and include the resulting geometry in forming simulations is of high importance. One example has been demonstrated in this paper with good results. However, there needs to be further investigations into efficient workflow and how to set parameters in the simulation softwares to best represent the blankholder conditions. This can be done by simulating more dies, blankholder designs and lubrication systems. For some dies there will probably be deformations during the forming operation. It might be handled by applying an average deformation based on different points in time during the drawing of the blank. Another benefit of the method is that the total simulation time of both models is very short compared to some other methods for incorporating die deformations, e.g. combining both structural and forming simulations in the same model.

The method can be used when support is requested from running production. This link between structural analysis and sheet metal forming will also enable methods for virtual design and rework of stamping dies. Structural optimization should be used for reducing the die deformations together with methods for virtual spotting. That would give an optimum design of the blankholder.

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