COMPENSATION OF DEEP DRAWING TOOLS FOR SPRINGBACK AND TOOL-DEFORMATION

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ABSTRACT. *Manual tool reworking is one of the most time-consuming stages in the preparation of a deep drawing process. Finite Elements (FE) analyses are now widely applied to test the feasibility of the forming process, and with the increasing accuracy of the results, even the springback of a blank can be predicted. In this paper, the results of an FE analysis are used to carry out tool compensation for both springback and tool/press deformations. Especially when high-strength steels are used, or when large body panels are produced, tool compensation in the digital domain helps to reduce work and save time in the press workshop. A successful compensation depends on accurate and efficient FE-prediction, as well as a flexible and process-oriented compensation algorithm. This paper is divided in two sections. The first section deals with efficient modeling of tool/press deformations, but does not discuss compensation. The second section is focused on springback, but here the focus is on the compensation algorithm instead of the springback phenomenon itself.*

1. INTRODUCTION

Computer-aided engineering (CAE) has significantly expedited product development in the automotive industry. In the process design and planning of deep drawing processes, shown in Figure 1 (top), computer-aided design tools and finite element (FE) simulations are used together in order to achieve a high-quality product within an acceptable time-span. Finding the right shape for the forming tools is one of the most important tasks that is carried out in the digital domain now (indicated with the white arrows). However, when the tools are manufactured and tested on the prototype press the quality of the prototype parts rarely satisfies the requirements straightaway. Therefore, manual reworking of the forming tools is required, indicated with black arrows. Because reworking is highly time-consuming [1] and because a lot of experience is required by the tool technicians, this is the most significant bottleneck in the process-planning today.

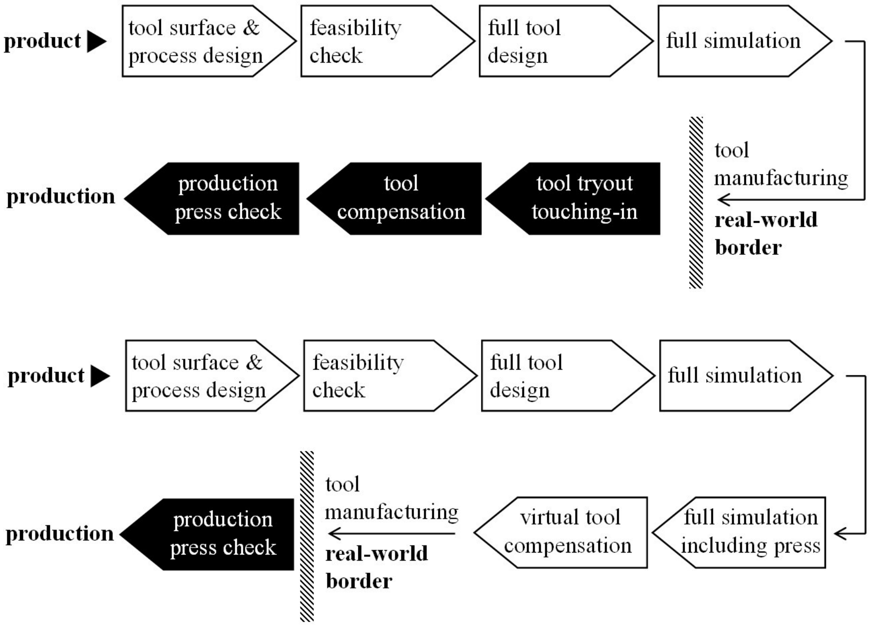

Figure 1. *The process planning (top) versus the ideal virtual-factory planning (bottom).*

The two phenomena that cause problems in the product quality are the deformation of the press and forming tools during forming, and the springback of the product after release of the tools. Especially when high-strength steels are used, both phenomena cause significant problems. To a large extent, they cannot be avoided and therefore they have to be compensated in the shape of the forming tools. In this paper, various algorithmic methods are developed to carry out this compensation in a numerical context. Ideally, the goal is to avoid tool reworking altogether (as shown in Figure 1, bottom), and to achieve this goal, two problems need to be solved: Firstly, the accuracy of the forming simulation must be improved in order to obtain a reliable representation of the forming process. Secondly, an algorithmic framework needs to be developed for the geometrical compensation of the forming tools.

2. EFFICIENT MODELLING OF TOOL AND PRESS DEFORMATION

2.1. The problem

The deformation of the press and tools can be divided into three categories: The deformation of the press frame is negligibly small. This is not the case for the global deformation of the bed-plate, slide and forming tools. Finally, local deformation occurs at the forming tool surface. Figure 2 shows the cross-die forming process. This is a blank-material testing process and the results of the material test were reported to vary due to tool deformation [2]. The reason for this is that in this experimental setup, the tools were supported by an array of supporting pins that allow more deformation than the bed-plate in a regular press. However, tool and press deformations also play an important role in regular production presses [3,1]. Whereas the actual deformations might appear insignificant, the changes in the contact pressure distribution from the tools on the blank are not. When the tools are modelled as rigid bodies, the contact pressure distribution and therefore the friction forces on the blank are wrongly predicted. Therefore, the simulated blank draw-in, and consequently other product properties like rupture risk or the amount of springback might be erroneous too. Therefore, the goal is to include tool deformations in a forming simulation.

Using a general purpose FE code, in this case ABAQUS, both global and local deformations can be reproduced, as Figure 3 (left) shows. As a reference, a simulation was performed with rigid tool models. The right figure shows the increased draw-in, indicated with the dotted line, due to the elastic tool models. Comparing the Forming-Limit curves of both blanks, shown in Figure 4, the regular simulation predicts a high risk for rupture, the simulation with deformable tools shows a higher risk for wrinkling. Unfortunately, the added accuracy of the deformable tool models comes at a very high numerical cost. In this case the additional calculation time amounted 200%, where the forming tools could be meshed efficiently due to the simple geometry. Carrying out such simulations is not feasible for full-scale industrial processes, where the tool-meshes will require more than a million DOFs and the CPU time is expected to increase by factors. A more efficient way of modelling tool elasticity needs to be found.

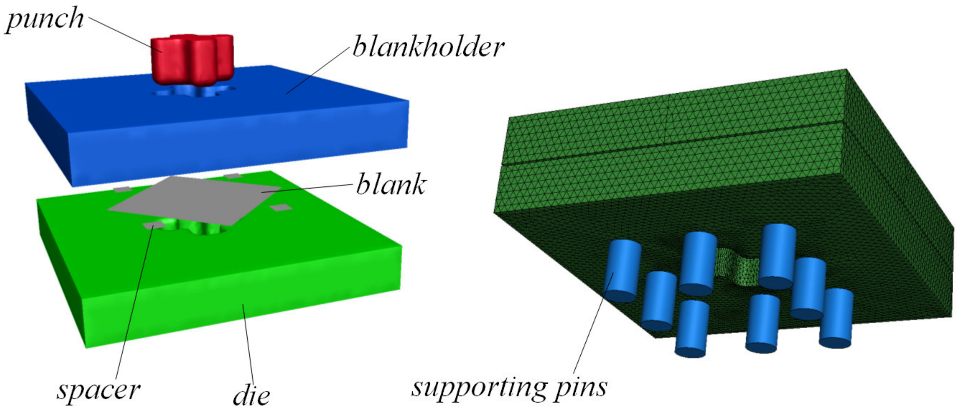

Figure 2. *The Cross-die process(Corus RD&T).*

Static condensation [4], a well-known technique for reducing the size of finite element models, does not bring the anticipated decrease of numerical cost [5]. The principle of the method is to pre-solve a part of the system of equations so the deformation is only calculated at locations in the tool geometry that are actively required during the forming simulation. However, the reduced set of equations turns out to be much harder to solve.

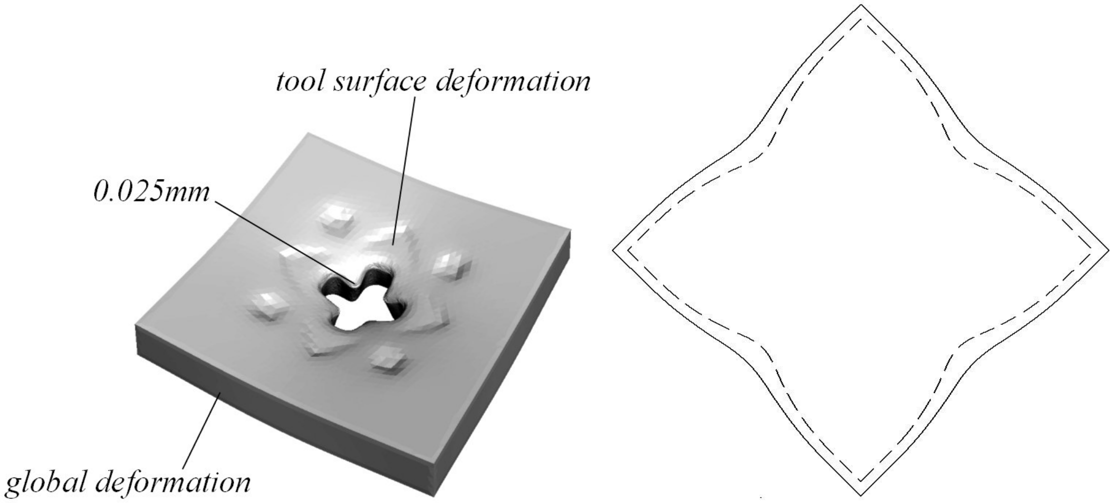

Figure 3. *Global and local deformation in the cross-die (deformations x5000) (left) and changed draw-in of the blank (right).*

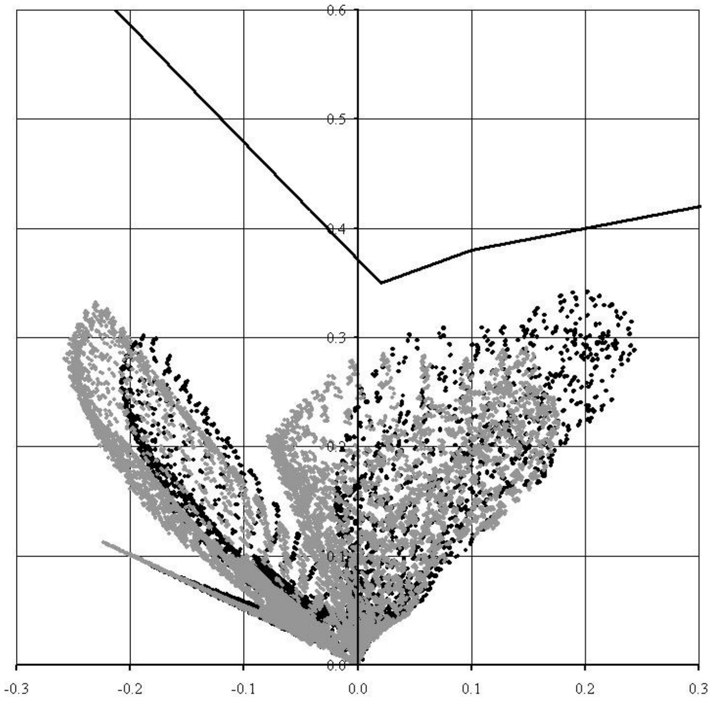

Figure 4. *FLC after forming for rigid (black) and deformable tool models (grey)*

2.2. Deformable Rigid Bodies

Avoiding the solution of the FE problem, the so-called Deformable Rigid Bodies (DRBs) *do* provide a tremendous reduction in the calculation cost. Here, the deformation of a body is approximated as a linear combination of pre-calculated deformation modes. Figure 5 demonstrates the principle for a simple press-component. The modes are calculated once in a separate program and then stored in a file. With increasing eigenvalue, their shape becomes more complex. This implies that when more modes are used, complex deformations can be approximated more accurately. When the deformation due to loading is global, a small number of modes provides sufficient accuracy.

The deformation of the tools is calculated at each forming increment in the forming simulation. The modes are loaded into the FE forming program at the start of the simulation and the following equation is used instead to directly calculate the displacement [5]:

$$\mathbf{u} = \sum_{i=1}^{m} \frac{\mathbf{v}_i^T \mathbf{f}}{\lambda_i} \mathbf{v}_i \qquad (1)$$

Here, $\mathbf{u}$ is the displacement, $\mathbf{f}$ is the load vector, $\mathbf{v}_i$ is a mode, λ_i is the eigenvalue that corresponds with the mode. As solving is not required anymore, this is highly efficient and makes it possible to include the entire press structure into the forming simulation [5]. As an example, Figure 6 shows the deformation of a die and die-connection plate under process load, using only 40 modes.

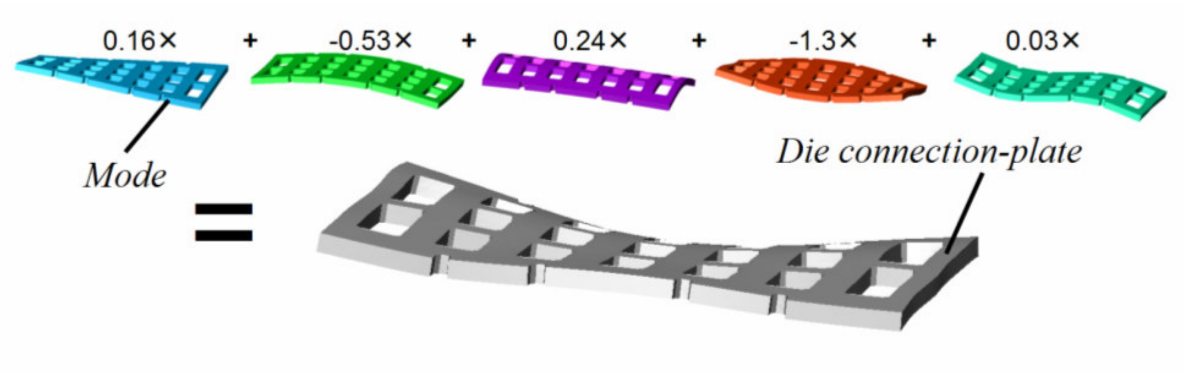

Figure 5. *Principle of the DRB approach demonstrated for a die connection plate.*

In [6] it has been shown that the accuracy of the calculation can be raised further by deriving the DRB approach with respect to the contact stress on the surface of the body instead of the regular load vector.

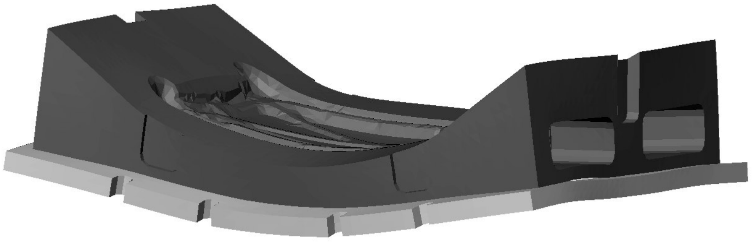

Figure 6. *Deformation of the die and die-connection plate under process loads*

2.3. Results: Example simulation

A DRB module has been developed and it is implemented in the FE simulation code DiekA [7]. As a test, the tools of the previously introduced cross-die forming process are modelled as DRBs. As a reference, also a regular simulation with rigid tools was carried out. The result is shown in Figure 7. The differences in the contact pressure distribution on the blank and spacers are obvious. Due to the deformation of the tools, the spacers overtake a large part of the blankholder load. This reduces the friction on the blank, and the blank draw-in increases. This was also concluded from the ABAQUS simulations, however, by using DRB models for the tools, the numerical cost had only increased by 8%.

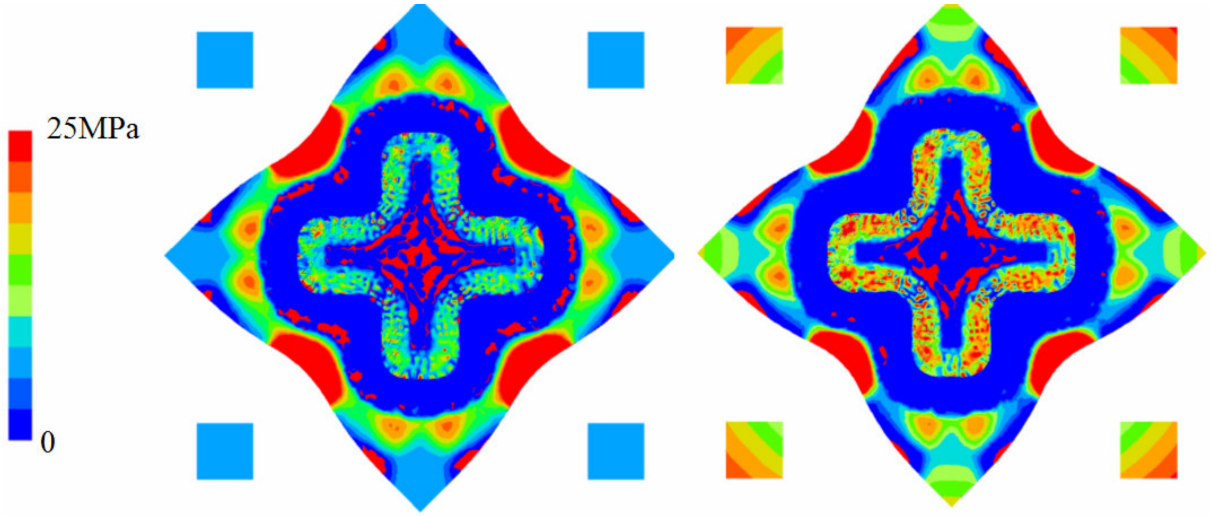

Figure 7. *Pressure distribution on the blank and spacers, rigid (left) and deformable tools (right)*

3. TOOL COMPENSATION

Springback is the deformation of the blank that occurs when the forming tools are opened. This shape deviation may cause problems in the assembly process for the car-body. In order to produce parts with the correct shape, the forming tools must be compensated. In tube-bending, compensation is achieved by overbending: the tube is bent further than the desired angle to obtain the right shape after springback. The mathematically generalized description of this idea is called the Displacement Adjustment (DA) method [8]. The prediction of springback still remains a sensitive calculation, however, the accuracy of the results has improved significantly in the last years. This makes it possible to carry out compensation based on FE simulations. Note that product shape deviations due to the deflection of the forming tools can be compensated with the following strategy too.

In Equation (2) and Figuire 8, **d** is the desired geometry, **s** the geometry of the blank after springback and **c** the forming geometry. This is the shape of the product when the tools are still closed. The shape of the forming tools needs to be derived from this forming shape.

$$\vec{\mathbf{c}} = \vec{\mathbf{d}} - 1 \cdot a(\vec{\mathbf{s}} - \vec{\mathbf{d}}) \qquad (2)$$

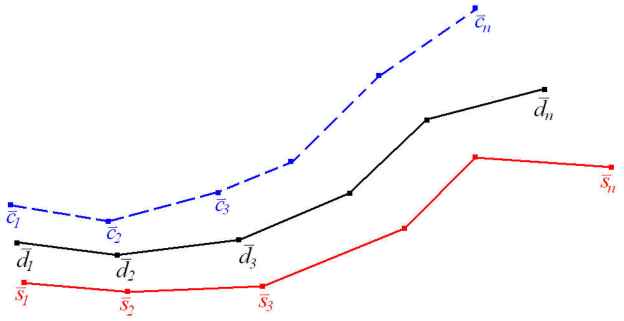

Figure 8. *The DA priciple*

The factor a is the compensation factor. Since changing the tool shape changes the forming process, the springback of the compensated process is not identical to the initial process. Typically, the compensation has to be slightly larger than the springback for the product to obtain the right shape, though this is not always the case.

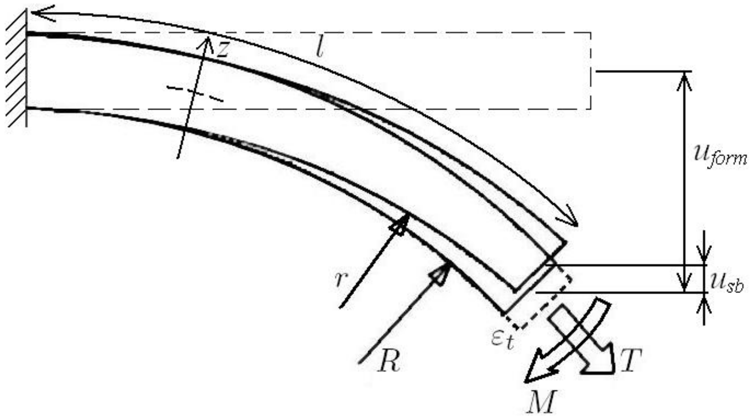

Figure 9. *Pressure distribution on the blank and spacers, rigid (left) and deformable tools (right)*

The value of the compensation factor has been analysed for a simple forming process [8], the stretch-benching of a bar, shown in Figure 9. The advantage of this process is that it can be described with analytical functions and FE simulations are not required. Therefore, the dependence of the compensation factor on process parameters, material and the formed geometry can be derived directly. Figure 10 shows the relationship between *a* and the (normalized) traction force *T* on the bar for two materials.

Because process conditions, geometry and even material properties vary over a deep drawn product, the consequence is that the optimal compensation factor is not constant over the product. This problem can be solved by using the DA method iteratively, as intended originally in [8]. This leads to more accurate results in only a few iterations:

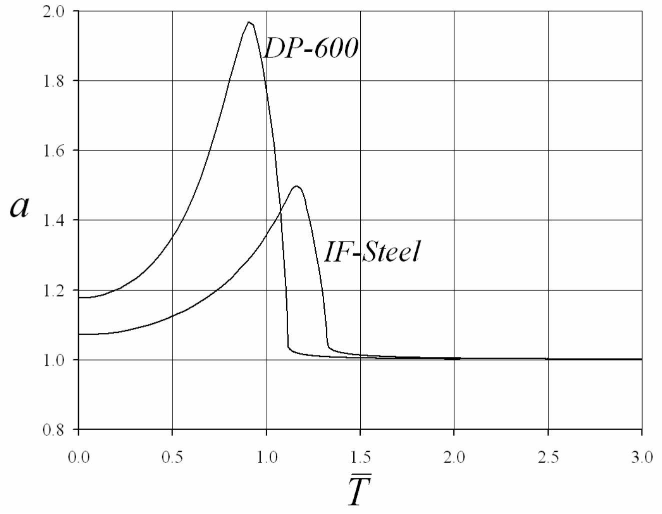

Figure 10. *Stretch-bending: The compensation factor for various materials and process parameters*

$$\vec{\mathbf{c}}^{j+1} = \vec{\mathbf{c}}^{j} - 1 \cdot (\vec{\mathbf{s}}^{j} - \vec{\mathbf{d}}) \tag{3}$$

Here, *j* indicates the iteration. In any case, the quality of the tool surfaces must be maintained during compensation. As an addition to the discrete DA principle, the smooth displacement adjustment (SDA) algorithm has been developed. The idea is to approximate the discrete compensation field with a smooth function. A B-spline volume is used here. This compensation function can be applied to any geometry, even to the CAD description of the tools. Additional algorithms have been added to maintain the usability of the tools: The blankholder area of the tools and the gap width between them are left unchanged. Undercuts that could occur during compensation are automatically removed.

3.1. Results

Many industrial springback problems have been solved using this method in combination with a commercial forming simulation program [9]. In Figure 11 below, the shape deviation of a trunk-lid inner panel, a NUMISHEET 2005 springback benchmark part, is shown with the original tools and after compensation. Generally, a reduction in shape deviation of 80% and more can be achieved. The algorithm does not require human interaction.

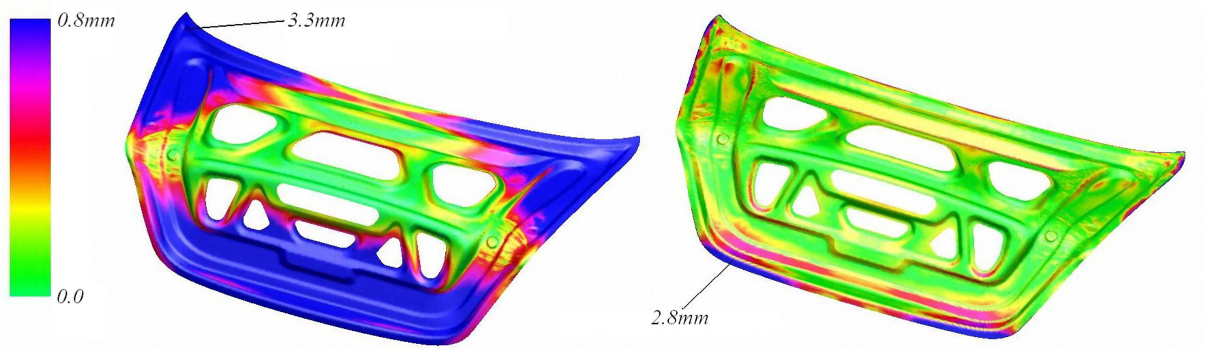

***Figure 11**. Shape deviation before (left) and after compensation with SDA*

4. CONCLUSIONS

In this paper, methods for virtual tool reworking have been explored. Whereas Finite Element simulations are applied in industry for process design and feasibility checks already, the focus of this research project was to use these simulations pro-actively in order to reduce the amount of tool reworking in the press workshop, or to avoid it altogether. It has been shown that the deformation of the forming tools and the press have a significant influence on the forming process. These deformations can be included efficiently in FE forming simulations, when Deformable Rigid Body models are used for the tools. The improved accuracy of the simulation results assists in avoiding tool reworking due to unexpected blank-flow. An important application is to compensate the tool shape for tool deformations in an FE context already.

Springback is another problem that requires tool compensation. The FE prediction of springback has improved significantly in recent years, and it is sufficiently accurate to be used for numerical tool modification algorithms. The Displacement Adjustment method gives good results. It can be applied with a compensation factor, which depends heavily on the process and materials used. The iterative variant does not require this factor and leads to a higher accuracy. The extensions of the SDA algorithm have been developed to retain the usability of the forming tools. This method has proven to work well for several industrial forming processes.

5. ACKNOWLEDGEMENTS

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