Tool And Blank Interaction In The Cross-Die Forming Process

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ABSTRACT: The deformation of the press and the forming tools during a deep drawing process is small. However, it has a significant influence on the formed product, since the draw-in is affected significantly by this deformation. This effect is demonstrated for the cross-die forming process. The process was simulated using the commercial code ABAQUS, comparing different models for the forming tools and blank. The simulated process behaves quite differently when rigid or deformable tools are applied. In the latter case, so-called tool-spacers absorb a significant part of the blankholder load, resulting in a stronger draw-in of the blank. In all cases, the results depended heavily on the blank element type and on numerical settings for the contact algorithm. These should be treated with great care when accurate results are required.

KEYWORDS: Die-design, Tool deformation, Sheet metal forming, Finite Element Method, Contact, Friction

1 INTRODUCTION

The deep drawing process is an extremely sensitive procedure. Even phenomena that are hard to measure may influence the blank flow and therefore the product quality. The deformation of the press and tools during forming is such a phenomenon. The deformations are small, but the influence on the contact pressure distribution is very large. In Finite Element (FE) simulations, the tools are generally modeled as rigid bodies, and simplifications are applied in the blank-tool contact calculations. Due to errors in the calculated pressure distribution, the blank draw-in is not always predicted accurately. As a solution, [4] shows an industrial strategy where the draw-in on the real press is made to fit the simulation results. The required tool reworkings are time-consuming, according to [3] approximately 350-500 hours are spent on the average forming tool, and they need to be carried out by experienced die technicians. The problems are aggravated by the increased use of high-strength steels.

The accurate prediction of the contact pressure distribution on the blank can help to reduce the amount of tool reworking and it is the main focus of this paper. The influence of the following three items will be investigated

- Tool deformations
- Blank thickness changes
- Contact parameters

2 THE CROSS-DIE BENCHMARK

The interaction between blank and tools is complex in any industrial deep drawing process. In order to provide a comprehensible overview, it is useful to assess the problem with a simpler forming process. The focus in this paper will be on a benchmark process called the cross-die, shown in Figure 1. It is used industrially as a material test [1] and provides insight in the formability of a steel grade: The idea is to increase the blank-size in a series of forming tests until fracture occurs. The maximum allowable blank-size is defined as the cross-die benchmark value.

During the experiments, the process revealed a high sensitivity to tool deformation. In the prototype press, the tools are supported by a set of pins. Depending on configurations of these pins different benchmark results were found [1]. In order to reduce this sensitivity, small squares called spacers were placed around the blank. These spacers are made from the same sheet-material as the blank. The experimenters intended to make the gap between blankholder and die more even, because due to tool deformations, the gap-width had become nonuniform. Unfortunately, the spacers made the problem worse. In regular forming processes, the forming tools are supported by a larger surface, however, problems due to tool deflection occur too.

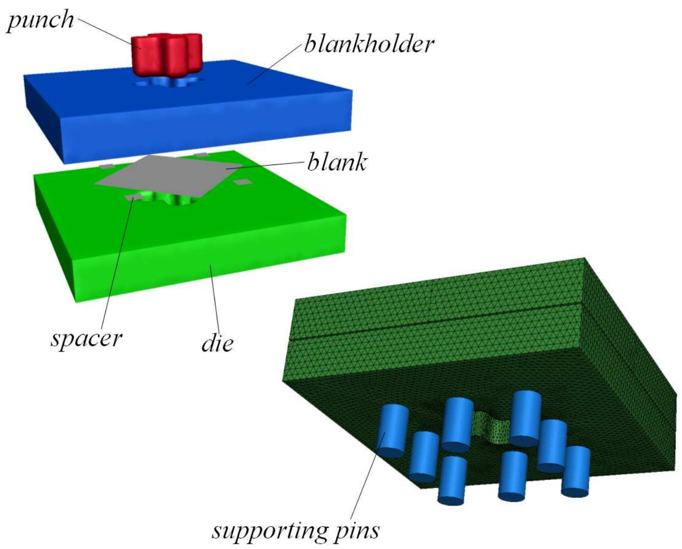

Figure 1: The cross-die process

Table 1: Settings for the ABAQUS simulations

Tool model	Rigid	Deformable
Type	Static implicit	
Blank	4-node red. integ. shell	
	8-node solid-shell	
Tools	Rigid-body elements	Solid elements
Contact	Penalty	
# of elements	33124	187298

A FE analysis is a good way to analyze the process and to show the influence of tool deformation and the use of spacers. Due to limitations of the forming simulation software, the tool deformation was calculated in a separate structural FE simulation in [1]. However, a full calculation with deformable tools is possible with a general purpose FE code. ABAQUS has been used here to perform both a regular simulation using rigid tool models, and a simulation with deformable tools. Table 1 shows the settings of both simulations.

3 TOOL DEFORMATION

The forming process is divided into two phases, blankholder loading and forming. The contact pressure from the tools onto the blank defines the amount of friction and therefore the amount of draw-in. The contact pressure distributions for deformable and rigid calculations are compared after the blankholder closing phase in Figure 2. Note that there is no pressure in the middle area of the blank, as forming has not yet started. In this process the blankholder area, the part of the blank where it is clamped between die and blankholder, is completely flat. Therefore, a homogeneous pressure distribution was expected.

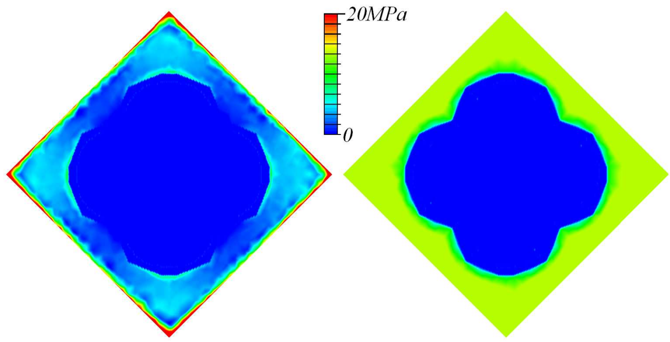

Figure 2: Pressure distribution after blankholder closing for deformable (left) and rigid tools (right)

This is the case for the calculation with rigid tools. When the tools are allowed to deform, even the slightest deflection (in the order of magnitude of 0.01mm) of the tools results in a localization of the pressure field to the edge of the blank. The reason for this is made clear schematically in Figure 3 (left). The deformation of the die after the completed forming stage is visualized in Figure 3 (right). The deformation was multiplied by 5000 for visualization purposes. Note that the spacers also cause deformation in the tools; they carry a part of the blankholder load.

Due to the in-plane compression the blank thickens considerably during draw-in. The contact pressure maximizes at the thickest spots, lifting up the blankholder slightly thereby relieving the spacers. These thickening spots can be observed on a photograph of an experimental blank (Figure 4) as shiny spots. In these areas the blank was 'polished' due to the high friction.

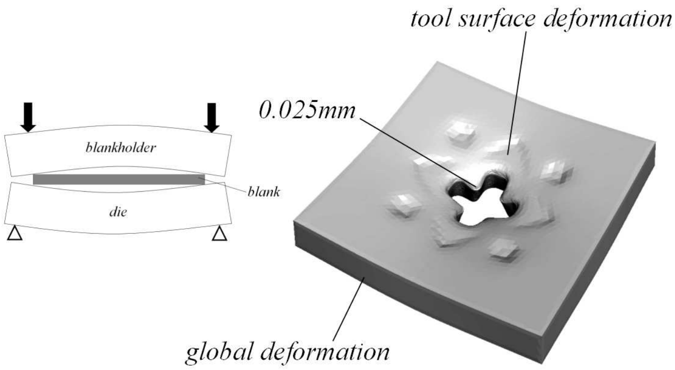

Figure 3: Deformation of tools (schematically) and FE result (x5000)

Figure 4: Shiny spots on the blank reveal high-pressure zones (picture courtesy of Corus RD&T)

The ABAQUS calculation shows the same pressure spots (see Figure 5). In the left picture, rigid tools were used. Because the blankholder is rigid, it is lifted up entirely, almost completely relieving the spacers. However, when the tools are allowed to deform, they do take a considerable amount of the blankholder force away from the blank. In the right picture, this can be seen clearly: There is a high pressure on the spacers, and the size of the high pressure spots is reduced. Because of the reduction in blankholder pressure on the blank, the draw-in is larger, as Figure 7 shows. Due to the larger draw-in, the calculation with deformable tools predicts a higher tendency for blank-wrinkling, whereas the calculation with rigid tools predicts a higher risk for rupture.

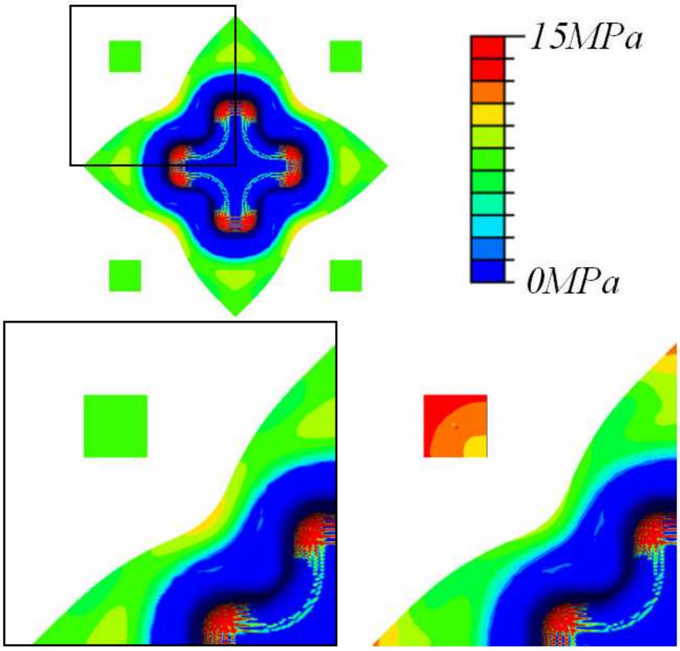

Figure 5: Pressure distribution for rigid (left) and deformable tools (right)

4 BLANK THICKNESS CHANGES AND CONTACT MODELING

When comparing the high pressure spot predicted by ABAQUS and the results from the experiment, the calculation with rigid tools appears to be closer to reality. The reason for this is not that the modeling of the deformable tools is wrong, experiments confirm that the spacers *do* carry a part of the blankholder load and allow larger blank draw-in. Instead, it is likely that the thickness distribution is predicted wrongly by the ABAQUS solid-shell elements. The use of these elements is required because the thickness change of regular shells is not taken into consideration during contact calculations.

As a comparison, a simulation was carried out with regular shell elements using the FE codes PAM-STAMP and DiekA. Each of these simulations predicts much more thinning in the vertical walls and thickening on the blankholder area of the blank. The results are shown in Figure 6. At the high-pressure spots the thickening now amounts 0.2mm instead of 0.02mm. Therefore, the thickening is now an order of magnitude larger than the tool deflection.

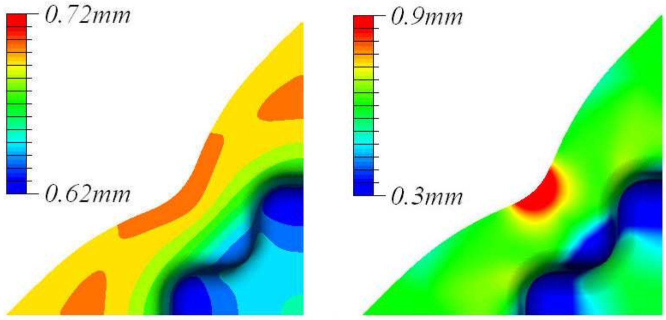

Figure 6: Thickness for solid (left) and regular shells (right)

5 CONTACT MODELING

Penalty contact is used most frequently in forming simulations. Even when the settings are numerical parameters, they influence the physical outcome of the simulation heavily. Two ABAQUS calculations were carried out, one with default contact stiffness and one where the contact stiffness was multiplied with a factor of 0.1. Regular shells and elastic tools were used. For the regular contact settings, the blank only sticks at the corners and slips at the other locations. In the case of the softer contact settings, the pressure is much more uniformly distributed around the edge of the blank. It is still high enough to prevent slip at the blank edge so draw-in is almost reduced to zero, an erroneous result. However, the contact settings are generally adjusted by the simulant to ensure convergence rather than to reflect reality. Softer penalty-factors generally reduce numerical problems and also the calculation time.

6 CONCLUSION

The cross-die benchmark is specifically sensitive to tool deformations, as shown in experiments and simulations. The simulation is able to reproduce the increased blank draw-in, caused by the spacers. Figure 7 shows that the difference is not negligible. Therefore, taking tool deformations into account increases the simulation accuracy. In this case the prediction of rupture risk was improved, which is essential for a material benchmark.

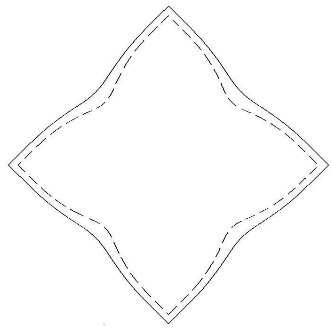

Figure 7: Blank contour for rigid (solid line) and deformable tools (dashed line)

It has proven to be even more important to predict blank thickness changes correctly. Also, the FE results have been found to depend heavily on the parameters of the contact algorithm. Because of these findings the authors believe, more research into contact and friction modeling could make a significant improvement in the accuracy of forming simulations.

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