Adjusting the Contact Surface of Forming Tools in Order to Compensate for Elastic Deformations during the Process

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Summary:

Nowadays, despite powerful simulation programs, the tool design process still contains manual and not reproducible work. In specific, the manual die spotting is mostly dependent on the workers experience and consumes a lot of time. A large potential to reduce time and costs is seen by decreasing the die maturing.

The paper introduces an approach to obtain deep drawing tools from FE simulation with LS-DYNA, which need less additional manual maturing until good parts can be manufactured.

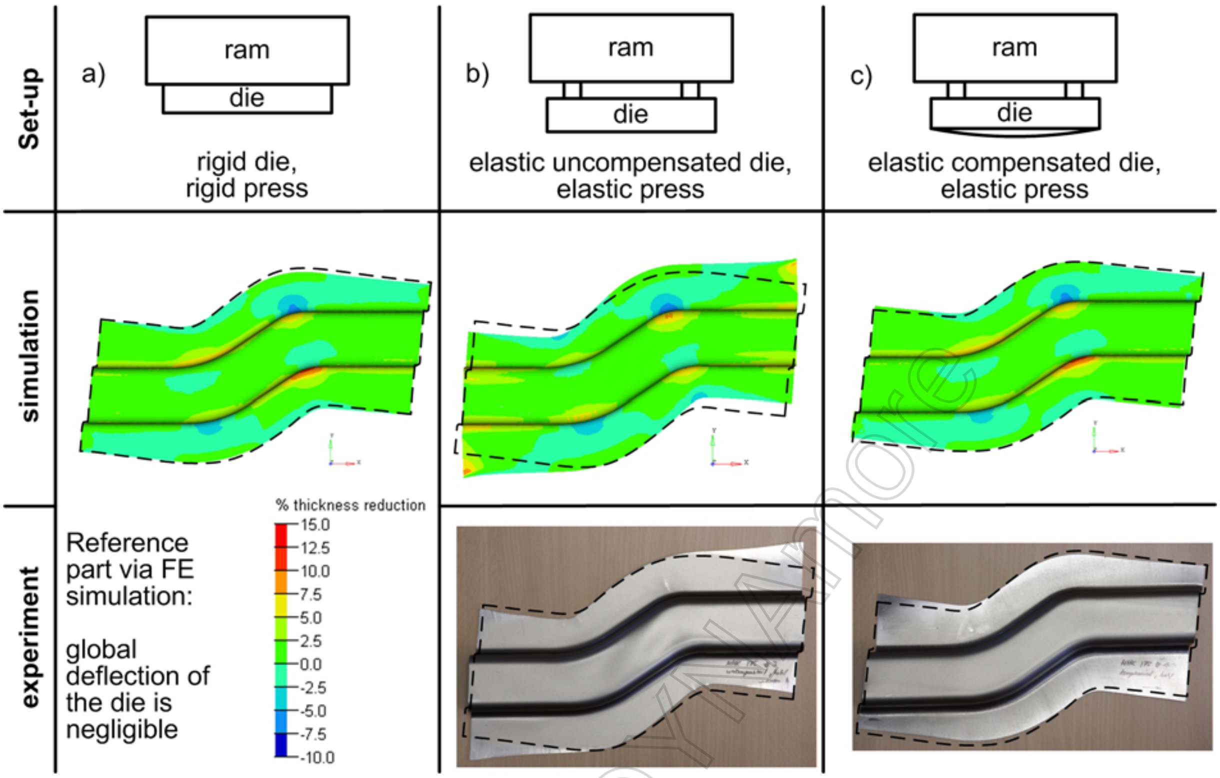
Therefore, the current tool design process was analyzed and it was found out, that not properly assessing elastic tool and press properties in FE simulations in one of a the causes that lead to additional die spotting effort.

Hence, a methodology was developed to compensate for the effects of those elastic properties. Depending on their intensity, afore mentioned machine and tool properties are included in the FE model. Based on former research work at the IWM the effects of elastic deformations and dislocations of the die surface on the final shape of the part are calculated. Derived from the calculated deformations, a transformations matrix is calculated and a new die surface is obtained after a few iterations. The new die surface has the same shape under load like the initial die surface without load.

The new method was tested through an experimental set-up, which allowed an excessive deformation of the die under load. This experiment does not reflect the reality but serves for general demonstration purposes of the compensation approach.

As expected the simulation and experiment show a massive impact of the die deflection on the draw-in of the manufactured part. The die deformation affects the distribution of the blankholderforce on the part. It was found a higher pressure on the die corners and lower pressure in the centre.

By means of the compensation method, the die surface was adjusted to achieve that the die surface under load is the same as the initial surface without deformations. The experiments show that the final shape of the part, which was drawn with the compensated die, is very close to the shape, which was predicted without calculating the die deformation.



This work shows the basic feasibility of the compensation for effects of elastic tool and press properties. Since it is unsure how much of an impact the compensation of the die has on the springback behaviour of the part, future research will take this effect into account.

Keywords:
Sheet metal forming, Tool deformation, Process simulation, Compensation

1 Introduction

Over the past years the design of deep drawing tools has developed remarkably from pure trial-and-error based design, to a design process based on finite element simulation. Today, even in the early stages of the design process, FEA is employed to obtain information about manufacturability and tool design [4].

The simulation-based compensation for springback is state-of-the-art technology in industrial tool manufacturing. The software industry is still working on developing different approaches to compensate for springback and to reconstruct the surfaces, which are obtained via FE simulation. In particular, springback simulation of high strength and ultra high strength steel demands better accuracy in forming simulation [4].

According to [6], tool try-outs represent approximately 30% of the overall cost of a tool. The adjustment of the tool surface in order to release or to restrain the material flow into the cavity is still dependent on the experience of the operator, and is neither part of the tool design nor of the FE simulations. Significant amounts of time and money can be saved by pre-calculating the die spotting during the tool design process.

Practical experience [3, 5] shows, that the elastic tool and press deformations under load considerably affect the deep drawing results. Since the tool design is based on the use of rigid tools, the previously mentioned elastic deformations can be assumed to be a main reason for the need for additional die spotting. In order to compensate for those deformations, the elastic properties of the press and tool must be considered during the design process, and therefore, be implemented into the FE process simulation.

Various studies at the IWM and other research institutions show the feasibility of simulating the effects of elastic tool and press properties on the final shape of the drawn part. The following paper introduces a methodology, which compensates for elastic deformations already in the early stages of the tool design process. It is expected to further reduce the die spotting time.

2 Current Tool Design Process

Figure 1 shows the common industrial tool design process. At the present time, after a part is designed, the tool geometry is then derived from the shape of the part. Subsequently, a formability analysis is conducted by means of an FE simulation. If wrinkles, excessive thinning or cracks are observed, the part and tool geometry are iteratively modified until these defects are no longer present. The resulting tool geometry serves as the basis for the springback simulation, which will follow.

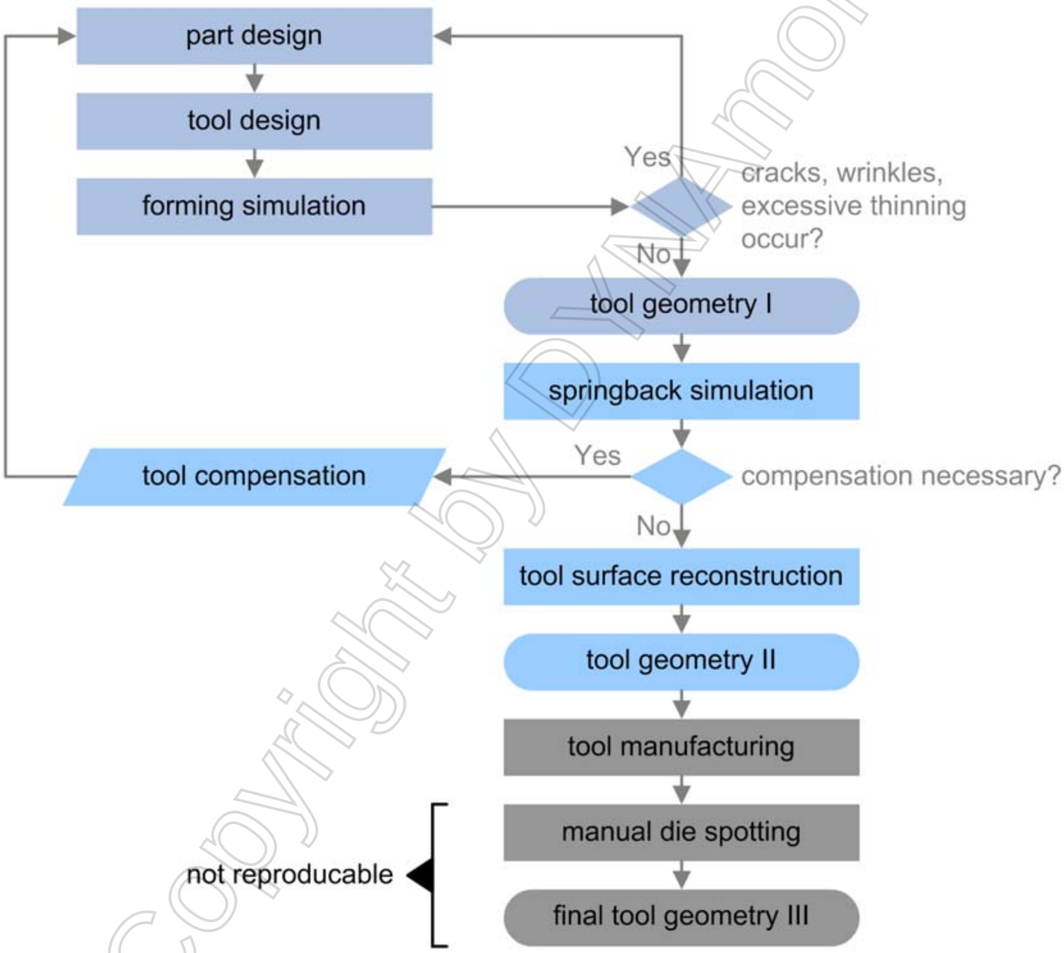


Figure 1: Current tool design process [2]

Simulation-based springback compensation is state-of-the-art technology. A complete springback simulation is generally implicit and involves a trimming simulation, followed by mesh coarsening and the actual calculation of the springback. With the exception of their node coordinates, the meshes before and after the springback simulation are identical, which enables the transformation matrix and the correction of the tool surface to be calculated [2]. The results are then checked for effectiveness by means of a forming- and a springback simulation. If the simulations deliver satisfactory results, no further compensation is required, and the tool surface is reconstructed from the FE mesh before being sent to be manufactured. Through manual die spotting, the tool surface is improved to meet the demanded shape accuracy and to control the draw-in. This step in the process is, however, dependent on the experience of the operator, is not reproducible and is very time consuming.

3 Tool Surface Compensation for Elastic Deformations

Failure to properly assess the elastic tool and press properties in the tool design process is one of the reasons why additional manual die spotting is needed. Therefore, the following methodology was developed to compensate for the negative effects resulting from elastic tool and press behaviour. Currently used deep drawing simulations utilize rigid tool surfaces and neglect elastic press properties. It is clear, that to be able to compensate for these effects, the FE model has to be capable of calculating them.

3.1 Effects of Elastic Tool and Press Properties

It is necessary to make a distinction between local and global elastic deformations, and to be aware of their causes. Figure 2 gives an overview of the influences that local deformations, global deflexions and global dislocations can have on the final shape of the part.

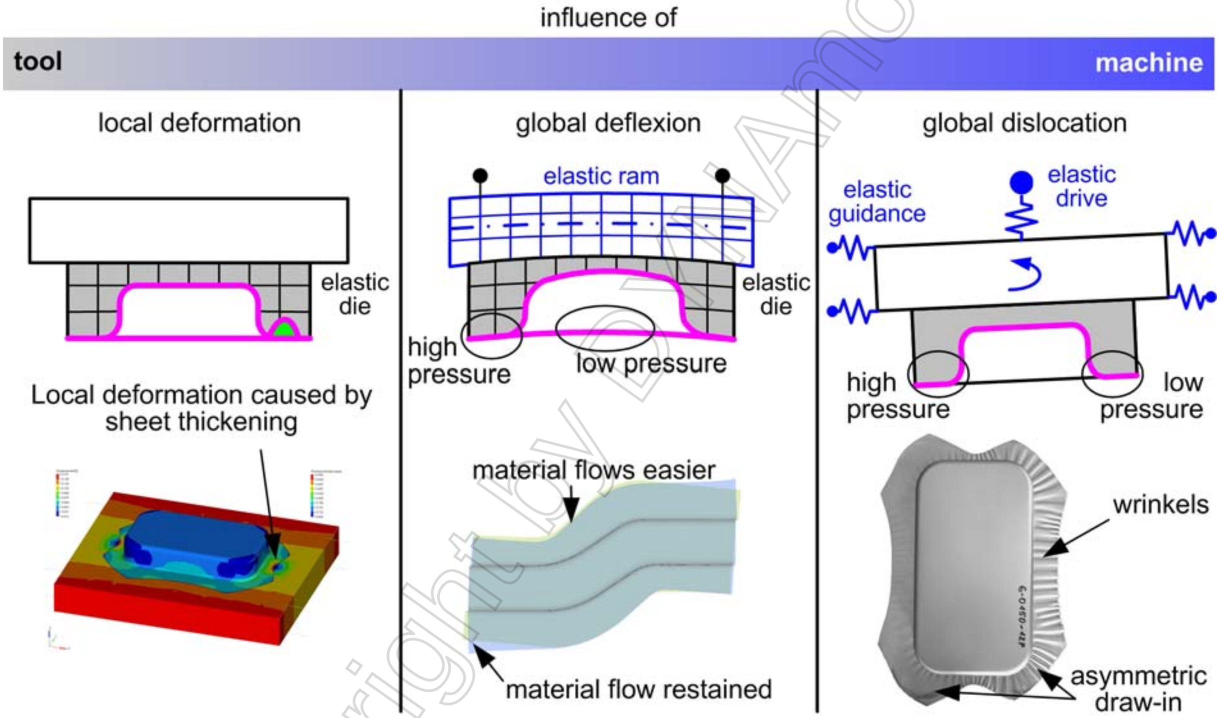


Figure 2: left: FE-simulation with solely elastic tool properties; middle: FE-simulation with elastic tool and ram; right: elastic influence of ram tilting on final part shape.

From the information above, it can be concluded, that the various factors taken into account produce the same result; the distribution of the blankholder force changes and thus influences the material flow. This requires that all factors be evaluated. If found to have a large enough intensity to significantly impact the result of the simulation, these factors then need to be consider in the simulation. Systematic consideration of elastic properties is now an additional and necessary step in the tool design process.

A simulation using elastic tools enables the user to pinpoint local tool deformations, which usually originate from sheet thickening and/or high normal surface pressure at the die radius (see Figure 2, left). Local tool deformations caused by sheet thickening are beneficial for the draw-in, whereas deformations at the die radius are undesired. Local deformations at the die radius are rather small and, in most cases, negligible. Therefore, it appears difficult and unlikely to be able to conduct compensation solely for local deformations.

In order to compensate for global tool deflexions and tool dislocations (see Figure 2, middle and right), the FE model has to be honed with the capability of considering elastic press properties. Former research work at the IWM and various other institutes has shown that it is possible to demonstrate the previously mentioned effects on the drawn part by means of FE simulation [5]. The linear and non-linear elastic properties of the press can be implemented in FEA by using discrete elements, such as springs and dampers, making the computation slightly more time consuming.

Calculating the tools elastic deformation in FE simulations entails a significant increase in computational time and effort. In [1], various approaches are introduced to decrease the number of degrees of freedom and hence reduce computation time. Since all reduction methods still have to contain the surface nodes in order to appropriately represent the contact conditions between the sheet and the tool, the compensation method introduced in this paper can be applied with all of reduction methods. Furthermore, due to the availability of multi-core processors and the ability of LS-DYNA for parallel computation with up to 8 processors, considerably larger FE models can be handled. Hence, the authors in [1] conclude that a full 3D discretization also shows great potential.

3.2 Advanced Tool Design Process

After springback compensation, the tool surface represents the best shape for achieving the springback of the drawn part back to the desired part shape. Therefore, it is useful to consider the elastic effects at this step in the tool design process. At this point, the elastic properties of the tool and press have not yet been assessed. Therefore, the tool surface during the actual deep drawing process will differ from the rigid tool surface that was used for the previous forming and springback simulation. In the following approach shown in Figure 3, the springback compensation is succeeded by the compensation for effects, which are results of elastic tool and press properties. The compensation process is iterated until the die surface nodes derived from springback simulation and the die surface nodes under process load match one another. The new surface is then reconstructed from the compensated node set and manufactured. Due to other influences on the deep drawing process which are not implemented in the FE simulations, e.g. friction and material properties, the die spotting time can not be eliminated, but can be reduced.

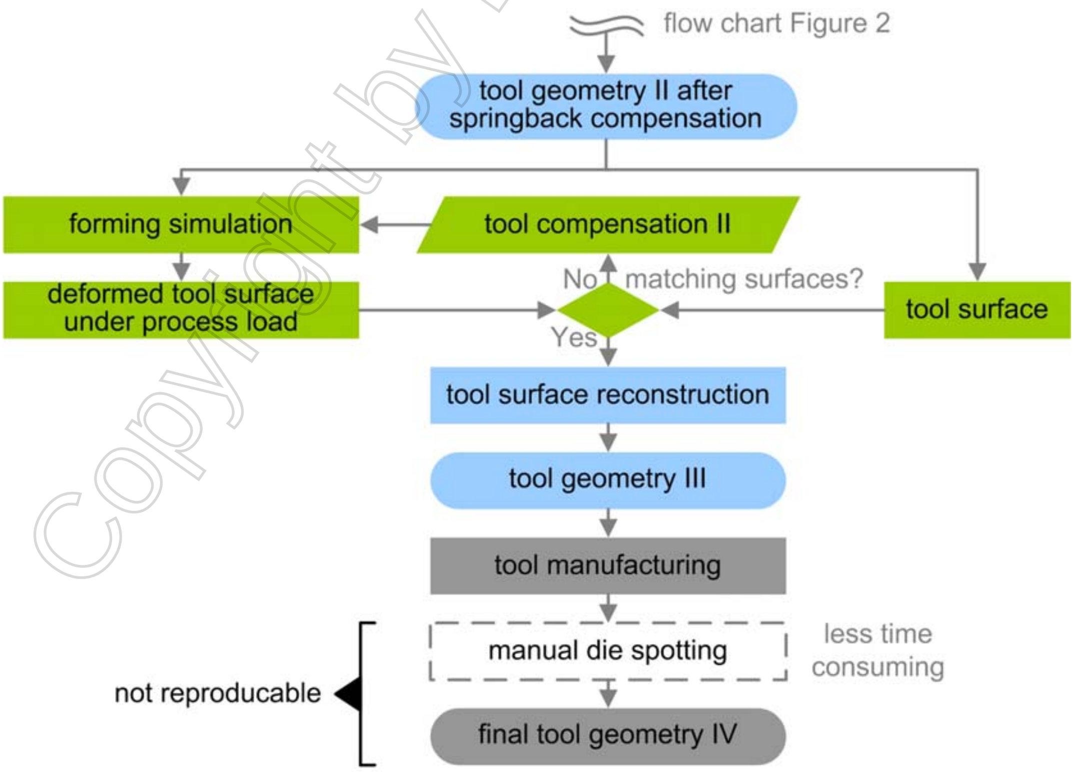


Figure 3: Tool design and stages of compensation

Figure 4 shows the four main stages of the compensation method. Using the die surface 1 (DS1), which is defined through springback compensation with rigid tool and press properties, the elastic deformations and/or dislocations of the die are calculated by means of FE simulation. DS2 shows different deformations, which result from considering ram tilting, global deflection, and/or local deformations, or any combination of these properties, in the FE model. As explained in chapter 3.3, DS2 serves as the input parameter for the surface compensation. The new die surface (DS3), a result of the compensation, is then implemented in an additional FE simulation, which delivers both the new die surface under process load and the influence on the final part shape. The new contact surface of the die under process load (DS4) now equals the desired die surface from the springback compensation with no process load placed on the die.

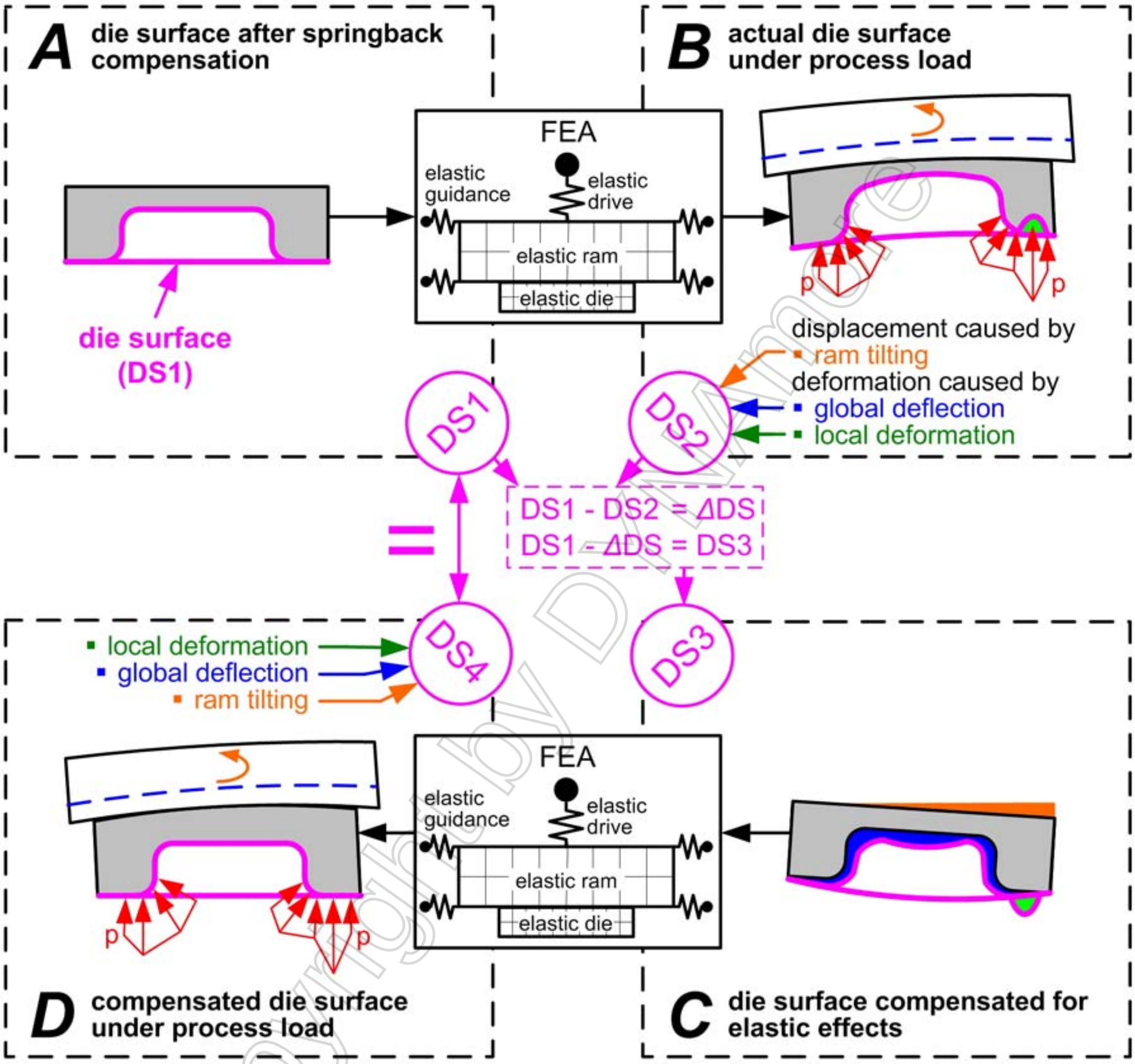


Figure 4: Types of elastic influences and their compensation

3.3 Automatic Tool Surface Compensation

The first step of the automatic surface compensation method is to calculate the tools elastic deformations, which are caused by process load. For this purpose, LS-DYNA is used. The FE model has to be able to contain the properties mentioned in chapter 3.1, which vary in dominance depending on the machine and tool. During the final step of deep drawing, the most pressure is placed on the tool, therefore causing the largest deformations of the entire process to occur. At this point the nodes and their new coordinates are extracted from the FE-model. The transformation vector is then calculated by subtracting the new node coordinates from the initial node coordinates.

$$\vec{\Delta}_i = \vec{p}_i - \vec{s}_0 = \begin{bmatrix} x_{p_i} - x_{s_0} \\ y_{p_i} - y_{s_0} \\ z_{p_i} - z_{s_0} \end{bmatrix} = \begin{bmatrix} \Delta x_i \\ \Delta y_i \\ \Delta z_i \end{bmatrix}$$

Subsequently, this vector is negated, then multiplied with a scale factor and ultimately added to the position vector of the initial nodes.

$$\vec{a}_i = -0.9 \cdot \vec{\Delta}_i$$

$$\vec{s}_i = \vec{s}_{i-1} + \vec{a}_i = \begin{bmatrix} x_{s_{i-1}} - 0.9 \cdot \Delta x_i \\ y_{s_{i-1}} - 0.9 \cdot \Delta y_i \\ z_{s_{i-1}} - 0.9 \cdot \Delta z_i \end{bmatrix}$$

The result is a new set of node coordinates, which defines the new die surface and serves as the input for the next iteration.

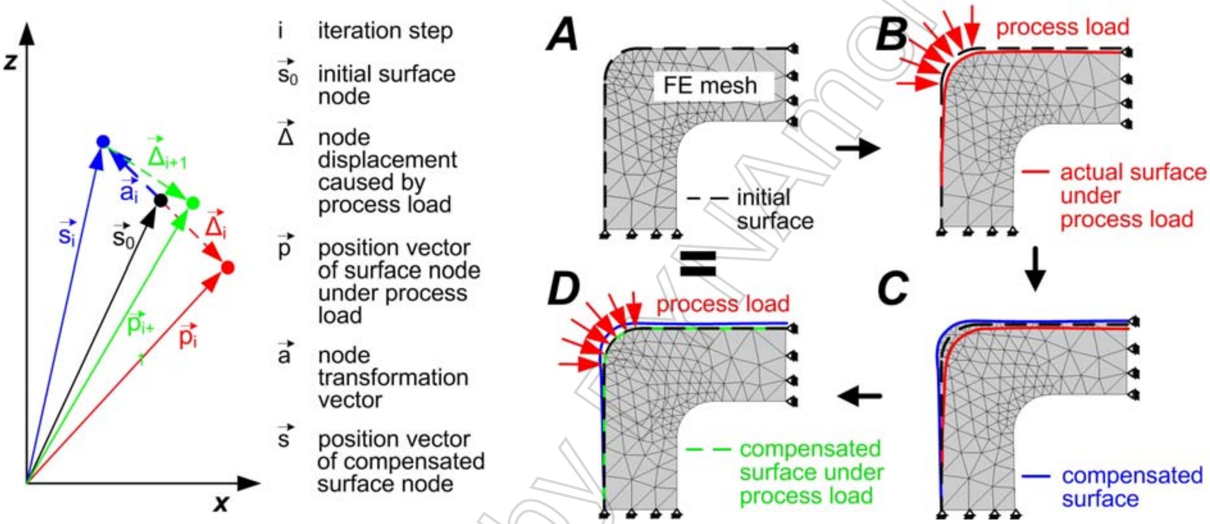


Figure 5: Automatic surface compensation

After every iteration the differences Δs_i are summed up for all die surface nodes and divided by the number of surface nodes. This number serves as the stop criterion. If the compensated surface nodes meet the stop criterion,

$$\sqrt{\frac{1}{n}\left\|\sum_{1}^{n} \vec{\Delta}_i\right\|^2} \leq C\,,$$

the compensation is aborted.

4 Application of the Compensation Method to S-Rail Tool

4.1 Experimental Set-up

Since the available hydraulic press has a small clamping area and the forces are comparatively small, no significant global deflections are expected. Hence, the four corners of the die sit on washers and enable an excessive deformation of the die under load to occur (see Figure 6). In addition, since the deflection of the die is by far the most dominant factor, the experimental set-up enables a well-defined compensation solely for this factor. It is clear, that this experiment does not reflect the reality and can only serve for general demonstration purposes.

Figure 6: Tool set-up for experimental evaluation of die surface compensation

4.2 FE model

Since the dies elasticity is the most dominant influence on the final part, elastic press properties are neglected in the FE model. However, due to the blankholder plate's height of just 37 mm, the blankholder elasticity can not be disregarded. Therefore, the die and blankholder are meshed with solid elements type 2, and possess an elastic material model MAT001.

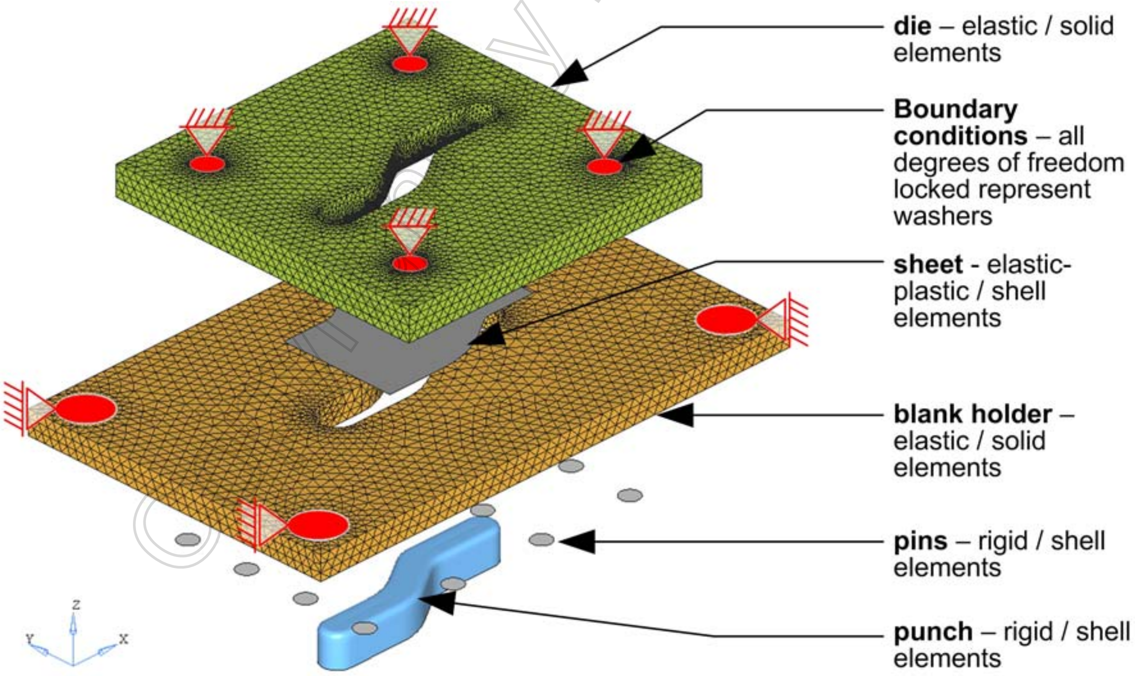


Figure 7: FE-model set-up for LS-DYNA with elastic blankholder and elastic die

The blankholder force is placed in +z direction through the use of rigid pin surfaces. The rigid punch displacement is defined by a velocity curve which reaches a drawing depth of 40 mm. The die mounting on the washers is represented by locking all degrees of freedom at the appropriate contact surface, see Figure 7. The contacts are defined using contact segments on the die and blankholder surface. The FE model contains 147.692 elements. In order to decrease computation time, the FE simulation runs simultaneously on four processors and takes 3 h 30 min.

4.3 Surface Compensation

The surface compensation method was applied to the experimental tool set-up. As previously mentioned, the main elastic influence is the global deflexion of the die. Since this deformation indicates values up to 0.6 mm, local deformations are of almost no impact.

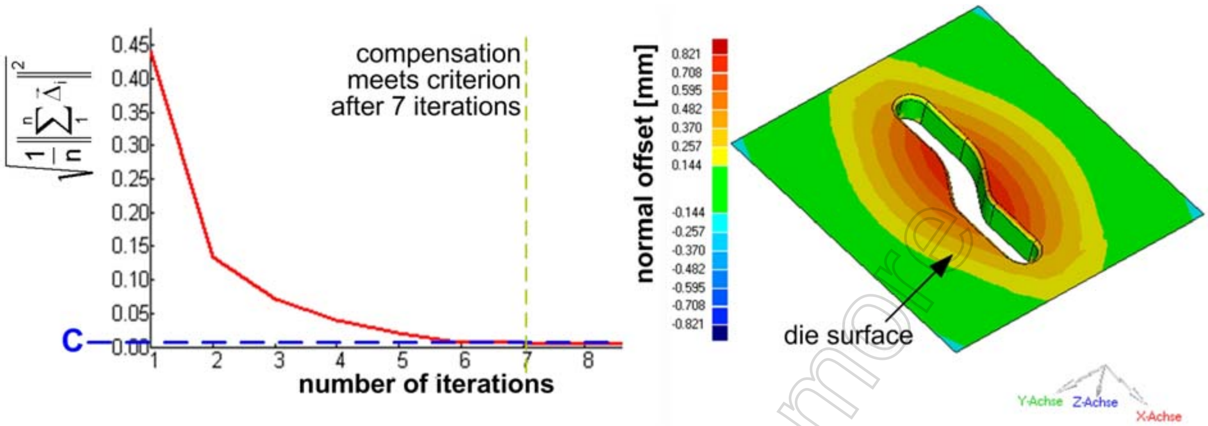


Figure 8: Die compensation: left: progress of stop criterion; right: offset of compensated die on initial die surface

In Figure 8, left, the progress of the stop criterion with each iteration is displayed. After 7 iterations the stop criterion is met and the compensated contact surface is extracted and reconstructed to get appropriate data for milling. Figure 9 shows the difference between both dies in FE simulation. Despite a larger deformation of the compensated die, the die clearance is improved, transformed back into the desired value of 1.4 mm and the die surface is a plane.

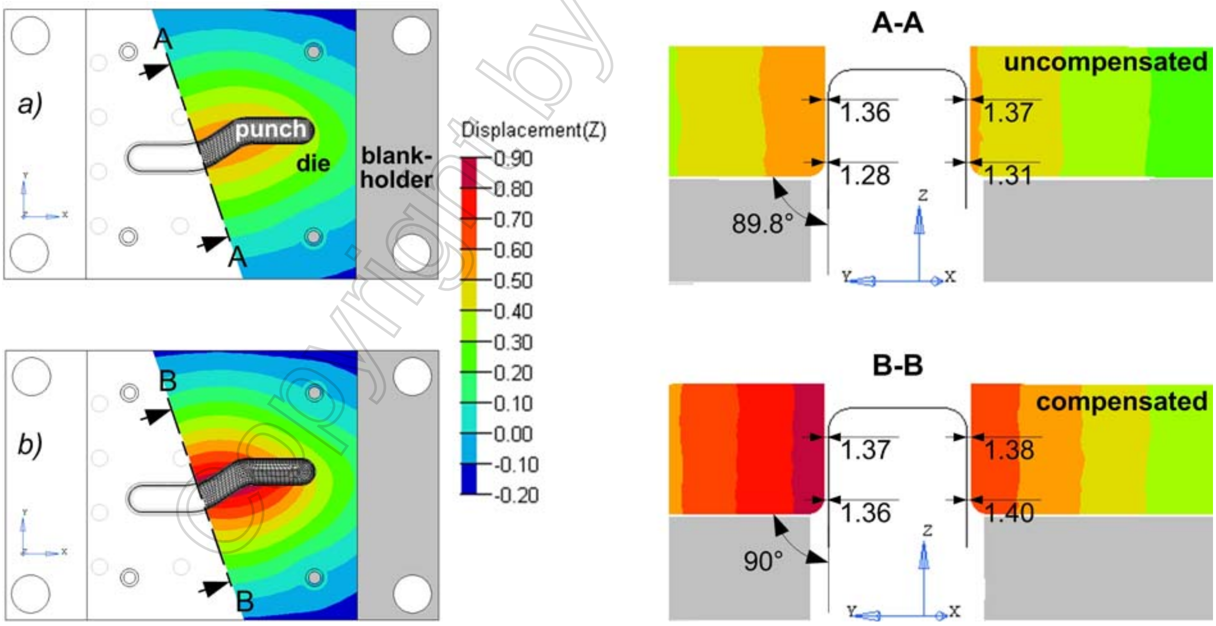


Figure 9: Deformation at the end of the deep drawing process and its influence on drawing clearance. a) uncompensated S-Rail die, b) compensated S-Rail die

4.4 Experimental Results

For the die compensation a reference part was defined by means of FE simulation. It was assumed, that the die would sit flat on the ram and no global deflections would occur. Therefore, the die nodes that were actually in contact with the ram were locked in all degrees of freedom. By conducting the compensation process, the FE simulation results for the uncompensated and compensated die, which both sat on the washers, were automatically obtained (see Figure 10).

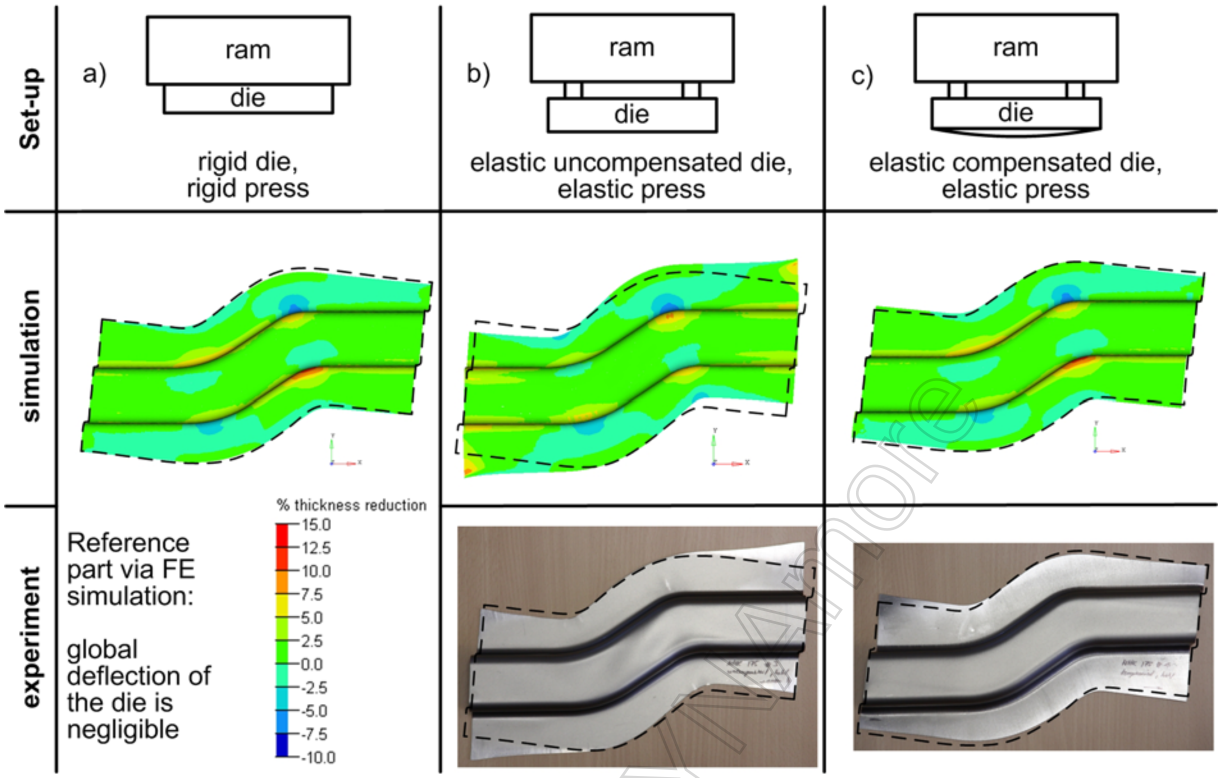


Figure 10 simulation compared with experimental results

As expected, the results from the simulation and experiment with the soft die, showed a significant influence of the die deflexion on the material flow. The global deflection caused the distribution of the blankholder pressure on the part to be affected and the material flow to be restrained on the outer corners of the part (see Figure 10 in the middle and Figure 11 a).

The forming simulation and experiment with the compensated die show a considerable improvement of the material draw-in. The uniform texture of the flange surface (Figure 11 b) indicates a homogeneous distribution of the blankholder pressure. It can be concluded that the die surface is now back to the desired surface shape.

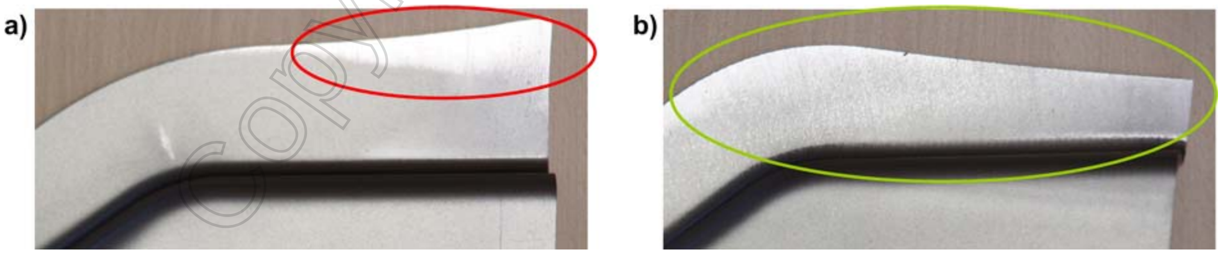


Figure 11: a) drawing with uncompensated die surface: the shining area reflects the high local pressure, which is placed on the part and holds the material from flowing; b) drawing with compensated die: uniform pressure distribution, material flow unrestrained

5 Conclusion

This paper illustrates a methodology that compensates for the effects of elastic tool and press properties on the final shape of the part. The new method was tested through an experiment, which induced a global deflection of the die and showed that using the conventional die leads to a massive impact on the draw-in. By applying the compensated draw, the draw-in was corrected.

6 Outlook of Future Research Work

Since it is unpredictable how much of an impact the compensation of the die will have on the springback behaviour of the part, future effort must take this effect into account. Additional research work needs to be done on local deformations. It is important to be able to distinguish between beneficial and harmful local deformations. Conceivably, lighter, and therefore less stiff, ram and press table construction could be used, which could result in improved dynamic behaviour, e.g. in servo presses.

7 Literature

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