Validation of the stoning method by numerical and experimental investigation of outer panels with and without surface deflections

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Abstract. Surface deflections have a negative effect on the appearance of exterior body panels in the automotive industry. They occur during springback and depend on part geometry and stress states. To detect whether a produced part has surface deflections, inspection methods, such as stoning, are applied. If the part has surface deflections, the tool geometry is modified in an iterative process until no more surface deflections are detected on the produced part. Besides stoning of physical parts, surface deflections can also be detected in post-processing of a finite element simulation by use of a numerical stoning method. The advantage is that the design of the tool can be modified before it is manufactured. However, the appearance of detected surface deflections depends on the software used and its settings. Therefore, the accuracy of surface deflections detected in simulations is worth investigating. This paper describes surface deflections detected by stoning method in experiments and compares them with the numerical results from AutoForm. In doing so, the influence of the numerical settings on the appearance of the surface deflections is analyzed. For this study, various parts with door handle pockets are produced. By changing the shape of the blank, and as a consequence, also the stress state, it is possible to generate parts with surface deflections of different sizes or parts without surface deflections. A blank of AA6016 with a sheet thickness of 1.0 mm is used. The results show that it is possible to detect surface deflections in simulations accurately if suitable settings are chosen. The meshing has a significant influence on the detected surface deflection whereas the draw bead model has less of an effect.

1. Introduction

Surface deflections are small depressions which can be described by a negative curvature on the surface of a part which has positive curvature before springback. They have very small dimensions with a depth of about 0.01 mm to 0.5 mm and a width and length of 15 mm to 100 mm. They typically occur on parts that are almost flat and have product features, such as door handle pockets [1], license plate pockets, and fuel-filler openings [2]. Surface deflections often cannot be seen immediately on the produced part but become visible easily, when viewed in sunlight because light is reflected irregulary [3]. There are also methods that can be used to detect surface deflections on a part that is not yet painted. A common method uses a stone with a length of 150 mm to 200 mm and a width of 20 mm to 30 mm to scratch the surface of the part [4]. The unscratched area represents the surface deflection. Another tool is a steel ruler which can be put on the convex surface of a part to detect surface deflections by looking

for a gap between the surface and the ruler [5]. The quantification of surface deflections is often difficult because it depends on the experience of the user or is easily affected by human error and additionally the classification of the defect is highly subjective [6].

It is also possible to detect surface deflections in finite element simulation software such as LS-Dyna (stoning), AutoForm (stoning, zebra lines, and three-point gauging), and PamStamp (stoning, senor, and rolling). The detection of surface deflections in simulation software has been investigated by different authors. Andersson used LS-Dyna and discovered that the simulation software was able to detect the location of surface deflections accurately but did not detect depth accurately [7]. Also, with the help of LS-Dyna, Fukumura et al. found a good agreement between the curvature distribution of the experiment and the simulation [1]. Weinschenk et al. showed that LS-Dyna is able to detect surface deflections, but the results strongly depend on the chosen set for stoning [8]. Chung showed that the results of the AutoForm simulation and the experimental results matched closely [9]. Schoenbach presented new user-defined variables to detect surface deflections [10].

2. Objective and Approach

The state of the art demonstrates that experimentally detected surface deflections and results of properly performed finite element simulations agree. The majority of authors compare experimental results with results in LS-Dyna while there are few investigations in AutoForm. Each author focuses on one single part which shows clearly visible surface deflections and they do not analyze the repeatability of the stoning method. There are no systematic investigations of numerical parameters' influence and the limit values of the stoning method in simulation and experiment are not investigated. Therefore, the main purpose of this paper is to investigate those issues that have not yet been investigated: parts with hardly visible surface deflection in experiments and their appearance in simulation and the influence of the meshing and draw bead model on the size of surface deflections. [8] introduced a tool to draw a part with a door handle pocket which is partially used for experiments and simulation in this paper. The punch and inner geometry of the die are slightly changed so that it is possible to produce parts with clearly visible, hardly visible and not visible surface deflections depending on the blank size. These surface deflections are compared to the ones detected with the stoning method in the finite element simulation in AutoForm. By doing so, it is possible to check the limit values of the stoning method. This study also focuses on the influence of the mesh and the model of the draw bead on the dimensions of surface deflections.

3. Experimental Investigation

3.1. Setup

The tool used for the experiments consists of a lower part with a punch and blank holder (Figure 1), and an upper part with the die (Figure 2). The produced part has a door handle pocket in the middle, as surface deflections often occur around it.

For the experiments, an AA6016 with a sheet thickness of 1.0 mm is used. The aim of the experiments is to produce parts with clearly visible, hardly visible or no surface deflections. This is made possible by the use of different blanks with a length of 800 mm and a width that varies between 300 mm and 700 mm. For stoning, a stone with a length of 150 mm is used in the direction of the minimum principal curvature, which is the x-direction. Three repetitions are conducted for each blank width.

3.2. Results

Figure 3 shows the detected surface deflection on the experimental parts with different initial widths. The width of the blank has a clear impact on the existence of surface deflections. For example, a part with a narrower width exhibits surface deflections whereas a part with a wider
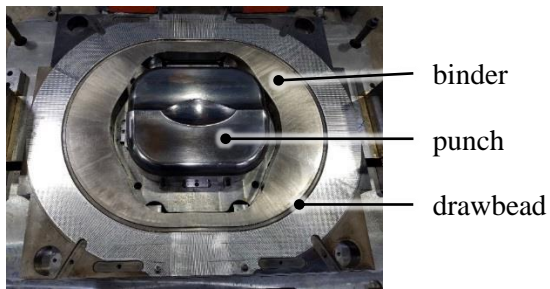
Figure 1. Lower part of the tool
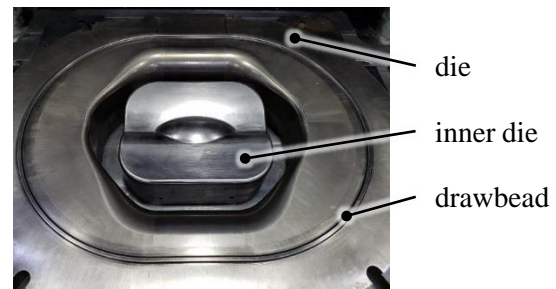
Figure 2. Upper part of the tool

width does not. The presence of surface deflections on the part strongly depends on the stress distribution of the part. An inhomogeneous stress distribution along the width of the blank leads to inhomogeneity of the curvature. The part with a width of 500 mm has clearly visible surface deflections above and beside the door handle pocket whereas the part with a width of 600 mm has surface deflections that are hardly detectable by the stoning method.
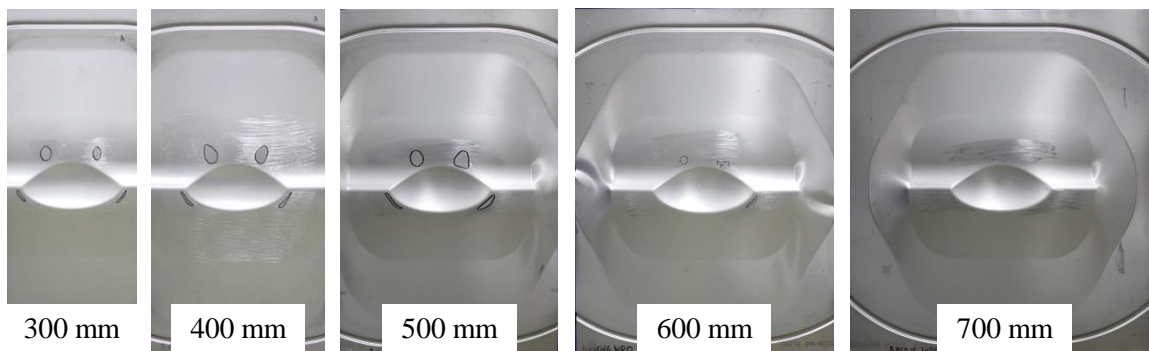
Figure 3. AA6016: Detection of surface deflections on the part with a stone length of 150 mm

4. Numerical Investigation

4.1. Setup

The finite element simulations of forming and springback are conducted in AutoForm R6. All surfaces of the tool which come into contact with the blank are modelled. The friction coefficient is set to 0.05. The strength of the line draw beads is 130 N/mm. Elements of the type EPS-11 (Elastic Plastic Shell Element with 11 layers) are chosen. A combined Swift and Hockett Sherby Approximation is used for the hardening curve of the AA6016 and Barlat89 is used to describe the yield surface. The effect of the material model on the predictive accuracy of the surface deflections is very small. Since the element size of the blank and the modelling of the draw bead have a huge impact on the results, four different combinations of these settings are investigated. Two different meshing options are investigated:

- initial element size of 5 mm and adaptive mesh refinement with the following settings: radius penetration 0.08 mm, maximum element angle 7°, maximum refinement level of 3
- initial element size of 1.3 mm with no adaptive mesh refinement.

Two different models of the draw bead are used:

- closing: constant line bead, drawing: constant line bead
- closing: 3D profile, drawing: adaptive line bead.

4.2. Results

Figure 4 shows the surface deflections detected by the stoning method in AutoForm R6 using a stone with a length of 150 mm along the x-direction on the upper side of the part. The initial element size of 5 mm and the constant line bead for closing and drawing are used.
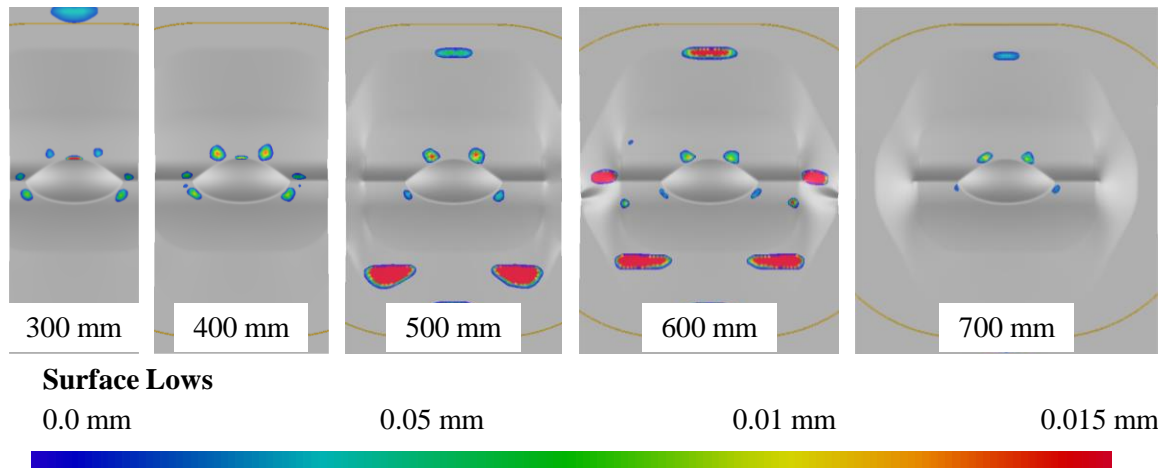

Figure 4. Stoning in AutoForm R6, stone length 150 mm

Figure 5 shows the minor curvature of the parts investigated. The area of the negative minor curvature is smaller than the area of the surface deflection detected by stoning. This is because the area with surface deflection contains both regions with positive curvature area and negative curvature. The surface deflection dimension, detected by the stoning method for a part with a blank width of 300 mm, is in the range of 20 mm in the x-direction, whereas the minor curvature, which has very small negative curvature, has a dimension of 12 mm in x-direction.
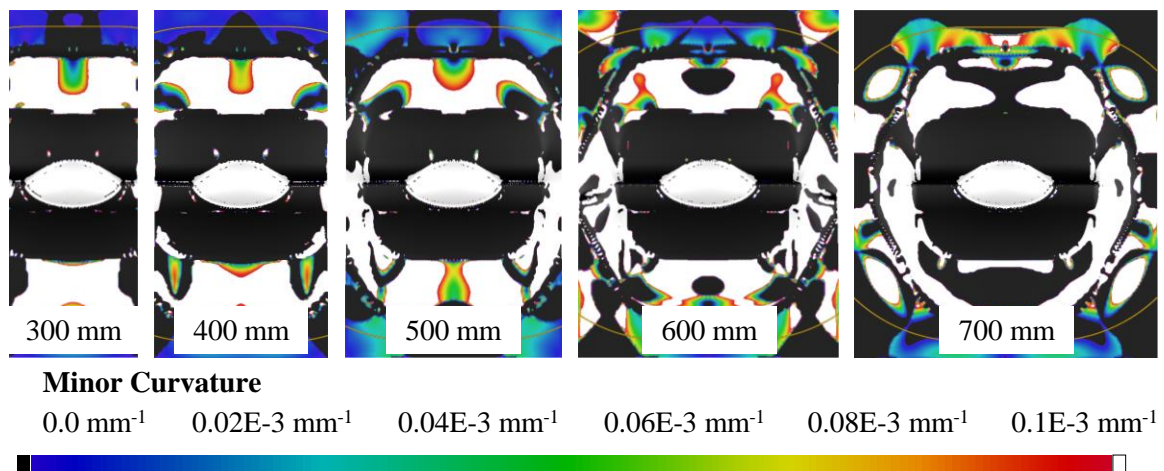

Figure 5. Minor curvature in AutoForm R6

4.3. Influence of Meshing and Draw Bead

The detected surface deflections from experiments and finite element simulations are compared to show the influence of the numerical settings on simulation accuracy. The validity of the simulation is determined by comparing the dimension of the surface deflections in the x-direction and the depth. For three parts of the same blank width, the surface deflections on both sides of the door handle pocket were measured. Consequently, Figure 6 shows six experimentally detected surface deflection dimensions for each blank width. The diagram also shows the results of the finite element simulation for the four numerical settings variants.

Although experimental stoning is a manual process, it shows good repeatability. One reason for the low level of variation is that surface deflections can easily be detected on aluminum compared to other materials. Since the surface deflections on this part are small and do not differ much in their x-dimension, they can be detected with the same stone length.

Where the results of the numerical settings are concerned, it can be seen that the data points of both draw bead models with meshing of 1.3 mm are close to each other for blank widths from 300 mm to 500 mm. The data points of both variants with meshing of 5 mm are also close to each other and, additionally, are higher for all parts than the data points of the finer mesh.

Figure 6 shows that the experimentally detected x-dimensions are close to the ones of the fine mesh for all parts. This can be explained by the difference between the x-dimension of surface deflections for both meshes. For example, in the case of the part with a width of 400 mm, the x-dimension of the surface deflection with a constant line bead with the mesh of 1.3 mm is about 23 mm, whereas for a mesh of 5 mm it is about 34 mm. With an element size of 5 mm this equates to a difference of one element on each side of the surface deflection. Surface deflections were detected on two physical parts with a width of 600 mm, whereas none were detected on the third part. To explain this, the maximum depths of the surface deflections in Figure 7 are considered.
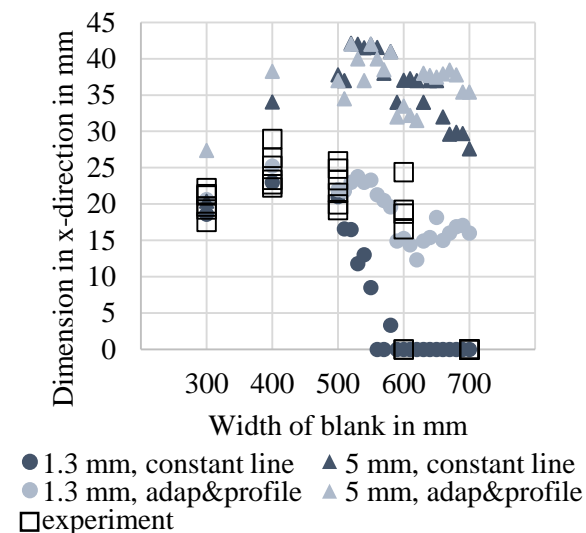

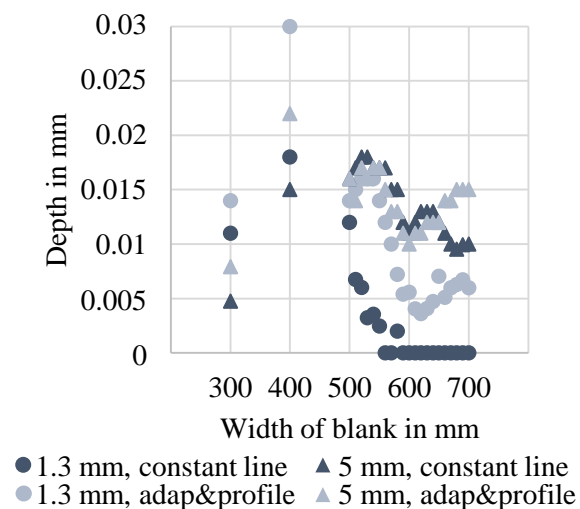**Figure 6.** Dimension of surface deflection in x-direction

Figure 7. Depth of surface deflection

The surface deflection depth of the 600 mm wide part is smaller than the depths on parts of smaller width. The stone scratches small depths easily because in contrast to the virtual stone it has grains of certain sizes. This is why the user does not always recognize if there is a surface deflection or not. It depends on the manual process and the pressure applied by the user to the stone to move it forward. On the 700 mm wide part there are clearly no surface deflections in

the experiments. The simulation with a fine mesh and a constant line draw bead also detects no surface deflection whereas the simulation with fine mesh and adaptive and profile draw bead still detects surface deflections. This can be explained by looking at the minor curvature in the area of the surface deflection. For both draw bead models, the simulations with a fine mesh show small negative minor curvatures on a 600 mm wide part, whereas none are shown on a part 700 mm wide part. Due to this, the physical 600 mm wide part exhibits surface deflections whereas the 700 mm wide part does not.

5. Conclusions and Future work
The results show that surface deflections can be detected in simulations if suitable numerical settings are chosen. It is especially important to chose the meshing carefully. With an element size of 1.3 mm, surface deflections exhibit a very good agreement with the experimental results while an element size of 5 mm leads to increased dimensions relative to the experimental results. The draw bead model also has an influence on the size of surface deflections but it is much smaller. It is so small that for blank widths between 300 mm and 500 mm the variation in the experimental results is greater than the difference caused by the two draw bead models. In this example, the use of the constant line draw bead leads to better results for parts with hardly or no visible surface deflections. For clearly visible surface deflections there is no significant difference.

In the next step, the influence of the stoning parameters will be analyzed in simulation and experiment. In addition, the influence of the material parameters will be investigated.

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