Strategy to prevent surface deflections for automotive sheet metal parts

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Abstract. Surface deflections are undesirable in automotive outer panels because they disturb their visual appearance. As a consequence, the geometry of the deep drawing tool is manually adjusted during tryout until the produced parts do not display any surface deflections. The aim of this paper is to reduce this time-consuming and cost-intensive tryout by slightly changing the geometry of the tool in an early state of the product development process to lower the risk of surface deflections. Therefore, this paper shows the influence of geometrical parameters of the deep drawing tool on the occurrence of surface deflections. A multiple curved outer panel with a door handle depression is chosen for the investigation. Typically, so-called “teddy bear ears” occur around the depression. The sheet metal material AA6016 with a sheet thickness of 1.0 mm is used. Numerical simulations of the draw operation and springback are performed in AutoForm. An analysis of the curvature before and after springback is used to detect surface deflections. The influence of the stresses and curvatures on the appearance of surface deflections is analyzed. For the experimental validation, stoning is used to detect surface deflections on a physical part. A very good agreement between the numerical and experimental results was obtained. The results show that the existence of surface deflections strongly depends on the initial curvature of the part and the appearance depends on the distribution of minor stresses. It is possible to reduce the risk of surface deflections during the design phase by changing the geometry.

1. Introduction
The surface quality of outer panels is of high importance for its visual appearance. Therefore, it is essential that these sheet metal parts do not have surface defects such as surface deflections, which typically occur due to compressive stresses around depressions on flat sheet metal parts with low stiffness [1]. While some surface defects like wrinkles are often easy to detect, surface deflections are shallower and therefore more difficult to detect. Methods like stoning are used to detect surface deflections on physical parts and on numerical results [2].

2. Objective and Approach
The main goal of this study is to reduce the risk of surface deflections on sheet metal parts by slightly modifying the deep drawing tool geometry while the process parameters remain constant. This can be done before the production of the tool and therefore enables a much faster tryout. Figure 1 illustrates the aim of the study. At first, surface deflections are detected. Then, the part geometry is modified. This is repeated until the part no longer has any more surface deflections.
An earlier study analyzed the influence of geometrical parameters of a sheet metal part with a door handle depression on the surface deflection depth [3]. It showed that an increase of the part’s global curvature reduces depth significantly. For a better understanding of the possibility to prevent surface deflections, the influence of the curvature on the stresses and occurring surface deflections is analyzed in this paper. By changing the blank size, the influence of the stress distribution on the appearance of surface deflections is also analyzed.

![Flow chart of the strategy to prevent surface deflections.](attachment:flow_chart.png)

**Figure 1.** Flow chart of the strategy to prevent surface deflections.

3. **Experimental Setup**

The deep drawing tool used for the study described in this paper is shown in figure 2 (a). It consists of a lower part with the punch and blank holder and an upper part with the die. It has a draw bead which locks the material flow to obtain a strain condition similar to the one of an actual door panel. A blank holder force of 1,300 kN was applied. Deep drawing oil and draw foil were used to reduce friction. The blank of AA6016 has a thickness of 1.0 mm and a size of 1000 mm x 800 mm. Figure 2 (b) shows the part which was produced with this tool. It has four surface deflections which were detected by the stoning method, as can be seen in figure 2 (c).

![Punch and blank holder of the experimental deep drawing tool (a), sheet metal part with door handle depression (b), and surface deflections (c).](attachment:figure2.png)

**Figure 2.** Punch and blank holder of the experimental deep drawing tool (a), sheet metal part with door handle depression (b), and surface deflections (c).

4. **Numerical Setup and Validation**

All finite element simulations were conducted in AutoForm plus R6. A constant line bead was used to lock the material flow. A master element size of 5.0 mm and a minimum element size of 0.62 mm were determined. A combined Swift/Hockett-Sherby approximation was used to model the material. An elastic plastic shell element with 11 layers (EPS-11) was chosen to accurately describe the stress state caused by springback.

To validate the finite element simulation, the strain distribution was compared to the experimental results determined by a measurement with the GOM Argus system. A good agreement was found, as can be seen in figure 3. The stoning method was used to detect surface deflections on the physical part.
For this, a thin stone with a length of 100 mm was used in x-direction (figure 2 (c)). The detected surface deflections were compared to the curvatures of the numerical results. Figure 4 shows the curvature cases of the numerical result of the springback simulation and the contours of the physical results. The surface deflections are in the area of the concave minor curvature. The reason why the contour of the physical surface deflection is smaller than the area of the minor curvature is that the curvature cases only indicate whether a curvature is negative or positive, but they give no information about the depth of a possible surface deflection. The depth of the area beyond the contour is too small to be detected by a stone and, therefore, the area does not belong to the surface deflection. In addition, the length of the stone limits the detected dimension of a surface deflection.

Figure 3. Strain measurement in experiment (a, c) and simulation (b, d).
5. **Strategy to Prevent Surface Deflections**

To investigate the influence of the geometrical modification on the occurrence of surface deflections, the part’s minor curvature about the y-axis was modified. The curvature of the physical part in figure 2 (b) is $2.9 \times 10^{-5}$ mm$^{-1}$. Figure 5 (d) shows the curvature cases after springback of this part. To determine a part without surface deflections, the minor curvature was increased until the part did not have any concave minor curvatures in areas of potential surface deflections after springback. It was found that a minor curvature of $6.3 \times 10^{-4}$ mm$^{-1}$ leads to a part without surface deflections (figure 5 (a)). Two more parts were investigated. The part shown in (b) has a minor curvature of $2 \times 10^{-4}$ mm$^{-1}$ and the one in (c) has a minor curvature of $1 \times 10^{-4}$ mm$^{-1}$.

The dimensions of the surface deflections decrease with an increase of the initial minor curvature. To analyze this phenomenon, the stresses and curvatures were investigated as they are responsible for the occurrence of surface deflections. For this analysis, the surface deflections above the door handle depression are chosen. Two sections are chosen for each part. Section 1 ranges from $x = -170$ mm to $x = 170$ mm with $y = 500$ mm. Section 2 spans the same range in x-direction with $y = 480$ mm.

![Curvature cases of the numerical result using AutoForm and contour of the physical surface deflection.](image)

**Figure 4.** Curvature cases of the numerical result using AutoForm and contour of the physical surface deflection.

![Curvature cases after springback for parts with an initial minor curvature of $6.3 \times 10^{-4}$ mm$^{-1}$ (a), $2 \times 10^{-4}$ mm$^{-1}$ (b), $1 \times 10^{-4}$ mm$^{-1}$ (c), and $2.9 \times 10^{-5}$ mm$^{-1}$ (d).](image)

**Figure 5.** Curvature cases after springback for parts with an initial minor curvature of $6.3 \times 10^{-4}$ mm$^{-1}$ (a), $2 \times 10^{-4}$ mm$^{-1}$ (b), $1 \times 10^{-4}$ mm$^{-1}$ (c), and $2.9 \times 10^{-5}$ mm$^{-1}$ (d).
Compressive stresses are commonly known to be responsible for the occurrence of surface deflections. Therefore, the minor stresses before and after springback are analyzed. For each section of each part, figure 6 shows the minor stresses of the shell elements’ top layer before springback. It is evident that the global trend of the minor stress course is the same for all parts and sections. The highest minor stresses are in the area of the potential surface deflections. It is also visible that the difference between the maximum minor stress in the area of the surface deflections and the minimum minor stress in the area between the two surface deflections is different for the two sections. The difference is smaller in section 1 than in section 2, and it also depends on the initial minor curvature of the part. The comparison of the minor stress in section 2 of the four parts shows that a higher minor curvature leads to a higher difference.

For all four parts, the minor stresses are positive before springback and negative after springback, as can be seen in figure 7. Areas of potential surface deflections have the highest absolute values which differ little between the four parts. This means that although compressive stresses are essential for the occurrence of surface deflections, they do not necessarily lead to surface deflections. There is another factor that is decisive whether surface deflections occur or not. To understand this, the minor curvatures before and after springback are analyzed.

Figure 8 shows the minor curvatures of the sheet metal part before and after springback. The solid lines show the course of the minor curvatures before springback and the dashed lines show the course after springback. Negative minor curvatures after springback indicate surface deflections.

All four parts have a similar course of the minor curvatures. The only significant difference is the occurrence of positive curvatures in (a) and negative curvatures in (b), (c), and (d). This strongly depends on the initial minor curvature of the part. In conclusion, despite minor stresses, surface deflections can be avoided if the minor curvature of the part is high enough.

Figure 6. Minor stresses before springback for parts with an initial minor curvature of $6.3 \times 10^{-4}$ mm$^{-1}$ (a), $2 \times 10^{-4}$ mm$^{-1}$ (b), $1 \times 10^{-4}$ mm$^{-1}$ (c), and $2.9 \times 10^{-5}$ mm$^{-1}$ (d).
To show the relationship between the distribution of the minor stresses and the appearance of surface deflections, blank sizes were varied. Figure 9 shows four different parts which were produced with the same punch used for the part in figure 5 (d) but which have different blank widths. The part in figure 9 (a) had an initial blank width of 400 mm, the part in (b) of 500 mm, and the one in (c) of 600 mm, while (d) had the same blank size as the original one in figure 5 (d). Apparently, all four parts have surface deflections which differ in their dimension. This depends on the minor stress distribution, as illustrated in figure 10. The contour of the areas with the concave minor curvature as
well as the concave minor and major curvatures from figure 9 are projected on the minor stresses in figure 10. The distribution of the minor stresses after springback shows a significant relation with the size of surface deflections.

**Figure 9.** Curvature cases after springback for parts with an initial minor curvature of $2.9 \times 10^{-5}$ mm$^{-1}$ and initial blank widths of 400 mm (a), 500 mm (b), 600 mm (c), and 1000 mm (d).

**Figure 10.** Minor stresses after springback for parts with an initial minor curvature of $2.9 \times 10^{-5}$ mm$^{-1}$ and initial blank widths of 400 mm (a), 500 mm (b), 600 mm (c), and 1000 mm (d).
6. Future Work
This paper shows the experimental results for the sheet metal part with surface deflections. In the next step, the part without surface deflections will be analyzed. In addition, different materials will be used.

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