Systematic investigation of geometrical parameters' influence on the appearance of surface deflections in sheet metal forming

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Abstract. Surface deflections occur during springback, which follows deep drawing. They highly affect the visual appearance of outer skin components and are, therefore, undesirable. In this work, the influence of the part geometry on the shaping of surface deflections is investigated. The geometrical parameters of an exemplary component are varied and existing surface deflections are detected. For this, a component consisting of a multiple curved surface with an inserted door handle hollow is used, and AA6016, with a sheet thickness of 1.0 mm, as well as DC06, with a sheet thickness of 0.7 mm, are chosen. After the simulations are performed in AutoForm plus R6^{TM}, a virtual stone, Three-Point Gauging and the analysis of curvatures of the part before and after springback are used to detect surface deflections.

1. Introduction

Surface deflections are small geometrical deviations from the ideal surface of a part. They distribute the course of the light and are, therefore, often visible after painting [1]. Various specifications of the dimension of surface deflections exist in the literature. Thus, a depth in the range of 10 µm up to several hundreds of µm can be found [2]. In contrast to the small size of the depth, the area of the surface deflection is much bigger. Values between 30 mm and 50 mm are indicated for length and width of the area [1].

Surface deflections occur due to springback during the opening of a deep drawing tool and can often be found near strong geometrical changes on large, flat parts with little thinning [2]. In this area, the part has lower stiffness and lower plastic strains compared to the surrounding area and is, therefore, especially prone to springback [3]. The springback calculation is sufficiently accurate to map such phenomena [4]. On curved parts, surface deflections occur mainly because of elastic forming during relief at the end of the forming process. Internal stresses, which remain in the part if the material cannot relax uniformly, are responsible for the occurrence of surface deflections on flat surfaces [5]. The position and visibility of surface deflections depend on several parameters. These are geometrical parameters such as curvature [6] and depth of hollows on the part, process parameters, like blank holding force as well as material parameters such as yield stress, r-value and sheet rolling direction [7].

In a virtual environment, such as AutoForm plus R6^{TM}, methods like stoning and Three-Point gauging can be used to detect surface deflections [5].

2. Objective and Approach

The formation of surface deflections depends on a sheet metal part's geometry and the stress state. This study focuses on the geometry. The influence of a sheet metal part's surface curvatures on the depth of surface deflections is systematically investigated.

A part geometry with a door handle hollow is chosen for the study. At first, a parametric CAD construction is created in CATIA V5^{TM}. For each set of geometrical parameters, a finite element model is created in AutoForm plus R6^{TM}. While the geometry of each finite element model is different, the settings of all the other parameters are the same. In post-processing, surface deflections are detected by a stoning method implemented in AutoForm plus R6^{TM}. The aluminium alloy AA6016, with a sheet thickness of 1.0 mm, and the steel DC06, with a sheet thickness of 0.7 mm, are chosen for the investigation.

3. Tool design and finite element model

The deep drawing tool consists of a two-part die, a blank holder, and a punch, as can be seen in Figure 1. The blank holder and the outer die remain constant for the parameter study. The dimensions of the punch and the inner part of the die are varied. The size of the blank is 800 mm x 1000 mm. A circumferential lock drawbead prevents draw-in of the material.

The part generated by the deep drawing tool consists of a single convex curved profile in x direction and a multiple curved profile in y direction, as shown in Figure 2. The profile in y direction is based on five tangentially merged radii. Four of these can be modified for the investigation. In addition, there is a door handle hollow with an entrance radius D whose dimension can be varied. The range of all parameters is limited by geometric constraints.

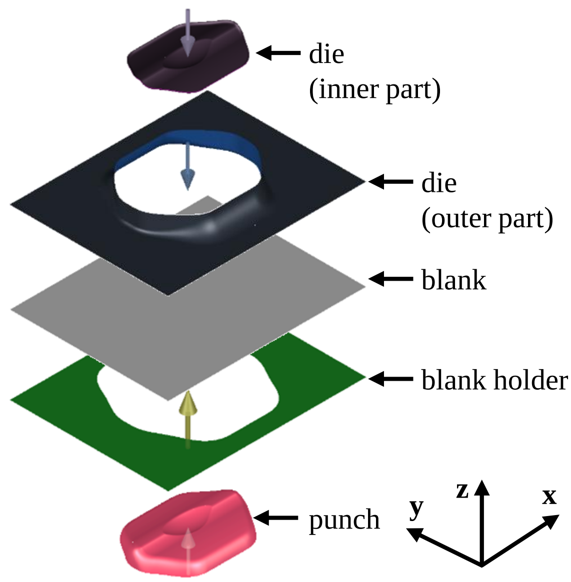

Figure 1. Surfaces of the deep drawing tool for the finite element simulation.

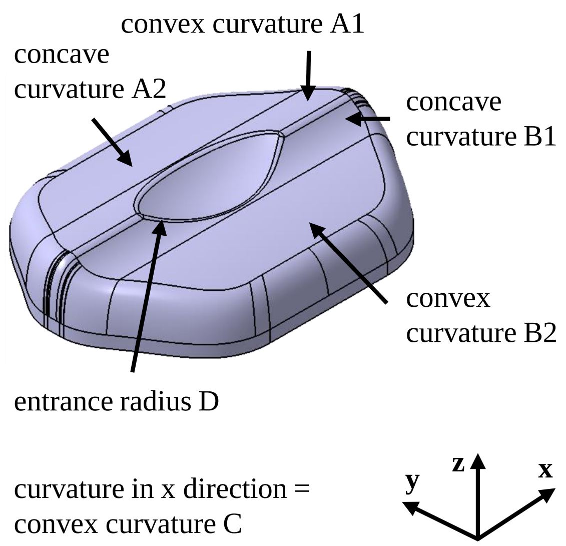

Figure 2. Punch of the deep drawing tool with variable parameters.

The clearances between the components of the tool depend on the used sheet thickness. The offset between blank holder and outer part of the die is always equal to the sheet thickness. When AA6016 is used, the offset between the punch and inner part of the die is 1.05 mm to take variations between material batches into account. For DC06 an offset of 0.75 mm is chosen.

The finite element model is built in AutoForm plus R6^{TM}, as described in Table 1.

Table 1. Settings for the finite element simulation in AutoForm plus R6^{TM}.

Option	Setting
geometries	The tool components and the blank of Figure 1 are used.
symmetry	The yz plane is used as a plane of symmetry.
operations	First: a deep drawing operation, second: free springback is performed.
anisotropy	The x axis is parallel to the rolling direction of the sheet.
lubrication	Drawing oil is used and, therefore, the friction coefficient is set to 0.05.
force	A constant force of 1300 kN is applied to the blank holder.
drawbead	An analytical constant line drawbead is used to represent the lock drawbead.
element type	Blank: An elastic plastic shell element with 11 layers is used.
meshing	Blank: An initial element size of 5.00 mm is used. Adaptive mesh refinement is allowed and restricted by a maximum refinement level of 3. Therefore, the minimum size of elements is 0.62 mm.

4. Evaluation and results

This initial configuration is used for the parametric study: A1 = 1/200 mm^{-1}, A2 = 1/600 mm^{-1}, B1 = 1/75 mm^{-1}, B2 = 1/450 mm^{-1}, C = 1/35000 mm^{-1}, and D = 10 mm.

The one-factor-at-a-time method is used to obtain an overview of the influence of the parameters on the depth of surface deflections. Virtual stones at various lengths are used to detect surface deflections on the upper side of each part. The length of a stone resulting in the lowest surface deflection is determined. For each part, the stone is moved in x direction, because this is the direction of the minimum principal curvature.

The results show that it is possible to reduce the depth significantly by a suitable selection of the parameters. Figure 3 shows an example for which a stone length of 150 mm was used.

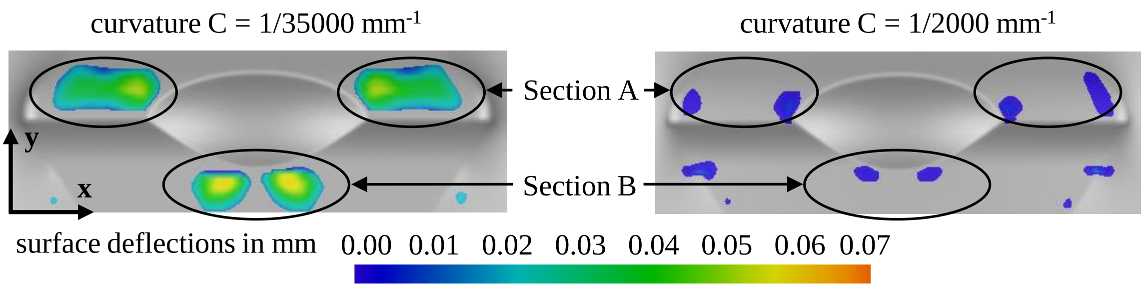

Figure 3. DC06: Detection of surface deflections on the part with a stone length of 150 mm

For DC06, the initial configuration of C = 1/35000 mm^{-1} results in a clearly visible surface deflection with a depth of 0.053 mm in Section A and 0.06 mm in Section B, while a larger curvature of C = 1/2000 mm^{-1} results in a depth of 0.006 mm in Section A and 0.003 mm in Section B. The relationship between C and depth is shown in detail in Figure 4. When C increases and the other parameters remain constant, the Gaussian curvature increases. Hence, the local stiffness of the part increases and the risk of surface deflections decreases.

As [2] pointed out, surface deflections occur near strong geometrical changes. Therefore, these should be avoided. As one can see in Figure 5, the depth decreases with an increase of D. With a radius of 28 mm or higher, the surface deflection in Section B disappears.

It was found that A2 has a small effect on the depth because it does not directly affect the areas with surface deflections. Within the given geometric constraints, a minimum depth of

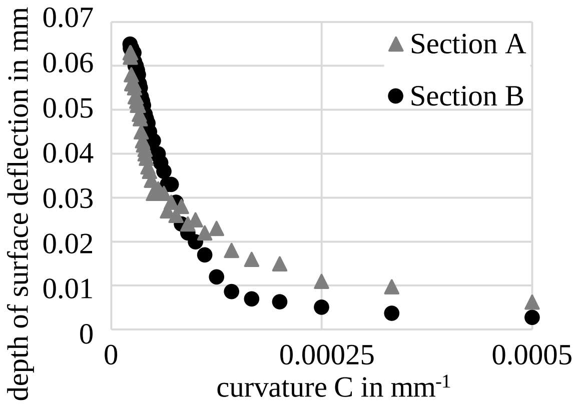

Figure 4. DC06: Influence of curvature C on depth of surface deflection

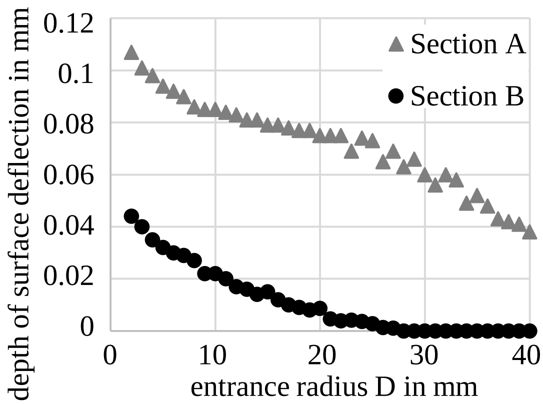

Figure 5. AA6016: Influence of entrance radius D on depth of surface deflection

0.048 mm in Section A, and 0.056 mm in Section B was detected for DC06. For AA6016, the initial configuration leads to 0.085 mm in Section A and 0.022 mm in Section B. An increase in A1 results in a decrease in depth in Section A. 1/100 mm^{-1} leads to 0.047 mm for AA6016 and 0.02 mm for DC06. By variation of A2, only a minimal depth of 0.084 mm in Section A and 0.017 mm in Section B can be achieved. With the variation of B1, the depth of the surface deflection in Section B can be reduced to 0.01 mm for AA6016 and for DC06 it even reaches 0 mm. B2 also has a high impact on the depth in Section B. It is possible to reduce the depth significantly.

5. Future work

In the next step, the interactions between the parameters and the influence of stress and strain on surface deflections will be investigated. In addition, robustness analyses will be carried out and for a selected set of parameters an experimental validation will be performed.

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References

[1] Hazra A, Williams D, Roy R, Aylmore R and Allen M 2011 Predicting the occurrence of cosmetic defects in automotive skin panels *AIP Conf. Proc.* **1353** 253-257

[2] Fukumura M, Yamasaki Y, Inage D and Fujita T 2004 Finite element simulation of surface defects in the automobile door outer panel *AIP Conf. Proc.* **712** 1917-22

[3] Anderson A 2005 Evaluation and visualization of surface defects a numerical and experimental study on sheet-metal parts *AIP Conf. Proc.* **778** 113-118

[4] Muthler A, Duester A, Volk W, Wagner M, Rank E 2006 High order thin-walled solid finite elements applied to elastic spring-back computations *Comput. Methods Appl. Mech. Engrg.* **195** 5377-89

[5] Schoenbach T and Avermann M 2013 Simulation based method of surface deflect detection *IDDRG Proc.* 243-248

[6] Port A, Thuillier S and Manach P 2009 Occurrence and numerical prediction of surface defects during flanging of metallic sheets *Int. Journal of Material Forming* **3** 215-223

[7] Yonemura S, Uenishi A, Kosugi S, Yoshida T, Hiwatashi S and Nakagawa J 2013 Advanced technologies related to simulation and evaluation for performance of automotive exterior panels *Nippon Steel Technical Report* **103** 11-17