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Simulation of the Deep-Drawing Process: Influence of geometrical parameters on elastic springback of sheet metal

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ABSTRACT

The process of plastic deformation by deep-drawing sheet metal is used on a large scale in the industry. The main users are the automotive and aeronautical sectors. Improved competitiveness in this industrial sector can be achieved by reducing production costs by combining traditional know-how with the forecasting capabilities offered by numerical simulation, in particular using the finite element method. In this article we propose to study the influence of some parameters of the deep-drawing process on the elastic springback of thin sheet metal.. The process parameters studied in this study are: the dimension of the gap during bending between the sheet metal / punch interfaces and the corner radius of the deep-drawing tools. A model of the deep-drawing process was carried out in ABAQUS by considering a Johnson Cook type law of elastoplastic material behavior. Simulations show that an increase in the gap between the sheet metal/punch interfaces promotes elastic springback. A larger corner radius also produces greater elastic springback.

KEYWORDS: Metal forming, Deep-drawing process, Finite Elements, elastic springback, Johnson Cook

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I. INTRODUCTION

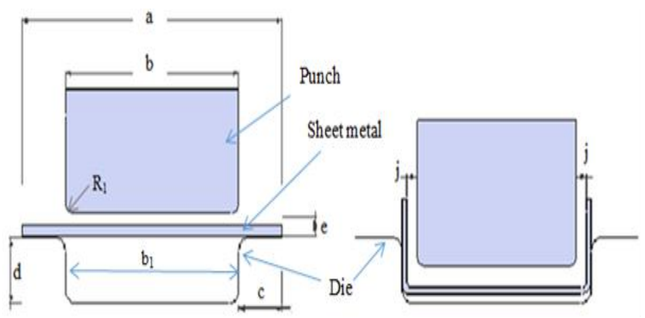
Sheet metal deep-drawing is a process commonly used in various industries (aeronautics, automotive, mechanical engineering, etc.). It consists of plastically deformed thin sheets of metal, either hot or cold, to obtain parts with complex shapes. Numerous undesirable phenomena may occur during or at the end of the forming process [1], [2], [3]. The part may have different defects such as necking, edge undulations due to buckling and distortion of the part by elastic springback after removal of the tools (restitution of the elastic energy stored during the discharge phase). In order to optimize this process, it is very practical to use numerical simulations to correct undesirable defects.

The finite element method is one of the most widely used numerical tools in the prediction of these deformation phenomena. In the context of this method, many authors have proposed approaches and models to simulate these thin sheet metal forming processes. Haddad [4] and many others [5], [6], [7] have proposed the introduction of high-performance Elasto-plastic behaviour models with combined strain-hardening, for reliable prediction of the behaviour after drawing. The phenomenon of elastic springback has also been studied [8], [9]. Most of the work in this area is focused on finding the most suitable and material behaviour for a given process. In order to study elastic springback during the deep-drawing of thin sheets metal, our work will be devoted to a forming process by deep-drawing using an axisymmetric punch. The objective of this paper is to study the influence of some parameters of the deep-drawing process on elastic springback. The simulation under ABAQUS [10] will consist in studying the influence of parameters such as the spacing between the sheet metal and the punch as well as the radius of the punch fillet on elastic springback.

II. DESCRIPTION OF THE DEEP-DRAWING PROCESS

The deep-drawing device consists of a sheet metal (bending part), a die (Possessing the final geometry of the sheet metal after bending) and a cylindrical punch (see figure 1). The vertical movement of the punch allows the sheet metal to be bending by plastic deformation. For all the simulations carried out, the sheet metal connection is without clamping. The weight of the structural elements is not taken into account. Figure 1 clearly illustrates the geometrical parameters that are the subject of the numerical study: R_1 (the corner radius of the punch and die) and j (the gap between the sheet metal and the punch interfaces).

Fig. 1: Deep-drawing process



The dimensions of the characteristic sizes of the process illustrated in figure 1 are as follows: a=15 cm, b=10- j (cm) c=2.5cm, d=1.5 cm. The corner radius are R_1= 3mm (die and punch rounding radius are identical). The radius R_1 and gap j will be the main variables in these simulations. The die and the punch will be considered as non-deformable solids in this study.

III. JOHNSON - COOK'S MATERIAL BEHAVIOUR LAW

In our simulations, the behaviour of the sheet will be described by a JOHNSON-COOK material behaviour law (eq. 1), which is a multiplicative behaviour model [11].

$$\sigma = [A + B\varepsilon^n] \cdot \left[1 + C \cdot ln\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right] \cdot \left[1 - \left(\frac{T - T_t}{T_{fusion} - T_t}\right)^m\right] \qquad (1)$$

This equation is composed, in order of appearance, of a strain hardening term, a dynamic term and a thermal softening term. The first term, referring to strain-hardening, corresponds to the flow stress at constant strain rate. **A** being the yield strength, **B** the strain-hardening modulus (linear parameter of strain-hardening) and n the strain-hardening coefficient (non-linear parameter of strain-hardening). The numerical quantities **A** and **B** used correspond to those of a standard steel. In this study, we do not take into account the effects of the temperature and deformation rate.

IV. NUMERICAL SIMULATION

In order to simulate the deep-drawing forming process described in figure 1, a finite element model (FEM) was developed using the ABAQUS calculation code. The following assumptions were considered: plane stress and strain, the problem is considered in 2 dimensions. Quadrilateral 4-node surface elements (type QUAD4) were used to mesh the sheet to take into account the effects of simple stresses. The thickness of the sheet is meshed by four elements to increase the prediction of elastic springback of the sheet. The deep - drawing tools, die and punch are considered as non-deformable solids. During the simulation, the sheet metal is placed on the die without fixing. Coulomb's law of friction was used to simulate the tribological behavior of the interfaces between punch and sheet metal.

V. RESULTS AND DISCUSSIONS

After presenting the material behavioural laws used and the geometrical model, we will focus in this part on the presentation of the results obtained by numerical simulation using ABAQUS/Explicit. The set of results detailed below focuses on the influence of the geometrical characteristics of the deep-drawing process on elastic springback. The main geometrical characteristics studied will be gap between the sheet metal and the punch and the corner radius R1 (see figure 1).

V. 1. Study of the influence of gap between the sheet metal and the punch

The sheet metal/punch clearance represents the empty space between the outer surfaces closest to the thin sheet and the punch (see figure 1). In order to highlight the influence of this geometrical characteristic on the deep-drawing process, we will consider the values of 0.25mm, 0.35mm and 0.5mm. For each gap, the results presented will be the mapping of the stresses in the sheet metal at the end of the deep-drawing process (corresponding to the low position of the punch) and the deformation of the sheet metal after the deep-drawing step, corresponding to the residual deformation of the sheet metal after elastic springback (see figures 2, 3 and 4).

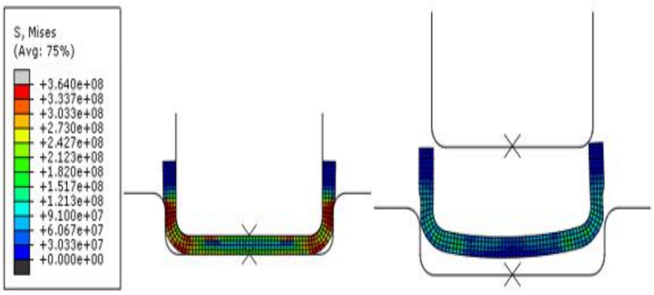


Fig.2: Stress fields for a 0.25mm gap between the sheet metal and the punch (Stress in Pascal). (a) Stress mapping during maximum deep-drawing, (b) deformation of the sheet metal after the deep-drawing operation.

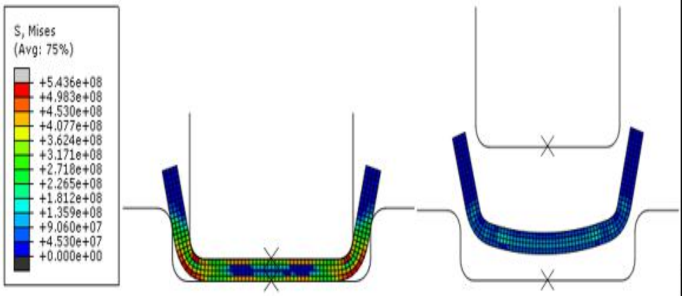


Fig.3: Stress fields for a 0.35mm gap between the sheet metal and the punch (Stress in Pascal). (a) Stress mapping during maximum deep-drawing, (b) deformation of the sheet metal after the deep-drawing operation

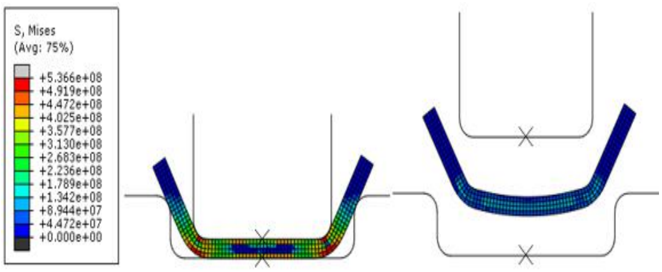


Fig.4: Stress fields for a 0. 5mm gap between the sheet metal and the punch (Stress in Pascal). (a) Stress mapping during maximum deep-drawing, (b) deformation of the sheet metal after the deep-drawing operation

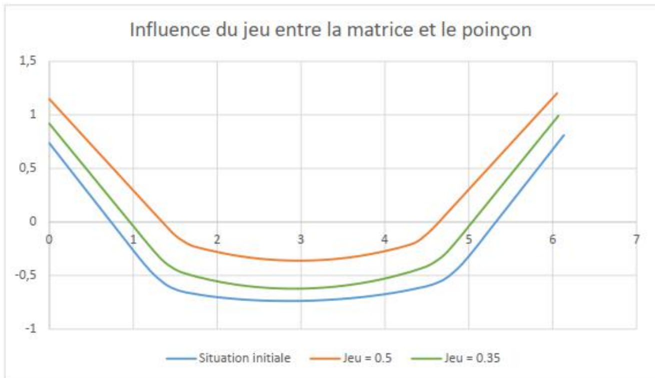


Fig.5: Sheet metal deformed after elastic springback for different gap between the sheet metal and the punch

Regardless of the selected spacing between punch/sheet metal, the maximum stresses are located in the bent area of the plates, thus corresponding to previous results obtained by other authors [4], [12]. The simulation clearly indicates an influence of the gap "j' on the elastic springback of the sheet metal. Figures 2b, 3b, and 4c show a noticeable change in the residual deformation of the sheet (result of elastic springback). A small gap between the sheet metal and the punch reduces the elastic springback phenomenon, while a larger value promotes it. The influence on gap on elastic springback is clearly shown in figure 5, and it can be seen that the greater the gap, the greater the elastic springback.

V.2. Study of the influence of the punch's corner radius

In this section, we will study the influence of the corner radius of the punch and die on the mechanical behaviour and more particularly the elastic springback after deep-drawing. We will consider in our simulations, 3 corner radius with values of 2.5mm, 4mm and 5mm. For each simulation, we will present the stress map at the end of the deep-drawing operation (corresponding to the low position of the punch) and the residual deformation of the sheet metal after the stamping operation (see figures 6, 7 and 8).

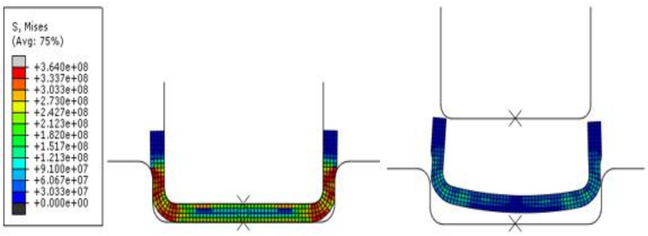


Fig.6: Stress fields for 2.5 mm corner radius (Stress in Pascal). (a) Stress mapping during maximum deep-drawing, (b) deformation of the sheet metal after the deep-drawing operation.

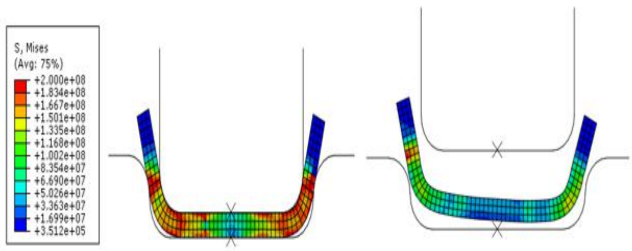


Fig.7: Stress fields for 4 mm corner radius (Stress in Pascal). (a) Stress mapping during maximum deep-drawing, (b) deformation of the sheet metal after the deep-drawing operation

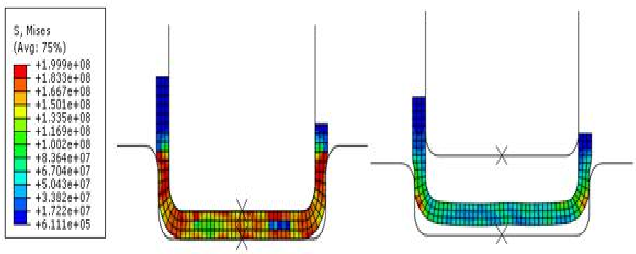


Fig.8: Stress fields for 5 mm corner radius (Stress in Pascal). (a) Stress mapping during maximum deep-drawing, (b) deformation of the sheet metal after the deep-drawing operation.

Figures 6, 7 and 8, showing the stress maps in the plate for different corner radius, show a slight decrease in the maximum stress states in the structure with increasing corner radius

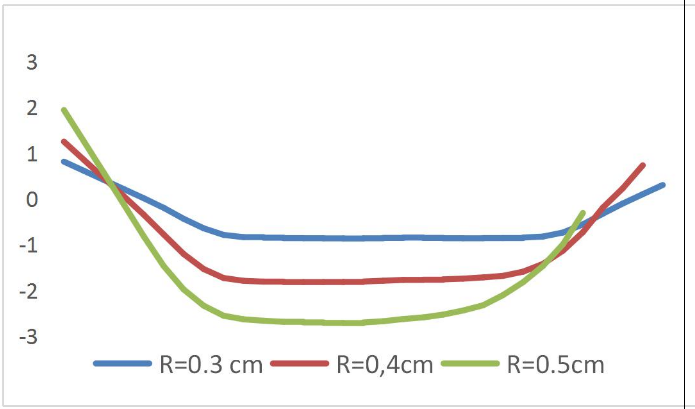


Fig.9: Comparison of the residual deformations of the sheet metal after the deep-drawing operation for different corner radius

In figures 6b, 7b, 8b and especially in figure 9 it can be seen that the radius of the corner clearly influences elastic springback. It can be seen that the larger the corner radius R1, the greater the elastic springback.

VI. CONCLUSION

In this article, we have highlighted the influence of some tool parameters in the deep-drawing process on the elastic springback of the deep-drawing part. A finite element model of the process has been constructed in the ABAQUS numerical code including an elastoplastic behaviour law. The simulations indicate a significant influence of the geometrical parameters (gap between the sheet metal and the punch and punch corner radius) on the often poorly controlled phenomenon of elastic springback.

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