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FINITE ELEMENT STUDY ON THE EFFECT OF DRAW BEADS

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ABSTRACT

Draw beads are commonly used in deep drawing processes to control the flow of the blank into the die cavity during the forming operation. It works with the application of a restraining force and a frictional force. A complicated deformation process takes place as the sheet flows through the bead. Those cycles of deformation (bending/unbending) are accompanied by traction stress and bending moment of the sheet, effects who can be used to avoid different defects like wrinkles and sprigback. This paper presents a finite element study in order to identify the effects of the draw beads during deep drawing of complex parts and to establish a numerical instrument for: i). identification of the material behaviour; ii). optimisation of the effects of draw bead in order to assure the high quality of deep drawed pieces. The draw bead efficiency and effects depends on several elements: the bead penetration, the clearances between the bead and the shoulder, the shape of the bead, the radius of the bead and shoulder, the groove width, and the location of the draw bead. The presented numerical study is performed with finite element code MARC and takes account of all this parameters.

KEYWORDS: deep drawing, finite element modelling, draw beads.

1. INTRODUCTION

Sheet metal forming is an important manufacturing process because of its high speed and low cost for mass production. The good quality (i.e., no tearing, no wrinkling, high dimensional accuracy) of stamped parts is critical in avoiding problems in assembly and in the final product performance. The control of flow of the material into the die cavity is crucial to good part quality and, generally, in sheet metal forming draw beads are used in order to achieve this objective.

Using a smooth binder surface and relying on the frictional force generated in the blank holder there will be no local restraining possible in the metal forming operation. Local restraining can be achieved by adding a draw bead. The additional local restraining force applied to the material as it flows through the draw bead is based on bending effects as well as the frictional forces generated. The draw beads is placed in the binder near the periphery of the die cavity. For a successful sheet metal forming operation a required restraining force can be generated by varying the indenter cross-section and penetration of the draw bead as well as clearance, groove width, inlet and outlet radii of the groove.

2. THEORETICAL ASPECTS

At the passing through the draw beads, the material suffers progressively cycles of deformation, type bending and stretching/unbending and stretching. Consequently, the material effect having draw beads is a residual strength and bending moment inverse proportional with the centreline curvature of the sheet, respectively with square.

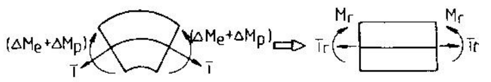


Fig.1. Effects of a single bending/unbending under tension cycle [5]

The mathematical model [5] necessary to calculate the residual stress and bending moment at the passing of the material by one cycle type bending and stretching/unbending and stretching it is determined considering that this cycle consist in two phases:

a). Bending and stretching phase

For the calculation of state parameters, the following assumption are made: plane sections remain plane after bending, strains in the width direction - ε_w - are neglected (plane strain), tangential strain - ε_T - is the linear sum of bending and stretching strains, stretching strain - ε_{mem} - is obtained from membrane solution, neutral axis position is caused by the stress in the sheet, normal compressive stress - σ_N - are neglected (plane stress).

Considering the figure 2 and assuming the above assumption, we can write the following expression for tangential strain, ε_T:

$$\varepsilon_T = \ln\left(\frac{R_m + z}{R_m - c}\right) \tag{1}$$

Tangential stress, σ_T, causing bending and stretching of each element are calculated with following relation:

$$\bar{\sigma} = K\bar{\varepsilon}^n \tag{2}$$

Where: $\bar{\sigma}$ and $\bar{\varepsilon}$ are effective stress and strain, respectively;

K is the stiffness matrix;

n is the strain hardening exponent

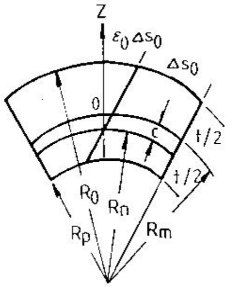


Fig.2 [5]

Considering plane state of stress and strain hypothesis and Hill’s 48 criterion assumed, for individual fibbers, relation (2) can be rewritten, for an anisotropic material, as the following:

$$\sigma_T = K'\varepsilon_T^n = K\left[\frac{1+r}{\sqrt{1+2r}}\right]^{n+1}\varepsilon_T^n \tag{3}$$

After springback, the centreline curvature of the sheet can be found as a function of bending moment, M:

$$\rho_{pl} = \rho_i - \frac{M}{\frac{\partial M}{\partial \rho}} = \rho_i - \frac{12\left(1-\nu^2\right)M}{Ebg^3} \tag{4}$$

b). Unbending and stretching phase

In order to calculate the strains and stresses induced in an initially bent element, stretched and later unbent with stretching, we made following assumptions: unbending occurs under the plane strain conditions, plane sections remain plane after unbending, the centreline curvature of the element is zero after unbending, straightening is caused by unbending and stretching, kinematics hardening govern the re-yielding in reverse loading.

In order to determine the effect of the material deformation at the passing through the draw beads it is necessary to establish the bending moment and force diagrams considering the different geometries of the draw beads. The residual strength and bending moment after the straightening are calculated by the following expressions [4]:

$$T_r = \frac{K'}{\Delta\rho_{pl}\cdot(n+1)}\cdot\Big[\left(A+\Delta\varepsilon_S\right)^{n+1} - \\ -\left(A-\Delta\varepsilon_S\right)^{n+1}\Big] \tag{5}$$

$$M_r = \frac{K'}{\Delta\rho_{pl}{}^2}\cdot\left\{\frac{-\left(A+\Delta\varepsilon_S\right)^{n+2}-\left(A-\Delta\varepsilon_S\right)^{n+2}}{n+2} + \\ +\Delta\varepsilon_S\cdot\frac{\left(A+\varepsilon_S\right)^{n+1}-\left(A-\Delta\varepsilon_S\right)^{n+1}}{n+1}\right\} \tag{6}$$

where:

$A = \Delta\rho_{pl}\cdot\dfrac{g}{2}$;

g is the material’s thickness;

$K' = K\cdot\left[\dfrac{1+r}{\sqrt{1+2r}}\right]^{n+1}$;

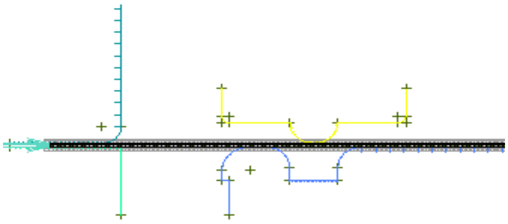
$\Delta\rho_{pl}$ is the net change in the centreline curvature of the element;

$\Delta\varepsilon_S$ is the stretching strain.

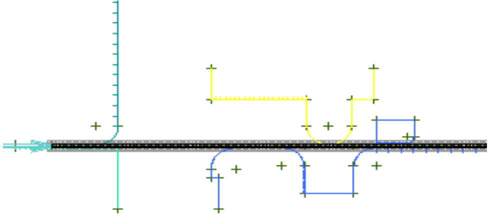
3. FINITE ELEMENT MODELING

The finite element model is developed and used to evaluate how numerical and process parameters influence the draw bead response in terms of residual restraining force and bending moment as well as thickness changes and stress history for material passing through the draw bead.

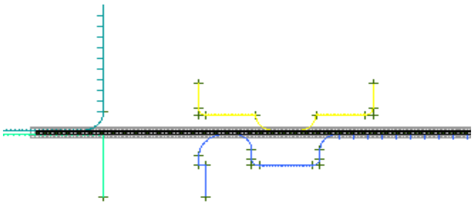
The finite element modelling is made with MARC Mentat 3.1 code considering three geometrical models (fig. 3.a-c) of the draw beads:



a) Model 1: round draw bead



b). Model 2: semi-circular draw bead



c). Model 3: flat-bottom draw bead

Figure 3. Models of the draw beads

The first step is closing of the draw bead. In the second step, the punch displacement determines the sheet metal passing through the draw bead during this deformation between the punch and die, while keeping the drawbead closed.

Different options are used in the finite element model like the element formulation and contact definition.

We consider the four-node, isoparametric, quadrilateral elements, and 2 layers on the sheet thickness in order to analyse stress history in different node position (intern or outer-surface and mid-surface). As this element uses bilinear interpolation functions, the strains tend to be constant throughout the element. This results in a poor representation of shear behaviour. The shear or bending characteristics may be using alternative interpolation function. This assumed strain procedure is flagged through the GEOMETRY option. The assumed strain formulation increases the stiffness assembly costs per element and improves the accuracy. This element is preferred over higher order element when used in a contact analysis. The stiffness of this element is formed using four-point Gaussian integration. All constitutive models can be used with this element.

The contact considered is Coulomb model with 0.05 friction coefficient. The discontinuity in the value of the tangential (friction) stress σ_{fr} can result in numerical difficulties. In order to avoid these difficulties a modified Coulomb friction is used:

$$\sigma_{fr} \le -\mu\sigma_n \mathrm{arctg}\left(\frac{v_r}{RVCNST}\right)t \qquad (7)$$

where RVCNST is the value of the relative velocity when sliding occurs, σ_{fr} and σ_n represent the tangential (friction) and the normal stress respectively, μ is the friction coefficient and t is the tangential vector in the direction of the relative velocity.

This model has a physical basis. Oden and Pires pointed about that for metals, there is an elastic-plastic deformation of the asperities at the microscopic level which leads to a nonlocal and nonlinear frictional contact behaviour. The arctan representation of the friction model is a mathematical idealization of this nonlinear behaviour. The tangential stress is then evaluated and a consistent nodal force is calculated.

Material data

A mild steel DP600 1 mm thickness was dues with the following mechanical properties: $Y_0 = 330.3$ MPa, $\varepsilon_0 = 0.00169$, $n = 0.187$, $C = 1093$ [1, 2]

4. RESULTS AND CONCLUSIONS

The curves σ_{11}=*function* (ε_{11}), in each case, include different steps during the deformation for the some element of the material: before draw beads, first and second part of the passing between the draw beads, after draw beads, passing over the radius of the die. A complex history [3] of the deformation is observed and a big amount of the deformation after the passing between the braw beads is obtained.

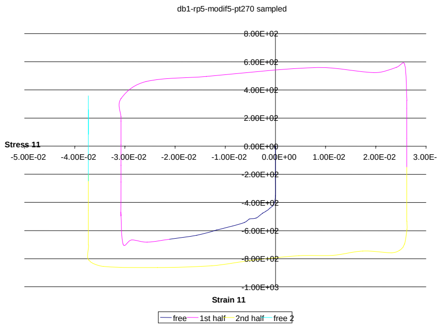


Figure 4. Variation of the function $\sigma_{11}=f(\varepsilon_{11})$ for the model1

The comparison is performed between the condsidered models. The amount of the deformation resulted after the passing of the material between the draw beads is different function on the draw beads geometry and depth penetration. By example, for the model 1 the amount of ε_{11} is $8 \cdot 10^{-2}$ after the passing between the draw beads and 5.710^{-2} after the passing by the die radius. In this case 58% of the total deformation is obtained by the passing of the material between the draw beads. In each case, we can see a cyclic solicitation of the material with change of the strain way. If we compare numerical values, the model three solicits more the material than the model one.

In order to make a full comparison, the $\sigma_{ech} = f$ *(increment)* have been drawn for a point located between the punch and the die (figure 5).

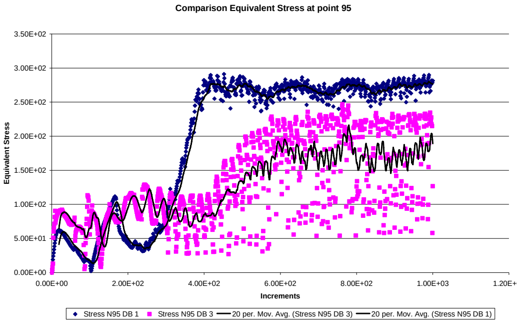


Figure 5. Equivalent von Misses stress evolution for different geometry and penetration of the draw beads

The equivalent stress at this point is about twice times more high in the first model than the third. The model1 of draw bead has a higher influence on the blank located in a free area than the model3.

The control of the sheet material flow into the die cavity by applying local restraining forces is very important in order to obtain a good quality of the formed parts. A required restraining force can be obtained by using an adequate geometry of draw bed.

The importance of the presented study is given by the fact that it identifies the material behavior and the effects of the draw beads geometry during deep drawing operation.

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