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NUMERICAL SIMULATION OF DEEP DRAWING PROCESS WITH DISCRETIZED DRAWBEADS

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ABSTRACT
In this paper we describe simulation of deep drawing process with discretized drawbeads. Due to CAD modelling simplicity and computational efficiency, in case of shallow parts drawing it is usual to use analytical or equivalent drawbead model. Unfortunately, in some cases, particularly in deep drawing of non-symmetric parts with increased depth, this simulation approach cannot lead to accurate predictions. Besides its complexity, more reliable results can be obtained by discretised model. We present such a drawbead model with triangular shell elements. By comparing numerical and experimental results, we show that discretized drawbead model leads to better predictions of deformations and deep drawing force.
Keywords: deep drawing, drawbeads, finite element model, restraining force, discretized drawbead.

1. INTRODUCTION
Drawbeads are usually used in deep drawing of parts with complex geometry and large dimensions. By numerical simulation it is possible to determine optimal shape and locations of drawbeads (with, height, profile, transient radii, distance of drawbead axis from the die edge, number of drawbeads and its mutual distance. These parameters are optimal in sense of achieved working part quality. The CAD modelling of drawbead and it precise positioning in drawing ring groove is cumbersome and time consuming in case of series of simulation with different drawbead geometry. Discretization on finite elements due to small dimensions of drawbeads leads to very high number of elements and corresponding number of degrees of freedom. This problem is even more emphasized in case of non-symmetricpartswhere model symmetry cannot be utilized. Additional complications arise due to nonlinearity introduced by contacts with friction between drawbead, blank and drawing ring. Those problems can be avoided with so called equivalent drawbead model. It is based on analytical or semi-analytical drawbead restraining force calculation and it realisation as external force acting at virtual drawbead position on discretised FEM model of blank without drawbead. Even with this simplification (deformation hardening, elastic spring back and anisotropy effects are not taken into account) this modelling approach is widely used and in many cases, especially in case of shallow symmetric parts leads to very good predictions. In this paper we present comparison of simulations with discretised and equivalent drawbead model with experimentally obtained results.

2.SIMULATION WITH DISCRETISED DRAWBEAD MODEL

The FEM simulation of deep drawing process of non-symmetric part with discretised drawbead model is related with many difficulties:

- CAD modelling of drawbead and groove geometry and its precise positioning
- High number of DOF due to FEM discretization of drawbead and its small groove geometry
- Additional surface contact modelling that leads to increase in necessary number of displacement increments and iterations per increment.

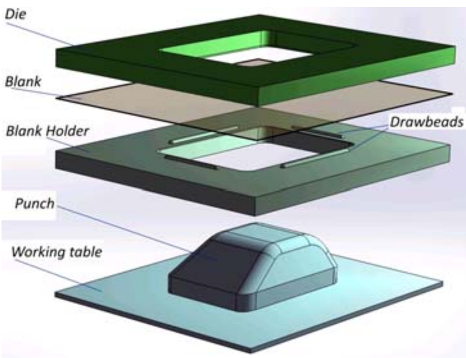
Due to previously mentioned complications it is highly recommendable to use equivalent drawbead model whenever possible. The restraining force is calculated analytically by simplified model, or for given drawbead geometry it is experimentally measured on specialized devices. After scaling (if necessary),calculated or measured forces are added to nodes on blank at the virtual bead position. The next simplification is to use rigid tool surfaces instead of discretised. Actually, the drawing tool parts (punch, die and blankholder) are much more rigid comparing to blank and its deformations can be disregarded with respect to blank deformations. Therefore, with small reduction of accuracy, it can be modelled as rigid that leads to significant reduction of number of degrees of freedom (DOF). As contact algorithm requires calculation of contact nodes penetration in to contacting surfaces, although rigid, tool surfaces are discretized in sense to be able to detect those nodal penetrations. Although it was shown in many cases that equivalent drawbead models gives very good predictions there are also cases in which this approach is not suitable. Main disadvantages are related to:

- Restraining forces, calculated analytically are inexact due to simplified, usually 2D models
- Effects of deformation hardening of blank material and anisotropy are not included in model
- Thinning of sheet material and related contact pressure reduction after drawbead is neglected
- Residual stresses in material that was slipped over the drawbead can produce unexpected springback effect after drawing operation and working part ejection.

In our research we have experimentally confirmed that equivalent drawbead model is adequate and sufficiently reliable for given working part. For one special case (S5-C) we have performed deep drawing simulation with discretized drawbeads. With this approach we obtained better results comparing to equivalent model but modelling and execution time was much longer.

2.1 CAD model of deepdrawing tool with discretized drawbeads

The 3D CAD model of working part was built in external pre-processor (CAD system) according to given shape and dimensions. The main parts required for FEM analysis are shown in figure 1 (a), and adaptively refined discretized zone of drawbeads is shown in figure 1 (b).



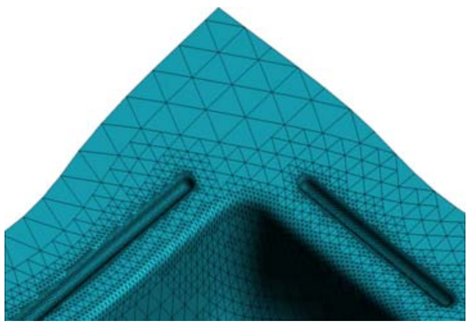


Figure 1. CAD model of tool partsFigure 2.2 The refined mesh in drawbead region

Due to longitudinal axial symmetry of working part, the finite element analysis can be performed at one half of the model. It leads to significant reduction of time necessary for nonlinear finite element analysis. The main geometrical parameters of drawbeads are presented in Table 1.

Table 1. Drawbeads geometry parameters

Simulation number:	Blank material	Blank size [mm]	Drawing depth [mm]	Number of rows, distance and length of drawbeads	Profile ,radiiand high of drawbeads
S5-Č	DC03	380 x 340	55	One row x_1=x_2=21,5 mm L_1=186mm, L_2=114mm	Half-circle r =2,5 mm h=3 mm

In this simulation we use elasto-plastic shell elements for blank discretization. This type of elements require much more numerical computations and corresponding analysis time with respect to bending enhanced membrane elements that are regularly used in equivalent drawbead model simulations. Besides, results obtained with this advanced elements are more accurate.

3. SIMULATION

The simulation process was performed in small displacement increments starting with blank holder closing at time t=0 and finishing at time t=55 sec. Punch speed was 1mm/s and drawing depth was 55 mm. The forming limit diagram (FLD) and corresponding surface defects height for model with discretized drawbeads are shown in figure 2 and 3. Except in drawbeads region, there is no significant difference between results obtained by equivalent and discretized drawbead models.

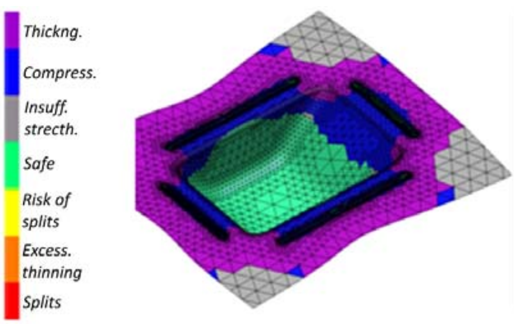


Figure 2. Forming Limit Diagram

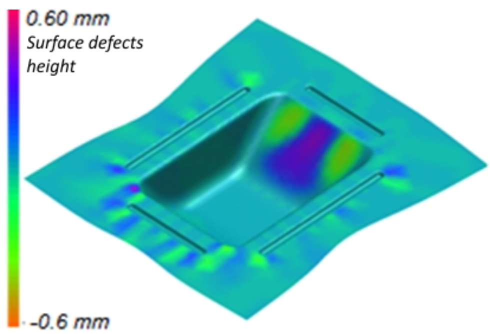


Figure 3. Surface defects height distribution

From figure 3. we see that maximum height of surface defects (wrinkles) is under 0.6 mm which is (for this type of working part) acceptable value. The model with discretized drawbeads predicts approximately the same maximum surface defects height although with little bit different distribution. In figures 4. and 5. we can see the thickness distribution after drawing and total drawing force with respect to time for discretized drawbead model respectively.

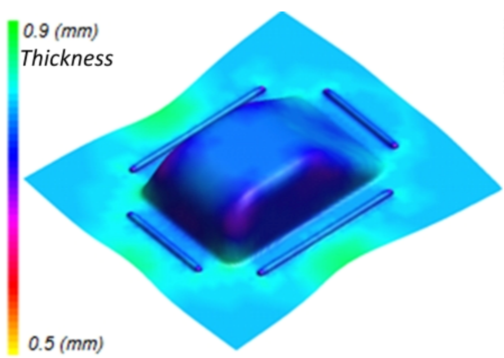


Figure 4. Thickness distribution

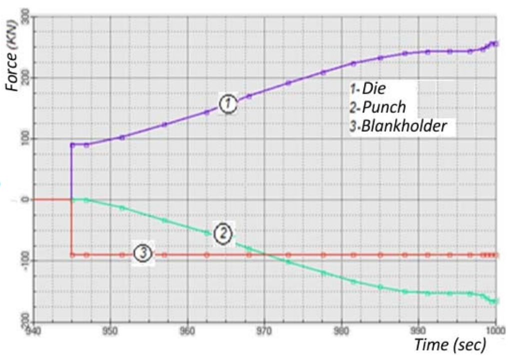


Figure 5. Total drawing force

In figure 4. we see intensive thinning at the end of drawbeads. It is consequence of half-spherical drawbead finishing in its CAD model. Therefor the calculated restraining force is falsely a little bit larger at the ends of drawbeads. In real settings there is no such problem because real drawbeads have continuously reduced height toward the ends.
Comparing with equivalent drawbead model in the same conditions, we can conclude that restraining force of discretized drawbeads is a little bit larger. It is result of strain hardening of blank material, effect which is not involved in equivalent model. Difference of total drawing force of two models is shown in figure 6. Difference is increasing with punch stroke. Consequently, it can have significant effect in case of deep working parts. Discretized drawbeads in these conditions give more reliable predictions.

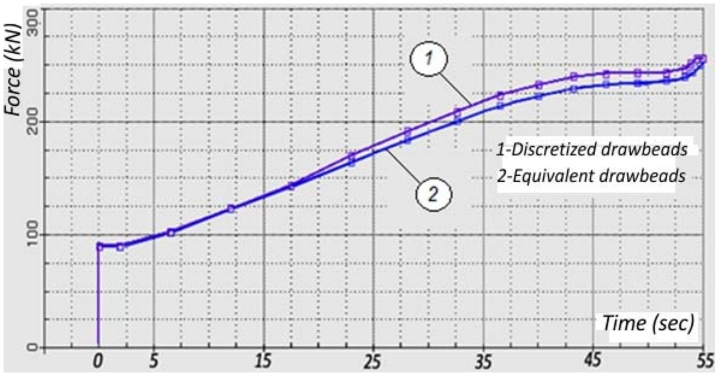


Figure 6. Total drawing forces for discretized (1) and equivalent (2) drawbeads

For shallow working part (up to 20 mm) this difference is small and can be neglected.

4. CONCLUSION

By comparison of equivalent and discretized drawbeads numerical results with experimental outcomes, we can conclude that (for given working part shape) differences are relatively small but model with discretized drawbeads was slightly more accurate in total drawing force and deformation distribution predictions. In case of axially non-symmetrical working parts with depth more than 20 mm, besides increased complexity it is recommendable to use discretized drawbead model due to more reliable results. For shallow working parts results obtained by equivalent drawbead model are reasonably accurate and therefore acceptable as better modelling approach.

5. REFERENCES

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