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Drawbead uplift force analytical model for deep drawing operations

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Drawbead uplift force analytical model for deep drawing operations

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Abstract. Drawbead uplift force calculation has been an open issue among the deep drawing tool maker and software developers in the last years. Starting from the original work of Stoughton (1988) many have been the models presented in order to improve the predictions. However, still nowadays, the main deep drawing software are not able to accurately predict the uplift force and clear example of that are the intensive effort of the software developers in that topic as well as the conversion factors used by the main OEM when acquiring a new tool. In this work, a new semi-analytic model of drawbead closing force calculation is presented. The model is not only able to predict the uplift force for different steps of the closing (very useful for the set-up process) but it has been validated when using a high strength steel (DP780) for different drawbead configuration.

1. Introduction

The analytical prediction of the retraining and up-lift force of a deep drawing drawbead is an open issue among the sheet metal forming simulation software developers [1]. Due to the reduced size of a drawbead compared with the total size of the component (a drawbead can be of around 20-30 mm while a full component can go from 200 to 2000 mm) the use of physical drawbead in finite element models implies, first, large computational effort [2], and second, numerical errors due to the fact of using shell elements in so small area [3].

In that regard, equivalent analytical models have been developed in where the drawbead is simulated with a simple line in the main drawing simulation and a restraining and up-lift force are introduced on the elements going through that line. The most relevant work in that area was performed by Stoughton in 1988 that established the basics for this kind of models [4]. From the industrial experience on the sector it is known that this kind of models usually accurately predict the restraining force but underestimate the up-lift force (the up-lift force is the necessary force to close the drawbead). The main reason for that underestimation is that most of those models are based and validated with the experimental performed by Nine in 1978 [5] where rolls were used instead of an industrial type blank holder and that underestimated the experimental closing force of the drawbead [6].

In view of all this, in the present work, a new drawbead up-lift analytical model is presented, able to not only predict the final up-lift force but the evolution of this one during the closure. The work is presented as follow: first the used material in this work, a high strength DP780 steel is presented. Then, the numerical model, using finite element method, used as a reference is presented and the key aspects of the process are summarized. Next, the basic hypothesis of the new analytical model are presented and the methodology for the up-lift force calculation detailed. Finally, the correlation of the prediction of the analytical model to the numerical results are presented for different drawbead height and the conclusions are drawn.

2. Materials

A high strength steel DP780 material has been used in this study in order to validate the developed analytical model. Conventional tensile tests under the ISO 6892-1:2009 standard have been conducted. The summary of the material properties can be found in Table 1.

Table 1. DP780 material characterized for the numerical vs analytical model.

Material	Thickness	Elastic modulus E	Elastic limit Rp02	Maximum stress Rm	Elongation at Rm	Anisotropy
DP780	1.49 mm	198 GPa	540 MPa	893 MPa	10 %	0.9

The above material is used in both the numerical analysis and the analytical model.

3. Numerical model

In order to have a reference of the evolution of the up-lift forces during the closing of the blank-holder, a numerical simulation has been conducted with the drawbead geometry shown in Figure 1.

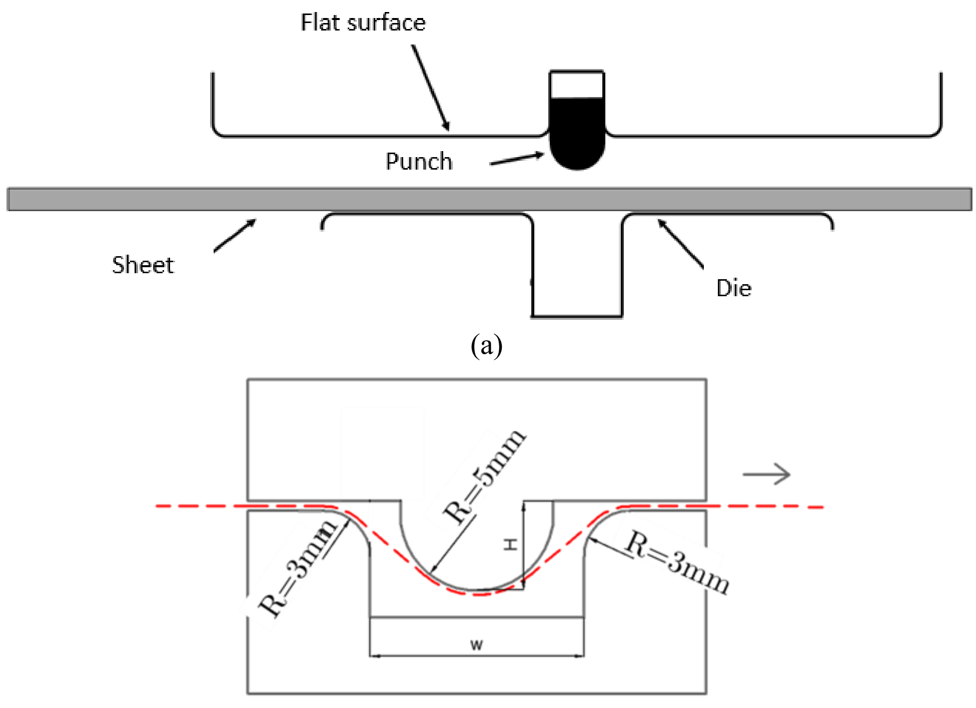

Figure 1. Drawbead simulations: a) Schematics of the drawbead and b) detail of the drawbead size.

The simulation was carried out using Abaqus/Explicit code with rigid tools for the flat surface, punch and die and a deformable sheet discretized in 11 reduced integration plane strain elements (CPE4R) though thickness with an aspect ratio close to the unit. Simulations with different punch

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heights (H) were conducted and the evolution of the up-lift force analyzed during the closure (more in detail in the last 0.3 mm as there is where the forces are exponentially increased).

(a) (b)

Figure 2. Numerical simulation result: a) shape of the sheet during the closure and b) stress distribution on the 'curly' area

From the numerical simulation, numerous conclusions could be drawn, but the most relevant one for the development of the analytical model is the shape that the sheet takes during the closure. As it can be observed on Figure 2a a 'curly' area is created close to the die radius that has to be flattened by the flat surfaces at the end of the closure (from previous works it has been concluded that that's the main origin of the exponential increase of the up-lift forces). In addition as it can be shown in Figure 2b, a stress concentration is obtained in that area once that is completely flattened.

4. Analytical model

The developed analytical model starts from the above hypothesis (Figure 3): If the sheet (at least the part of the sheet in contact with the tools) is analyzed with the classical theory of beam statics, a series of forces can be assumed (the left forces on the die surface, the Fm force of the flat surfaces, the central force of the die radius and the Fp force on the punch).

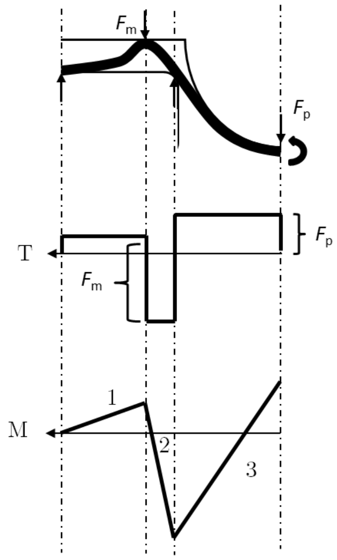

Figure 3. Analytical model hypothesis.

On the one hand, in Figure 3 it can be seen the shear forces distribution and therefore the bending moment diagram that it should be created (this moment diagram was compared with the moment diagram obtained from the numerical simulation to validate the hypothesis).

On the other hand, if the sheet is discretized and the stress distribution through thickness taken into account (Figure 4), the internal bending moment can be calculated.

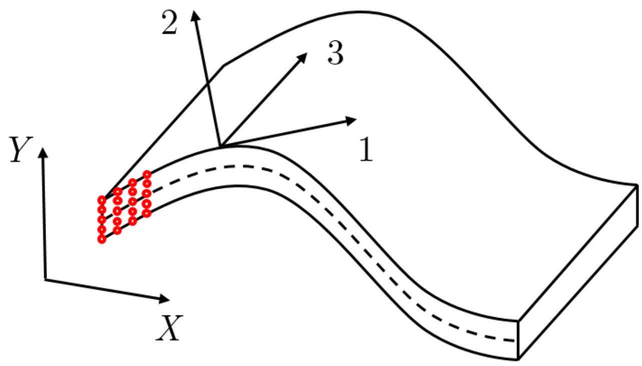

Figure 4. Sheet discretization for the internal bending moment evaluation.

The main idea of the model follows the path:

1. *Geometry of the sheet.*
   Starting from the material properties and drawbead geometry, the evolution of the sheet shape is predicted (this step is still under development).

2. *Curvature of the sheet.*
   The curvature (ρ) of the neutral fibre is assumed to be the second derivative of the position (y):

$$\rho = \frac{d^2y}{dx^2}. \tag{1}$$

3. *Strain distribution.*
   From the curvature history, the strain history is calculated in each fibre of the sheet (spatial discretization, Figure 4). In order to do so, the assumption of pure bending strain distribution is assumed where the neutral fibre remains in the centre of the thickness. Under that assumption, the strain at each "fibre" is supposed to follow a linear relation with the curvature.

$$\varepsilon(h) = h\rho, \tag{2}$$

   being h the distance in thickness direction from the neutral fibre to the fibre under analysis.

4. *Stress distribution.*
   Starting from the strain history at each fibre/section; an elastic predictor-plastic corrector algorithm [7] is used under the assumption of plane strain and plane stress though thickness (typical assumptions under pure bending [8]).

5. *Moment distribution.*
   From the stress distribution of each section, the moment is directly calculated computing the integral though thickness.

$$M = \int_{-t/2}^{t/2} \sigma(h) h \, \mathrm{d}h, \tag{3}$$

where, t represents the thickness of the sheet and σ represents the stress.

6. *Force calculation.*
From the moment distribution, knowing the moment slopes (1, 2 and 3 in Figure 3) the up-lift force can be calculated.

5. Results

Figure 5 shows the comparison of the predicted up-lift force using the analytical model and the numerical model.

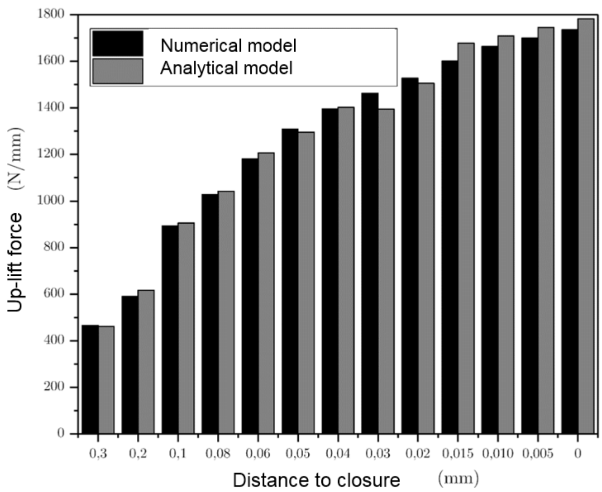

Figure 5. Comparison of the evolution of the up-lift force of the numerical model and the analytical model.

It can be seen that even if some small errors can be found on the prediction, the analytical model is able to reproduce the evolution of the up-lift force quite accurately. Table 2 shows the comparison between the up-lift forces predicted with the numerical model and the analytical model.

Table 2. Comparison between the up-lift forces predicted by the analytical model and the numerical model.

Material	Height (mm)	Min error (%)	Max error (%)	Averaged error (%)
DP780	2	0.7	6.1	3.3
	3	0.5	4.8	1.1
	4	10.2	14.5	12.5
	5	0.1	11.6	2.6

It can be observed how even if for the height of 4 mm the error values increase up to a maximum of 14.5 %, on the overall picture the analytical model is able to reproduce the numerical up-lift forces. In addition, in order to stress the relevance of the model, in Table 3 simulations times for both the FEM model and the analytical model are shown.

Table 3. Comparison between the simulation time of the FEM drawbead and the analytical model.

Material and Height	FEM model time	Analytical model time
DP780 with 2 mm	14 min	2-3 s

It can be seen the high flexibility that allows the analytical model where the time reduction is more than 420 times.

6. Conclusions

The main conclusions of the presented work can be summarized in the following key sentences:

- A new analytical model for the prediction of the up-lift forces on drawbead is presented.
- The model is not only able to predict the final up-lift force but also the evolution of this one during the closure.
- The comparison with the data obtained for different drawbead height for the DP780 high strength material validates the accuracy of the model.
- The prosed analytical model reduces the drawbead up-lift force calculation from 14 min to 2-3 s.

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