Influence of numerical parameters on springback prediction in sheet metal forming

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ABSTRACT: Prediction of springback is still one of the major challenges in the modern die manufacturing industry. In this paper an attempt is made to discover extra reasons for inaccurate prediction of this phenomenon. Using several industrial parts a numerical study is performed to understand sensitivity of springback to various material and process parameters. The study reveals that some modelling assumptions, that are usually made in analysis of forming processes, are inapplicable in simulation of springback. Also, it is shown that springback prediction accuracy can be improved by minimising the discretisation error.

Key words: springback, metal forming, finite element method, discretisation, equivalent drawbeads

1 INTRODUCTION

Currently, numerical analysis is not able to accurately predict springback in sheet metal forming. Frequently there is a difference between springback predicted in simulation and observed in reality, especially for products with a complicated geometry. Springback is an elastically driven change of product shape after forming. The accuracy of its prediction is significantly affected by factors that control the quality of forming simulation.

When using finite element (FE) analysis it is necessary to keep in mind that there are two major sources of error: modelling error and discretisation error. Various assumptions, introduced for making a numerical analysis of forming more efficient, may have a significant influence on springback prediction accuracy and should be reanalysed. For example, many studies show that under certain conditions assumptions made in modelling a material behaviour [1–3], loading conditions [4, 5], assumptions underlying a shell elements theory [6] may be contrary to reality and are not applicable in springback analysis. Additionally, spatial discretisation introduces another approximation and it has been shown that an accurate springback simulation requires finer meshes comparing to those recommended for forming analysis [6, 7].

To understand better the phenomenon and to develop practical guidelines for accurate springback prediction a numerical and experimental work was initiated. Several parts of various complexity produced by sheet metal forming were chosen. Stamping of these parts was simulated using several FE packages. The springback prediction error was quantified by comparing numerical and experimental shapes of the parts. The sensitivity of springback prediction to various parameters was studied. Important subjects of FE analysis were considered, such as: yield criterion and hardening law, modelling of contact, use of stabilisation techniques, unloading methods, through-thickness integration, mesh densities and mesh refinement. Some findings of the performed sensitivity analysis are discussed in chapter 2. Participation in the latest NUMISHEET benchmark study helped to reveal an extra source of errors in springback prediction. Some results of simulations of the NUMISHEET’05 benchmark #2 are examined in chapter 3, which discusses applicability of an equivalent drawbead model in springback analysis. The chapter is finished with an example that shows how a decrease of apparent unloading modulus affects the prediction of springback.

2 DISCRETISATION ERROR

A discretisation error is the difference between a mathematical model and its discretised FE model. To reduce the discretisation error it is necessary to use meshes that are sufficiently fine in places of high stress gradients. If one considers a real industrial product manufactured by sheet metal forming, high stress gradients appear in places of abrupt changes of geometry, for example at a tool

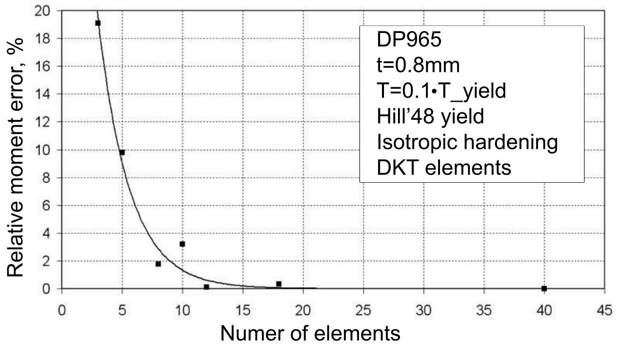

Fig. 1: Variation of relative moment error depending on mesh density

radius. Recommendations from literature about blank discretisation suggest, that for satisfactory results of a springback analysis a turning angle for an element which is in contact with a tool curvature should be about 5°-10°, (see e.g. [6–8]). A turning angle of 5° per element places high CPU power demands. To define a number of elements for blank discretisation that can help to establish a balance between efficiency and accuracy of springback prediction, a numerical study is performed. In this study two tests are simulated, i.e. a beam bending test under tension and a top hat section test.

In the bending with tension test a strip specimen is bent over a tool radius ($R = 10mm$) and during the bending a constant value of tension is applied. This test has an advantage to simply control the process parameters and allows using a single parameter to quantify springback, i.e the internal bending moment. The blank is discretised using the Discrete Kirchhoff triangular elements with 7 integration points through the thickness. Several materials are used in the analysis, namely: aluminium alloy (AL5182) and dual phase steels (DP965 and DP600). To model behaviour of the aluminium alloy the Vegter yield criterion with isotropic hardening is used. Behaviour of the dual phase steels is described by the Hill'48 yield function with isotropic hardening. The stress-strain relation is represented by the Nadai hardening law.

Tangential stresses in the thickness direction, recorded after completing the forming step, are used to calculate the internal bending moments. A bending moment obtained from a simulation with the finest mesh is chosen to be a reference bending moment. A relative moment error is obtained by using values of the reference bending moment and a bending moment calculated from simulations with other mesh densities. A springback error induced by the discretisation error is proportional to the relative moment error.

When the strip is deformed in pure bending the relative moment error for all meshes is negligible. The situation changes when the strip is bent over the tool radius and stress gradients appear in the blank. Figure 1 shows the simulation results of DP965. In this figure the relative moment error is plotted versus the number of elements that are in contact with the tool curvature. The value of tension is equal to 0.1 times the value of tension needed to cause yielding of the material ($T = 0.1 \cdot T_{yield}$). It can be seen from this figure that the relative moment error for 10 or more elements is about 1%. Simulations with other materials under the same process conditions lead to similar results and thus are not presented here. As a result, one may say that to have an accuracy of 1% in this springback analysis it is necessary to minimise the discretisation error by using about 10 elements over the tool radius, an angle of 9° per element.
The above mentioned rule is checked on the top hat section test. This test resembles the NUMISHEET'93 benchmark except for the tools' radii. Results of simulations with the aluminium alloy are reported in figure 2, where the shape of the aluminium blank after unloading in one of the cross-sections is shown.

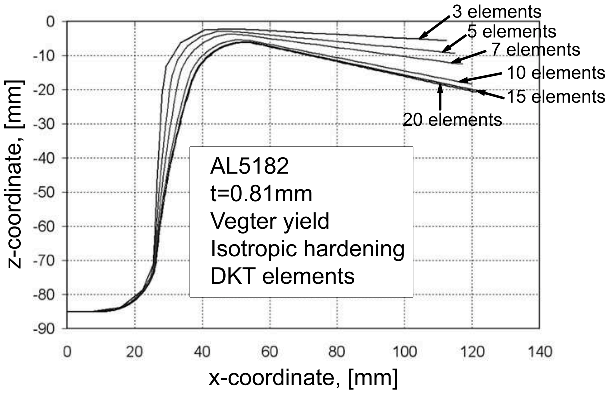

Fig. 2: Top hat section test. Shape after springback

It can be seen from this figure that starting from 9° per element around the tool radius (a mark with 10 elements) the final shape does not differ significantly. Additionally, comparing to this test, realistic industrial products usually have a higher section modulus and thus may display much smaller change of shape during unloading. In that case, even though the discretisation error is high its influence on the springback prediction accuracy will be diminished.
It is important to stress that higher-order elements can have a higher convergence rate towards an accurate solution. Therefore, accurate results of springback analysis can be obtained using fewer higher-order elements [7].

3 IMPORTANCE OF ADEQUATE MODELLING

3.1 *Equivalent drawbead model*

It is a common practice to use an equivalent drawbead model in simulations of sheet metal forming. The model replaces real drawbeads and helps to avoid a drastic increase in computation time. An equivalent drawbead can be represented by a line on a tool surface. When a finite element passes this line it obtains an additional drawbead restraining force and a plastic strain, while a lift force is subtracted from a total blankholder force. The simulation results of benchmark #2 (see figure 3) presented at the NUMISHEET'05 conference [9] revealed, that for a springback analysis an equivalent drawbead model should be applied with caution.

Fig. 3: Automotive underbody cross member - Numisheet'05 benchmark #2

This conclusion comes from evaluating the distribution of true thickness strain in one of the product cross-sections (shown in figure 4). In this figure only the experimental results and results of a participant BM2.03 ('University of Twente, The Netherlands', using FE package DiekA) are shown. As can be seen, the simulation with the equivalent drawbeads predicted thickening of the material in the region from $-100mm$ till $-200mm$. A similar trend can be found in the results submitted by other benchmark participants, who made use of an equivalent drawbead model (see e.g. [9], part B, p.1060-1061). However, the experiments show thinning of the material in that region, which is also predicted by the benchmark participants who used real drawbeads in their analysis. An extra simulation was performed outside the benchmark study with the real drawbeads and all other parameters similar to original ones. Results of the simulation show that predicted distribution of the true thickness strain is in better correspondence with the experimental results (see figure 4).

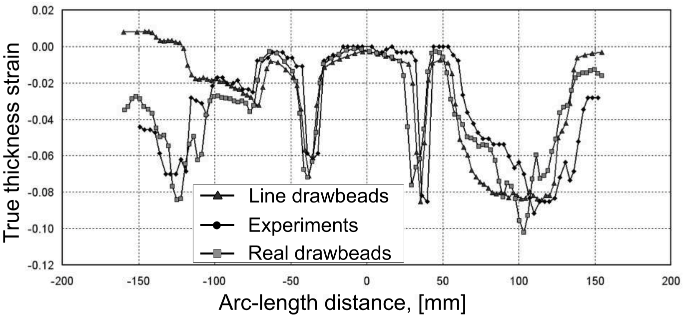

Fig. 4: True thickness strain distribution after forming at section I for DP965

A reasonable explanation can be found in a difficulty of selection of parameters of an equivalent drawbead model. These parameters can be calculated using a plane strain set-up that simulates a situation when material is pulled through a drawbead. Results of this simulation are influenced by the gap between the male and the female bead and a correct value of this gap is difficult to identify. Besides, it is arguable if the gap stays constant during real forming. The plane strain assumption and the uncertainty with the gap value make the parameters of an equivalent drawbead model to be under- or overestimated which leads to a difference in process conditions and thus affects the final stress state.

Also, when using an equivalent drawbead model one has to keep in mind that information about a complex stress state which occurs when a material passes several subsequent bending / unbending regions inside a drawbead is lost. This complex stress state may be responsible for appearance of an extra curvature in a product wall after unloading, as shown in figure 5. This figure shows the springback profile in one of the cross-sections of the automotive underbody cross member. The curvature in the product wall predicted by the simulation with the real drawbeads corresponds more to the experimental shape.

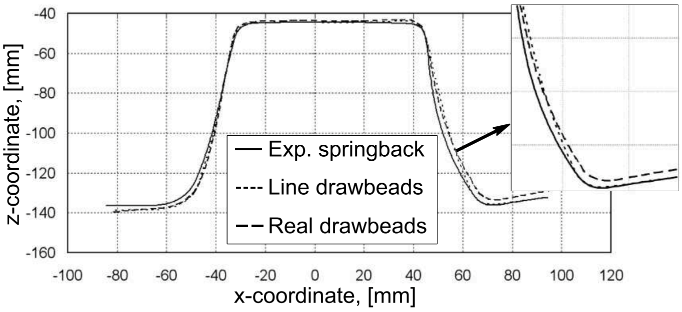

Fig. 5: Springback profile at section I for DP965

3.2 *Nonlinearity of unloading*

A decrease of the apparent unloading modulus is an important fact that should be considered in a springback analysis. The reduction of the unloading modulus is related to a plastic strain recovery during unloading and can be seen as an extra nonlinear part to the total springback strain (see e.g. [10]). The importance of taking into account this phenomenon is shown using simulations of a scaled-down car roof. During the numerical analysis the reduction of the apparent unloading modulus is roughly approximated by decreasing the Young's modulus by 10% and 20%. Figure 6 shows a geometry of the scaled-down car roof in one of the symmetry planes. The shape in a bottom of the product changes considerably when the elastic modulus decreases.

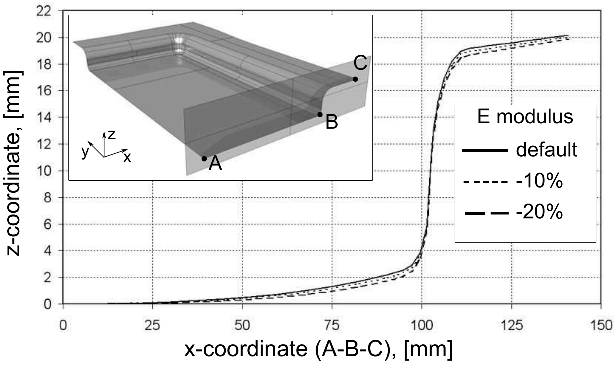

Fig. 6: Shape of car roof after springback at x-symmetry plane

4 DISCUSSION

To improve accuracy of numerical prediction of springback one has to minimise modelling and discretisation errors. This can be done by taking the following into account:

- a turning angle of 9° per element which is in contact with a tool curvature can help to keep the discretisation error low;
- it is important to use real drawbeads in a springback analysis. If an equivalent drawbead model has to be used its parameters should be carefully defined;
- the change of the apparent unloading modulus should be considered in a springback analysis.

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