Simulation and verification of different parameters effect on springback results

Andersson, Alf; Holmberg, Stefan

Published in:
Proceedings of the 5th International Conference and Workshop on Numerical Simulation of 3D Sheet Forming Processes (NUMISHEET 2002)

2002

PAPER D

Simulation and verification of different parameters effect on springback results

SIMULATION AND VERIFICATION OF DIFFERENT PARAMETERS EFFECT ON SPRINGBACK RESULTS

Alf Andersson[*,**] and Stefan Holmberg[*]
[*]*Volvo Car Corporation, Body Components, 293 80 Olofström, Sweden*
[**]*Division of Production and Materials Engineering, Lund University, Lund, Sweden*

ABSTRACT: Today, simulation of springback has still not reached enough accuracy for acceptance as a production tool in the automotive industry. Further investigations need to be done in order to understand how to improve the results in an efficient way.

In order to investigate which parameters that are important for the accuracy in a springback simulation, a parameter study of a U-shaped rail was performed. In the literature several similar studies can be found, but few of them have been analysing the effect of the stress variation. In our investigation these were studied together with the geometrical springback.

In order to see the effect of different restraining conditions, five different blank holder forces were applied. Three different materials were studied both experimentally and numerically. The analysed materials were: a mild steel, an extra high strength steel and an aluminium grade.

It can be concluded that several of the studied parameters show small effect on the springback results whereas other parameters show significant influence, such as element size in blank and tool and choice of hardening law. The result showed good agreement for the case, which were tuned in to experimental results. The materials showed that different settings were needed for the different materials.

1. INTRODUCTION

Simulation of springback has still not reached enough accuracy for acceptance as a production tool in the automotive industry. Further investigations needs to be done in order to understand how to improve the results in an efficient way.

In order to investigate which parameters that are important for the accuracy in a springback simulation, a parameter study of a U-shaped rail was performed. The effects of parameters such as: element size, material model, hardening behaviour, stress variation, etc. were studied. In the literature several authors have investigated the influence of different parameter settings on springback results (Andersson [2001], Chu [1991], Lee and Yang [1998], Mattiasson et al. [1992], Mattiasson et al. [1995], Shi and Zhang [1999]). Few of them have been analysing the effect of stress variation, however.

The simulation results were evaluated after springback in terms of deviation in angle and co-ordinate for the flange as well as the achieved stress distribution after forming. In order to verify the simulation results, experiments were performed of the same geometry and process set-up as mentioned above. The forming simulations were tuned by comparison of draw in and strain distribution for a specified section.

In order to see the effect of different restraining conditions, five different blank holder forces were applied in the experiments. Three different materials were included in the study: a mild steel, an extra high strength steel and an aluminium alloy.

2. OBJECTIVE

The overall purpose of this study was to increase knowledge about how to simulate springback accurately. The study was divided into two parts, one experimental part and one numerical. The objectives of the experimental part were:

- Establish reference results for the numerical simulations.
- Study the effect of different blank holder forces for the different materials.
- Study the effect of drawing to full draw depth compared to drawing to 0.1 mm distance from full draw depth.
- Study the effect of anisotropy of the materials.

The main objective of the numerical simulations was to investigate the influence of different parameters effect on the springback results. Another aim was to find appropriate settings of these parameters for the different materials studied in order to get simulation results as close to the experiments as possible. Furthermore, the influence of the different blank holder forces was simulated and compared to the experimental results.

3. MATERIALS

Three different material qualities were included in the study. The materials were chosen with respect to what is commonly used in the car industry today representing the categories: mild steel (1157-32), extra high strength steel (Docol 600) and aluminium 5000-series (521MF). The basic mechanical properties for the materials included in the study are given in table 1.

R_{p02} and R_m denote the tensile yield stress and the ultimate tensile strength, respectively. n is the strain hardening exponent and R_0, R_{45} and R_{90} denote the anisotropy coefficients. $R_{average}$ is calculated according to:

$$R_{average} = \frac{R_0 + 2 \cdot R_{45} + R_{90}}{4}$$

For Docol600 it was not possible to achieve values for R in all directions.

4. METHODOLOGY

4.1 Experimental procedure

A single action mechanical press was used for the experiments. The amount and type of lubricant used for the experiments are given in table 2. The amount of lubricant was controlled by weighing the blank before and after adding the lubricant. The lubricant was applied to the blank with a roller. The tool was cleaned between each experiment.

The influence of the anisotropy was tested by that the blank was trimmed in different directions. Since the only material with a significant anisotropy was mild steel this was tested with regard to the anisotropy

Similar process conditions were applied for all the different materials. This means that the same blank holder forces and the same amount of lubricant were used in order to get comparable results. In order to see the variance of the results, three identical parts were formed for each process setup and material.

The experimental parts were evaluated with respect to strains, flange width and geometrical springback. The strains were measured by circle grid measurement. The strains in three points in the wall were measured. The flange width was measured with a steel scale (accuracy ±0.25mm) from the draw radius to the edge of the blank, see figure 1.

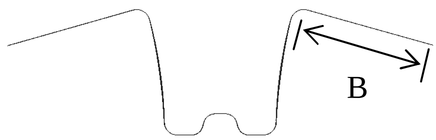


Figure 1. The flange length is measured as the distance B.

The springback was measured according to the procedure shown in figure 2. The contours of the parts were plotted on a paper and the deviances from the nominal value were measured with a steel scale (accuracy ±0.25mm). The embossment in the bottom of the part was used as the reference surface (see figure 2).

Table 1. Basic mechanical properties for the materials included in the study

Material	t [mm]	$R_{p0.2}$ [MPa]	R_m [MPa]	R_0	R_{45}	R_{90}	$R_{av.}$	n
1157-32	1.0	152	287	2.39	1.67	2.6	2.08	0.235
Docol600	1.0	392	652	-	-	1.03	-	0.147
521MF	1.0	96	188	0.65	0.63	0.72	0.66	0.213

Table 2. Lubricant conditions in the experiments.

Material	Type of lubricant	Amount of Lubrication (g/m^2)
1157-32	Aral Ropa 4093LN	3
Docol600	Aral Ropa 4093LN	3
521MF	Aral Ropa 4231	3

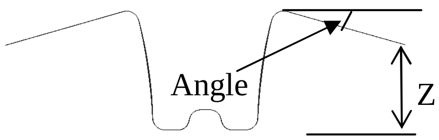


Figure 2. Definition of the distance Z and the angle used for the springback evaluation.

4.2 Numerical procedure

The numerical study was divided into three parts. Firstly, a parameter study was carried out. In the parameter study general simulation parameters as well as material related parameters were evaluated with respect to stresses and springback. The second part consisted of finding the appropriate material parameter settings for each material in order to get results as close to the experimental results as possible. The numerical results were compared to the experimental results in terms of strains and flange length after forming and amount of springback. This was done for one blank holder force for each material. In the third part these parameters were used in the simulation of the rest of the blank holder forces and compared with the experimental results.

The simulations of the forming process were done in the explicit code LS-DYNA [2001] and the subsequent springback analyses were carried out in the implicit part of LS-DYNA [2001]. The element formulation used was Belytschko-Tsai (Belytschko et al. [1984]), with one integration point in the plane, for the forming part and fully integrated elements for the springback analysis. In the parameter analysis the influence of the following parameters on the springback results were investigated:

- Element size in tools and blank
- Forming speed
- Number of integration points through the thickness
- Contact damping
- Restraining conditions in the springback analysis
- Material model
- Hardening law

The material models tested were Barlat'89 (Barlat and Lian [1989]) and Hill'48 (Hill [1948]). Since the kinematic hardening model in LS-DYNA [2001] is based on Hill'48, this material model was used for evaluation of the effect of different hardening laws.

5. RESULTS

From the experiments it could be concluded that the materials have different springback behaviour. Mild steel has the smallest springback angle, followed by aluminium and the largest has Docol600. The relation could be written as 1/2.3/3.6 if mild steel is chosen as the normalising value. Another clear trend in the experiments was that an increasing blank holder force resulted in a decreasing springback for aluminium and extra high strength steel while mild steel was rather constant. The experiments showed no effect of anisotropy and only a negligible effect of a change in draw depth.

A general observation from the simulations was that there were large stress oscillations in the end of the forming analysis. The importance of these stress oscillations on the springback was tested by stopping the forming simulation at different stress levels. The stress level was evaluated for one element in the side wall which had been gliding over the draw radius. Thereafter, the springback calculation was performed. The results indicated, however, a very small effect of the different stress states even though the difference in stress levels was as high as up to 400 MPa, see figure 3. No clear trend of the influence of the stress relaxation could be seen.

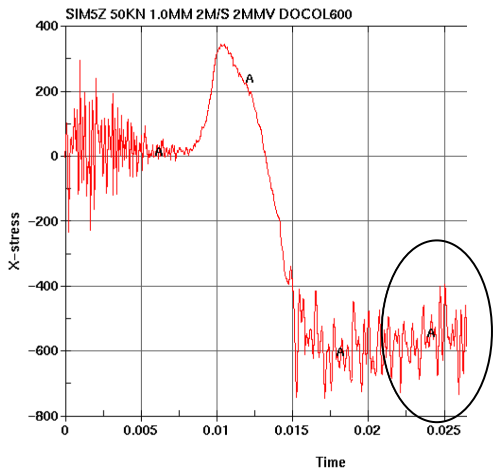


Figure 3. Stress oscillations at the end of the forming simulation.

The effect of contact damping showed no effect on the springback result. The influence of using one node or three nodes for boundary conditions in the springback analysis was small. Therefore, a 6DOF locking of the centre was chosen as default restraining condition. Furthermore test of the element size showed that convergence was reached for 1mm element size in the blank which corresponds to a relation of 0.2 between element size and radius. The tool descretisation indicated an increasing springback for a decreasing element size. Convergence was never reached and VDA-surfaces indicated the largest springback. The test of discretisised model was performed down to an element size of 1mm in the tools.

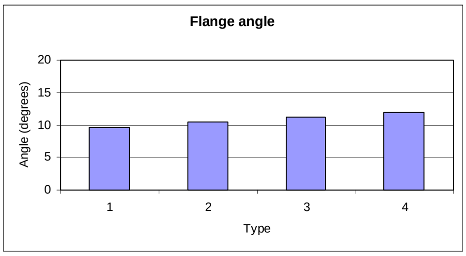
The influence of the forming speed was found to be small but convergent results was found for a punch velocity of 2m/s.

The number of integration points through the thickness was varied (3, 5, 7 and 10). The influence on the springback results was very small, no clear trend could be found.

The results showed that the two different material models adopted gave a small difference concerning the springback prediction. Barlat's model gives a slightly larger springback than Hill'48.

The hardening behaviour was based on Hill'48 material model. The amount of kinematic hardening was varied, with four different settings: 100, 70, 30, and 0%. The results can be seen in figure 4. As expected the springback decreased with increasing amount of kinematic hardening.

A calibration of the appropriate material parameter settings was made for each material. The calibration was made for one blank holder force. The blank holder force which was used for the mild steel and the extra high strength-steel was 50kN and for the aluminium 15kN. The parameters varied were: material model, hardening law and coefficient of friction. The settings of the other simulation input parameters (such as element size, forming speed, integration point, contact damping and restraining conditions) were chosen on the basis of the results from the parameter study. The material parameters above were varied in order to get as close agreement with the experiments as possible. The experimental results considered were the strain levels in the flange and the flange length after forming as well as the measured springback in terms of the springback angle and the distance Z. A maximum variation of 10% between the experimental results and simulation results was obtained with the following material parameter settings (see table 3).



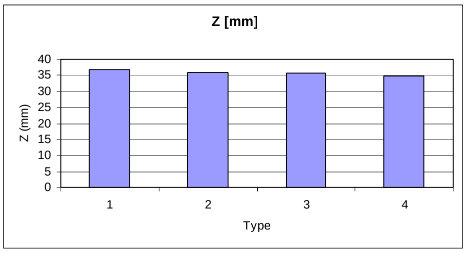


Figure 4. Predicted springback. Type 1, 2, 3 and 4 corresponds to 100%, 70%, 30% and 0% kinematic hardening.

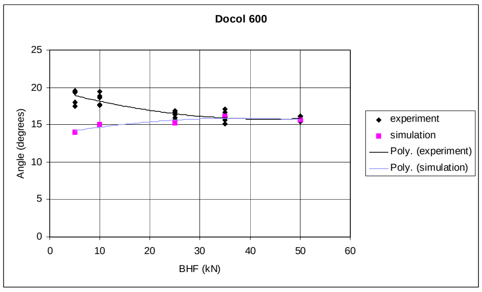
These parameter settings were used for the different blank holder forces and the results were compared to the experimental results, see figure 5-7. As can be seen the simulations do not predict the correct influence of varying the blank holder force.

6. CONCLUSION AND DISCUSSION

From the parameter study it can be concluded that several of the investigated parameters show a small or negligible effect on the springback results. Example of such parameters are: the number of integration point and contact damping. The forming speed had a small influence, however was a convergent result found for 2m/s. Parameters that show a significant influence on the results are the element size in the blank and the tool. Concerning the element size in the blank it was concluded that convergence in the results was reached for 1mm element size. The tool descretisation indicated an increasing springback for a decreasing element size. Convergence was never reached and VDA-surfaces indicated the largest springback. The influence of different hardening laws was also investigated. Pure isotropic, mixed and pure kinematic hardening was evaluated As expected the springback decreased with increasing amount of kinematic hardening. From the results it can be seen that different material requires a different parameter set-up concerning the material description in order to get results close to the experimental results.

Table 3. Best parameter setting compared to experimental tests.

Material	Material model & hardening model	Friction coefficient
1157-32	Hill’48, mixed hardening with 70% kinematic and 30% isotropic	0.09
Docol600	Barlat’89 (m=8) with isotropic hardening	0.10
521MF	Hill’48, mixed hardening with 60% kinematic and 40% isotropic	0.09



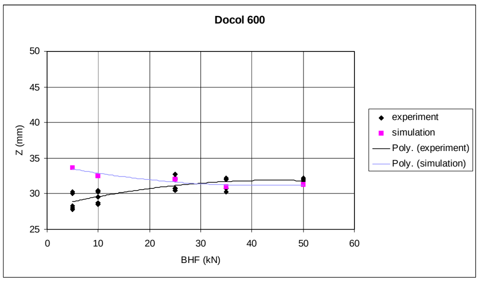
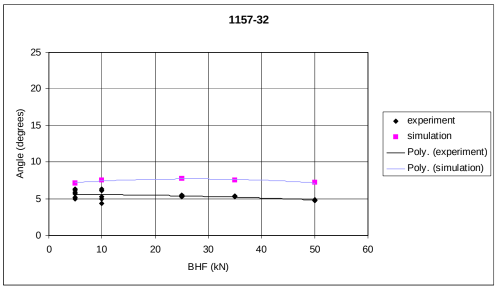


Figure 5. Springback as function of the blank holder force. The diagrams show the results for the extra high strength-steel (Docol 600).



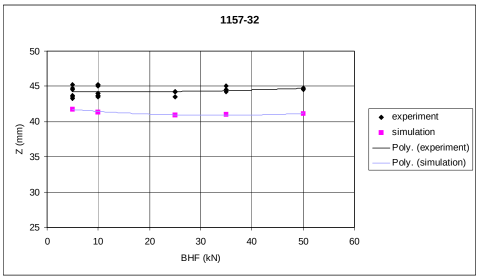
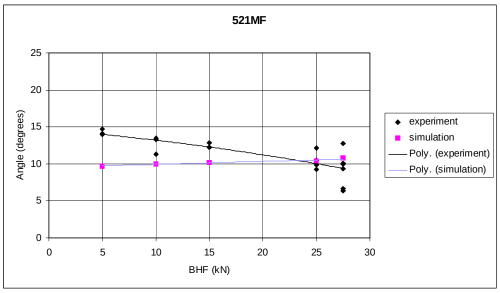


Figure 6. Springback as function of the blank holder force. The diagrams show the results for the mild steel (1157-32).



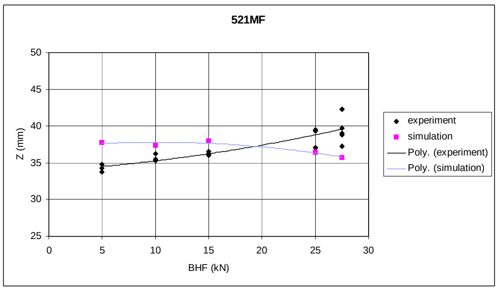


Figure 7. Springback as function of the blank holder force. The diagrams show the results for the aluminium (521MF).

A general observation from the simulations was that there were large stress oscillations in the end of the forming analysis. The importance of these stress oscillations on the springback was tested by stopping the forming simulation at different stress levels. The stress level was evaluated for one element in the side wall which had been gliding over the draw radius. The results indicated, however, a very small effect of the different stress states. An explanation to this can be that even though there are large stress oscillations in the individual elements the overall stress state is rather constant and therefore results in comparable springback.

A clear trend in the experiments was that an increasing blank holder force resulted in a decreasing springback for aluminium and extra high strength steel while mild steel was rather constant. The simulations indicates good correlance for the tuned blank holder cases. However, the predicted trends are wrong since the other cases do not show the same correlance to experimental results. This indicates the need for accurate material descriptions which are correlated to suitable experimental tests for a general description of a simulation model.

The fact that the same sheet thickness was used for all materials must be noted. For automotive applications it is customary to use thicker material for aluminium and mild steel and thinner material for high strength steels (for the same application). Since the springback is decreasing with increasing thickness the comparison between the magnitude of springback of the different materials is more a verification of the behaviour for changes in process conditions (blank holder force) than a comparison between the materials.

The results from this study does not indicate the same trends as a previous similar study performed by Mattiasson et al. [1995]. Mattiasson et al. analysed a 2D-draw bending benchmark from Numisheet -93 and found, among other things, that stress relaxation affected the results of the springback simulation which this study could not prove. Mattiasson et al. used a model with plane strain state, however. In this study, a 3D model of the U-shaped rail was used. This difference might explain some of differences in results between the studies.

ACKNOWLEDGEMENT

The authors are sincerely grateful to Markus Adler and Erik Andersson (Lund University) who wrote, in co-operation with the authors, the master thesis, which this article is based upon. We are also grateful to Professor Kjell Mattiasson (Chalmers University of Technology) for encouraging discussions and help during the project. At last we wish to thank Professor Jan-Eric Ståhl (Division of Production and Materials Engineering, Lund University) for his support of this project.

REFERENCES

[1] A. Andersson, 2001, Use of FE-analysis in predicting and verifying the design of an automotive component forming process, with special regards to macro geometric defects, Licentiate thesis, Lund University, Sweden

[2] F. Barlat and J. Lian 1989. Plastic behaviour and stretchability of sheet metals, Part I, A yield function for orthotropic sheets under plane stress conditions, International Journal of Plasticity 5: 51-66.

[3] T. Belytschko, J. Lin and C. S. Tsay, 1984, Explicit algorithms for nonlinear dynamics of shells. Comp. Meth. Appl. Mech. Eng 42: 225-251.

[4] C. C. Chu, 1991, The Effect of Restraining Force on Springback, International Journal Solids and Structures, Vol. 27, No. 8, pp 1035-1046.

[5] R. Hill, 1948, A Theory of the Yielding and Plastic Flow of Anisotropic Metals, Proceedings of the Royal Society of London, series A., 193, page 281.

[6] S. W. Lee and D. Y. Yang, 1998, An Assessment of Numerical Parameters Influencing Springback in Explicit Finite Element Analysis of Sheet Metal Forming Process, Journal of Materials Processing Technology. Vol. 80-81, pp 60-67.

[7] Livermore Software Technology Corporation, 2001, LS-DYNA User´s Manual, Livermore Software Technology Corporation. Livermore.

[8] K. Mattiasson, L. Bernsprång, T. Hamman, E. Schedin, A. Melander and A. Samuelsson, 1992, Evaluation of a Dynamic Approach, Using Explicit Integration, in 3D Sheet Metal Forming Simulation, NUMIFORM'92, Sophia-Antipolis, France.

[9] K. Mattiasson, A. Strange, P. Thilderkvist and A. Samuelsson, 1995, Simulation of springback in sheet metal forming, NUMIFORM '95. Ithaca, NY. USA.

[10] M. Shi and L. Zhang, 1999, Issues Concerning Material Constitutive Laws and Parameters in Springback Simulations, SAE Technical Paper No. 1999-01-1002.