

ANALYTICAL AND NUMERICAL PREDICTION OF SPRINGBACK IN SHEET METAL BENDING

Slota Ján, Jurčíšin Miroslav

*Department of Technologies and Materials, Faculty of Mechanical Engineering, Technical
University of Košice, Slovakia*

ABSTRACT

The objective of this paper is springback determination of the sheet metals in various cases of an flanging process. The experimental work consists of three parts. The first part deals with experiment of an bending process with different geometry using two different categories of the steel, the second part consists of analytical determination of the springback and the third part is devoted to the numerical simulation of this process. A modern measurement methods performed in MATLAB system was used. Achieved results were compared and discussed.

Key words: *Springback, Analytical Prediction, Finite Element Method, Flanging Process*

1. INTRODUCTION

In the bending technology it is difficult to achieve accurate and repeatable angle of a bend. This problem is caused by elastic springback, which is considerable in processes of the sheet metal forming [1]. Problems associated with the springback affect the economic aspect of each production plant [2]. Therefore is necessary to predict springback and basis on this compensate tools. In the past, handy tables [3, 4] or graphs [5] were the traditional ways used for prediction of the springback. Nowadays, numerical simulation of the springback is frequently used tool to the springback prediction. Although it seems that this method is nowadays accurate enough, there were observed a lot of problems associated with this method, especially when AHS or UHS steels are used. Current problems associated with numerical simulation of the springback are detail described in several publications [6, 7]. Except numerical methods, there exists a number of publications which are devoted to analytical springback prediction [8, 9, 10]. Problems associated with the analytical methods are that they can be used only in simplified cases. In this paper was used analytical method for springback determination developed for straight flanging process [10]. Following assumptions are used in analytical model:

* Corresponding author E-mail address: Jan.Slota@tuke.sk

- the sheet metal is in plane strain conditions along the flange width direction and in plane stress conditions along the sheet thickness direction,
- the sheet metal is homogeneous and isotropic,
- the sheet metal follows the power hardening law and von Mises yield criterion,
- planes normal to the sheet surface remain planes during the deformation process,
- the Bauschinger effect is neglected,
- the middle layer of the sheet is considered to be bending-strain-free,
- volume conservation is assumed so that the volume variation due to elastic deformation is negligible,
- moment distributions along the straight and curved parts are linear,
- only elastic deformation occurs in the unloading stage.

All equations which were used for computation process are described and derived in the paper [10]. The advantage of analytical methods lies in their economical aspect. Analytical method is obviously much less economically demanding compared to numerical simulations. Numerical simulation was performed in static implicit finite element (FE) code Autoform. A yield function that can capture orthotropy has been proposed by Hill as an extension of the von Mises criterion. In its most general form, the Hill'48 yield criterion [11, 12] can be written as:

$$\begin{aligned} \varphi(\sigma_{ij}) = & F(\sigma_{22} - \sigma_{33})^2 + G(\sigma_{33} - \sigma_{11})^2 + H(\sigma_{11} - \sigma_{22})^2 + \\ & 2L\sigma_{23}^2 + 2M\sigma_{31}^2 + 2N\sigma_{12}^2 - \bar{\sigma}^2 = 0 \end{aligned} \quad (1)$$

where: F, G, H, L, M and N [-] - Hill's anisotropic parameters, which can be expressed by Lankford's coefficients,

σ_{xy} [MPa] - x, y are the principal anisotropic axes. In the case of sheet metals, axis 1 is usually parallel to the rolling direction, 2 is parallel to the transverse direction.

$$F = \frac{r_0}{r_{90}(r_0+1)}, G = \frac{1}{r_0+1}, H = \frac{r_0}{r_0+1}, N = \frac{(r_0+r_{90})(1+2r_{45})}{2r_{90}(1+r_0)} \quad (2)$$

where: r_0, r_{45}, r_{90} [-] - Lankford's coefficient which represents anisotropy values measured in 0° , 45° and 90° to the rolling direction,

L and M are equal to N

Hill 48 yield criterion was set in the combination with hardening curve defined by Hollomon which is described by law:

$$\sigma = C \varepsilon^n \quad (3)$$

where: σ [MPa] - true stress

ε [-] - true plastic strain

C [MPa] - strain hardening coefficient

n [-] - strain hardening exponent.

2. EXPERIMENTAL PROCEDURE

Aim of this experimental work was to determine amount of the springback in two different ways. Determination of the springback in sheet metal forming is a first step to the tool compensation. Analytical and experimental methods were compared with the results of real experiment of bending. Geometry of tools is illustrated in the Figure 1.

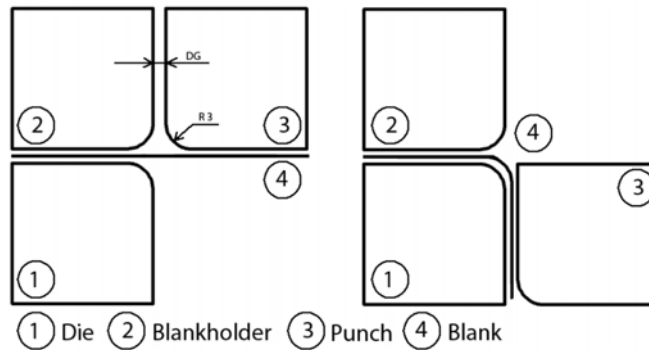


Fig.1 - Tools used in the bending process where DG is gap between punch and die

2.1 Real experiment

In this experiment, different die gap was chosen. Different angle of bending is achievable by this parameter. In this paper is presented experiment where DG is equal to the thickness of the sheet $DG = t$ and $DG = 2 \text{ mm} + t$. Two different materials were used – material TRIP RAK 40/70 with thickness 0.75 and material DP 600 of thickness 1 mm. Mechanical properties of these sheets are presented in the Table 1 and Table 2.

Table 1 - Mechanical properties of the TRIP steel

Angle from the R.D. [°]	$R_{p0.2} (R_e)$ [MPa]	R_m [MPa]	A_{80} [%]	n [-]	C [MPa]	r [-]
0	434	746	31.2	0.291	1445.56	0.690
45	431	744	32.3			0.914
90	442	752	26.8			0.848

Table 2 - Mechanical properties of the UHSS – TRIP RAK 40/70

Angle from the R.D. [°]	$R_{p0.2} (R_e)$ [MPa]	R_m [MPa]	A_{80} [%]	n [-]	C [MPa]	r [-]
0	378	627	25.2	0.179	1008.28	0.882
45	386	612	26.7			0.903
90	385	620	26.4			1.072

Specimens were cut in the direction of steel rolling and were bent perpendicular to the rolling direction. Process of real experiment was performed on hydraulic press ZD 40 and bending process was carried out without use of lubrication. After bending process, angle between arms of specimens were measured using MATLAB system. After geometries of specimens were digitized, five points on the each arm of specimen were selected. After points were selected, linear regression was used to reach equation of straight line for each arm of specimen. Based on equations of straight lines, angle between them was computed. Then, the angle of the springback was calculated using following formula:

$$\beta = \alpha - 90^\circ \quad (4)$$

where: β [°] – angle of springback,
 α [°] – angle between specimen arms after unloading.

In both cases, in case of DG equal to t and DG equal to the $t+2$, angle of 90° was reached. Difference between this was in the different bending curvature and thus also in amount of springback angle. Dimension of blank was 140 x 40 mm.

2.2 Numerical simulation

Numerical simulation of bending process was performed in static implicit FEM code Autoform. All information necessary to define process of numerical simulation are presented in the Table 3.

Table 3 - Parameters of the numerical simulation

Parameter	Value
Mesh type	Triangular
Mesh size	0.4 mm
Level of refinement	0
Mesh size after refinement	0.4 mm
Number of integration points	11
Element type	Shell
Friction value	0.2
Yield curve	Hill' 48
Hardening curve	Hollomon

Very important parameter is size of mesh. Using different size of mesh, different angle of the springback may be achieved. There is a rule [8], that minimum 10 elements around the curvature would be used. Since, in this experiment there is 3 mm die radius which have circumference 4.71 mm. From this implies that 0.4 mm mesh size is sufficient for accurate numerical simulation process. Using greater mesh size, there has been observed differences in results from 25-30 %. Differences between bending curvature using different gap die is illustrated in the Figure 2.



Fig.2 - Influence of die gap to the curvatures in loaded state

2.3 Analytical prediction of springback

Analytical prediction of the springback was calculated using equations formulated by Buranathity and Cao [10]. Except material parameters defined in the Table 1 and Table 2 there were used values of the Poisson ratio which is equal to 0.3 and the value of Young's modulus which is equal to value 210 GPa. There were necessary to compute approximately 30 values of various parameters and also use iterative method which was performed in Excel software. Iterative method was necessary to use only in the case when ratio between sheet thickness and gap die was greater than two. This ratio was greater than two in case where $DG = 2+t$. Amount of the springback in this analytical method was very sensitive to the value of the die gap. Even if the die gap was increased about value 0.02 mm, angle of the springback was increased about value 0.2° .

3 RESULTS OF EXPERIMENT

In this chapter, differences between experimental measuring, results of the numerical simulation and results of analytical calculations will be described. First of all, results for the DP and TRIP steel in cases where $DG = t$ and $DG = 2 + t$.

In this first case, the analytical computation was more accurate compared to the numerical simulation. As we can see on the Fig.3, the analytical method underestimated the result of 17.2 %. In the case of the numerical simulation, this method underestimated the real result of 27.6 %.

As opposed to the previous case, here was more accurate numerical simulation of the flanging process, because difference between real experiment and the numerical simulation was 22.3 % and 30.6 % difference between analytical computation and the real experiment (Fig. 4). Both methods underestimated the result. Differences were greater than in previous case where $DG = t$.

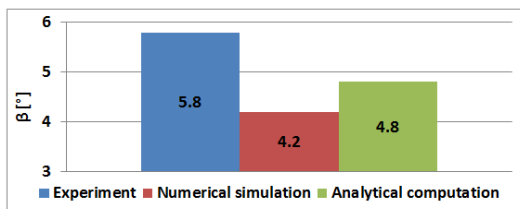


Fig.3 - Experimental, numerical and analytical results for TRIP steel where $DG=t$

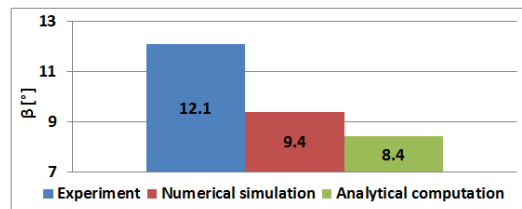


Fig.4 - Experimental, numerical and analytical results for TRIP steel where $DG=t + 2$

If DP steel was used, numerical simulation and analytical computation have proven to be very little accurate, because results were underestimated in great range. The numerical simulation underestimated the result about the value 58.7 % and the analytical computation about the value 46.7 %. Both results shows (Fig. 5), that numerical simulation and the analytical computation for this case of smaller die gap are insufficient accurate.

In case of DP steel and $DG=2+t$ were results of numerical simulation more accurate than results of analytical computation. As is shown on the Fig. 6, the difference in case of numerical simulation was 6.1 % and in case of analytical computation 20.4 %. Also as in previous cases, both methods underestimated real experimental results of flanging.

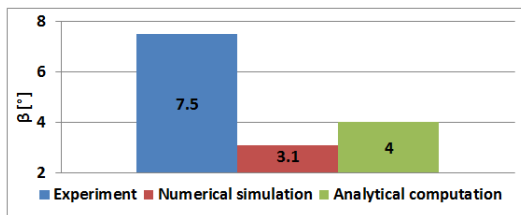


Fig.5 - Results of experimental, numerical and analytical methods for DP steel where $DG=t$

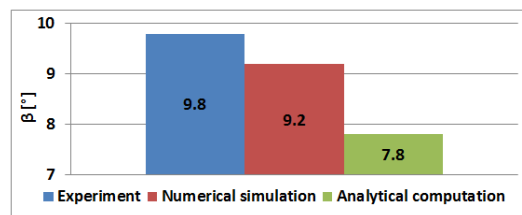


Fig.6 - Results of experimental, numerical and analytical methods for DP steel where $DG=t+2$

Since the DP steel and the TRIP steel have different structure and mechanical properties, there was observed different springback angle. In the case of smaller die gap was observed, that the TRIP steel has smaller springback than the DP steel (Fig. 7) and in the case of greater die gap it was the other way. This was caused by the different thickness of blanks. Blanks made from the TRIP steel had 0.75 mm thickness and the thickness of the DP steel blank was equal to 1 mm. This caused, that DG in the case of the TRIP steel was DG smaller than in the case of the DP steel. This difference of the sheet thickness is small, but it is demonstrated that sheet thickness influence is more visible in case of smaller die gap. With increasing DG is this influence decreasing.

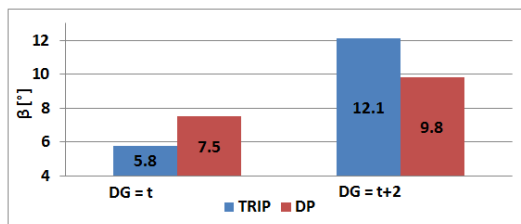


Fig.7 - Results of experimental springback measurement for TRIP and DP steel in both cases of different die gap

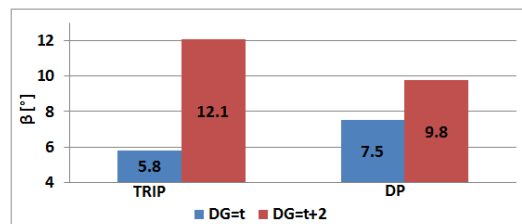


Fig.8 - Influence of die gap to the springback amount

Influence of the die gap to the amount of springback is shown on the Fig. 8. Greater die gap cause the different curvature of the bend radius. The curvature has a smaller radius in the case of smaller die gap, therefore, there is also observed smaller amount of the springback. Greater die gap cause a greater amount of the springback. It could be concluded, that there is also a limit to this value, because from the certain value of the die gap is achieved bending angle different from value 90° .

4 CONCLUSION

In this paper, analytical and numerical simulation method of the springback prediction was discussed. Results shown, that both of these methods are insufficiently accurate. A smaller difference between these methods was 6.1 %. In two cases, numerical simulation was more accurate, and in two cases, analytical computation was more accurate in compare with experiment. All results underestimated the result of experimentally obtained values of the springback. It was proved that greater radius of bend curvature causes a greater value of a springback. If it is necessary to bend sample to the 90° it is recommended to use smaller die gap. Both, the DP and the TRIP steel are high strength steels and therefore there was observed significant amount of springback. For more accurate springback prediction, in both methods, is necessary to use a more complex description of steel behavior. It is necessary to use mixed hardening model, implement Bauschinger effect and use less simplifications.

MISCELLANEOUS

Acknowledgement: Authors are grateful for the support of experimental works by project VEGA No. 1/0396/11.

REFERENCES

- [1] Marciniak, Z., Duncan J.L., Hu, S.J.: *Mechanics of sheet metal forming*. London: Edward Arnold, 231 p., 2002.
- [2] Gan W., Wagoner R.H.: *Die design method for sheet springback*, International Journal of Mechanical Sciences, Volume 46, pages 1097-1113, 2004.
- [3] Lange, K., Pohlandt, P.: *Handbook of Metal Forming*, McGraw-Hill, New York, 1985.
- [4] Society of *Manufacturing Engineers*, D.B. Dallas and American Society of Tool and Manufacturing Engineers, Tool and Manufacturing Engineers Handbook: *A Reference Work for Manufacturing Engineers*, McGraw-Hill, New York, 1976.
- [5] Sachs. G.: *Principles and Methods of Sheet-Metal Fabricating*, Reinhold Pub., New York, 1951.
- [6] Wagoner, R. H., Lim, H., Lee, M. G.: *Advanced issues in springback*, International Journal of Plasticity, Volume 45, pages 3-20, 2013.
- [7] Slota, J., Jurčičin, M.: *Springback prediction in sheet metal forming processes*, Journal for Technology of Plasticity. Volume 37, No. 1, p. 93-103, 2012.
- [8] Burchitz, I.A.,: *Improvement of Springback Prediction in Sheet Metal Forming*. The Netherlands : Universiteit Twente, 156p. ISBN 978-90-365-2656-2, 2008.
- [9] Osman, M.A., Shazly, M., El-Mokaddem, A., Wifi, A.S.: *Springback prediction in V-die bending: modelling and experimentation*, Journal of Achievements in Materials and Manufacturing Engineering, Volume 38, No. 2, pages 179-186, 2010.
- [10] Buranathiti T., Cao, J.: *An effective analytical model for springback prediction in straight flanging processes*, International Journal of Materials and Product Technology, Volume 21, No. 1/2/3, pages 137-153, 2004.

- [11] Zhiying, Ch., Xianghuai, D.: *The GTN damage model based on Hill'48 anisotropic yield criterion and its application in sheet metal forming*, Computational Materials Science, Volume 44, Issue 3, pages 1013-1021, 2009.
- [12] Banabic, D.: *Sheet Metal Forming Processes. Constitutive Modeling and Numerical Simulation*. Springer. 2010. ISBN : 978-3-540-88112-4.

ANALITIČKO I NUMERIČKO ODREĐIVANJE VELIČINE ELASTIČNOG VRAĆANJA („SPRING- BACK“) KOD SAVIJANJA LIMA

Slota Ján, Jurčišin Miroslav

Departman za tehnologije i materijale, Mašinski Fakultet, Tehnički Univerzitet Košice, Slovačka

REZIME

Cilj ovog rada je određivanje elastičnog vraćanja lima u različitim slučajevima ivičnog savijanja. U prvom delu rada dat je prikaz eksperimentalnih istraživanja savijanja lima različitih dimenzija I to korišćenjem dve vrste čeličnih materijala (limova). Drugi deo rada sadrži analitičko rešenje elastičnog vraćanja dok se u trećem delu proces analizira numeričkom metodom (konačni elementi). Varirani su geometrijski parametri, debljina lima, zazor, ugao savijanja kao i vrsta materijala. Pripreмки su isecani iz table u pravcu valjanja a samo savijanje je vršeno u pravcu normalnom na pravac valjanja. Za merenje veličine elastičnog vraćanja korišćen je MATLAB sistem. Rezultati dobijeni pomoću ove tri metode su analizirani i međusobno upoređeni. Pokazalo se da kako analitičko tako i numeričko rešenje ne daje dovoljno dobro slaganje sa realnošću (eksperimentom). U oba slučaja (analitičko i numeričko) dobijaju se manje vrednosti elastičnog vraćanja nego što je to u eksperimentu. Veći radijus savijanja rezultira u većoj vrednosti spring back-a. U zaključku se navodi da je za dobijanje boljeg slaganja eksperimenta i drugih metoda neophodno egzaktnije analitički opisati ponašanje materijala (ojačanje i dr.), uzeti u obzir Baušingerov efekat i usvojiti manji broj pojednostavljenja.

Ključne reči: *elastično vraćanje, analitički proračun, metoda konačnih elemenata, savijanje lima*