NUMERICAL AND EXPERIMENTAL DETERMINATION OF SPRINGBACK IN U-BENDING PROCESS

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The most common problem in area of bending technology is problem of achieving accurate and repeatable bending angle. This problem is caused by elastic springback. Springback can be defined as an elastically-driven change of shape of the deformed part upon removal of external loads. This phenomenon is observed also in other sheet metal forming processes. Several technological parameters influence springback amount. In this paper were presented results for different bending curvature and its influence to the springback amount springback. Difference between springback amount caused by Bauschinger effect was also discussed. Process was also modelled in the static implicit finite element (FE) code – Autoform. In this paper were used two different materials – UHS and mild steel. Experimental and numerical results were compared and discussed.

Keywords:
Springback, Bauschinger Effect, Bending, Numerical Simulation, Autoform

1. Introduction

In the metal stamping industry, one of the major technological problems is getting the sheet metal to conform exactly to the shape of the die. Due to the springback effects, die designs are usually finalized only after the fabrication and testing of multiple prototypes [Ling 2005]. The main springback effects on the formed parts are as follows: the part shape and dimension alteration after tools removing and also the change of the stress and strain state in the the deformed material [Brabie 2009]. The determination, elimination or avoidance of the defects generated by springback requires the analysis and knowledge of its specific causes and its relation with different factors [Nanu 2012]. Among factors which influence a springback amount belongs for example: the material mechanical properties [Wagoner 2013], the friction coefficient [Slota 2013], the die gap [Hu 2000], the die radius [Ling 2005], blankholder force [Slota 2013], bending curvature [Slota 2012], etc. Since springback is causing also problems associated with economical aspect, it is necessary to predict it. This can be realized using analytical, empirical and also numerical methods. Nowadays is very frequently used numerical simulation method as a tool for springback compensation but this is also associated with problems of neglecting and simplifying important parameters during material models definition. In this paper was realized bending process of sheet metals on the different radiuses to the angle of 180° in order to extend existing knowledge. Several publications [Wagoner 2013, Gau 2001] were also devoted to the cyclic bending problematic, namely in connection with Bauschinger effect influence to the springback amount. Gau et al. [Gau 2001] studied influence of the Bauschinger effect to the springback and concluded that two identical sheet metal specimens can have the same final total strains but have distinctly different springback amounts. The reason is that their deformation histories in the strain area are different. The Bauschinger effect on springback depends not only on the material type but also on the deformation history in the strain space [Gau 2001]. Bending process was modeled in FEM (finite element method) code Autoform. Autoform is simulation software which is developed in cooperation with many world known companies as for example Audi, Arcelor, Thyssen Krup but also by HP whether IBM [Autoform 2001]. Autoform is using static implicit time integration scheme. As a hardening curve was used the Hollomon curve, and yield function was defined using the Hill 48 material model. As was mentioned software works with implicit a time integration strategy which is in the every time step starting from the previous time step and a mesh is generated using local refinement due to requiring accuracy of problem which is calculated resulting from current mesh. This solving process is iterated until the estimated error is between bounds of the interval of requiring precision. If the time step between new iteration is not too large the time of solving process is usually very small [Schmidt 2004]. This paper is aimed to the investigation of influence these factors to the springback amount: Bauschinger effect different die geometry and also numerical simulation of this process with different mesh sizes.

2. Experimental procedure

Aim of this experiment can be divided to the three parts. First part was devoted to the sheet metal strips bending on the different die radiuses. Second part dealt with bending sheet metal strips to the angle of 180 ° and the last part was to measure springback and subsequently bend this strip to the angle 180 ° in the reverse direction and measure springback. The last part was about modelling process of first cycle in FE software and compare results. For this experiment, two steel categories were used. Springback amount significantly depends on used materials. The first material was steel of DQ category DC 06 with thickness 0.85 mm, and the second material was UHS steel TRIP RAK 40/70 with the thickness 0.75 mm. Mechanical properties for these steels are in the Tab. 1 – 2. Specimen dimensions were 20 x 120 mm and all specimens were cut in direction which is parallel to the rolling direction.

Rolling direction [°]	$R_{p0,2}$ (R_e) [MPa]	Rm [MPa]	A_{80} [%]	n [–]	C [MPa]	r [–]
0	442	771	27.7	0.29	1492.28	0.686
45	441	762	25.4			0.87
90	450	766	25.9			0.838

Table 1. *Mechanical properties for UHSS – TRIP RAK 40/70*

Rolling direction [°]	$R_{p0,2}$ (R_e) [MPa]	Rm [MPa]	A_{80} [%]	n [–]	C [MPa]	r [–]
0	138	277	53.0	0.261	538.54	1.665
45	142	282	50.4			1.601
90	141	277	51.7			2.112

Table 2. *Mechanical properties for mild steel DC06*

Tool geometry used in this experiment is illustrated in the Fig. 1. Two different die radiuses were used – R 11 and R 17. First of all in cycle 1 specimen was bent over die and after bending and the springback angle was measured. Then in the cycle 2 specimen was positioned and bent again over the die and the springback angle was measured. The angle of springback β is shown in the Fig. 1 in the middle and mesh of blank in the Fig. 1 right. Since springback amount depends on the mesh size, two different mesh sizes were set.

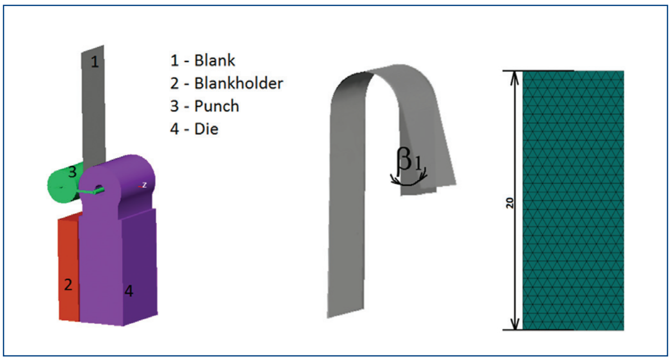

Figure 1. *Geometry of tools (left), illustration of springback angle β (middle) and mesh of blank (right)*

Due to difficulty of using conventional methods, angle measurement after springback was performed using MATLAB system. Springback angle can be calculated and evaluated accurately using MATLAB measuring method [Kardes 2012, Slota 2012]. Five points on the each arm of specimen was selected. After points were selected, linear regression was used to reach equation of straight line for each specimen arm. Based on equations of straight lines an angle between them was computed. First cycle was modelled in the static implicit code Autoform. Parameters set in the numerical simulation are described in the Tab. 3.

Parameter	Value	Parameter	Value
Mesh type	Triangular	**Element type**	Shell
Mesh size	0.75 and 1 mm	**Friction value**	0
Level of refinement	2	**Yield curve**	Hill' 48
Mesh size after refinement	0.375 mm	**Hardening curve**	Hollomon
Number of integration points	11	**Tool mesh**	0.5 mm

Table 3. *Parameters of numerical simulation*

Die radius – R 11					
Cycle	**Experiment**		**Difference between cycles**	**Simulation**	
	β_1 [°]	β_2 [°]	β_D [°]	β_{1s} [°] –0.75 mm	β_{1s} [°] –1 mm
1	**43**		2.5	**20.6**	**21.5**
2	45.5				
Die radius – R 17					
	β_1 [°]	β_2 [°]	β_D	β_{1s} [°] –0.75 mm	β_{1s} [°] –1 mm
1	**39.3**		1.9	**25.4**	**27.1**
2	41.2				

Table 4. *Results for specimen of steel TRIP RAK 40/70*

3. Results of the experiment

In the Tab. 4 are presented results for the springback measuring of specimen of TRIP steel. Since, only the first cycle was modelled in the FE code, for second cycle results of numerical simulation will be not presented.

β_1 is springback angle after first cycle, β_2 is springback angle after second cycle, β_{1s} is springback angle after first cycle obtained from numerical simulation, 0.75 mm and 1 mm are numerical simulations results for different mesh size.

Difference between springback angles after first and second cycle in experiment is β_D and is calculated using following formula $\beta_2 - \beta_1$.

In the following table are presented results for the DQ steel DC 06. This steel has the lower strength in compare with TRIP steel.

Die radius – R 11					
Cycle	**Experiment**		**Difference between cycles**	**Simulation**	
	β_1 [°]	β_2 [°]	β_D [°]	β_{1s} [°] –0.75 mm	β_{1s} [°] –1 mm
1	**14.1**		0.7	**12.1**	**15.8**
2	14.8				
Die radius – R 17					
	β_1 [°]	β_2 [°]	β_D	β_{1s} [°] –0.75 mm	β_{1s} [°] –1 mm
1	**8.8**		–2.3	**8.6**	**12.9**
2	6.5				

Table 5. *Results for specimen of steel DC06*

4. Discussion

Since the TRIP steel has the higher strength, highest springback amount in this case was measured. Results of numerical simulation in the case of TRIP steel shown, that this approach of springback prediction was accurate insufficient. In the case of TRIP steel was

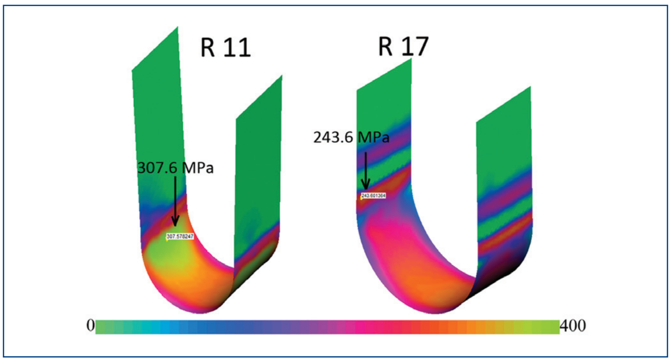

Figure 2. *Major stress for DC 06 steel for different die radius*

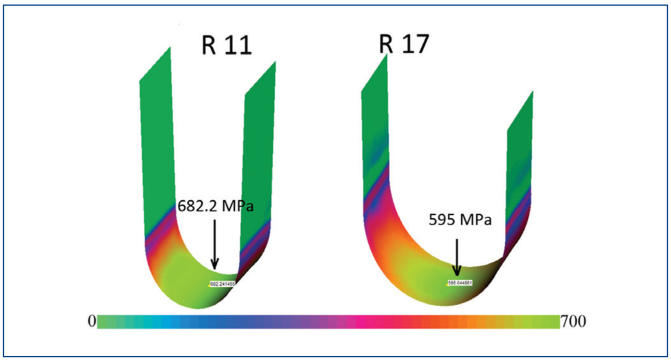

Figure 3. *Major stress for TRIP steel for different die radius*

observed the greatest difference. This is caused by the issue of difficult material structure definition and namely residual austenite to martensite transformation. Numerical modelling with conventional steel DC 06 was the more accurate in the comparison with the real experiment result. In the case of measurement springback angle after cycle 2 was observed increased value in the case of TRIP steel and decreased springback amount in the case of DC 06 steel. This was caused by the transformation process of austenite to the martensite. By this transformation TRIP steel has become stronger and thus, greater springback was observed. Conventional steels as DC 06 did not undergo this transformation and therefore there was observed smaller springback. Higher springback occurred in the smaller die radius case with the steel DC 06. Since smaller die radius caused higher amount of stress in the area of bend section, greater value of springback was observed. This is illustrated in the Fig. 2 for both steels, maximal major stress is highlighted. In case of greater mesh size was observed greater amount of springback in numerical simulation. Value of this parameter is questionable because in the case of DC steel result less corresponds with real experiment and in the case for TRIP steel result more correspond with reality. Some publications are devoted to this issue [Wagoner 2013]. In the Fig. 2 and Fig. 3 is illustrated stress distribution in the area of bending. The more uneven this distribution is, greater amount of springback will be observed.

In the case of die radius R 11 was measured greater value of major stress for both steels as in the case of with die radius R 17. Greater stress caused greater springback amount. Therefore, higher springback amount was observed in the case of die radius R 17.

5. Conclusion

Based on results presented in this paper, following conclusions could be noted that:

- Size of the mesh in the numerical simulation is questionable, because there is no correlation between accurate simulation of springback and mesh size.
- This experiment confirmed that the forming of high strength steel is associated with springback problems largely.
- In the case of DC 06 and TRIP steel, greater die radius caused smaller amount of springback, because greater die radius caused smaller major stresses in comparison with smaller die radius.
- Numerical simulation approach was accurate sufficient only in the case where DC 06 steel was used. In case with TRIP and steels, simulation of springback was not accurate enough. This problem may be solved using modern material models which consider mixed hardening, apparent Young modulus, Bauschinger effect, permanent softening etc.
- Influence of Bauschinger effect to the springback amount was observed after second cycle of bending. With TRIP steel, Bauschinger effect caused increased value of springback because transformed martensite increased total strength of material. With DC 06 steel was observed smaller amount of springback after second cycle.

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