

## SPRINGBACK PREDICTION IN SHEET METAL FORMING PROCESSES

*Slota Ján, Jurčišin 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 sheet metals in various cases in air bending process. The practical part consists of two parts. First part deals with experiment of air bending process using three different categories of steel, different bending depths and different die geometry. Influence of these technological variables is illustrated and compared with results of numerical simulation of these processes. Implicit and explicit commercial codes were used. This paper used a modern measurement methods performed in MATLAB system.*

**Key words:** *finite element method, air bending, AutoForm, Pam-Stamp, springback*

### 1. INTRODUCTION

The most common problem in area of bending technology is problem of achieving accurate and repeatable bending angle. In processes of sheet metal forming is this problem frequently observed, and is caused by elastic springback [1]. Elastic springback can be briefly defined as a dimensional change generated in the part, which occurs due to elastic recovery after the tool is released. This phenomenon causes the dimensional deviations [2]. Importance of springback prediction is significant also from economical aspect [3]. Nowadays is problematic of springback the current issue in automotive industry, considering use UHSS, AHSS, CP, TWIP etc. which have high strength [21]. The handy tables [4, 5] and graphs [6] were in the past the traditional ways to predict springback. But these methods didn't describe the whole scale of reached bending angles [2]. Another way to springback determination is analytical determination [24, 25] but these methods are time-consuming and computationally intensive. Technological variables for example blank thickness, tool radius, bending angle etc. influence springback amount [7, 8]. Material properties, as for example Young's modulus, constitutive behavior in plastic field, yield stress, Bauschinger

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\*Corresponding author's email: [jan.slota@tuke.sk](mailto:jan.slota@tuke.sk)

effect etc have also influence to the springback amount [9,10,11]. Air bending is the process, where different bending angle could be achieved [2]. Due to this circumstance, this method of bending in this work was used. Due to fact that AHSS steels have been intensively used in the automotive industry, this category of steel among the UHSS and mild steel has been used [12, 21]. Modern way of springback prediction is aimed to the numerical simulation of springback. Several codes can be use for numerical simulation of springback, for example Autoform, PAM – STAMP, Dynaform etc. In this work two commercial FEM codes were used. Definition of input parameters of simulation software is very important. The most important is selection of material models. It means the hardening curve and yield function. Early developed material models were for example Tresca and von Misses. These models were developed according to parameters obtained from simple tensile test. These material models were soon insufficient, because they didn't describe several parameters of material behavior as for example anisotropy, kinetic hardening, etc [13, 14]. The most accurate material description is using experimentally measured mechanical properties and use approximation for defining hardening curve [22, 23]. In air bending, increasingly adaptive control is applied to address the problem of variable material properties [20]. In experimental part of this paper, the same yield criterion and hardening curve in both of software were used. This was done on account of ensuring the same condition in codes, and also on account to the determination, if used material models are convenient for all categories of steel.

As was mentioned, in both numerical simulation of experiment, Hill 48 yield criterion was used. This criterion is defined as follows [15, 16]:

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

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

$\sigma_{xy}$  [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 [15].

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

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 yield criterion was set in the combination with hardening curve defined by Hollomon which is described by law [17]:

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

where:  $\sigma$  [MPa] - true stress

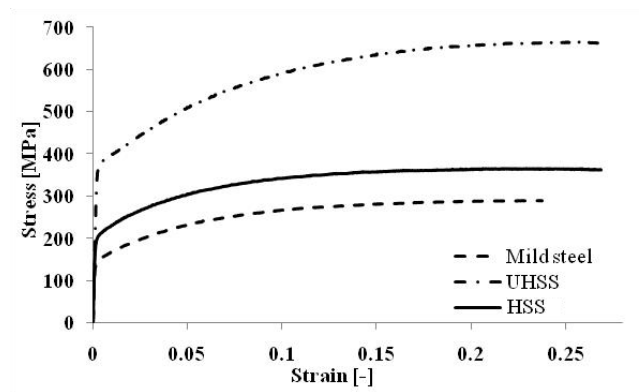
$\varepsilon$  [-] - true plastic strain

C [MPa] - strain hardening coefficient

n [-] - strain hardening exponent

## 2. OBJECTIVES AND PROCESS OF EXPERIMENT

The aim of this experiment was first to determine the influence of technological parameters on the amount of springback, and secondly accuracy of springback prediction using simulation software PA-STAMP 2G and Autoform. During the experiment, ten different bending angle, and two different die width were used. Three different categories of steels were used: HSS, UHSS and mild steel. Since yield stress has a significant influence to the springback amount, the different springback angle after unloading was observed. The stress strain curves of used materials are illustrated on Fig. 1. The thicknesses of materials were as follows: UHSS – 0.75 mm, HSS – 0.8 mm and mild steel 0.85 mm. All specimens were cut in direction transverse to the bending direction.



*Fig.1 - Stress – strain diagram of used steels*

Mechanical properties were measured in three mentioned rolling directions. Exams were performed on machine Tiratest 2300. Test rod of 80 mm according to EN 10002-1 was used. Results of mechanical properties illustrate Table 1, 2 and 3.

*Table 1 - Mechanical properties of HSS – H220PD*

Rolling Direction [°]	Rp0,2 (Re) [MPa]	Rm [MPa]	A80 [%]	n [-]	C [MPa]	r [-]
0	219	385	34.5	0.231	673.27	1.172
45	225	368	37.4			1.782
90	238	383	35.8			1.823

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

Rolling Direction [°]	Rp0,2 (Re) [MPa]	Rm [MPa]	A80 [%]	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 3 - Mechanical properties of mild steel DC06

Rolling Direction [°]	Rp0,2 (Re) [MPa]	Rm [MPa]	A80 [%]	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

Parameters in Tables 1-3 are necessary to define Hill 48 yield criterion and Hollomon hardening curve. Real experiment was performed onto hydraulic press ZD40. All specimens were bent in equal conditions.

## 2.1 Process of experiment

As was mentioned, experiment was performed on hydraulic press ZD40. Sheet metal strips were cut from three different categories of steel at dimension of 160 x 40 mm. Fig. 2 illustrates the used tool. Diameter of die was 50 mm and diameter of punch was 30 mm. Two different die widths were set. First, 50 mm die width and second 110 mm die width.

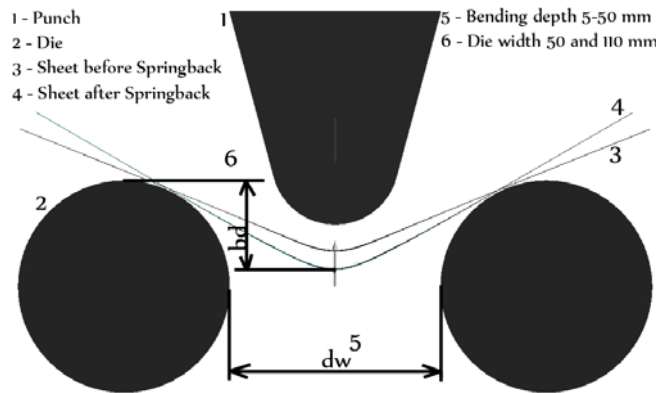


Fig.2 - Assembly of tool with indicating variables of process

Various bending depth cause various bending angle. After the punch stopped, and assembly was closed, picture was taken. Pictures were taken by camera from the same distance for each bending depth. After tool was released, another picture was taken. It was done due to graphical MATLAB measuring method, which were used on account the difficulty of conventional measuring method. MATLAB measuring method will be explained in stage 2.3. After all bending depths in addition of two die widths were performed, and pictures were taken, next step was numerical simulation of this process.

## 2.2 Process of numerical simulation

Two different types of numerical codes were used – explicit and implicit. The assembly of punch and die was modeled in CAD software and exported to the codes. Ten different punch paths were set, and after post processing, images of assembly were exported due to measuring method which was also performed using MATLAB code. As was mentioned, for both numerical codes, Hill 48 yield criterion and Hollomon hardening law were set. Both codes used shell elements of tools and blank [18].

Table- 4 - Information about numerical simulation

Code	Autoform	PAM-STAMP
Algorithm type	Implicit	Explicit
Mesh type	Triangular	Square
Mesh size	30° - defined by angle of triangle	20 mm
Number of integration points	11	5
Element type	Shell	Shell

Illustrations of processes are illustrated on Figure 3 and 4.

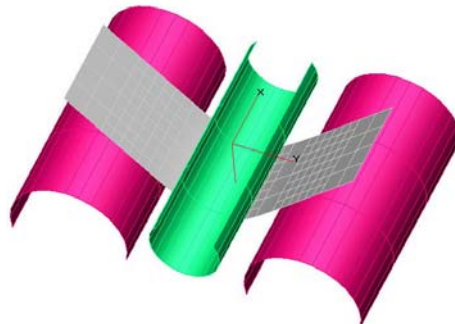


Fig. 3 – Simulation of process in PAM-STAMP code, where  $dw=50$  mm

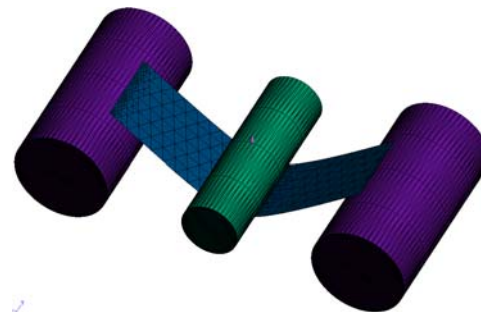


Fig. 4 – Simulation of process in Autoform code, where  $dw=110$ mm

## 2.3 Springback measuring method

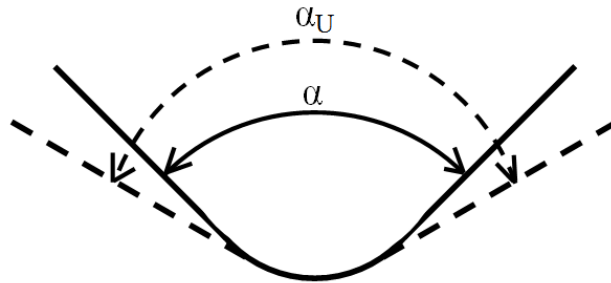
Measuring of the angle after springback and difference between depth of specimen before springback and depth of specimen after springback was measured. Due to difficulty of using conventional methods, measuring in MATLAB was used. It could be concluded that springback angle can be calculated and evaluated accurately using MATLAB measuring method [19].

Photos of real experiment were loaded in the MATLAB and then 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. Then based on equations of straight lines, angle between two straight lines was computed.

### 3. RESULTS

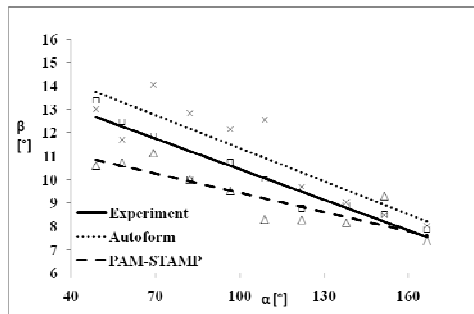
In this chapter, the results of experiment will be described. Notation of variables used in the figures is illustrated on Figure 5. Angle of springback  $\beta$  is calculated by using following relation :

$$\beta = \alpha_U - \alpha \quad (4)$$

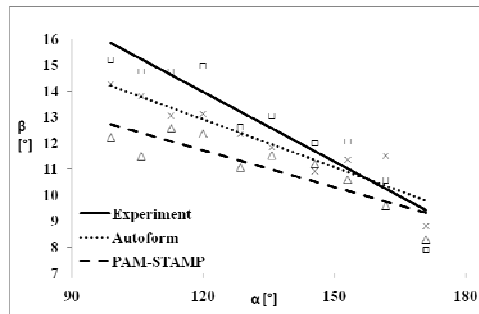


*Fig.5 - Schematic illustration of experiment:  $\alpha_U$  – angle after unloading,  $\alpha$  – angle before unloading. Springback angle  $\beta$  equals to the difference of these variables*

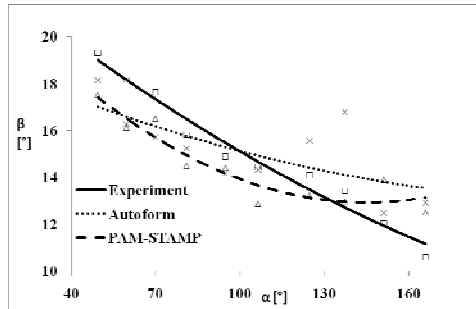
Following figures Fig. 5 – Fig. 10 illustrate the depending between loaded angle and amount of springback, in comparison with Autoform and PAM-STAMP results for different  $dw$  and category of steel.



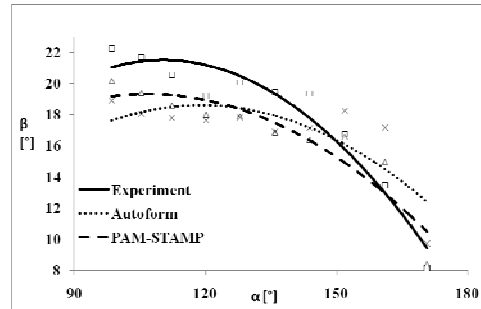
*Fig. 6 - Bend angle ( $\alpha$ ) and springback angle ( $\beta$ ), where  $dw = 50$  mm for mild steel.*



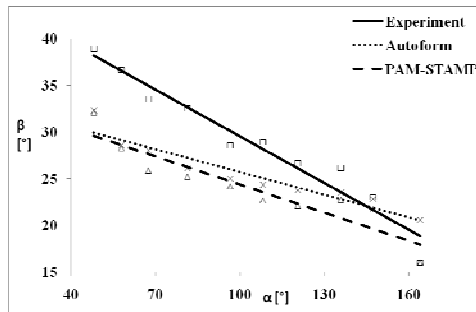
*Fig. 7 - Bend angle ( $\alpha$ ) and springback angle ( $\beta$ ), where  $dw = 110$  mm for mild steel.*



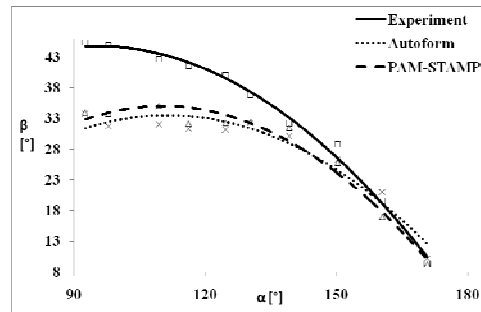
**Fig. 8 - Bend angle ( $\alpha$ ) and springback angle ( $\beta$ ), where  $dw = 50$  mm for HSS.**



**Fig. 9 - Bend angle ( $\alpha$ ) and springback angle ( $\beta$ ), where  $dw = 110$  mm for HSS.**

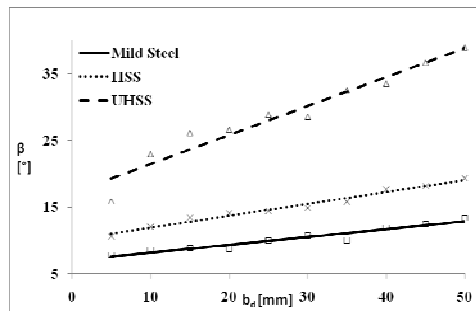


**Fig. 10 - Bend angle ( $\alpha$ ) and springback angle ( $\beta$ ), where  $dw = 50$  mm for UHSS.**

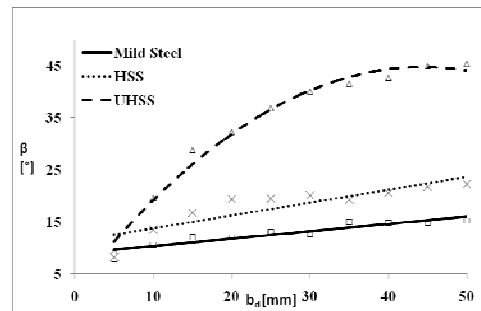


**Fig. 11 - Bend angle ( $\alpha$ ) and springback angle ( $\beta$ ), where  $dw = 110$  mm for UHSS.**

Comparisons of each springback amount depending on bending depth for individual material are illustrated on Fig. 17 and Fig. 18.



**Fig. 12 - Springback ( $\beta$ ) for different steels depending on bending depth ( $b_a$ ), where  $dw = 50$  mm.**



**Fig. 13 - Springback ( $\beta$ ) for different steels depending on bending depth ( $b_a$ ), where  $dw = 110$  mm.**

#### 4. DISCUSSIONS AND CONCLUSIONS

The greater springback occurred in the case where 110 mm die width was used. It is caused by the smaller deformation in comparison with the case where 50 mm die width was used. It can be concluded that results of numerical simulation in comparison with real experiment are as follows :

*Table 5 - Differences between results of numerical simulation and real experiment*

Category of steel	Mild Steel		HSS		UHSS	
Die width [mm]	50	110	50	110	50	110
Deviation to experiment [%]						
Autoform	7.2	5	1.1	5.7	12.7	18.6
PAM-STAMP	9.7	14.4	3.5	7.3	18.6	18.4

As shown in Fig. 12 and Fig. 13, the greater bend depth causes the higher bending angle, and the higher bending causes the higher springback amount. From figures also implies, that the slope of the function for UHSS is greater than for HSS and mild steel. It means that for AHSS and mild steel, increasing bending depth will causes the smaller increase of springback angle in compare to UHSS.

Although two different solvers type – implicit in Autoform and explicit in PAM-STAMP were used, the results of numerical simulation are very similar. Implying from this could be concluded, that dynamic factors have no influence to this experiment.

Described MATLAB measuring graphical method could be considered as an accurate tool for a measurement of springback amount. Several test shows that this method has a deviation only in 1 % in comparison with real experiment.

#### 5. MISCELLANEOUS

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## ODREĐIVANJE VELIČINE ELASTIČNOG VRAĆANJA U PROCESIMA OBRADE LIMA

*Slota Ján, Jurčišin Miroslav*

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

### REZIME

*Cilj ovog rada je određivanje elastičnog vraćanja limova u raznim slučajevima u procesima slobodnog savijanja. Praktični deo sastojao se iz dva dela. Prvi deo je vezan za eksperiment slobodnog savijanja za tri različite vrste čelika, različite iznose savijanja i različite geometrije alata. Uticaj ovih tehnoloških varijabli je ilustrovan i upoređen sa rezultatima numeričkih simulacija. Za simulacije su korišćeni implicit i eksplicit komercijalni kodovi. Ovaj rad koristi savremeni metodu merenja u okviru MATLAB sistema.*

***Ključne reči:*** *metoda konačnih elemenata, slobodno savijanje, AutoForm, Pam-Stamp, elastično vraćanje*