AmirKabir University of Technology
(Tehran Polytechnic)

AmirKabir Jounrnal of Science & Research
(Mechanical Engineering) (ASJR-ME)

Vol. 47, No. 2, Winter 2015, pp. 13-16

Obtaining the Equations to Predict Values of Springback and Side-Wall Curl Radius of U-Bending of DP600 Dual Phase Steel Plates

M. Shafiei Alavijeh[1], H. Torabian[2*], H. Amirabadi[3]

1- PhD Student, Department of Mechanical Engineering, Birjand University

2- Assistant Professor, Department of Mechanical Engineering, Central Tehran branch, Islamic Azad University, Tehran

3- Associate Professor, Department of Mechanical Engineering, Birjand University

(Received 21 January, 2012, Accepted 18 May, 2015)

ABSTRACT

The most prominent feature of sheet material forming process is an elastic recovery phenomenon during unloading which leads to springback and side-wall curl. Therefore, evaluation of the springback and side-wall curl is mandatory for production of precise products. In this research, effects of friction coefficient, sheet thickness, yield strength of sheet and blank-holder force on the springback and side-wall curl in U-bending of DP600 dual-phase steel sheets are investigated. These investigations are done by computer simulation. The simulations are done by ABAQUS finite element software and then, results are compared with experimental results. The finite element results have been validated with experimental results. MINITAB, a statistical software, is used to analyze finite element results. With the use of MINITAB, equations are obtained to predict the springback and side-wall curl radius by the friction coefficient, sheet thickness, yield strength and blank-holder force. From these equations it can be concluded that first, increase in yield strength of sheet will lead to increases in the spring back and side wall curl. Second, increase in the sheet thickness will cause a reduction in the spring back and side wall curl. Third, increase in the blank holder force and friction coefficient will cause increase in the spring back and side wall curl to the certain value, but after that, they will reduce values related to the spring back and side wall curl.

KEYWORDS:

Forming, U Shape, Springback, Side Wall Curl Radius, Dual Phase Steel

* Corresponding Author, Email: h_torabian@iauctb.ac.ir

1- Introduction

In U-bending process of metal sheets, some phenomena such as spring back and side wall curl decrease precision of manufactured workpieces. Many researches have been performed to model this kind of forming process and reasons behind two aforementioned phenomena and factors affecting them. In activities close to current paper subject, Samuel has studied influence of punch radius, die radius and also anisotropy rate on the spring back and side wall curl [1]. In order to compensate reduction in the spring back and side wall curl in draw bending of U-bending pieces, Liu et al. recommended using variable holding force [2,3]. Ragai et al. have investigated influence of anisotropy rate on the spring back rate of stainless steel 410 using finite element simulation and experiment[4]. In this paper, in U-bending process, DP600 dual-phase steel sheets, spring back and side wall curl phenomena and also effect of factors such as the blank holder force, friction coefficient, yield strength of sheets and thickness of sheets on these phenomena have been examined. At the end, relations have been obtained to anticipate values of these phenomena using rates of the blank holder force, friction coefficient, yield strength of sheet and sheet thickness.

2- Experiments

In this paper, all of experiments have been conducted in the constant temperature of workshop environment. Die, Punch and blank holder, all have been made of steel with hardness 55 HRc and sheets have been chosen from DP600 dual-phase steel. The sheet material properties presented in Figure 1 and Table 1. Length of each sheet is 300 mm and their width is 35 mm. Thickness of sheets used in this study are 1, 1.2, 1.5 mm, respectively. To perform each experiment, at first, sheet has been put in its precise position over die using dial gauge, then the blank holder is lowered. After exerting blank holder force, upper shoe of press is started to come down and punch moved down by 1 mm/s. When punch is pervading into die about 70 mm, the sheet forming operation is finished. Then, punch backs to top, the blank holder is removed from the sheet and ultimately the sheet is entirely brought out from the die.

In this research, each experiment has been done on two sheets and in each sheet; four measurements of the four corners of the sheet have been done for each of factors of the spring back of wall opening angle (β_1), the spring back of flange angle (β_2) and the side wall curl (ρ). Mean of these 8 measurements for each one of factors β_1, β_2 and ρ have been considered as the value of this factor. This action reduces errors caused by sheet torsion.

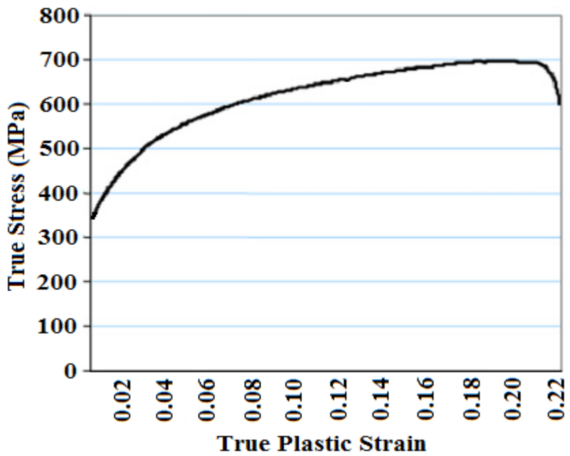

Figure 1. True stress–strain curve of DP600 dual-phase steel

Table 1. Sheet material properties

Property	Value
Young’s modulus (GPa)	205.35
r_0	0.79
r_{45}	1.03
r_{90}	1.01
Poisson’s ratio	0.3
Density (kg/m^3)	7800
Yield strength (MPa)	365

3- Finite Element Simulation

The U-bending process has been simulated using finite element simulation and ABAQUS software. In Figure 2, schematic figure of the U-bending problem has been displayed. Due to the symmetry of the problem with respect to the middle sheet, the right half of the model has been presented. This will cause an increase in simulation speed and decrease in analysis time.

Required points for measuring the spring back of wall opening angle (β_1), spring back of flange angle (β_2) and side wall curl (ρ) values have been shown in Figure 3. To measure $\beta 1$, β_2 and ρ values, at first, coordinate of points A, B, C, D and E after the spring back phenomenon occurrence and coordinate of points A and B before happening the spring back phenomenon (coordinate of points A_0 and B_0) are measured and then the spring back of wall opening angle (β_1), spring back of flange angle (β_2) and side wall curl (ρ) values are obtained using these coordinates and Eqs.(1-8).

$$\beta_1 = \theta_1 - \theta_1^0 \tag{1}$$

$$\beta_2 = \theta_2^0 - \theta_2 \tag{2}$$

$$\theta_1^0 = \theta_2^0 = \arccos\left(\frac{\overrightarrow{ox}\,.\overrightarrow{A_0B_0}}{|ox|\,\|A_0B_0|}\right) \tag{3}$$

$$\theta_1 = \arccos\left(\frac{\overrightarrow{ox}.\overrightarrow{AB}}{|ox||AB|}\right) \tag{4}$$

$$\theta_2 = \arccos\left(\frac{\overrightarrow{AB}.\overrightarrow{ED}}{|AB||ED|}\right) \tag{5}$$

$$x_R = \frac{x_B^2 + y_B^2 - x_A^2 - y_A^2 - \frac{y_A - y_B}{y_C - y_B}\left(x_C^2 + y_C^2 - x_B^2 - y_B^2\right)}{2\left[x_B - x_A + \left(x_C - x_B\right)\frac{y_A - y_B}{y_C - y_B}\right]} \tag{6}$$

$$y_R = \frac{x_A^2 + y_A^2 - x_B^2 - y_B^2 + 2x_R\left(x_B - x_A\right)}{2\left(y_A - y_B\right)} \tag{7}$$

$$\rho = \sqrt{(x_A - x_R)^2 + (y_A - y_R)^2} \tag{8}$$

4- Results

To obtain relations to predict the spring back of wall opening angle (β_1), spring back of flange angle (β_2) and side wall curl (ρ) values, the MINITAB software

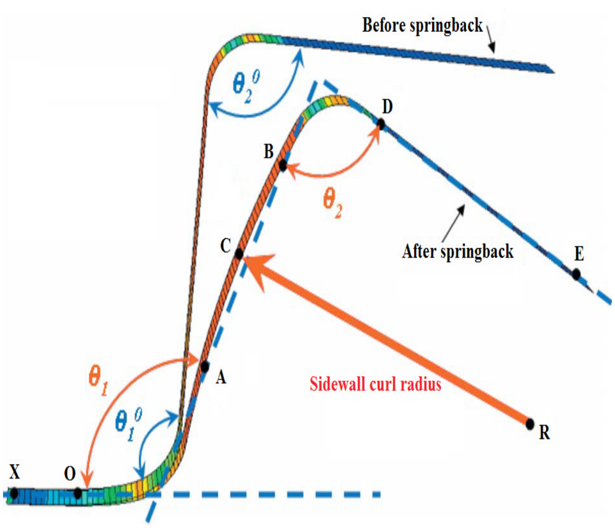

Figure 2. Required points for measuring values of β_1, β_2 and ρ

has been employed for regression analysis of these values which have been obtained from finite element simulation. Then, Eqs. (9-11) have been acquired.

$$\beta_1 = 0.2631X_1 - 0.0044X_1^2 + 0.0544X_2 - 5.6222X_3 + 40X_4 - 100X_4^2 + 0.1687X_1X_4 - 4.1241 \tag{9}$$

$$\beta_2 = 0.2023X_1 - 0.0034X_1^2 + 0.0477X_2 - 4.152X_3 + 21.3947X_4 - 56.1913X_4^2 + 0.1027X_1X_4 - 6.1436 \tag{10}$$

$$\rho = 271.8246 - 0.5953X_1 + 0.0119X_1^2 - 0.3712X_2 + 88.9552X_3 - 744X_4 + 1935X_4^2 - 0.0443X_2X_4 \tag{11}$$

In aforementioned equations, X_1 is equal to the blank holder force based on kN, X_2 is equal to the yield strength of sheet based on MPa, X_3 is equal to the sheet thickness based on mm, X_4 is equal to the friction coefficient between sheet and forming equipment, β_1 is equal to the spring back of wall opening angle based on degree, β_2 is equal to the spring back of flange angle based on degree and ρ is equal to the side wall curl radius based on mm.

5- Conclusions

Comparing results obtained from the finite element simulation using the ABAQUS software with experimental results, it is shown that values of the spring back and side wall curl radius in both cases are in agreement with each other. Therefore, it can be concluded that the ABAQUS software is a reliable tool to anticipate values of the spring back and side wall curl radius.

At the end, equations have been obtained to predict values of the spring back of wall opening angle (β_1), the spring back of flange angle (β_2) and the side wall curl (ρ) using the MINITAB software and values obtained from the ABAQUS software for β_1, β_2 and ρ. From these equations it can be concluded that first, increase in the yield strength of the sheet will lead to increases in the spring back and side wall curl. Second, increase in the sheet thickness will cause reduction in the spring back and side wall curl. Third, increase in the blank holder force and the friction coefficient will cause increase in the spring back and side wall curl to the certain value, but after that, they will reduce values related to the spring back and side wall curl.

6- References

[1] Samuel, M., "Experimental and numerical prediction of springback and side wall curl in U-bending of anisotropic sheet metals", Journal of Materials Processing Technology, Vol. 105, No. 3: pp. 382- 393, 2000.

[2] Liu, G., Lin, Z. and Bao, Y., "Improving dimensional accuracy of a U-shaped part through an orthogonal design experiment", Finite Elements in Analysis and Design, Vol. 39, No. 2: pp. 107- 118, 2002.

[3] Liu, G., Lin, Z., Xu, W. and Bao, Y., "Variable blankholder force in U-shaped part forming for eliminating springback error", Journal of Materials Processing Technology, Vol. 120: pp. 259- 264, 2002.

[4] Ragai, I., Lazim, D. and Nemes, J.A., "Anisotropy and springback in draw-bending of stainless steel 410: experimental and numerical study", Journal of Materials Processing Technology, Vol. 166: pp. 116-127, 2005.