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

M. Shafiei Alavijeh¹, H. Torabian²*, H. Amirabadi³

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
Obtaining the Equations to Predict Values of Springback and Side-Wall Curl Radius of U-Bending...

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 ($\beta_1$), the spring back of flange angle ($\beta_2$) and the side wall curl ($\rho$). Mean of these 8 measurements for each one of factors $\beta_1$, $\beta_2$, and $\rho$ 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](image)

Table 1. Sheet material properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young’s modulus (GPa)</td>
<td>205.35</td>
</tr>
<tr>
<td>$r_0$</td>
<td>0.79</td>
</tr>
<tr>
<td>$r_{45}$</td>
<td>1.03</td>
</tr>
<tr>
<td>$r_{90}$</td>
<td>1.01</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>0.3</td>
</tr>
<tr>
<td>Density (kg/m$^3$)</td>
<td>7800</td>
</tr>
<tr>
<td>Yield strength (MPa)</td>
<td>365</td>
</tr>
</tbody>
</table>

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 ($\beta_1$), spring back of flange angle ($\beta_2$) and side wall curl ($\rho$) values have been shown in Figure 3. To measure $\beta_1$, $\beta_2$, and $\rho$ 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 ($\beta_1$), spring back of flange angle ($\beta_2$) and side wall curl ($\rho$) values are obtained using these coordinates and Eqs. (1-8).

\[ \beta_1 = \theta_i - \theta_i^o \]  
\[ \beta_2 = \theta_2 - \theta_2^o \]  
\[ \theta_i^o = \theta_2^o = \arccos \left( \frac{\sigma_{AB}B_0}{\|AB\|B_0} \right) \]  
\[ \theta_i = \arccos \left( \frac{\overrightarrow{ax} \cdot \overrightarrow{AB}}{\|ax\| \|AB\|} \right) \]  
\[ \theta_2 = \arccos \left( \frac{\overrightarrow{AB} \cdot \overrightarrow{ED}}{\|AB\| \|ED\|} \right) \]  
\[ x_B = \frac{x_A^2 + y_A^2 - x_B^2 - y_B^2 - y_A - y_B (x_C^2 + y_C^2 - x_B^2 - y_B^2)}{2 (x_B - x_A + (x_C - x_B) (y_A + y_B))} \]  
\[ y_B = \frac{x_A^2 + y_A^2 - x_B^2 - y_B^2 + 2 x_R (x_B - x_A)}{2 (y_A + y_B)} \]  
\[ \rho = \sqrt{(x_A - x_R)^2 + (y_A - y_R)^2} \]  

\[ \theta_i^o = \theta_2^o = \arccos \left( \frac{\sigma_{AB}B_0}{\|AB\|B_0} \right) \]

4- Results

To obtain relations to predict the spring back of wall opening angle ($\beta_1$), spring back of flange angle ($\beta_2$) and side wall curl ($\rho$) values, the MINITAB software has been employed for regression analysis of these values which have been obtained from finite element simulation. Then, Eqs. (9-11) have been acquired.

\[ \beta_1 = 0.2631 X_1 - 0.0044 X_1^2 + 0.0544 X_2 - 5.6222 X_3 + 40 X_4 - 100 X_4^2 + 0.1687 X_1 X_4 - 4.1241 \]  
\[ \beta_2 = 0.2023 X_1 - 0.0034 X_1^2 + 0.0477 X_2 - 4.152 X_3 + 21.3947 X_4 - 56.1913 X_4^2 + 0.1027 X_1 X_4 - 6.1436 \]  
\[ \rho = 271.8246 - 0.5953 X_1 + 0.0119 X_1^2 - 0.3712 X_2 + 88.9552 X_4 - 744 X_4 + 1935 X_4^2 - 0.0443 X_4^3 \]

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, $\beta_1$ is equal to the spring back of wall opening angle based on degree, $\beta_2$ is equal to the spring back of flange angle based on degree and $\rho$ 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.
6- References


