Optimization of the Spring-Back in Roll Forming Process with Finite Element Simulation

Ya. Zhang, Ha-Phong. Nguyen, and Dong-Won. Jung
Department of Mechanical Engineering, Jeju National University, Jeju, Republic of Korea
Email: zhangya777@gmail.com, phongnhhn92@gmail.com, jdwcheju@jejunu.ac.kr*

***Abstract*—This study presents a finite model of U-bending roll forming process with COPRA software. Based on the design and simulation of the U-bending's roll forming process, the bending and spring-back regulations are investigated. A number of U-bending processes are also analyzed in order to determine the springback level. The material used in this roll forming process is Mg-Al alloy. There are many factors which have a significant influence in the forming process, such as the width of the U-bending, the radius of the roll die, lubrication, roll velocity and sheet thickness. In order to predict the performance of the sheet forming process and improve the spring-back, the FEM method and Taguchi method are used in this sheet process design. The sheet with 1, 2 and 3mm thickness pass through 6 stages of bending process. Every stage is uniform with 15°. With three kinds of widths of the U-bending and 3 kinds of radius, there are total 9 simulations are established in this study. The optimal design parameters are obtained with the minimum spring-back angle and the sheet forming quality has been controlled.**

***Index Terms*—U bending, spring back, taguchi method, FE simulation**

I. Introduction

U bending as one kind of cold roll forming now is widely used in metal forming industry and our surrounding environment. AL-Mg steel is widely used in automotive sector, home applications, due to its low cost and easy forming.

Zhang Dongjuan established an analysis model based on Hill48 yielding criterion and plane strain condition to predict the spring-back in the U-bending process [1]. You-Min Huang discusses the application of updating Lagrangian elasto-plastic finite element method towards analyzing the sheet metal U-bending process under the plane strain condition [2]. J. R. Cho aims to investigate the spring-back characteristics by numerical method. For the goal, the updated Lagrangian thermo-elasto plastic finite element method was applied to a plane-strain sheet U-bending forming process and the formulation and finite element approximation is also presented [3]. L. C. Sousa presents an optimization method applied to the design of V and U bending sheet metal processes. The method couples the numerical simulation of sheet metal forming processes with an evolutionary genetic algorithm searching the optimal design parameters of the process [4]. Sung Ho Chang investigated the springback characteristics of tailor-welded strips in U-bending processing. Several groups of simulation and experiment developed and the spring back were compared between the experiments and simulations [5]. Bending is the uniform straining of material, usually flat sheet or strip metal, pass through a group of dies along a straight axis. Sheet metal flow within the mold cavity and at last gets the shape according to physics and dimension requirements [6]. The spring back of the U bending is the combine effect of the forming region and informing region. It's not only depended on the bending method, but also depends on other factors such as die structural and so on. So it is difficult to calculate the spring back with simple math formula. Nowadays, with the advent of computation technology, sheet metal bending process can be analyzed using the finite element method prior to the experiment which depends on the designer's experience and involve trials and errors to obtain desired result [7].

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II. U Bending

The U bending process is shown on the Fig.1. The model is set up with the roll forming. Depending on the shape of the die, the sheet deforms progressively into expected shape we want [8]. With the plastic bending form of the sheet, the elastic deform happen together. After the deformation finish, elastic recovery happened together with the unloaded of the die. This elastic recovery is called spring back. There are many methods to calculate the spring back angle. In this paper, the BISWAS is used to calculate the spring back angle.

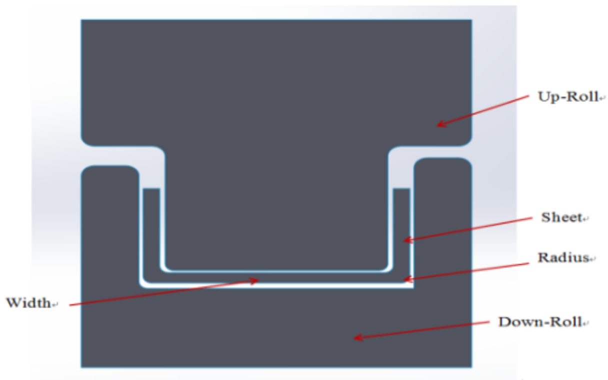

Figure 1. The U bending model.

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III. Element Model and Evaluation

The investigated material, Al-Mg steel was used in this design. The Young's module is 70500N/mm^2, the yield point is 110N/ mm^2.The simulation used 6 stations with finite element software COPRA. The strip width is calculated with DIN 6935.And every station has a uniform bending angle of 15 degrees. The flower design is show in Fig. 2.

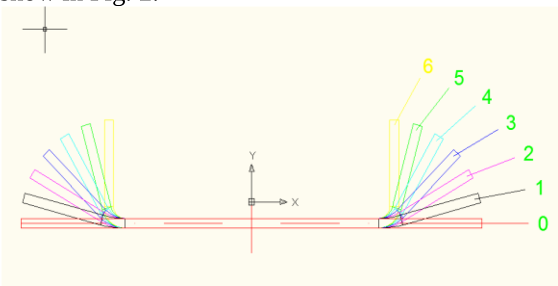

Figure 2. The flower design of the u bending

The dimension of the test sample is 100mm width and 300mm longitude. The distance between the stages is 150mm. The simulation calculation method is Hauschild's statement and the exponent is 2.5. The number of surface element along the axis is 32 and cross axis is 14. The sheet is varied in many types based on three different thicknesses (1, 2 and 3 mm), three different radiuses (1.5, 2.5 and 3.5mm) and three different widths (20, 40 and 60mm). The process is at room temperature and the roll velocity is not considered in this process.

The calibrating method used in the COPRA software is a constant length. It is shown on the Fig. 3; the bending phenomenon happens with the outer moment. In the bending region, the sheet at the inner side has been compressed and the outer side has stretched. Between the compressed zone and stretched zone, there will be a layer with a constant length. This layer is called neutral layer.

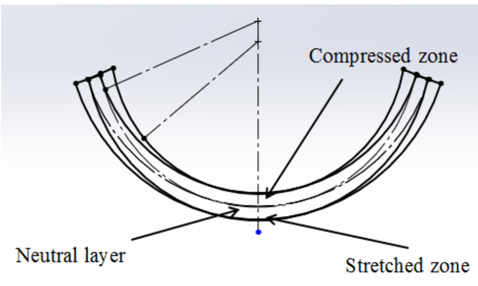

Figure 3. The neutral layer of the bending

To conduct the optimization, there are three factors are applied to the simulation which were the width of the U bending, radius and sheet thickness as shown in the Table I.

TABLE I. Process Parameters and Their Levels

Symbol	Factor	Unit	Level 1	Level 2	Level 3
A	Width	mm	20	40	60
B	Thickness	mm	1	2	3
C	Radius	mm	1.5	2.5	3.5

For three levels with three factors, there will be totally 23 combinations need to be required. However, considering about the time while the effect of each factor, the orthogonal array L3 (33) is chosen to arrange the simulations. The combination of the simulations is listed in Table II.

TABLE II. Orthogonal Array

Experiment No.	Parameter Level		
	A	B	C
	Width	Thickness	Radius
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

IV. Finite Element Modeling and Results

The Taguchi method has been applying to the simulations to optimize the spring back angle. We can determine the effect of each factor with Signal-to-Noise (S/N) ratio. Depending on the object of the experiment, different S/N may be applicable. For this study of spring back angle in the U bending process, the S/N is "smaller is better". The S/N formula is shown on Eq. 1.

$$S/N = -10\log_{10}[\frac{1}{n}\sum_{i=1}^{n} y_i^2] \qquad (1)$$

In the formula, the n is the number of experiment or simulation repetitions, y_i is the simulation or experiment result, and i stand for the number of design parameters arranged in the Taguchi orthogonal array (OA).

The S/N and spring back angle is calculated in each simulation as shown in Table III. According to the criterion "smaller is better", the corresponded S/N shows that the optimum levels are experiment 2 with A1, B3 and C3. The minimum spring back angle will be 1 degree.

TABLE III. Comparison of Measured Roughness Data

Experiment No.	Parameter Level				Calculated S/N ration for spring back(DB)
	A(mm)	B(mm)	C(mm)	Maximum spring back(°)	
1	20	1	1.5	1.12	-0.984
2	20	2	2.5	1.03	-0.258
3	20	3	3.5	1.0	0
4	40	1	2.5	1.51	-3.579
5	40	2	3.5	1.22	-1.727
6	40	3	1.5	1.84	-5.296
7	60	1	3.5	1.92	-5.666
8	60	2	1.5	1.87	-5.437
9	60	3	2.5	1.89	-5.527

V. Parameter Design and Optimization

The effects of the factors on the spring back were evaluated from Fig. 4. As a result of the application of

Taguchi method, the optimum levels of the factors were A1, B2 and C3.

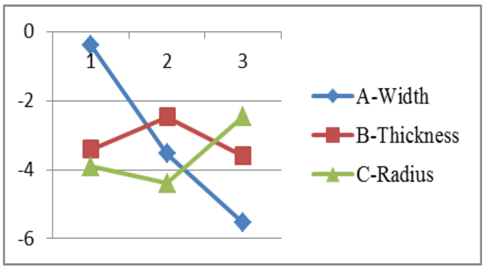

Figure 4. Parameter level

The simulation was elaborated with the optimum factor and the result is shown in the Fig. 5 and Fig. 6. Fig. 5 showed the strain distribution along the longitudinal distance with optimized factors. The strain distributions at first three stages are out of the strain limited and the strain decreased with the forming process. From which we can know that the deformation angle at first three stages are too big and need to be reduced. The strain at the last three stages although within the strain limit but still have the tendency to exceed the limitation. In this situation, an optimization should be come out that we should increase the forming stages and the forming angels also need to reduce. In the Fig. 6, the plastic strain of the sheet along the longitudinal seems to increase with the roll forming process and the residual strain is up to 0.65%.

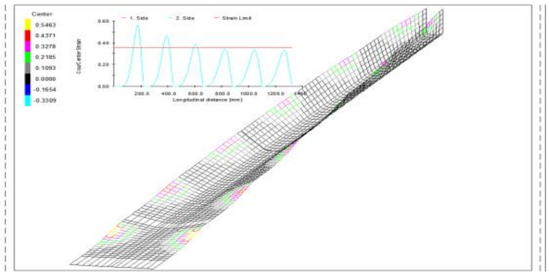

Figure 5. The strain distribution along the longitudinal distance

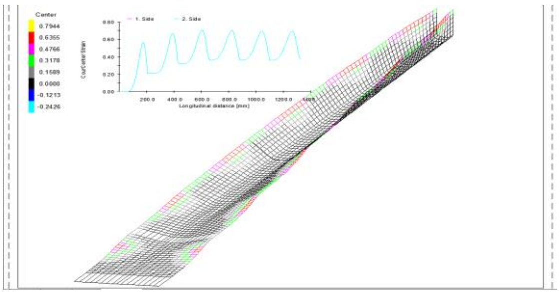

Figure 6. The plastic strain distribution along the longitudinal distance

Fig. 7 shows the spring back angle with the optimized factor. The spring back angle of the optimum factors is 1.22 degree. By using the Taguchi method as above, the spring back angle has been reduced. This result is obviously larger than the combination simulations we did. This is because the factors we considered are not enough. These factors have no significant influence on the spring back. Which means more factors and combinations need to apply to the optimize process.

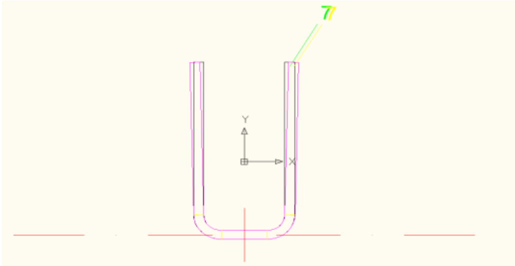

Figure 7. The spring back angel with the optimized factor

VI. The Sensitivity Study of the Factors

The sensitivity study is a kind of method to analysis the most sensitive factor among groups of uncertainties. And predict the influence of the factors on the results. We can divide the method into univariate sensitivity analysis multivariate sensitivity analysis according to the number of the varieties. In this paper, the univariate sensitivity has been used to analysis the sensitivity of the three factors. The changes will reference to the spring back angle when the width is 40mm, thickness is 2mm and the radius is 2.5mm. The spring back angel under the circumstances above is 1.06 degree. The sensitivity intervals and results are shown in Table IV. From which we can know that the thickness is the most sensitivity factor among the three parameters. The width of the sheet has the smallest influence on the spring back.

TABLE IV. The Sensitivity Analysis

Experiment No.	Factor	interval		Spring back angle interval	
1	Width	-50%	+50%	-2.9%	2.9%
2	Thickness	-50%	+50%	-16.3%	42.4%
3	radius	-66%	+66%	-11.6%	15.1%

VII. Experimental Verification

A U bending experiment has been set up to verify the simulation result. As shown in the Fig. 8, the roll forming machine with 4 stages of rolls has been set up and the deformation angle for each step is constant. The deformation angle for each stage is 22.5 degree. The distance between the stages is 220mm. We can control the gap of the rolls by the screw nut above the mills.

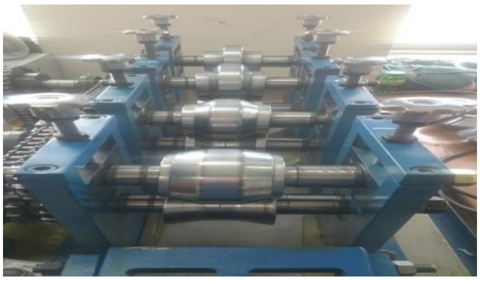

Figure 8. The roll forming machines

The material used in this experiment is mild steel with a Young's module is 70500N/mm^2 and the yield point is 251N/ mm^2. The thickness of the sheet is 1mm and the radius of the roll is 5mm. The final width of the sheet is 20mm. The experiment result is shown in the Fig. 9.

Figure 9. The sheet after U bending process

VIII. Conclusions

With the study of the U bending process combines with Taguchi method, the springback of the U bending was studied and optimized. With these simulations, we can conclude out that:

1. After analyzing the 9 groups of simulations, the spring back angle has been optimized. The spring back decreased with the width of the sheet and increased with the sheet thickness and bending radius.
2. For the U bending process, the factors considered in this study are not enough to reveal the inner relationship of the spring back. The spring back of the U bending is an elastic recovery of the plastic forming; the accurate calculation need to apply and more factors should be considered.
3. The sensitivity study has been done to analysis the parameters come out that the thickness is the most sensitive factor.

Other factors such as lubrication, velocity, distance of the stages can be considered to the simulation to get a more accurate result.

Acknowledgment

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Ya Zhang studied mechanical engineering at Henan university of Science and Technology in China and obtains his degree in 2012. Currently, he studies mechanical engineering at Jeju National University in Korea.

Ha-Phong. Nguyen studied mechatronics at Ha Noi University of Science and Technology in Vietnam and obtain his degree in 2015. Currently, he studies mechanical engineering at Jeju National University in Korea.

Dong-Won. Jung studied mechanical engineering at Korea advanced institute of science and technology. He received his Ph.D. degree in 1995 with a thesis of rigid-plastic finite element analysis of sheet metal forming processes using explicit time integration scheme. His areas of emphasis are finite element method, sheet metal forming and elastic-plastic theory.