

REDUCTION OF SPRINGBACK PHENOMENON IN U BENDING OF SHEET METAL USING DESIGN EXPERIMENT

CHIRITA BOGDAN

University of Bacau

Abstract. Springback is the most important failure mode for the sheet metal parts obtained by U-bending. Numerous studies have been conducted in order to develop a method for an accurate prediction and limitation or elimination of this phenomenon. As there is not possible to use an analitical method for this problem, numerical methods, especially finite element method, have been developed and applied for sheet metal forming. This paper uses U-bending simulation by finite element analysis combined with a fractional factorial design in order to establish a method for the reduction of springback parameters.

Keywords: springback, U-bending, finite element method, fractional factorial design

1. INTRODUCTION

The increasing demand of the industry for higher precision of the parts lead to numerous theoretical and experimental studies in this domain of sheet metal forming. The development of numerical methods gave the opportunity to obtain good simulations of the sheet metal forming processes. The simulation of springback is still uncertain due to the complexity of the phenomenon. Different simulations led to various results depending on the factors taken into consideration: boundary conditions, material models, integration methods (explicit vs. implicit) etc.

In the literature there are various researches concerning the optimization of springback in sheet metal U bending. Li et al [1] proposed an explicit finite element method in conjunction with the ortogonal regresion analysis for the prediction of springback. Choi and Kim [2] used an optimization method that relies on a mesh-free nonlinear analysis and continuum based design sensitivity analysis. Lee and Yang [3] have used explicit time integration method for the simulation of forming, implicit time integration for springback stage and the factors influencing springback have been evaluated quantitatively using Taguchi method. Pourboghraat and Chu [4,5] have developed a robust method for predicting springback and sidewall curvature in U bending operations using moment-curvature relationships derived for sheets undergoing plane-strain stretching, bending and unbending deformations using a membrane finite element solution. Ruffini and Cao [6] proposed a neural network control system for springback reduction in a chanel section stamping process. Tan et al [7] used an aproach consisting in finite element method analysis model to predict the value of the objective function and an evolutionary algorithm optimization procedure.

This paper describes a numerical procedure that combines simulation of springback by finite element simulation with a fractional factorial design and proposes an optimization of forming parameters and tool geometry for the reduction of springback intensity.

2. PROBLEM FORMULATION

2.1. ANALYSIS BY FEM SIMULATION OF THE U BENDING AND SPRINGBACK PROCESS

Springback is one of the main defects of the parts made of sheet metals that appear after the removal of the tools and forming forces. The goal of a plastic forming operation is to obtain a part that should be as close as possible to nominal dimensions. Obtaining parts free of deviations is very difficult, expensive and time consuming process.

The simulation of U bending operation used an explicit finite element method while springback was simulated using an implicit integration method. The objective was to obtain a model with an accurate prediction of springback intensity, stress and strain state at the end of the forming process.

Springback parameters that were observed during the analysis are presented in fig. 1:

- sidewall radius ρ ;
- bottom angle θ_1 ;
- flange angle θ_2 ;
- bottom profile radius R_b ;
- flange profile radius R_f .

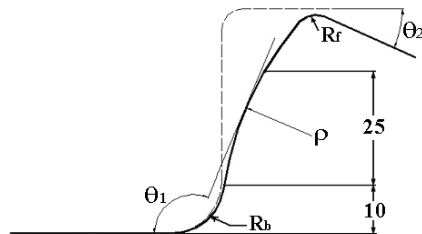


Fig. 1 Geometrical springback parameters

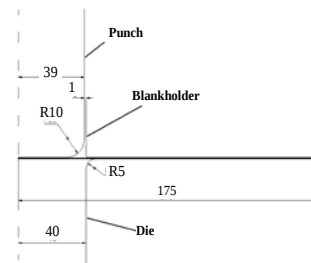


Fig. 2 Geometry of the simulation model

The simulations considered a plane strain state and because of the symmetry only half of the assembly was modeled. The geometrical model and tools dimensions are presented in fig. 2. The initial dimensions of the sheet are 350 mm length, 30 mm width and 0.8 mm thick. The sheet was considered deformable body and the model used shell elements (S4R) on one row with 5 integration points through the thickness. The tools (punch, die and blankholder) were modeled as rigid because they have the advantage of reduced calculus efforts and a good contact behavior. The material is a mild steel that was modeled as elasto-plastic, where elasticity is considered isotropic and plasticity is modeled as anisotropic using Hill quadratic anisotropic yield criterion. As only half of the assembly was modeled, a symmetry condition was necessary. The boundary conditions imposed to the tools were intended to describe the experimental conditions as accurate as possible. For contact conditions a modified Coulomb friction law combined with penalty method was used.

2.2. FRACTIONAL FACTORIAL DESIGN

The purpose of the study was to develop a method for the reduction or the elimination of the springback from the designing stage of the forming process. An optimal solution could be obtained using process simulation in combination with a statistical modeling that allows the mathematical description of the influence of different process parameters on the geometry of the parts. For this purpose we have used factorial design methods. The fractional factorial design can take a project with many combinations of variables, and quickly reduce it to simple experiments that can be run simultaneously and will determine the cheapest way to achieve a goal. Instead of considering one variable at a time, factorial design is able to test many variables at once, which is why the number of tests can be conveniently small. This method uses some predefined tables and on their basis it is possible to establish the relative importance of process parameters and their interactions on the influence of springback parameters.

The factorial design in this study considered six factors of influence for the process and five geometrical parameters of the part. The main stages of the optimization method are as follows:

- selection of five geometrical parameters of the part that are about to be monitored;
- selection of six parameters of influence for the forming process;
- for every process parameter two levels of variation are established and the fractional factorial design is constructed;
- based on the experience matrix that combines the levels of the parameters, the U bending process is simulated and different geometrical parameters of the part are obtained;
- for every geometrical parameter a dependency polynomial function is determined;
- global optimization of process parameters so that the geometrical parameters of the part are closest to nominal values;
- verification of optimized process parameters by finite element analysis.

The method was applied using the software Design-Expert 6 that allows the elaboration of different factorial plans, analysis of variance and elaboration of different dependency functions and optimization of the process.

2.2.1. Choice of geometrical parameters and of parameters of influence

In this optimization case the geometrical parameters of the part taken into consideration were: sidewall radius ρ , bottom angle θ_1 , flange angle θ_2 , bottom profile radius R_b and flange profile radius R_f . The factors of influence were blankholder force F , punch profile radius R_p , die profile radius R_m , die angle A and the gap between punch and die u . Material strain rate determines the modification of mechanical properties and consequently the behavior of the material during U bending process is different. For this reason the punch speed v is included on the list of the parameters influencing the process. The process parameters are presented in fig. 3 and the variation levels are presented in table 1.

Table 1. Variation field of the parameters

Parameters	Initial value	Minimum value (-1)	Maximum value (+1)
Blankholder force F [kN]	40	40	200
Punch profile radius R_p [mm]	10	10	12
Die profile radius R_m [mm]	5	5	6
Die angle A [°]	0	0	20
Gap u [mm]	1	1	1.5
Punch speed v [mm/min]	10	10	18

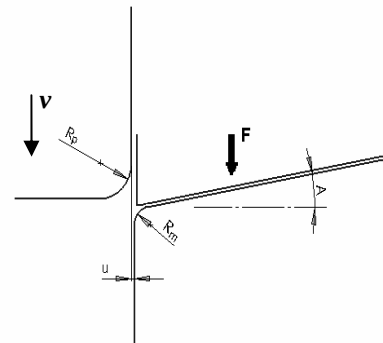


Fig. 3 Parameters of influence

2.2.2. Construction of fractional factorial design and determination of dependency functions

In order to reach a maximum efficiency of the method with a minimum number of simulations, a half fractional factorial design was used; for the six process parameters were necessary 32 trials and a supplemental one was realized for the center of the variation levels. In fig. 4 the 33 trials of the factorial design are presented together with the results of the geometrical parameters resulted from the simulations. The dependency among process parameters and geometrical parameters of the part is modeled by quadratic polynomial functions that are generated by the program.

After the analysis of the results the following functions were determined:

- for the sidewall radius

$$\begin{aligned} \rho = & 1224.06 - 131.23F'^2 - 435.33R_p'^2 + 144.64R_m'^2 + 151.49A'^2 - 233.02u'^2 + 229.89v'^2 + \\ & + 186.53F'R_p' + 590.70F'R_m' - 178.15F'A' + 349.41F'u' - 566.26F'v' + 236.38R_p'R_m' - \\ & - 464.63R_p'A' + 410.59R_p'u' - 409.47R_p'v' - 376.02R_m'A' + 193.80R_m'u' - 406.59R_m'v' - \\ & - 236.38A'u' + 268.09A'v' - 525.14u'v' \end{aligned} \quad (1)$$

Std	Run	Block	Factor 1 A: forta retiner mm	Factor 2 B: Raza poanson mm	Factor 3 C: Raza metritaj mm	Factor 4 D: Unghi metritaj grad	Factor 5 E: Joc mm	Factor 6 F: viteza mm/s	Response 1 raza perete mm	Response 2 unghi baza grad	Response 3 unghi flansa grad	Response 4 raza fund mm	Response 5 raza umar mm
16	1	Block 1	1.00	1.00	1.00	1.00	-1.00	-1.00	218.9	90.4	17.1	12.32	6.35
9	2	Block 1	-1.00	-1.00	-1.00	1.00	-1.00	1.00	9724.22	92.9	11.1	10.01	6.45
4	3	Block 1	1.00	1.00	-1.00	-1.00	-1.00	-1.00	368.9	91.1	1.6	12.35	5.31
20	4	Block 1	1.00	1.00	-1.00	-1.00	1.00	1.00	160.2	101.3	-19	12.96	5.66
31	5	Block 1	-1.00	1.00	1.00	1.00	1.00	-1.00	684.09	98.9	5.2	12.64	8.45
30	6	Block 1	1.00	-1.00	1.00	1.00	1.00	-1.00	3445.91	90.8	12.5	10.22	7.04
17	7	Block 1	-1.00	-1.00	-1.00	-1.00	1.00	1.00	1962.19	92.7	-5.3	10.56	5.43
13	8	Block 1	-1.00	-1.00	1.00	1.00	-1.00	-1.00	420.78	90.6	18.9	10.4	6.94
18	9	Block 1	1.00	-1.00	-1.00	-1.00	1.00	-1.00	211.48	96.3	-10.9	10.73	6.07
22	10	Block 1	1.00	-1.00	1.00	-1.00	1.00	1.00	790.93	92.4	-5.8	10.42	6.67
7	11	Block 1	-1.00	1.00	1.00	-1.00	-1.00	-1.00	1394.29	92	-5.3	12.36	6.65
27	12	Block 1	-1.00	1.00	-1.00	1.00	1.00	1.00	436.17	92.7	14	12.38	6.6
11	13	Block 1	-1.00	1.00	-1.00	1.00	-1.00	-1.00	196.62	90.5	21.1	12.72	6.3
15	14	Block 1	-1.00	1.00	1.00	1.00	-1.00	1.00	879.63	92.5	14.6	12.37	6.69
32	15	Block 1	1.00	1.00	1.00	1.00	1.00	1.00	213.1	91.3	14.9	12.29	7.39
28	16	Block 1	1.00	1.00	-1.00	1.00	1.00	-1.00	1032.02	92.1	13	12.21	6.62
1	17	Block 1	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	380.72	94.5	-6.3	10.57	5.49
21	18	Block 1	-1.00	-1.00	1.00	-1.00	1.00	-1.00	277.83	96	-8.9	10.63	6.55
23	19	Block 1	-1.00	1.00	1.00	-1.00	1.00	1.00	1353.17	93.6	-6.8	12.56	6.34
2	20	Block 1	1.00	-1.00	-1.00	-1.00	-1.00	1.00	408.26	89.6	-1.7	11.49	5.25
6	21	Block 1	1.00	-1.00	1.00	-1.00	-1.00	-1.00	2401.27	90.78	-2.7	10.41	5.73
24	22	Block 1	1.00	1.00	1.00	-1.00	1.00	-1.00	3520.14	92.23	-2.2	12.32	6.52
29	23	Block 1	-1.00	-1.00	1.00	1.00	1.00	1.00	350.62	90.8	14.9	10.21	7.37
12	24	Block 1	1.00	1.00	-1.00	1.00	-1.00	1.00	144.21	90.7	19.2	12.35	5.62
3	25	Block 1	-1.00	1.00	-1.00	-1.00	-1.00	1.00	592.04	92.3	-4.4	12.56	5.39
19	26	Block 1	-1.00	1.00	-1.00	-1.00	1.00	-1.00	331.48	97.1	-8.9	12.83	5.55
5	27	Block 1	-1.00	-1.00	1.00	-1.00	-1.00	1.00	1913.49	92.6	-4.8	10.57	6.38
8	28	Block 1	1.00	1.00	1.00	-1.00	-1.00	1.00	1094.74	92.4	-7.7	12.37	6.55
33	29	Block 1	0.00	0.00	0.00	0.00	0.00	0.00	528.02	91	4.7	11.37	6.6
25	30	Block 1	-1.00	-1.00	-1.00	1.00	1.00	-1.00	787.32	96.74	8	10.91	6.73
10	31	Block 1	1.00	-1.00	-1.00	1.00	-1.00	-1.00	234.93	89.8	17.5	10.46	5.36
14	32	Block 1	1.00	-1.00	1.00	1.00	-1.00	1.00	2940.35	91.4	14.7	10.36	6.78
26	33	Block 1	1.00	-1.00	-1.00	1.00	1.00	1.00	299.91	92.8	12	10.36	6.5

Fig. 4 Factorial design and the results of the simulations

- for the bottom angle

$$\begin{aligned} \theta_1 = & 92.87 - 0.66F'^2 + 0.33R_p'^2 - 0.45R_m'^2 - 0.69A'^2 + 1.37u'^2 - 0.25v'^2 + 0.15F'R_p' - \\ & - 0.29F'R_m' - 0.36F'A' + 0.08F'u' + 0.77F'v' + 0.17R_p'R_m' - 0.12R_p'A' + 0.34R_p'u' + \\ & + 0.39R_p'v' + 0.35R_m'A' - 0.53R_m'u' - 0.05R_m'v' - 0.28A'u' - 0.05A'v' - 0.54u'v' \end{aligned} \quad (2)$$

- for the flange angle

$$\begin{aligned} \theta_2 = & 4.05 + 0.48F'^2 + 0.1R_p'^2 + 0.24R_m'^2 + 10.24A'^2 - 2.38u'^2 - 0.31v'^2 - 0.02F'R_p' \\ & + 0.33F'R_m' + 0.34F'A' - 0.34F'u' - 0.90F'v' - 0.66R_p'R_m' + 0.49R_p'A' - 0.49R_p'u' - \\ & - 0.74R_p'v' - 0.43R_m'A' + 1.07R_m'u' + 0.27R_m'v' - 0.10A'u' + 0.44A'v' + 1.0u'v' \end{aligned} \quad (3)$$

- for the bottom profile radius

$$\begin{aligned} R_b = & 11.49 - 0.021F'^2 + 0.97R_p'^2 - 0.094R_m'^2 - 0.11A'^2 + 0.017u'^2 - 0.008v'^2 - \\ & - 0.058F'R_p' - 0.043F'R_m' - 0.046F'A' - 0.055F'u' + 0.107F'v' + 0.023R_p'R_m' + \\ & + 0.044R_p'A' + 0.032R_p'u' + 0.014R_p'v' + 0.057R_m'A' - 0.009R_m'u' - 0.001R_m'v' - \\ & - 0.003A'u' - 0.089A'v' - 0.039u'v' \end{aligned} \quad (4)$$

- for the flange profile radius

$$\begin{aligned}
 R_f = & 6.34 - 0.12F'^2 + 0.04R_p'^2 + 0.44R_m'^2 + 0.36A'^2 + 0.26u'^2 - 0.02v'^2 - \\
 & -0.0003F'R_p' - 0.025F'R_m' - 0.12F'A' + 0.09F'u' + 0.107F'v' + 0.053R_p'R_m' + \\
 & +0.014R_p'A' + 0.009R_p'u' - 0.076R_p'v' - 0.013R_m'A' + 0.008R_m'u' + 0.015R_m'v' + \\
 & +0.13A'u' - 0.006A'v' - 0.08u'v'
 \end{aligned} \quad (5)$$

where the parameters (F' , R_p' , R_m' , u' , A') represent the reduced values of the process parameters (F , R_p , R_m , u , A). For every process parameter P the reduced value P' is calculated according to the relation:

$$P' = \frac{P - \frac{P_{\max} + P_{\min}}{2}}{\frac{P_{\max} - P_{\min}}{2}} \quad (6)$$

3. NUMERICAL RESULTS OF THE OPTIMIZATION METHOD

The optimization module of Design-Expert searches for a combination of factor levels that simultaneously satisfy the requirements placed on each of the influencing process parameters and geometrical parameters of the part. The conditions are combined into an overall desirability function and the program seeks to maximize this function.

The conditions for an optimal solution in the case of U bending springback were the following:

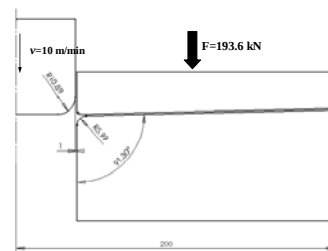
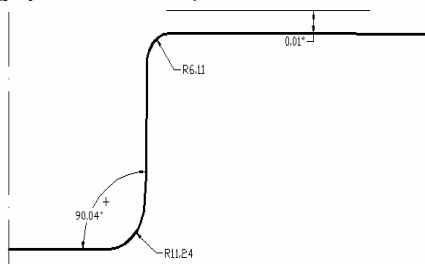
- for the process parameters: blankholder force must be inside the variation domain; punch profile radius and die profile radius must be in the variation domains established in *Table 1*; die face angle must be minimum; the gap between punch and die must be within the variation domain; the punch speed must be also within the limits of the variation domain;
- for the geometrical parameters of the part: sidewall curvature radius must be maximum so the wall could be considered straight; bottom angle must be $90^\circ \pm 0.1^\circ$; flange angle must be $0^\circ \pm 0.1^\circ$; bottom profile radius and flange profile radius must be within the variation limits.

The program determined the following optimal process parameters:

- blankholder force $F=193.6 \text{ kN}$;
- punch profile radius $R_p=10.89 \text{ mm}$;
- die profile radius $R_m=5.985 \text{ mm}$; die angle $A=1.3^\circ$;
- gap between punch and die $u=1.0025 \text{ mm}$; punch speed $v=10 \text{ mm/min}$.

The estimated values of the geometrical parameters of the part are:

- sidewall radius $\rho=1977.31 \text{ mm}$;
- bottom angle $\theta_1=90.0002^\circ$;
- flange angle $\theta_2=3.8e-6^\circ$;
- bottom profile radius $R_b=11.36 \text{ mm}$;
- flange profile radius $R_f=5.99 \text{ mm}$.



*Fig. 5 Part obtained with optimized tools**Fig. 6 Optimum process parameters*

For the verification of the results generated by fractional factorial design, a simulation by finite element method was made using ABAQUS software using as input data the above process parameters. From the simulation was obtained a part with the following geometry (fig. 5): the sidewall is a straight line so no radius is necessary for the approximation; bottom angle is $\theta_1=90.04^\circ$; flange angle may be considered null, $\theta_2=0.01^\circ$; bottom profile radius $R_b=11.24\text{ mm}$; flange profile radius $R_f=6.11\text{ mm}$. When comparing these results with the estimations a good correlation is found and we can conclude that the process parameters have indeed optimal values (fig. 6).

4. CONCLUSIONS

The applied optimization method is based on fractional factorial design that takes into considerations a series of U bending process parameters and describe their effect on the geometry of the part. This method have used six parameters of influence.

The choice of process parameters and geometrical parameters of the part must be made so they are independent from one another. For each combination of process parameters values a simulation by finite element method is made and a file containing the values of the geometrical parameters is obtained.

Using the results from FEM simulations a series of quadratic polynomial functions, describing the relations of dependence among geometrical parameters of the part and the parameters of U bending process, were determined. This fact offered the possibility of global optimization of the parameters of U bending process. The values of the geometrical parameters of the part before and after process optimization can be observed in table 2.

Based on the optimum parameters that were determined, it was possible to make the correction of the tools and to get the technological parameters from the designing stage that led to minimum springback of the U bended part.

Table 2. Evolution of the process parameters and of the geometrical parameters

	F [kN]	R_p [mm]	R_m [mm]	A [grd]	u [mm]	v [mm/min]	ρ [mm]	θ_1 [grd]	θ_2 [grd]	R_b [mm]	R_f [mm]
Values in the initial configuration	40	10	5	0	1.00	10	290.91	95.0	6.4	10.65	5.53
Values obtained from process optimization	193.6	10.89	5.985	1.3°	1.0025	10	∞	90.04	0.01	11.24	6.11

References

- [1] Li G.Y., Tan M.J., Liew K.M.: Springback analysis for sheet forming processes by explicit finite element method in conjunction with the orthogonal regression analysis, International Journal of Solids and Structures, 1999, no. 36, p. 4653 – 4668.
- [2] Choi K.K., Kim N.H.: Design optimization of springback in a deepdrawing process, AIAA Journal, 2002, vol. 40, no. 1, p. 147 – 153.
- [3] Lee S.W., Yang D.Y.: An assessment of numerical parameters influencing springback in explicit finite element analysis of sheet metal forming process, Journal of Materials Processing Technology, 1998, no. 80-81, p. 60 – 67.
- [4] Pourboghrat F., Chu E.: Prediction of spring-back and side-wall curl in 2-D draw bending, Journal of Material Processing Technology, 1995, no. 50, p. 361 – 374.
- [5] Pourboghrat F., Chu E.: Springback in plane strain stretch/draw sheet forming, International Journal of Mechanical Sciences, no. 3, 1995, vol. 36, p 327 – 341.
- [6] Ruffini R, Cao, J.: Using neural network for springback minimization in a channel forming process, Journal of Materials & Manufacturing, section 5, no. 107, 1998, p. 65 – 73.