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OPTIMIZATION OF U-BENDING FOR THE REDUCTION OF SPRINGBACK

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ABSTRACT
Springback is the main failure of the sheet metal parts obtained by U bending. The multitude of the factors involved in this process makes it difficult to estimate and control the amount of springback in the formed parts. 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. This paper describes a numerical procedure that combines simulation of springback by finite element method with a fractional factorial design and proposes an optimization of forming parameters and tool geometry for the reduction of springback intensity.
Keywords: U-bending, springback, FEM, fractional factorial design

1. INTRODUCTION
The literature presents various researches concerning the optimization of springback in sheet metal U bending. Li et al [1] proposed an explicit finite element method in conjuction 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. Pourboghrat 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 channel section stamping process. Tan et al [7] used an approach 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 combining simulation of springback by finite element 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. U-bending and springback analysis by finite element
The simulation of U bending operation used an explicit finite element method while springback was simulated using an implicit integration method. Springback parameters are presented in figure 1: sidewall radius ρ, bottom angle θ_1, flange angle θ_2. The simulations considered a plane strain state and because of the symmetry only half of the assembly was modeled. The initial configuration of the process considered the tools with the geometry presented in figure 2, a blankholder force F = 40kN and a punch speed v = 10mm/min. 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 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. 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.

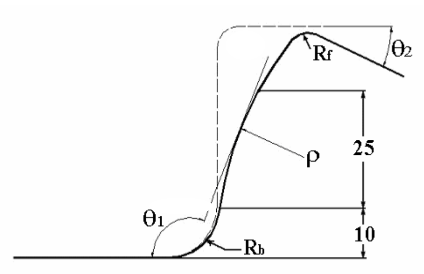

Figure 1. Springback parameters

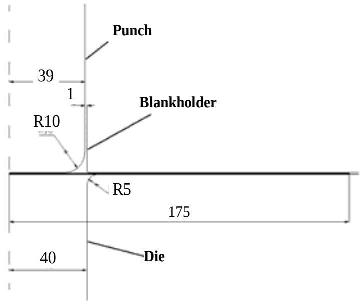

Figure 2. Model parameters

2.2. Development of factorial design

The goal in this study was to develop a method that would eliminate or reduce the amount of springback even from the designing stage of the forming process. The resulting part should be as close as possible to the desired shape. For this we have combined analysis by finite element with fractional factorial design. The factorial design takes into consideration the multitude of factors influencing the process and the interactions among them and quantifies this into an overall function of influence.

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 were:

- 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 quadratic 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.

Table 1. Variation field

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 [^{o}]	0	0	20
Gap u [mm]	1	1	1.5
Punch speed *v* [mm/min]	10	10	18

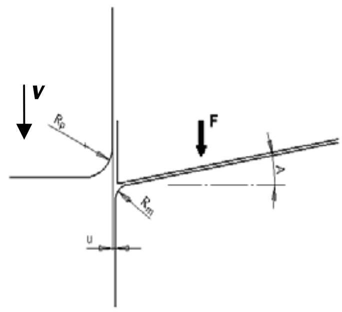

Figure 3. Parameters of influence

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 figure 3 and the variation levels are presented in table 1.

A half fractional factorial design was used resulting 32 trials for the six process parameters with two levels of variation. A supplemental trial was carried for the center of the variation levels.

The analysis of the results yielded the following quadratic polynomial functions:

- sidewall radius

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

- bottom angle

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

- flange angle

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

- bottom profile radius

$$\begin{aligned}R_b = {} & 11.49 - 0.021F'^2 + 0.97R_p'^2 - 0.094R_m'^2 - 0.11A'^2 + 0.017u'^2 - 0.008v'^2 - 0.058F'R_p' - \\ & -0.043F'R_m' - 0.046F'A' - 0.055F'u' + 0.107F'v' + 0.023R_p'R_m' + 0.044R_p'A' + 0.032R_p'u' + \\ & +0.014R_p'v' + 0.057R_m'A' - 0.009R_m'u' - 0.001R_m'v' - 0.003A'u' - 0.089A'v' - 0039u'v'\end{aligned} \tag{4}$$

- flange profile radius

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

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:

$$P' = \frac{P - \frac{P_{max} + P_{min}}{2}}{\frac{P_{max} - P_{min}}{2}} \tag{6}$$

3. OPTIMIZATION OF THE FORMING PROCESS

An optimum solution of the problem was determined for the following conditions:

- for the process parameters: blankholder force must be within 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 $90^{\circ}\pm0.1^{\circ}$; flange angle must be $0^{\circ}\pm0.1^{o}$; bottom profile radius and flange profile radius must be within the variation limits.

Based on the above conditions the process parameters have the following optimal values: blankholder force F = 193.6 kN, punch profile radius R_p = 10.89 mm, die profile radius R_m = 5.98 mm, die angle A = 1.3º, gap between punch and die u = 1 mm, punch speed v = 10 mm/min.

Using this configuration for the forming process, the estimated values of the geometrical parameters were: sidewall radius ρ=1977.31 mm, bottom angle θ_1=90.0002º, flange angle $\theta_2=3.8e^{-6o}$, bottom profile radius R_b=11.36 mm, flange profile radius R_f =5.99 mm.

For the validation of the optimization method, a new simulation was carried based on the optimum process parameters. The part resulted with the following parameters: the sidewall was a straight line (so the radius was considered infinite), bottom angle is $\theta_1=90.04^{\circ}$, flange angel may be considered null, $\theta_2=0.01^{o}$, bottom profile radius $R_b=11.24$ *mm*, flange profile radius $R_f=6.11$ *mm*.

4. CONCLUSIONS

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

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	1.3º	1.0025	10	∞	90.04	0.01	11.24	6.11

5. ACKNOWLEDGMENTS

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