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OPTIMIZATION OF SHEET FORMING PROCESS FOR THE REDUCTION OF SPRINGBACK

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ABSTRACT
The introduction on large scale of high strength materials in automotive industry provided the possibility to reduce weight and produce safer cars. But at the same time these materials yield more springback than deep drawing steels. This can lead to problems designing the right tools for the forming process. This paper presents a method for the optimization of sheet metal forming parameters in order to reduce the effects of springback phenomenon. A central composite response surface method (RSM) was used. U-bending test was used for the validation of the method and the results in springback reduction seem promising.
Keywords: response surface, springback, U-bending

1. INTRODUCTION
Prediction of springback raises numerous problems for the design of sheet metal forming processes in automotive and aircraft industry. At the end of the forming, after tools removal, springback will generate a supplemental straining of the material leading to failures from the imposed dimensions and shapes. High strength steels yield more springback than the mild steels.
The evolution of finite element methods and computers has created the premises for an increasing accurate estimation of the final shape of the sheet metal parts. Application of optimization techniques to metal forming problems [1, 2, 3] leads often to high numbers of expensive function evaluations. This is particularly the case when cost and constraint functions are obtained via complete finite element simulations involving fine meshes, high numbers of degrees of freedom, nonlinear geometrical and material behavior. Response surface methodology (RSM) is used as an alternative method [3, 4, 5] for replacing a complex model by an approximate one based on results calculated at various points in the design space. RSM can thus be used to diminish the cost of functions evaluation in structural optimization. The optimization is then performed at a lower cost over such response surfaces. RSM are well established for physical processes as documented by Myers and Montgomery [3] while the applications to simulation models in computational mechanics form a relatively young research field.

2. PROBLEM FORMULATION
2.1. Background of the optimization problem
In the optimization process, the goal is to minimize a function $F(x)$, $x \in R^n$ subjected to a number of constraints $g_j(x) \le 0,\ j = 1...m$, with $l_i \le x_i \le u_i,\ i = 1...n$, where F represents the cost function, x_i are design variables and g_j is the j-th nonlinear constraint, l_i and u_i are the lower and upper bounds of the design variables and define the interest interval. The RSM approach consist in solving a problem where the cost function and the constraint functions are replaced by some approximations $\tilde{F}$ and $\tilde{g}_j$. The approximations are based on a set of experimental values of the function F.

Knowing the function values for a set of experimental points x_i distributed according to a certain design of experiments, the function $\tilde{F}$ may be defined in terms of basis functions p and some adjusting coefficients a as:

$$\tilde{F}(x) = p^T(x)a(x) \tag{1}$$

The coefficients a_i are determined by a weighted least squares method minimizing the error between the experimental and approximated values of the objective function:

$$J(a) = \sum_{i=1}^{N} w(\|x_i - x\|)\left(p^T(x_i - x)a - F(x_i)\right)^2 \tag{2}$$

where N is the number of experiments and x_i are the experimental designs.

2.2. Springback simulation

The U-bending was simulated considering a plain strain state. Considering the symmetric form of the part, only half of the assembly was modeled in order to reduce the calculus efforts. The geometry of the model is illustrated in figure 1. The sheet is 350 mm long, 30 mm width and 0.8 mm in thickness and was modeled using shell elements (S4R, Abaqus elements) on one row with 5 integration points through thickness.

The material properties are presented in table 1. The steel was modeled as elasto-plastic, considering an isotropic elasticity and anisotropic plasticity. Taking the anisotropy into account the yield locus was represented using Hill 48 quadratic criterion:

$$\sigma_f^2 = \sigma_1^2 - \left(\frac{2r_0}{1+r_0}\right)\sigma_1\sigma_2 + \left(\frac{1+r_{90}}{1+r_0}\right)\sigma_2^2 \tag{3}$$

where σ_f, σ_1, σ_2 are the equivalent stress and principal stresses and r_0, r_{90} are the Lankford parameters for the parallel and transverse to rolling direction.

For contact conditions a modified Coulomb friction law combined with penalty method was used.

The forming stage was simulated using an explicit FEM formulation and for the springback step an implicit formulation was used.

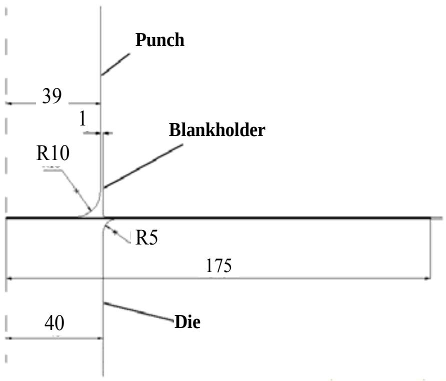

Figure 1. Geometry of the model

Table 1. Characteristics of the material

Material properties	value
Young's modlus E	200 GPa
Poisson coefficient □	0.3
Yield stress	306 MPa
Anisotropy coefficients	
r_0	0.82
r_{45}	0.77
r_{90}	0.81

3. PROCESS OPTIMIZATION

Three parameters were considered for the design of experiments: blankholder force, punch radius and die radius (table 2). The objective function represents the maximum opening distance of the final part, formulated as follows:

$$F = \max\|d_i\| \tag{4}$$

where d_i represents the difference of the positions of each node before and after springback (figure 2). The above relation may also be written as:

$$F = \sqrt{\sum_{i=1}^{n_d} \left(x_i^2 + y_i^2 + z_i^2 \right)} \tag{5}$$

where x_i, y_i and z_i are the components of d_i in a cartesian reference system and n_d is the number of nodes of the mesh.

Table 2.Variation of the parameters

Parameters	Minimum value (-1)	Maximum value (+1)
A: Blankholder force [kN]	40	200
B: Punch radius [mm]	10	12
C: Die radius [mm]	5	6

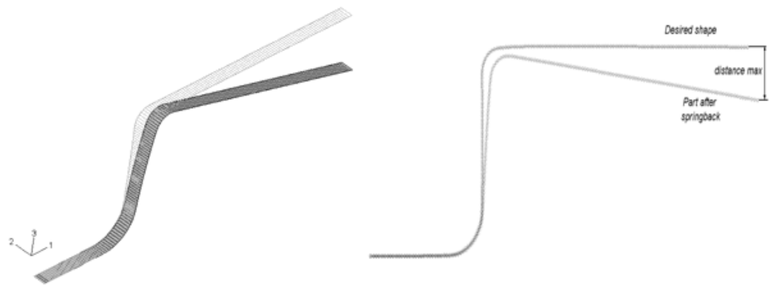

Figure 2. Shape before and after the springback

Std	Run	Block	Factor 1 A:Blankholder kN	Factor 2 B:Punch radius mm	Factor 3 C:Die radius mm	Response 1 Objective mm
6	1	Block 1	200.00	10.00	6.00	5.312
4	2	Block 1	200.00	12.00	5.00	2.51
19	3	Block 1	120.00	11.00	5.50	10.548
14	4	Block 1	120.00	11.00	6.34	4.739
7	5	Block 1	40.00	12.00	6.00	9.412
10	6	Block 1	254.54	11.00	5.50	13.293
9	7	Block 1	-14.54	11.00	5.50	9.062
12	8	Block 1	120.00	12.68	5.50	7.841
8	9	Block 1	200.00	12.00	6.00	14.263
15	10	Block 1	120.00	11.00	5.50	10.548
13	11	Block 1	120.00	11.00	4.66	2.952
5	12	Block 1	40.00	10.00	6.00	11.328
16	13	Block 1	120.00	11.00	5.50	10.548
18	14	Block 1	120.00	11.00	5.50	10.548
11	15	Block 1	120.00	9.32	5.50	8.326
2	16	Block 1	200.00	10.00	5.00	4.14
1	17	Block 1	40.00	10.00	5.00	11.459
3	18	Block 1	40.00	12.00	5.00	7.803
20	19	Block 1	120.00	11.00	5.50	10.548
17	20	Block 1	120.00	11.00	5.50	10.548

Figure 3.Table of experiments

The optimization of the forming problem was carried using central composite design (CCD) formulation of the response surface method. CCD's are designed to estimate the coefficients of a quadratic model.

The experiments table is presented in figure 3 and requested 20 simulations with combinations of values of the process factors according to the table. Based on the analysis of the results the objective function is modeled as quadratic. The analysis of variance (ANOVA) showed that the model was significant and gave the equation of the model:

$$\begin{aligned} Objective = &-398.009 - 3.979A - 170.385B + 583.803C - \\ &-82.268C^2 + 0.179AB + 0.356AC + 27.223BC \end{aligned} \tag{6}$$

After that a global optimization procedure is carried out. The optimum solution has a desirability factor of 0.805 (out of maximum 1). The desirability graph and the response surface are illustrated in figures 4 and 5 respectively.

The optimum corresponds to the following combination of values for the process factors: blankholder force (A) 199.73 kN, punch radius (B) 10 mm, die radius (C) 5 mm for which the objective function has an estimated value of 41.728.

For the verification of the proposed solutions a simulation was carried in ABAQUS® under these conditions. The opening of the resulted part was 42.869. It means that the error of the estimation is only 2.734% so the response surface method has created very good results.

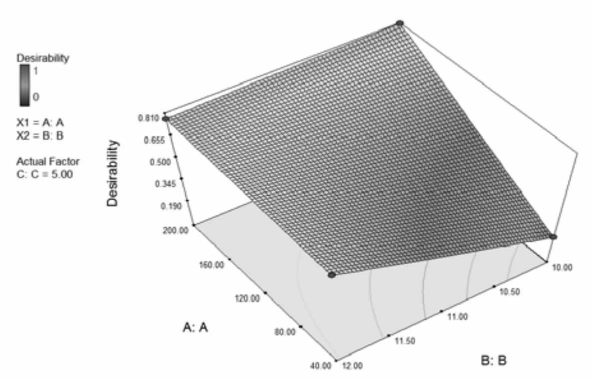

Figure 4. Desirability of the solution

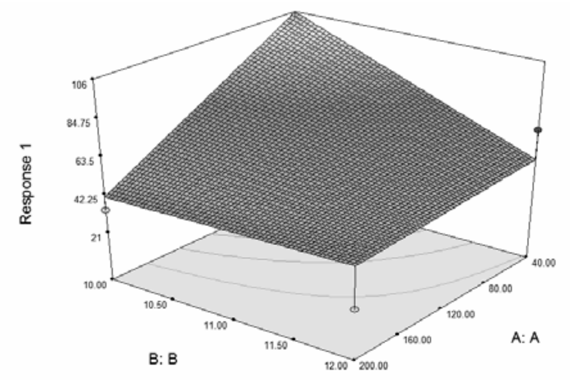

Figure 5. Response surface model

5. CONCLUSIONS

The paper has presented a response surface method applied for the optimization of sheet metal U-bending process in order to reduce the effects of springback.

The methodology conducted to good results that may be improved using more process variables and more constraints. The simulations were carried using ABAQUS® code.

6. REFERENCES

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