Application of the Taguchi method for the compensation of errors determined by springback in the case of a draw half-rim with stiffness channels made from metal sheets

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Abstract: Springback of draw parts considerably affects their accuracy and deviations from the theoretical profile, this instability phenomenon determining the following changes of the part shape and geometric parameters: arching of the part sidewall, modification of the angle formed by the part bottom and the sidewall, modification of the angle between the flange and the sidewall. The methods applied in order to reduce or eliminate springback are based on tools correction after designing and testing, on the utilization of special tools and devices, on the optimization of process parameters based on some methods that establish a link among springback parameters and the influencing factors of this phenomenon. These methods are expensive and necessitate a big number of experimental tests. Based on these conclusions, it is necessary the development of a method for the reduction or the elimination of the springback from the designing stage.

Keywords: springback, half-rim parts, tools correction, Taguchi's method

1. INTRODUCTION

The analysis of the researches concerning the drawing process, emphasizes the following aspects concerning the springback phenomenon and the methods applied in order to increase the precision of the formed parts: springback of draw parts affects considerably the precision and the deviations from the theoretical profile, this instability phenomenon determining the following changes of the part shape and geometric parameters: arching of the part sidewall, modification of the angle formed by the part bottom and the sidewall, modification of the angle between the flange and the sidewall; blank holder force is the main process parameter that has an essential influence on springback intensity; the methods applied in order to reduce or to eliminate springback are based on tools correction after designing and testing, on the utilization of special tools and devices, on the optimization of process parameters based on some methods that establish a link among springback parameters and the influencing factors of this phenomenon. These methods are expensive and necessitate a big number of experimental tests.

Starting from the above presented aspects, we can conclude that in order to increase the accuracy of the drawing processes it is necessary the development of a method for the reduction or the elimination of the springback from the designing stage. An optimal solution can be obtained by using the process simulation in combination with a statistical modelling that allows the mathematical description of the influence of different process parameters on the draw part geometry and accuracy. For this purpose, the factorial design offers the possibility to use a statistical method – for example Taguchi method. 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 springback intensity. The present paper analyses the possibilities to apply such method in the case of a half-rim part with stiffness channels made from steel sheets.

2. APPLICATION OF THE TAGUCHI METHOD

2.1. Description of optimization method

The optimization method of the forming process using Taguchi method has the purpose to reduce springback of a draw part. The Method is applied in the following six steps: 1. Definition of geometric parameters that characterize the geometric deviations of the part. 2. Selection of process parameters that influence the part geometry and its field of variation. 3. Selection of the model of linear or quadratic polynomial dependence and construction of fractioned factorial plane of experiment. 4. Process simulation according to experimental plane and the measurement of geometric deviations of the resulted parts. 5. Calculation of coefficients of the polynomial models and verification of the models. 6. Optimization of the process parameters in order to obtain the desired geometric parameters of the draw part. In order to obtain the part represented in Fig. 1 the technologic process - using the tool presented in Fig. 2- must be achieved in the following two steps: drawing operation; trimming, shearing and punching operations. The geometric model considered in simulation using ABAQUS software is represented in Fig. 3

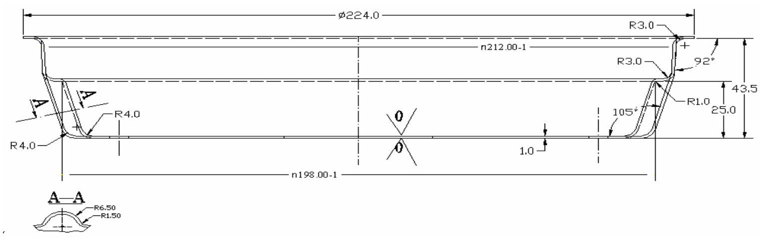


Fig.1 Nominal dimensions of the part

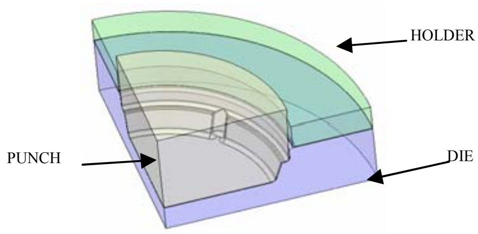


Fig.2 Tools configuration

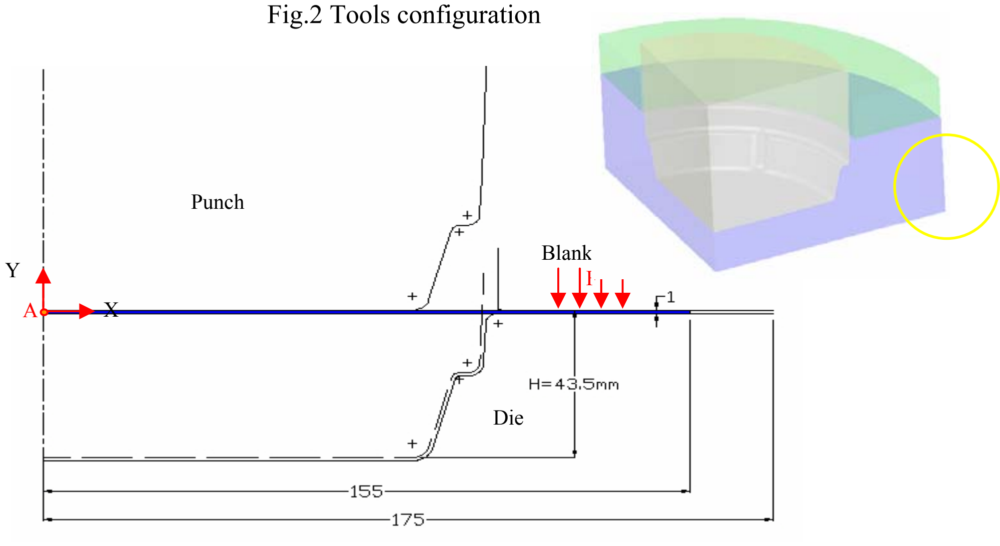


Fig.3 Simulation model with the main dimensions

2.2 Parameters used in simulation:

The blank was made from FEPO 5MBH steel having the following dimensions: diameter Ø = 155 mm and thickness g = 1 mm. The material parameters were as follows: Young's modulus = $2x10^5$ MPa; Poisson's coefficient = 0,3; density ρ = 7800 kg/m^3. For the description of the material plastic behaviour 10 points from the stress-strain curve were chosen. The integration method applied in simulation was Gaussian with 5 integration points equally distributed on the sheet thickness, the type of the finite element was triangular shell S3R and the discretization of the blank was made in 3 zones, 50 elements and 58 nodes. The working conditions and parameters were as follows: Friction coefficient μ = 0.1; Punch displacement in the negative sense of Y axis: 43.5 mm; Drawing speed: 30mm/s. In order to decrease the calculation time needed for simulation the following simplifications were applied: a bi-dimensional symmetric model was used; a condition of symmetry in the point A in comparison with the axis Y (axis of symmetry) was imposed for the blank (Fig. 3); the die components were considered as no deformable; this condition eliminated the need of their discretization in finite elements but it imposed to associate a symbolic weight equal to 1kg for the blank holder; the die was considered as fixed, but for the punch and blank holder component a condition of displacement on Y axis was imposed. The shape of the part after simulation used to determine the geometric parameters in the symmetry planes is presented in Fig. 4. The state of stresses before and after springback of the formed part is presented in Fig. 5.

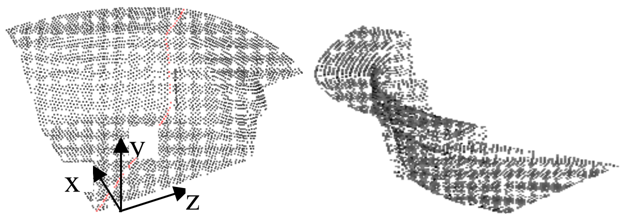
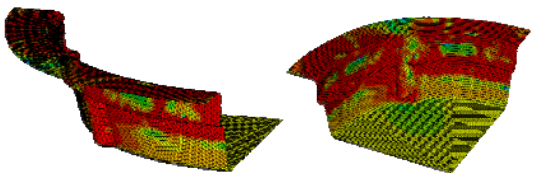
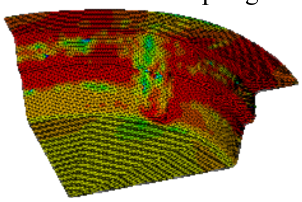


Fig.4 Part shape after simulation



Stress state before springback



Stress state after springback

Fig. 5 Stress states before and after springback

2.3 Application of the optimization method

2.3.1 Basic considerations

The parameters that must be optimized in order to eliminate the effects of springback are as follows: R, H1, H2 and α (Fig.6). These parameters will be modified according to the experimental plane elaborated on the basis of the Taguchi method. The domains of variation of the parameters that influence the process (Fig. 7) are given in table 1 and will be also controlled.

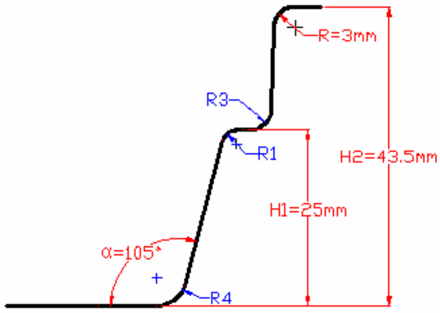


Fig.6 Parameters that must be optimized

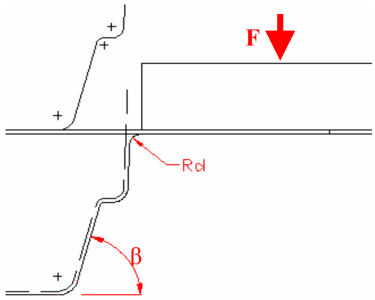


Fig. 7 Parameters that influence the process

Table 1

Parameters of influence	Minimum value	Maximum value
Blank holder force F [kN]	50	100
Friction coefficient μ	0.1	0.15
Die radius Rd [mm]	2.5	4
Angle of inclination of the tools β [grade]	103	107

2.3.2 Linear optimization

We considered the following polynomial function:

$$Y = a_0 + a_1X_1 + a_2X_2 + \ldots + a_nX_n + a_{12}X_1X_2 + \ldots + a_{n-1,n}X_{n-1}X_n \qquad (1)$$

where: Y represents the followed value (R, H1, H2, α) and $X_1..X_n$ represent the reduced values of the input parameters that must be optimized (F, μ, Rd and β). Hence it result the following equations that correspond to each followed parameter:

$$R = a_{0(R)} + a_{1(R)}F' + a_{2(R)}\mu' + a_{3(R)}R_d' + a_{4(R)}\beta' + a_{12(R)}F'\mu' + a_{13(R)}F'Rd' + a_{14(R)}F'\beta' + a_{23(R)}\mu'Rd' + a_{24(R)}\mu'\beta' + a_{34(R)}R'_d\beta' \qquad (2)$$

$$H1 = a_{0(H1)} + a_{1(H1)}F' + a_{2(H1)}\mu' + a_{3(H1)}R_d' + a_{4(H1)}\beta' + a_{12(H1)}F'\mu' + a_{13(H1)}F'Rd' + a_{14(H1)}F'\beta' + a_{23(H1)}\mu'Rd' + a_{24(H1)}\mu'\beta' + a_{34(H1)}R'_d\beta' \qquad (3)$$

$$H2 = a_{0(H2)} + a_{1(H2)}F' + a_{2(H2)}\mu' + a_{3(H2)}R_d' + a_{4(H2)}\beta' + a_{12(H2)}F'\mu' + a_{13(H2)}F'Rd' + a_{14(H2)}F'\beta' + a_{23(H2)}\mu'Rd' + a_{24(H2)}\mu'\beta' + a_{34(H2)}R'_d\beta' \qquad (4)$$

$$\alpha = a_{0(\alpha)} + a_{1(\alpha)}F' + a_{2(\alpha)}\mu' + a_{3(\alpha)}R_d' + a_{4(\alpha)}\beta' + a_{12(\alpha)}F'\mu' + a_{13(\alpha)}F'Rd' + a_{14(\alpha)}F'\beta' + a_{23(\alpha)}\mu'Rd' + a_{24(\alpha)}\mu'\beta' + a_{34(\alpha)}R'_d\beta \qquad (5)$$

The reduced values (F’, μ’, R_d’ and β’) used in the above presented equations present a linear correspondence with the real values (F, μ, Rd, β) according to the following function:

$$X' = \frac{X - \dfrac{X_{\max} + X_{\min}}{2}}{\dfrac{X_{\max} - X_{\min}}{2}} \qquad (6)$$

In order to determine the coefficients a_0, a_1, a_2...a_{12}...a_{34} corresponding to each function a series of 16 simulations was performed. The results obtained from simulations are presented in table no. 2.

Table 2

Nr.	Modified values F [kN]	μ [mm]	Rd [mm]	β [grd]	Followed values (obtained part) R [mm]	H1 [mm]	H2 [mm]	α
1	50	0.1	2.5	103	4.56	25.02	43.48	107.44
2	50	0.1	2.5	107	4.48	25.14	43.25	106.15
3	50	0.1	4	103	5.02	25.03	43.36	105.24
4	50	0.1	4	107	5.12	25.16	43.42	105.48
5	50	0.15	2.5	103	4.68	25.18	43.6	104.98
6	50	0.15	2.5	107	4.73	25.09	43.38	105.63
7	50	0.15	4	103	5.14	25.01	43.16	106.23
8	50	0.15	4	107	5.69	25.22	43.29	105.83
9	100	0.1	2.5	103	4.03	25.17	43.08	104.78
10	100	0.1	2.5	107	4.21	25.036	43.24	104.86
11	100	0.1	4	103	4.44	25.19	43.33	105.02
12	100	0.1	4	107	4.38	25.12	43.51	104.92
13	100	0.15	2.5	103	4.012	25.06	43.49	104.22
14	100	0.15	2.5	107	4.18	25.11	43.38	104.35
15	100	0.15	4	103	4.34	25.08	43.54	105.14
16	100	0.15	4	107	4.52	25.18	43.44	106.22

After calculation the following equations were obtained:

$$R = 4.596 - 0.332 F' + 0.066\mu' + 0.236R_d' + 0.068\beta' - 0.067F'\mu' - 0.08F'Rd' - 0.01F'\beta' + 0.025\mu'Rd' + 0.051\mu'\beta' + 0.028R'_d\beta' \quad (7)$$

$$H1 = 25.112 + 0.006F' + 0.004\mu' + 0.012R_d' + 0.02\beta' - 0.015F'\mu' + 0.013F'Rd' - 0.026F'\beta' - 0.005\mu'Rd' \; 0.014\mu'\beta' + 0.026R'_d\beta' \quad (8)$$

$$H2 = 43.372 + 0.004F' + 0.038\mu' + 0.009R_d' - 0.008\beta' + 0.048F'\mu' + 0.069F'Rd' + 0.024F'\beta' - 0.062\mu'Rd' - 0.029\mu'\beta' + 0.042R'_d\beta' \quad (9)$$

$$\alpha = 105.406 - 0.467F' - 0.081\mu' + 0.104R_d' + 0.024\beta' + 0.124F'\mu' + 0.282F'Rd' + 0.124F'\beta' + 0.426\mu'Rd' + 0.158\mu'\beta' + 0.078R'_d\beta' \quad (10)$$

In order to test the above presented relations, a simulation for the case when: F = 75 kN, μ = 0.125, Rd = 3.25 mm, β = 105^o (in the centre of the domain of variation) was performed. The obtained results from simulation were compared with that obtained using the relations 7…10 (where the parameters F', μ', Rd' and β' were calculated using equation 6). The results of these calculations are presented in table no 3.

Table 3

	Values obtained from relations (7) – (10)	Values obtained from simulation	Absolute deviation	Relative deviation [%]
R	4.5958	4.215	0.3808	9.03
H1	25.112	25.11	0.0023	0.01
H2	43.372	43.36	0.0119	0.03
α	105.41	104.86	0.5456	0.52

From the analysis of the above presented results we can observe small differences between the two modalities of calculation. Hence we can conclude that the geometric parameters of the draw part can be approximated by linear functions in comparison with variation of the geometric parameters of tools and with variation of blank holder force.

3. OPTIMIZATION OF THE TOOL GEOMETRY

In order to optimize the tool geometry we tried the simultaneous accomplishment of the three conditions of optimization (R = 3 mm, H1 = 25 mm, H2 = 43.5 mm, α = 105°) by using the following function:

$$L\,(R, H1, H2, \alpha) = (R-3)^2 + (H1-25)^2 + (H2-43.5)^2 + (\alpha-105)^2 \qquad (11)$$

For the domain of variation between -1 and +1 in the case of reduced values, the function 1.13 presents some minima but any of these are not equal to 0 (L = 0 for R = 3 mm, H1 = 25 mm, H2 = 43.5 mm, α = 105°). Thus we must choose for this domain the smallest values of function L as being the optimum value for which the three conditions of optimization are better and simultaneous satisfied. The function L will present a minimum for the values indicated in table no.4.

Table 4

	Values for which the function L has a minimum value				Values resulted for the followed parameters			
	F [kN]	μ	Rd [mm]	β [grd]	R [mm]	H1 [mm]	H2 [mm]	α [grd]
Values obtained from calculation using the equations (10) – (12)					2.93	25.14	43.58	105.1
Values obtained from simulation	105.9	0.13	2.84	104.37	4.02	25.19	43.36	104.93
Measured values from the initial part					3.3	25.1	43.3	105.5

From the results presented in table 4, we can conclude that the optimized parameters of tools have a small variation in comparison with the geometry of the initial tools considered in the optimization procedure. Significant differences are registered in the case of blank holder force and friction coefficient. But, taking into account the deviations of the parts resulted after their measurement, the geometry of the initial tools must be modified. The geometry of the corrected tools and the parameters of the drawing process (optimized values) are indicated in Fig. 8. The geometry of the modified tool is presented in Fig. 9.

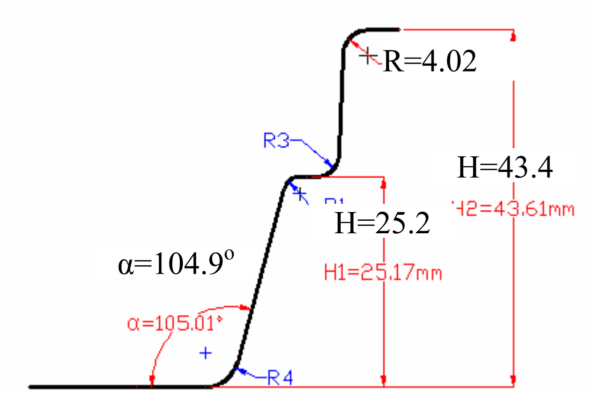
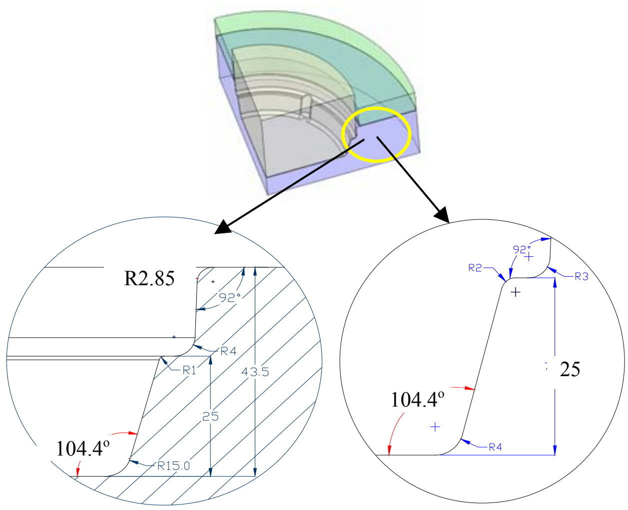


Fig. 8 Geometric parameters of the part resulted from simulation after the process optimization



a. Die detail b. Punch detail

Fig. 9 Geometry of the corrected tool

4. CONCLUSIONS

1.The selection of the process parameters and geometric parameters of the part must be performed taking into account that these parameters must be independents. For each combination of the process parameter values will be achieved a FEM simulation and from the data post-processing will result the desired geometric parameters of the draw part.
2.The best results were obtained by using the polynomial quadratic functions that offered the possibility of a global optimization of the factors of influence of the drawing process.
3.Based on the optimized parameters it is possible the correction of the tools geometry in their designing stage and also the determination of the optimum process parameters. In this way, a minimization of the springback effects will be obtained.
4.The method applied for the half rim part can be extended for all drawing processes of metal sheets, indifferently by the parts configuration.

Acknowledgments

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