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Optimization of Input Process Parameters Affecting on Springback Effect in Sheet Metal 'V' Bending Process for CR2 Grade Steel Sheet of IS 513-2008 Material by Using Taguchi Method

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Abstract - *One of the sensitive features of sheet metal bending is elastic recovery called springback effect. There are various parameters which affect this springback, so accurate prediction and controlling of springback is essential while designing the tools for bending. In this research work, punch angle, die opening and sheet width are taken as input process parameters affecting springback effect in sheet metal V bending of CR2 grade steel sheet of IS 513-2008 material. Optimization of these parameters done by using Taguchi method and determine the contribution of each process parameters towards springback effect. Experiments design by using Taguchi Techniques, performed experiment, analyze the result, ANOVA carried out and find out the contribution of each parameter on the outcome i.e. springback effect. The experiment is performed on UTM and measured the angle on profile projector. It is seen that among these three parameters the punch angle has 62.92% contribution towards the influence on springbok effect, 29.22% of Die opening and least contribution of sheet width i.e. 4.38%.*

***Key Words*: Sheet Metal Bending, Springback effect, Taguchi Technique, Steel sheet.**

1. INTRODUCTION

Common Air type of bending is mostly used in sheet metal industries today. The bending processes of sheet metal are widely used to produce structural stamping parts. Today Automobile industries depend largely on sheet metal forming processes to manufacture components. The popularity of sheet metal products is because of their light weight, great inter changeability, good surface finish and low cost. In this process, the blank is deformed under punch pressure in a die along one axis. The blank is initially deformed in the elastic region and as the process continues of deformation it will enter into plastic deformation zone, thereby changing its shape. In bending process, the bending load increases until the elastic limit of the material is exceeded after that load increases in the plastic zone and deformation occurs, thus sheet metal can be formed. Specifically, stress generated in the blank is greater than the yield strength but lower than the UTS of material. The blank initially deform where the bending moment is maximum.

All materials have a finite modulus of elasticity, plastic deformation is followed by some elastic recovery as the punch load is removed and this phenomenon is called springback. In bending process, springback affects the final shape and geometry of the work piece when the punch is removed. This springback causes deviations in the desired final shape and thus the part after the springback may not be within tolerance limits, so not suitable for the application for which it was designed.

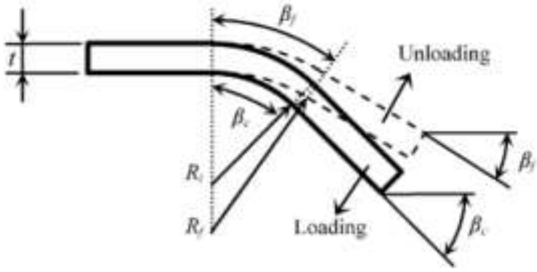


Fig 1-: Springback Effect in L Bending [12]

The final bent radius (R_f) larger than loading situation and the final bent angle after springback (β_f) is smaller (Fig. 1). Springback amount may be defined either by a non-dimensional springback factor (K_r), which is the ratio between the final unloading bending angle (β_f) and the loading bending angle (β_c) or by a springback angle ($\Delta\beta$), which can be expressed by Eq. (1):

$$\beta_c = \beta_f + \Delta\beta \quad (1)$$

Angle and radius are related one to each other; hence springback can be estimated approximately by Eq. (2). This equation has turned into a simplified reference expression for springback computation, assuming constant thickness and arc length.

$$\frac{R_i}{R_f} = 4\left(\frac{R_i S_Y}{Et}\right)^3 - 3\left(\frac{R_i S_Y}{Et}\right) + 1 \quad (2)$$

Where R_i is the radius in a loading state, R_f the final radius, t the thickness, S_y the yielding stress and springback decreases with it and E is Young's modulus.

In bending the ductility of the sheet metal plays a very important role. If the ductility is lower, the minimum bend radius is larger at the same time a state of biaxial stresses in bend region may also reduce ductility on outer fibres. As width to thickness ratio value is larger (w/t) of the sheet, the state of biaxial stress can be expected. Greater is the w/t ratios reduce the critical strain required for fracture resulted in the bend radius will be higher. Narrow sheets get crack at the edge when the state of stress along the edge is more biaxial than at the centre. Wider sheets, when subjected to the larger radius of the bend, undergo crack at centre because the centre is subjected to a more biaxial state of stress. In order to increase the minimum radius, sheets are polished or ground.

Spring-back effect is a common and critical or major factor in sheet metal forming processes, which is due to the redistribution of the internal stresses because of elastic strength after the removal of deforming forces from the sheet metals. So the prediction of Spring-back is a major factor to achieve the exact shape of the components which is used in the automotive and aerospace industry. This springback criteria change from material to material because every material has different mechanical properties.

1.1 Literature Review

Several experimental and numerical studies have been done to study the springback effect in sheet metal forming process. M. L. Garcia-Romeu et al (2007) presents new springback graphics for air V bent sheet metal parts. He conducted experimental works in two stages on two different materials. This work presents the same kind of useful graphics that relate spring back with the main parameters that have influence over phenomenon [1]. Vasudevan et al (2011) study the springback behaviour of electro-galvanized steel sheets during air bending process. An experiment conducted to show the influence of various process parameters onspringback effect. Here mainly focuses on the influence of coating thickness over springback along with other process parameters, the result shows the springback increases with coating thickness [2]. Viorel Paunoiu et al (2015) measures the springback by new experimental device against influencing process parameters as bending angle, the punch radius and sheet metal thickness [3]. K. Dilip Kumar et al (2014) conducted an experiment to determine the springback and thinning effect of aluminium sheet metal during L Bending operation. He found one critical clearance between the punch and die and observed the effect of it. It shows beyond a particular clearance the springback and thinning effect was linearly increasing, however below critical clearance scratches on the surface of the sheet metal were seen due to wear [4]. K. yilamu et al (2010) study and investigate the bending characteristics such as uniformity in sheet thickness change and the bending angles of the sheet before/after springback. Conducted both experimental and analysis work to analyze the objective of the experiment [5].

Hezong Li et al (2010) to investigate the springback behaviour of pure aluminium foils, scaled micro bending experiments with different thicknesses ranging from 25 μm to 500 μm were carried out. In the experiments, it is observed that springback angle increases with decreasing foil thickness, which indicates the obvious presence of size effects and is attributed to plastic strain gradient hardening. A constitutive model is proposed to predict the springback angle after micro bending both by analytical expression and by FE simulation [6]. M.H. Parsa et al (2014) in this research, the effect of punch radius on springback in the early stage of V-die bending process of aluminum/polypropylene/aluminum sheets is studied both numerically and experimentally. To analyze springback behavior, contact pressure evolution during bending process was studied using numerical simulation [7]. Daw-Kwei Leu et al (2016) study proposed a simplified approach to distinguish between spring-back and spring-go in free U-die bending process of SPFC 440 sheets [8]. R. Narayansamy et al (2009) describes the development of regression based mathematical models for the prediction of springback in air bending process of interstitial free (IF) steel sheet with five input process parameters and the springback as output process parameter to develop the quadratic model to predict the output [9]. Zhang dong-Juan et al (2007), in this paper an analytical model is proposed which takes into account the effects of contact pressure, the length of bending arm between the punch and die, transverse stress, neutral surface shifting and sheet thickness thinning on the sheet springback of V-bending. The predicted results by this analytical model indicated that the contact pressure and transverse stress have much effect on the springback when the bending is less than five [10]. Faiez Gassara et al (2009), an optimization algorithm using Gauss-Newton method was developed by coupling the Abaqus/standard code and Python script which is an object-oriented language. For a given bending process problem, the proposed algorithm allows for the optimization of a set of material and/or process factors in order to minimize the work piecespringback [11].

Many researchers have studied various factors affecting on springback effect in bending, but there is less combined work done on the parameters such as Sheet width, Die opening and Punch angle on CR2 of graded IS 513-2008 material in sheet metal V bending. This research work examining the degree of importance of process parameters such as width, Die opening and Punch angle for sheet metal steel by DOE (By Taguchi Technique) and the ANOVA (Analysis of variance) technique and by experimentation. Experimentation is performed on UTM machine. The percentage contribution of above-mentioned parameters is determined by ANOVA technique, so it gives an idea about which factor is affecting most and least.

2. Methodology

2.1 Design of Experiment (DOE)

In this research work the Design of experiment is done by using Taguchi technique, where the standard L9 orthogonal array is used. Three process parameters that are Sheet Width, Die Opening and Punch Angle as Input process parameters with varying in three level and Springback angle as an output parameter. Process parameters along with their selected levels for the experimentation are shown in Table I. The spring-back angle is taken as process response. The characteristics "Smaller is better" for signal-to-noise ratio is considered for process response. The array is created by using MINITAB 17.0 software as per Taguchi design. For 3 process parameters and 3 levels, L9 Orthogonal Array is created which is shown in following table 2.

Table 1-: Process parameters and their levels

Process Parameter	Level1 (Low)	Level 2 (Medium)	Level 3 (High)
A. Punch Angle	86º	88º	90º
B. Die Opening	30 mm	40 mm	50 mm
C. Sheet Width	30 mm	50 mm	70 mm

Table 2-: L9 Orthogonal Array

Experimentation No.	Punch Angle 1	Die Width 2	Sheet Width 3
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

2.2 Experimental Performance

Before actual experimentation the chemical composition of the steel sheet was discovered by using spectroscopy, and the major elements are given in table 3. From composition, it is seen that the material belongs to the CR2 steel grade as per IS 513 - 2008 material. At the same time, the tensile test is conducted to determine the mechanical properties of the sheet material which is being used for experimentation as per ASTM E8, 2008.

Table 3-: Composition of CR2 steel grade sheet

Chemical Elements	% composition (% w/w)	Specified for 'CR2' Grade
C	0.030	0.12 Max
Mn	0.31	0.050 Max
S	0.009	0.035 Max
P	0.017	0.040 Max
Si	0.010	----
Al	0.035	0.020-0.070
Hardness HRB	96 Hv	----
Tensile strength	310.52 MPa	270-370 MPa
Yield Strength	191.61 MPa	240.0 MPa
% Elongation	31.36	31.0 Min.

As per the Taguchi technique, the experiment is designed. The experiment is carried out on the Universal Testing machine in Mechanics laboratory. First, the punch and Die are designed with standard specification and made from hardened steel. The die is designed by varying the die opening as 30, 40 and 50 mm, where die radius and angle kept constant i.e. 3 mm and 90º respectively. In the same way, Punch is designed by taking punch radius as constant i.e. 3 mm and varying the punch angle as 86º, 88º and 90º. Sample specimens consist of 1.2 mm thickness are prepared of CR2 steel sheet with dimension as 90*30, 90*50, 90*70 mm. Before start of experimentation the punch is fixed on moving ram of UTM and die is mounted on the base of UTM machine. Punch and die are aligned properly before moving to the actual bending of the sheet. Test sample placed at a marked position on the top face of die and force is applied gradually until the sheet is bent completely. After bent, the force is released and sample marked for next angle measurement on profile projector. Total 9 experiments are carried out on UTM machine in the same way and each experiment repeated three times to get a better result. Angle measurement was performed on profile projector and calculates the springback by taking the difference between the angle of the sample after removal of load and before application of load. The experimental result with the L9 orthogonal table is shown in the below table 4.

Table 4-: Experimental result

Experimentation No.	Punch Angle 1	Die Width 2	Sheet Width 3	Springback angle
1	86	30	30	5.45
2	86	40	50	4.20
3	86	50	70	3.65
4	88	30	50	4.35
5	88	40	70	3.12
6	88	50	30	2.42
7	90	30	70	2.98
8	90	40	30	1.28
9	90	50	50	0.80

Fig 2-: Experimental setup, Die & punch, and Bent sample

2.3 Experimental Analysis

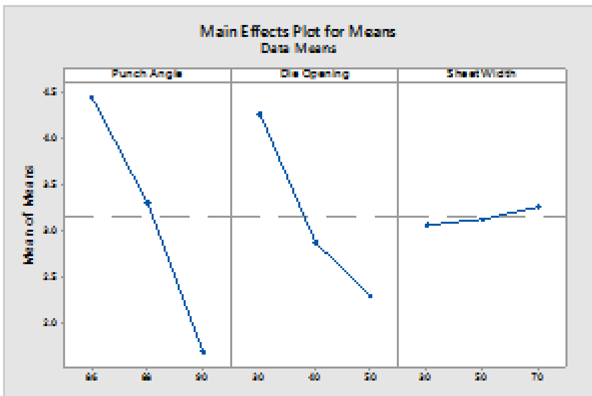
All 9 experiments are performed as per design of experiment by using Taguchi method. Next step is to analyze the data of experimental result. Taguchi method uses the signal to noise ratio to determine the optimal process parameters. The S/N ratio reflects both amounts of variability in the response data and closeness of the average response to the target value. Here signal represents the parameters which are controllable by user and noise cannot be controllable by the user, which affect on the outcome i.e. springback effect due to external factors. In this experimental analysis springback is the outcome, so lesser the springback, there will be less quality loss which is advantageous to the customer. So lower is better quality characteristic has been chosen for analysis. The goal of any experiment is always to determine the highest signal to noise ratio for the result. This ratio with high value represent signal has dominance over the noise, so it is desirable. Following are the response tables for S/N ratios and for Means showing all the factors with their ranking of influence.

Table 5-: Response Table for Signal to Noise Ratios

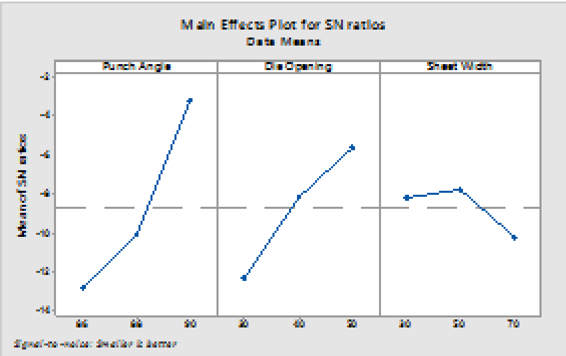
Level	Punch Angle	Die opening	Sheet width
1	-12.813	-12.327	-8.183
2	-10.11	-8.164	-7.766
3	-3.23	-5.661	-10.204
Delta	9.583	6.666	2.439
Rank	1	2	3

Table 6-: Response Table for Means

Level	Punch Angle	Die Opening	Sheet Width
1	4.433	4.26	3.05
2	3.297	2.867	3.117
3	1.687	2.29	3.25
Delta	2.747	1.97	0.2
Rank	1	2	3



Graph 1-: Main Effect plot for Mean



Graph 2-: Main effect plot for S/N ratio

The graph 1 & 2 shows the plot for S/N ratio and Means. From response table and graph it is seen that springback is affected by these three parameters i.e. punch angle, die width and sheet width. In response table, the parameters ranking is shown. As per ranking, the most influencing is punch angle, second is die width and third is sheet width. From the graph 1 of main effect plot, we can determine the optimum level parameter. From S/N ratio of main effect plot, highest S/N ratio chosen for optimum level response measured. As shown in the plot of S/N ratio, the optimum parameters are punch angle 90º (level 3), Die width 50 mm(level 3) and 50 mm sheet width (level 2). From mains effect plot of Mean, the influence of Punch angle and Die width is more because the plot has more slope and sheet width effect is least since the plot has less slope, so punch angle and die width has dominant factor affecting on springback.

2.4 Analysis of Variance (ANOVA)

Analysis of variance is a standard statistical technique to interpret experimental results. It is widely used to detect a difference in average performance of no. of items under investigation. It breaks down the variation in the experimental result into accountable sources and thus finds the parameters whose contribution to total variation is significant. Thus the ANOVA is used to study the relative influence of multiple variables, and their significance. For this experimentation the ANOVA table is as follow:

Table 7-: ANOVA

Source	DF	Adj SS	Adj MS	F – Value	% Contribution
Punch Angle	2	146.467	73.233	18.18	62.92%
Die Width	2	68.032	34.016	8.44	29.22 %
Sheet Width	2	10.209	5.105	1.27	4.38%
Error	2	8.057	4.028		3.16%
Total	8	232.765			

From ANOVA table 7 it is concluded that two process parameters Punch angle and Die width has a major influence on springback with their approximate contribution is 62.92% and 29.22% respectively. Third parameter i.e. sheet width has very less effect on springback with the approximate contribution is only 4.38% only. So in such a way it has very less influence on the outcome. The residual error always occurs in the experiment and in this experiment that error is only 3.46%. The table 8 shows optimum levels for this research work.

Table 8-: Optimum value for springback Effect

Punch Angle	Die Opening	Sheet Width	Predicted springback angle	Confirmation test result of springback	% error
90º	50 mm	50 mm	0.82	0.80	2.43%

As per Taguchi designed method, to achieve optimal levels of the parameter, S/N ratio should have a higher value. It means where the ratio is higher means signal factor has dominance over noise factor and that is desirable, at that point the optimum level is achieved. In this experimentation the S/N ratio is higher for 90º punch angle; 50 mm die width and 50 mm sheet width. Taking these parameters for optimum, confirmation test is performed for above said optimum parameters. Three trials are taken for a confirmation test and compared the result with the predicted values by regression equation given by Minitab 17.0 software for above optimum parameters. It is found that there is approximately the same result up to 2.43 % error between the predicted values and confirmation test result.

3. Conclusion

In this research work, three input process parameters are optimized using Taguchi method. The optimized parameters are validated by a confirmation test. The following are the conclusion of this experimentation.

- The input process parameters that are punch angle die opening and sheet width affect on the springback effect. Out of these parameters punch angle affect mostly then die opening and sheet width affect least.
- The contribution of input process parameters towards springback effect is 62.92% of punch angle, 29.22% of die opening and least contribution of sheet width i.e. 4.38%.
- So the most affecting parameters among these is Punch angle, least affecting is sheet width and die opening affected intermediately.
- With respect to three parameters, the springback effect decreases as these parameters value increases.

- As punch angle and die opening increases, the bending moment increases and thus springback effect reduces.
- With the increase in sheet width, the stress distribution area increases and it helps to reduce springback effect.

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