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OPTIMIZATION OF SPRINGBACK EFFECT IN AIR BENDING PROCESS FOR TIN COATED PERFORATED SHEET BY TAGUCHI APPROACH

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Abstract *- The Springback in sheet metal is major problem associated during air bending process which is mainly affected by thickness of sheet, tool and process parameters along with material properties, surface roughness, temperature and lubrication conditions. This work aims at finding best parameters for tin coated sheet which produce minimum springback with less number of trial by using taguchi design of experiment. The level of importance of air bending process parameters on the springback is determined by using analysis of variance (ANOVA). The optimum process parameter combination was obtained by using the analysis of signal-to-noise (S/N) ratio. The confirmation tests indicated that it is possible to decrees springback significantly. Through experimental work, it has been derived that die opening, punch & die radius have significant effect on springback while hole diameter & lubrication have minor effect.*

Keywords – *Springback; Air bending process; DOE; S/N Ratio; Optimization*

I . INTRODUCTION

The sheet metal products has a very wide range of applications , which fulfil our household needs, electrical instruments, automotive body panels, decoration work and vital aeronautical engineering articles whose production through other methods will be either uneconomical or involve too many complications. During bending operation, force is applied to a sheet metal blank & shape is changed as the metal is deformed plastically along a straight line.

After bending, residual energy remains in the bent part causing it to partially recover its original shape. This elastic recovery which is additional deformation of the material during the unloading, called springback. Springback cannot be completely eliminated but can be minimised using suitable die designs [1].By applying tension, over bending, warm and hot forming are servel other techniques for minimising springback [2]. Sheet forming behaviour is influenced by material properties, tool and process parameters in a complex fashion.

For a designer, the information on springback is essentially to provide allowances in die design and for process control to produce accurate bends. While bend force is needed to select press brake. In the air bending (three point bending), by adjusting the depth to which the punch enters the die opening produced required angle on the work pieces. This study investigates & optimizes the springback effect on perforated tin coated sheet which has an extremely beautiful metallic luster as well as excellent properties in corrosion resistance, solderability, and weldability. Tinplate is a thin steel sheet coated by tin mainly used in making all types of containers, battery cases, heat exchangers, etc.

I I. MECHANISM OF SPRINGBACK

During bending, the inner surface of the material is subjected to the compressive stress and it propagates inward towards the neutral plane. It means that the metal near the neutral axis has been stressed to values below the elastic limit. This creates a narrow elastic band on both sides of the neutral axis. The metal far away from the neutral axis may be stressed beyond the yield stress and has been plastically or permanently deformed. When the bending load is removed at the end of the bending stroke, the elastic band tries to return to the original condition but is restricted by the plastic zone. When the elastic and plastic zones reach in equilibrium, it results in a partial elastic recovery which is called as springback. The effect of spring back in air bending is the dimensional change of the formed part after the pressure of punching tool has been released. The final shape of the formed part is seriously affected by springback phenomenon [3].

The bent sheet can be divided into four deformation zones, namely: plastic, elastoplastic, elastic and rigid zones. Though a non-linear strain distribution of sheet thickness was considered by some researchers, the shift in the neutral axis and reduction of the sheet thickness during bending were not considered [9].

However, during bending, the position of the neutral axis shifts towards the inner radius of the sheet. Moreover in the plastic zone, where the sheet is in contact with the punch, thickness reduction takes place [14].

III. LITERATURE REVIEW

Air bending process is widely used for its flexibility, low tooling cost & less punch load but suffer from more springback in absence of any bottoming which is present in conventional V-die bending process and it is also necessary to have precise stroke control during process to form required bend angle.

Mentink et al described the role of geometric and material properties in the air bending process. As it is extremely difficult to determine the material properties under industrial conditions, a procedure for determining material characteristics based on measurements of the punch force, punch displacement and angle of bending was outlined. The resulting material characteristics can be used as input parameters in a process model for air bending [7].

Bruni et al investigated the effect of processing parameters on the springback of AZ31 Magnesium alloy by carrying out the air bending tests under warm and hot forming conditions. The results showed that the major parameters influencing the springback were punch radius and temperature. They revealed that springback decreases with increasing forming temperature and decreasing punch radius[8].

Kim et al proposed an analytical model to predict springback and bend allowance simultaneously in air bending and a computer program(BEND) was developed for uncoated sheets. The model considers the material properties and realistic non-linear curvature of the bent sheet. The springback and punch stroke results obtained from BEND were compared to Wang et al's model and experimental results found in their papers. It was observed that the springback results for Aluminium 2024 material obtained from BEND program predicted satisfactory results[12].

Garcia-Romeu et al carried out experiments in air bending of aluminium and stainless steel sheets to obtain springback values for different bend angles. The influence of die width to thickness ratio over springback was analysed and it was found that when the ratio value increases, springback increases[1].

Narayanasamy, R. and Padmanabhan, P. investigated the effect of orientation, punch velocity, punch travel & punch radius on the springback for Indian interstitial Free(IF) steel sheet & concluded that Springback varies inversely with punch radius, directly with punch travel and punch velocity, irrespective of material orientations[13].

Yilamu et al investigated the springback phenomena of a stainless-steel clad aluminium sheet in air bending and it was found that when the inside layer of the bent clad sheet is strong material, the overall thickness of the bent clad sheet decreases and for the reversed sheet-set condition the sheet thickens. The sheet-set condition has minor effect on the springback[10].

Narayanan et al studied the influences of hole size, hole shape and arrangement of holes on sheets angles for commercially available aluminium to determine springback on ANSYS FEA software. It has been found that spring-back decreases when hole size increases. Sheets with square holes exhibit more spring-back than that of circular holes. Springback of sheets with holes arranged in triangular pattern is less than that of holes arranged in square pattern[11].

ShahrulAzam Abdullah et al conducted experiment by using taguchi approach on advance high strength steel-DP590 for 1 & 2 mm thick sheet. ANOVA results reflected that, most affecting parameters were sheet thickness followed by die gap & punch travel[15].

The present work is motivated to study effect of processing parameters on springback for tin coated sheet as most of the earlier studies have been made on aluminium or other commercially available materials with smaller curvature bending & in most of cases for just only plain sheet.

IV. TAGUCHI METHOD FOR OPTIMIZATION OF PROCESS PARAMETERS

A large number of experiments have to be carried out when the number of the process parameters increases. To solve this task, the Taguchi method uses a special design of orthogonal arrays to study the entire process parameter space with only a small number of experiments. The main disadvantage of the Taguchi method is that the results obtained are only relative and do not exactly indicate what parameter has the highest effect on the performance characteristic value. Also, since orthogonal arrays do not test all variable combinations, this method should not be used with all relationships between all variables[4].

An advantage of the Taguchi method is that it emphasizes a mean performance characteristic value close to the target value rather than a value within certain specification limits, thus improving the product quality. Additionally, Taguchi's method for experimental design is straightforward and easy to apply to many engineering situations, making it a powerful yet simple tool [5].

V. EXPERIMENTAL WORK

The operating factors such as Punch & Die radius, Die Opening, hole diameter and Lubrication condition have been selected for parametric optimization for 0.2 mm thick sheet. The identified process parameters which affect the springback in air bending process and their levels are given in Table 1. In this process four parameters at three levels and one parameter at two level hence L18 orthogonal array was selected for the controllable factors. Springback test was carried out using bench hydraulic press machine of 10 tones capacity. Schematic diagram of the tool set as shown in figure 1.

Table 1. Process Parameters with corresponds

Sr. no.	Process Parameters	Factors Designation	Level I	Level II	Level III
1	Lubricant Viscosity (Pa.s)	μ	0.132	0.363	-
2	Punch radius (mm)	R_p	3	5	7
3	Die radius (mm)	R_d	4	7	10
4	Die opening (mm)	W	20	30	40
5	Hole Diameter (mm)	r	5	8	10

Each experiment was carried out for three times to obtain 90° bend on 110×40 mm tin coated sheet of E 2.8/2.8 grade under loading condition by adjusting punch stroke value, which was obtain from CAD model. As it is very difficult to measure angle during loading condition, same was performed with the help of digitized image taken from 14 Mega pixel camera very carefully. Autocad®2013 was used to measure angle by drawing two line on longer edge of bend part image. After unloading, the profile was taken on a thick white paper by coating longer edge of bend sample with blue ink. Then, the sheet was scanned, converted into digitized image and to measure the angle, above mention steps was repeated again. During bending of tin coated steel steel sheets, tin acts as a solid lubricant because of its low shear strength. Yet, the coating can be damaged catastrophically by shear separation. In order to avoid the damage of the coating and to reduce the friction forces, lubrication becomes essential. The lubricants were applied on the tool surfaces. After every experiment, the lubricant was wiped off and the tooling surfaces were degreased with acetone. Fresh lubricant was applied for every experiment. Experiment results are given in table no. 2.

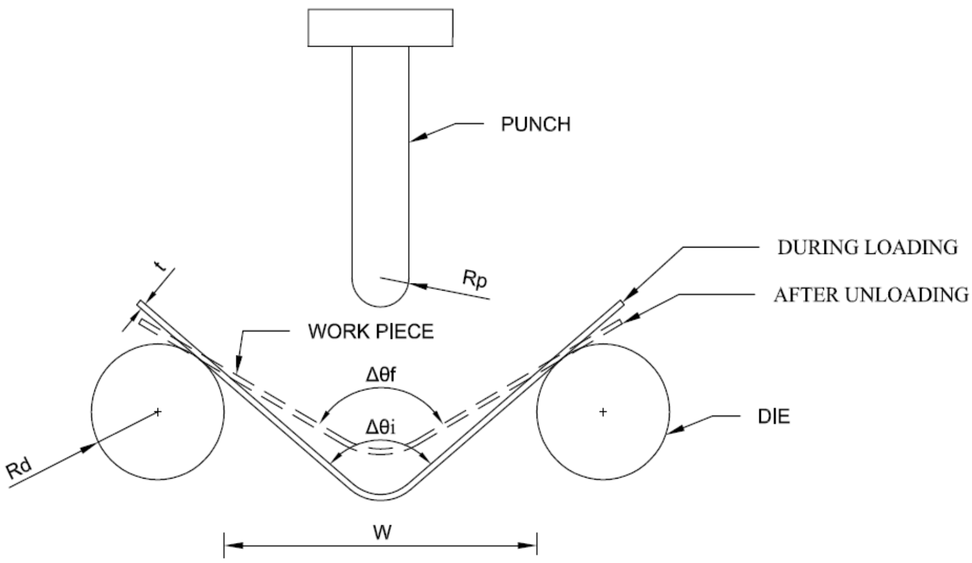

Figure 1. Schematic diagram of the tool set

VI. SIGNAL TO NOISE RATIO

By using a signal-to-noise ratio to analyse the experimental data could help the designers or the manufacturer to easily find out the optimal parametric combinations. A loss function is then defined to calculate the deviation between the experimental value and the desired value. Taguchi recommends the use of the loss function to measure the deviation of the quality characteristic from the desired value. The value of the overall loss function is further transformed into a signal-to-noise (S/N) ratio. Usually, there are three categories of the quality characteristic in the analysis of the S/N ratio, i.e. the lower-the-better, the larger-the-better, and the more-nominal-the-better. The S/N ratio for each level of process parameters is computed based on the S/N analysis. Regardless of the category of the quality characteristic, a larger S/N ratio corresponds to a better quality characteristic. Therefore, the optimal level of the process parameters is the level with the highest S/N ratio[6]. As aim was to minimise springback effect, lower-the-better was selected & S/N ration for each run is calculated & given in Table no. 3

Table 2. Experimental Results

Experiment No.	μ	R_p	W	R_d	r	Springback angle(in degree)			
						S_1	S_2	S_3	S_{avg}
1	1	1	1	1	1	17.95	15.65	16.08	16.56
2	1	1	2	2	2	24.75	25.23	24.06	24.68
3	1	1	3	3	3	31.48	29.14	30.34	30.32
4	1	2	1	1	2	18.56	17.85	19	18.47
5	1	2	2	2	3	25.5	25.85	25.9	25.75
6	1	2	3	3	1	33	33.59	33.16	33.25
7	1	3	1	2	1	22.02	21.95	20.38	21.45
8	1	3	2	3	2	26.45	26.65	26.85	26.65
9	1	3	3	1	3	30.4	30.2	29.46	30.02
10	2	1	1	3	3	17.2	17.65	18.7	17.85
11	2	1	2	1	1	22.94	22.2	22.21	22.45
12	2	1	3	2	2	28.2	28	28.22	28.14
13	2	2	1	2	3	20.27	19.42	19.53	19.74
14	2	2	2	3	1	27.8	28.1	27.05	27.65
15	2	2	3	1	2	30.74	29.6	29.72	30.02
16	2	3	1	3	2	21.5	22.83	21.97	22.1
17	2	3	2	1	3	24.31	23.1	23.09	23.5
18	2	3	3	2	1	29.1	30.66	29.19	29.65

Table 3. Signal to Noise (S/N) Ratio

Experiment No.	1	2	3	4	5	6	7	8	9
S/N Ratio (dB)	-24.397	-27.848	-29.638	-25.332	-28.215	-30.436	-26.634	-28.514	-29.549
Experiment No.	10	11	12	13	14	15	16	17	18
S/N Ratio (dB)	-25.038	-27.025	-28.986	-25.908	-28.835	-29.549	-26.890	-27.423	-29.443

Table 4. Response table for S/N ratio of the factors

Sr. no.	Factors	**S/N Ratio**		
		Level I	Level II	Level III
1	μ	-27.84	-27.68*	-
2	R_p	-27.15*	-28.04	-28.07
3	W	-25.69*	-27.98	-29.6
4	R_d	-27.21*	-27.84	-28.22
5	r	-27.79	-27.85	-27.63*

* Optimum level

Optimum parameter levels were chosen from the peaks in the response table for S/N ratio as shown in Table 4. The graphical representation of S/N ratio for parameter considered at different levels is presented in the Figure.2.

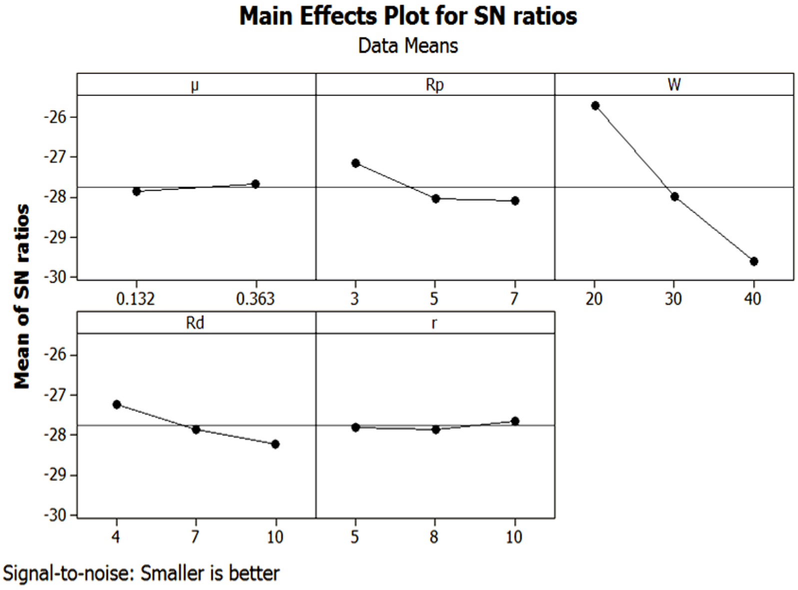

Fig no. 2 S/N graph for all factor

VII. ANALYSIS OF VARIANCE

Analysis of Variance is a tool for quantitative evaluation of the influence of the independent variables on the dependent variables. The Taguchi method could not determine the effect of individual variables in the experimentation, ANOVA can be used to compensate for that effect. The relative effect of the different factors can be obtained by decompositions of variables, which is commonly called as ANOVA[5]. The results of ANOVA are presented in Tables no. 5. Statistically, F-test provides a decision at some confidence level as to whether these estimates are significantly different. Larger F-value indicates that the variation of the process parameter makes a big change on the performance. For a factor with a high percentage contribution, a small variation will have a great influence on the performance.

Table 5. Results of ANOVA

Process Parameters	Degree of freedom	Sum of Square	F test	Percentage Contribution(%)
Lubricant Viscosity (Pa.s)	1	2.033	2.43	1.00
Punch radius (mm)	2	22.352	13.35	5.50
Die opening (mm)	2	354.978	211.90	87.37
Die radius (mm)	2	23.520	14.04	5.78
Hole Diameter (mm)	2	1.326	0.79	0.32
Error	8	6.701	-	-
Total	17	-	-	100

Significant at 95% confidence level
R-Sq = 98.37% R-Sq(adj) = 96.53%

VIII. Confirmation Experiment

To verify the application of the Taguchi method, further experimental observations were collected under the found optimal factor & the results are summarized in the Table 4.7. It is observed that the chosen optimal combination yielded a smaller springback value than all the other factor combination level.

Table 6. Confirmation experimental results

Factor	μ (Pa.s)	R_p (mm)	R_d (mm)	W (mm)	r (mm)	Springback angle(in degree)			
						S_1	S_2	S_3	S_{avg}
Factor Value	0.363	3	4	20	10	15.45	15.96	15.6	15.67

IX. CONCLUSION

Taguchi's Design of experiments is adapted for optimization of process parameters such as Punch & Die radius, Die opening & Hole diameter in sheet along with lubricant on tin coated steel sheet. Result shows the Die opening , Punch & Die radius influences the springback mainly. Among these, the Hole diameter and lubricant have least effect on the springback behaviour for studied sheet.

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