

Experimental and Statistical Study on Spring-back Behavior in Incremental Sheet Metal Forming Process

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ABSTRACT: As increasing the demand for low volume production and rapid prototyping, incremental forming provides a flexible and cost effectiveness in metal forming process. In incremental sheet metal forming, spring back is very important factor that affects the quality of parts. Spring back is an unappeasable forming defect in the sheet metal forming process. Controlling spring back precisely is most important for the design of formed part in incremental sheet forming. In this paper, spring back is investigated using effect of process parameters such as wall angle, tool diameter and step depth. Design of experiment (DOE) is used to plan the experiments conducted on AA 1200 H14 aluminum alloys and analyzed the results. Experimental results are tested by Analysis of variance (ANOVA) technique. Importance of each parameter has been carried out easily by statistical geometric analysis. The obtained result allows selecting suitable parameter to optimize spring back.

KEYWORDS: Incremental sheet metal forming, Spring-back, Taguchi L9 method, ANOVA.

I. INTRODUCTION

Incremental forming is a flexible sheet metal forming process which permits compound shapes to be formed without need of any die. Incremental sheet metal forming concept consisting in a localized deformation of sheet metal part is flexible because no specialized tool is necessary. This process overcome to use of advanced technology for turning raw material into usable goods. Tool with hemispherical head is used to move over the surface of the sheet by which sheet is plastically deformed only around the contact area and then the whole product shape is incrementally formed with traveling of tool around the predefined 3D tool path. One of the main advantages in this process is highly formability of sheet metal that change shape with high forming depth.

However, spring back is major concern in the ISF process and larger spring back leading to dimensional inaccuracy in the formed part. Spring back cannot be avoided but can be decreased by selecting appropriate parametric values that cause effect to the formed part. Spring back in ISMF has been investigated by many researchers, who have highlight its great flexibility due to absence of specific dies. . Hosien Mohammadi et al.[1] analyzed the effect of process parameters by both numerically and experimentally and found that spring back is getting minimized by taking small tool diameter. Alireza Vehdati and Mehdi Vehdati[2] studied the effect of different process parameters and initiate that vertical step size and tool diameter has most effective parameters to effect spring back. Fei Han et al.[3] investigated spring back value by taking different parameters that as increase in wall angle, spring back gets decreased. On the basis of this study, selection of parameters was done. The experiments were conducted on the aluminum AA1200-H14 sheet in Computer Numeric Control (CNC) machine. Spring back values were calculated by Co-ordinate measuring Machine (CMM) machine. In this process, a number of experimental tests have been implemented to find the spring back effect. Taguchi method was implemented to design the different experiments to be conducted so that the optimum value can be described.

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II. MATERIAL AND METHOD

1. Selections of process parameters: According to recent researches in ISF process, three factors: vertical step depth(v), tool diameter (d) and wall angle (α) were selected as effective factors on spring back.

Table1. Process parameters and their levels

Process factor	Level 1	Level 2	Level 3
Vertical step depth (mm)	0.2	0.5	0.8
Tool diameter (mm)	8	10	12
Wall angle	30	45	60

Table 1 represents three factors (vertical step depth, tool diameter and wall angle) in three levels which had been studied in this paper.

2. Material used: Material used for this study is AA1200-H14 aluminum alloys with 1.2mm thickness sheet. The chemical composition of material is shown below in table (2)

Table 2 Chemical composition of work piece

	Cu%	Mg%	Si%	Fe%	Ni%	Mn%
Value	0.0063	<0.00400	0.393	0.552	0.0043	0.0239
	Zn%	Pb%	Sn%	Ti%	Cr%	Al%
Value	0.00456	<0.0200	<0.0100	0.022	<0.0030	98.92

Table 2 represents the chemical composition of aluminum AA1200-H14 alloys which shows that the percentage of aluminum is 98.92%.

Table 3 Mechanical properties of work piece

Material sheet	Temper	Thickness (mm)	Tensile Strength (N/mm)	Elongation percentage (%)	Tensile Strength (Mpa)
1200	H14	1.2	129.438	7.220	129.438

The mechanical properties are shown in table (3) as the maximum elongation of AA 1200 H14 is 7.22%.

3. Taguchi method and Design of Experiments: The Taguchi method is a quality tool that helps improve the work efficiently. Each condition will be determined by the factors for instance the first condition is identified by the step depth at 0.2 mm, tool diameter at 8 mm and wall angle at 30° as well. Therefore, the orthogonal array is selected with L9 method which gave the order of experiment as shown in Table 4. In general, the parameter optimization process of the Taguchi method is based on planning, conducting and evaluating results of matrix experiments to determine the best levels of process parameters.

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Table 4 Experimental layout based on an L9 orthogonal array

Experiment number	Cutting parameter levels		
	Step Depth(mm)	Tool diameter(mm)	Wall angle
1	0.2	8	30
2	0.2	10	45
3	0.2	12	60
4	0.5	8	45
5	0.5	10	60
6	0.5	12	30
7	0.8	8	60
8	0.8	10	30
9	0.8	12	45

Table 4 presents the 9 different experiments strategies used to conduct the experiment at different levels to obtain the precise result.

4. Experimental setup: The process starts from a flat sheet blank clamped on a fixture and mounted on the table of CNC machine. Then the forming is done with help of hemispherical tool shown in figure 1 to move over the surface of plate Hemispherical type forming tool with 8mm, 10mm and 12mm diameters were used as shown in figure 1. Also fixture with clamping system was designed and machined according to desirable dimensions shown in figure 2.



Fig.1. Tools used to conduct the experiment and deform the sheet



Fig.2. Fixture designed to hold the plate

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Figure 2 shows the fixture designed to clamp the plate tightly so that it is easy to conduct the experiment. Aluminum blank is held on this plate and tightened with help of bolts afterwards tool is move over the plate and plate is deformed accordingly.

After applying L9 runs, the effective value of spring back of the sheet is obtained from the software. Spring back is measured from four equidistant points on the sheet with help of co-ordinates measuring machine (CMM WENZEL XORBIT XO 55).

III. RESULTS AND DISCUSSION

1. Analysis to signal to noise ratio: In Taguchi method, the term signal represents the desirable value, and noise represents the undesirable value. Process parameters with the highest S/N ratio always give the best quality with minimum variance. In order to find the influence of process parameters on response the signal to noise ratio and mean for each parameter was calculated. In this current work, the S/N ratio was chosen according to the principle of ‘smaller the better’ characteristics shown in equation 1.

$$S/N = 10 \log \left[\frac{1}{\frac{1}{n} \sum_{i=1}^n y_i^2} \right]$$

Where n is the number of repetitions and Yi is the value of spring back of the test. The process parameters, calculated spring back and signal to noise (S/N) ratio are given in table 5.

Table 5 Results of spring-back

Experiments	Step Depth (mm)	Tool Diameter (mm)	Wall Angle	Spring-Back (mm)	S/N ratios
1	0.2	8	30	0.18655	14.58409
2	0.2	10	45	0.1064	19.46117
3	0.2	12	60	0.0645	23.80881
4	0.5	8	45	0.1395	17.10852
5	0.5	10	60	0.0889	21.02196
6	0.5	12	30	0.16135	15.84462
7	0.8	8	60	0.0463	26.68838
8	0.8	10	30	0.15445	16.22424
9	0.8	12	45	0.077	22.27019

Table 5 represents the results of experiments conducted. Value of spring back is obtained and S/N ratio is calculated.

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Response Table for Signal to Noise Ratios Smaller is better			
Level	A	B	C
1	19.28	19.46	15.55
2	17.99	18.90	19.61
3	21.73	20.64	23.84
Delta	3.74	1.74	8.29
Rank	2	3	1

Fig. 3 Response table for S/N ratio of spring back

Figure 3 shows the response table for S/N ratio of spring back smaller is better obtained for different parameter levels. The analysis of S/N ratio of spring back found that the first factor that causes spring back to be great is wall angle, having step depth and tool diameter as secondary factors respectively. After that, the analysis is made to determine suitable factor of each main factor from S/N ratio and mean graphs is shown in Figure 4 & Figure 5.

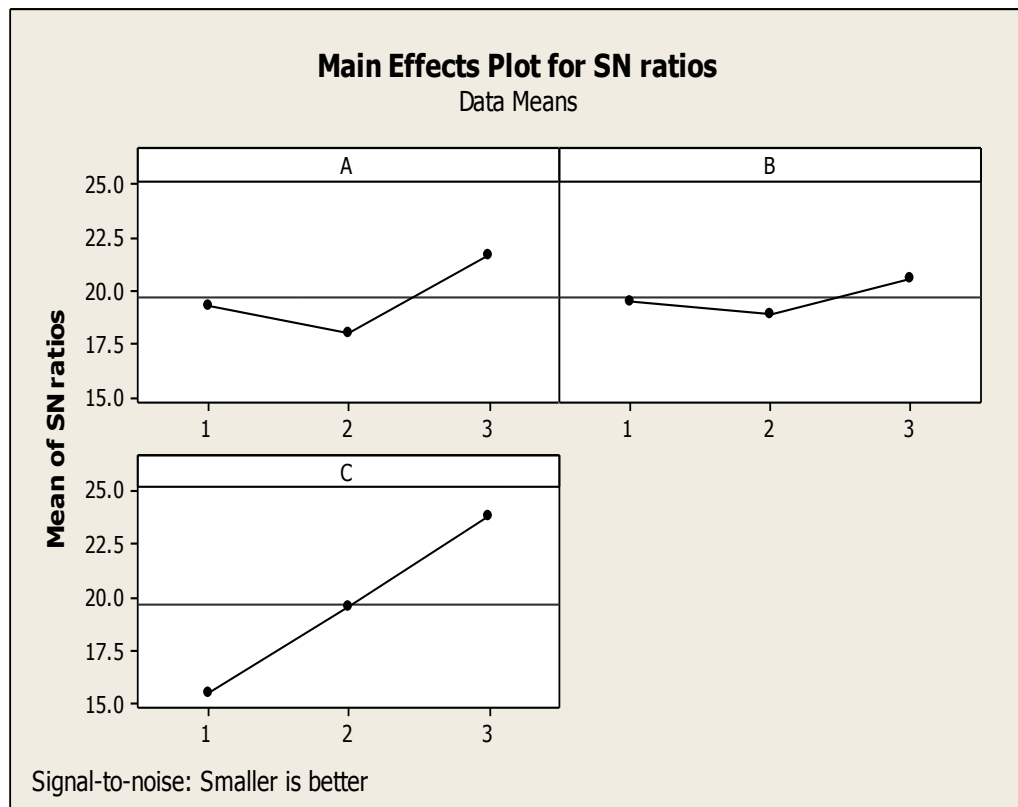


Fig. 4 Main effect plot for Signal to Noise ratios of spring back

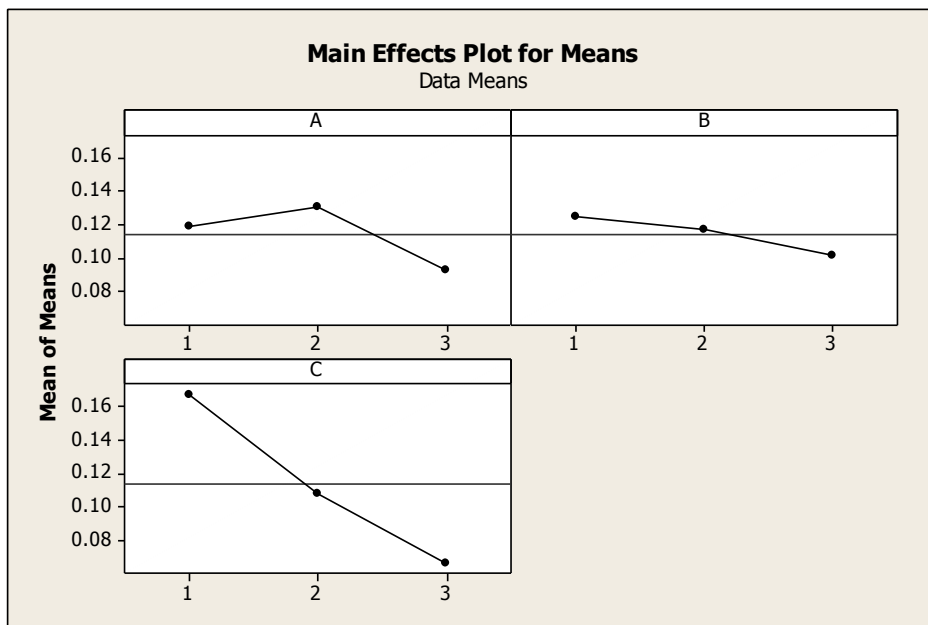


Fig.5. Main effects plot for means for spring back

In the impact analysis of S/N ratio, factor level will be selected to give maximum S/N ratio as the most suitable factor level.

2. Analysis of variance: The ANOVA study performed to investigate the statistical significance of the process parameters affecting the response (spring back). This is achieved by separating the total variability of the S/N ratios, which is measured by the sum of the squared deviations from the total mean of the S/N ratio, into contributions by each of the process parameters and the error. F-test is carried out to judge the significant parameter affecting the tool life. The larger F value affects more on the performance characteristics.

Table 5 Results of ANOVA using data from signal to noise ratios for spring back

Analysis of variance for spring back, using adjusted SS for tests							
Source	DF	Seq SS	Adj SS	Adj MS	F	P	% C
Depth	2	0.0022155	0.0022155	0.0011077	5.73	0.149	11.73
Diameter	2	0.0008378	0.0008378	0.0004189	2.17	0.316	4.44
Angle	2	0.0154420	0.0154420	0.0077210	39.91	0.024	81.78
Error	2	0.0003869	0.0003869	0.0001934			2.05
Total	8	0.0188822					
S = 0.0139083			R-Sq = 97.95%		R-Sq(adj) = 91.80%		

Table 5 shows result of ANOVA for spring back. From ANOVA, it is found that parameter C that is wall angle is the significant level on spring back. The step depth and tool diameter found to be insignificant from ANOVA for spring back study. Hence, the best values of parameters can be selected to achieve the lower spring back and higher values of geometrical and dimensional accuracy. The selection of the most suitable factor level from the graph found that level of factor that causes spring back to be minimum is when level of step depth is 0.8mm, tool diameter is 12mm and wall angle is 60°.

IV. CONCLUSION

In this study, effect of different parameters was investigated on spring back using AA1200 H14 tempered aluminum sheet. The parameters for experimental tests were step depth, tool diameter, wall angle. Spring back was measured by

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performing different experimental tests. The experimental design was followed by DOE with taguchi L9 methodology. The conclusion from this study is summarized as follows:

- The L9 taguchi orthogonal designed experiments of ISF AA1200 H14 were successfully conducted.
- From the selected parameters wall angle found to be the most effective parameter in spring back as to step depth and tool diameter.
- Increase of wall angle and tool diameter and reduction of step depth can lead to a reduction in spring back.
- Accurate combination of process parameters can be selected for lowering spring back in sheet metal forming.

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