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Research Paper

TAGUCHI APPROACH FOR INVESTIGATION OF SPRINGBACK EFFECT IN ALUMINUM SHEET

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The major problem associated with sheet metal forming is the springback, the geometric difference between the loaded condition and unloaded configuration and is affected by many factors such as orientation, force, gauge, and temperature. This work aims at predicting the influence of various operating parameters on springback in bending of Aluminum (Al) sheets. Taguchi's Design of experiments is adapted to design the experiments and is conducted under different working conditions. The optimum condition that results in minimum springback is identified. This can be used to help design of tools in the metal forming industry. The purpose of this work is to present Taguchi's approach for optimization of process parameters such as orientation, force, gauge, temperature on sample. The factors influencing springback effect of plane sheet of aluminum materials have been predicted quantitatively using the Taguchi Design of Experiment method. The bending process is chosen as an evaluation problem because of its larger springback effect.

Keywords: Springback effect, S/N ratio, Taguchi, DOE

INTRODUCTION

Elastic recovery of formed part in unloading known as springback causes shape error in final product of sheet metal forming processes (Behrouzi, 2008). Springback occurs in various forms like torsion, bending, twisting, etc.and is known to have many factors affecting such as blank holding force, punch velocity, lubricating condition, orientation, and temperature, etc. The factors design phase determines the optimal setting for the product. These factors have been identified during the product designing phase. Springback is influenced by several factors, such as sheet thickness, elastic modulus; yield stress, work hardening exponent, etc. (Moon, 2003).

The final shape of the formed part is seriously affected by springback phenomenon. It is prove that the important role the metal sheet thickness on the springback. The

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springback problem approach has been dealt with on a try and error basis for many years in forming industry. Due to the production raise and production cost reduction requirements it is necessary a better comprehension of such effect in order to avoid waste of time with tryout operation and expenses associated to part discharge (Braga, 2008).

Bending is widely used metal forming process in various sheet metal products such as automobile panels, supermarket shelves, and housing utensils (Dhurairaj and Padmnabhan, 2011).

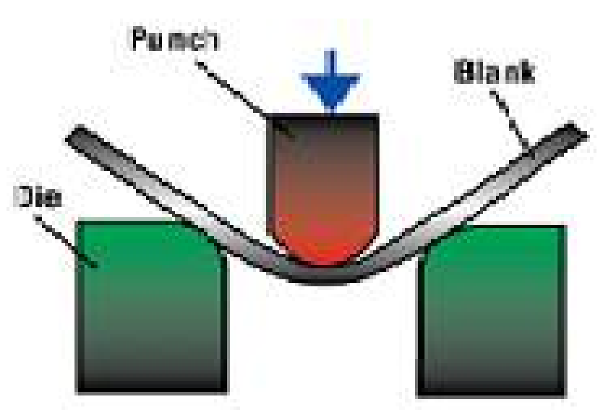
Sheet metal bending process is one of the most frequently used manufacturing operations in industry. Springback is a primary issue which is encountered during most sheet metal bending processes. Springback is influenced by several factors such as sheet thickness, elastic modulus, yield stress, work hardening exponent. This study investigates the springback effect on sheet by several factors like gauge, force, temperature, and orientation and also describes the experimental study of the springback effect on sheet of various metals, varying gauge by means of an optimization of springback effect parameters.

Springback Effect

It is defined as a change in the final bend angle after the blank undergoes bending by the release of the elastic component of the bending moment. The effect of spring back in air bending is the dimensional change of the formed part after the pressure of forming tool has been released. It results from the changes in strain produced by elastic recovery when the load is released. The final shape of the formed part is seriously affected by springback phenomenon (Aurelian, 2008).

At the end of the metal working operation, when the pressure on the metal is released, there is elastic recovery by the material and the total deformation will get reduced a little. This phenomenon is called "SPRINGBACK".

Figure 1: V Shape Air Bending



The springback can be the origin of the defect of dimensional accuracy in a product. Two methods have been performed for controlling the springback deviations. The first has focused on mechanical methods for reduction of springback by increasing sheet tension during forming process. Applying such methods causes greater plastic zone during forming and less amount of springback occurs during unloading. Although these approaches are efficient in many processes, for many forming operations, increasing tension causes tearing of work piece. In the second method, the purpose is to compensate springback error by modification of tool design, in a way that the target shape results after springback. In such methods, the amount of springback is considerable but by accurate springback analysis and applying trial-error algorithms, this error would be compensated by correction of die geometry. Air bending process is the most commonly used bending process because of its flexibility and reduction in punch load (Ihab, 2005).

TAGUCHI DESIGN OF EXPERIMENT

Taguchi asserted that the development of his methods of experimental design started in Japan about 1948. These methods were then refined over the next several decades. They were introduced in the United States around 1980. Although, Taguchi's approach was built on traditional concepts of Design of Experiments (DOE), such as factorial and fractional factorial designs and orthogonal arrays, he created and promoted some new DOE techniques such as signal-to-noise ratios, robust designs, and parameter and tolerance designs. Design of experiments is a powerful technique introduced by R.A.Fisher in England to study the effect on the outcome of multi-variables simultaneously. The process or system is usually influenced by two sets of process variables the controllable and uncontrollable ones (Avani, 2003).

In improving quality, both the average response of a quality and its variation are important. Taguchi suggests that it may be advantageous to combine both the average response and variation into a single measure and Taguchi did this with his signal-to-noise ratios (S/N). Consequently, Taguchi’s approach is to select design parameter levels that will maximize the appropriate S/N ratio. These S/N ratios can be used to get closer to a given target value, or to reduce variation in the product’s quality characteristic(s).

Taguchi used the signal-to-noise (S/N) ratio as the quality characteristic of choice. S/N ratio is used as a measurable value instead of standard deviation due to the fact that as the mean decreases, the standard deviation also decreases and vice versa. In other words, the standard deviation cannot be minimized first and the mean brought to the target. Taguchi has empirically found that the two-stage optimization procedure involving S/N ratios indeed gives the parameter level combination, where the standard deviation is minimum while keeping the mean on target. This implies that engineering systems behave in such a way, that the manipulated production factors can be divided into following three categories.

1. Control factors, which affect process variability as measured by the S/N ratio.
2. Signal factors, which do not influence the S/N ratio or process mean.
3. Factors, which do not affect the S/N ratio or process mean.

The S/N ratio characteristics can be divided into three categories when the characteristic is continuous. They are as follows:

- Nominal is the best characteristic

  $S/N = 10 \log [\bar{y}/S^2]$

- Smaller the better characteristics

  $$S/N = -10 \log \frac{1}{n} \sum y^2$$

- Larger the better characteristics

  $$S/N = -10 \log \frac{1}{n} \sum \frac{1}{y^2}$$

where, $\bar{y}$ is the average of observed data

y^2, variance of y

n, number of observations (http://www.qualitytrainingportal.com/resources/doe/taguchi_concepts.htm).

For each type of the characteristics, with the above S/N ratio transformation, the higher the S/N ratio the better is the result.

PLANNING OF EXPERIMENTATION

The operating factors such as force, gauges, orientation and temperature have been selected for parametric optimization and each parameter has three levels. The identified process parameters affect the springback in bending process and their levels are given in Table 1. Orthogonal array gives more reliable estimation of factor effects with less number of experiments, when compare compound to the traditional method. In this process four parameters at three levels, the total degree of freedom are 8. Hence L_9 orthogonal array having 8 degrees of freedom was selected for the controllable factors. Springback test was carried out using Universal Testing Machine (UTM) of 40 tones capacity.

Aluminum sheet having different gauges considered as testing material. Sheets are heated up to a particular temperature with the help of gas burner uniformly. Temperature of the sheets at a particular instant is measured with the help of Thermocouple Temperature Measuring Device.

During the experimentation extreme care should be taken to place the sheet on the support of UTM. For each test, three trials were conducted and deformed to the different conditions.

Table 1: Process Parameters for Aluminum Sheets with Three Levels

S. No.	Process Parameters or Factors	Factors Desig-nation	Factor Levels		
			Level 1	Level 2	Level 3
1.	Gauge	A	16	18	20
2.	Force (in kg)	B	8	12	16
3.	Temperature (in °C)	C	22	60	100
4.	Orientation (in degree)	D	0	20	30

Table 2: Experimental Results for the Aluminum Sheets

Ex. No.	A	B	C	D	Springback Ratio		
					Y_1	Y_2	Y_3
1	1	1	1	1	0.4166	0.3846	0.3500
2	1	2	2	2	0.4500	0.2500	0.2800
3	1	3	3	3	0.6285	0.6285	0.6600
4	2	1	2	3	0.3636	0.3636	0.3000
5	2	2	3	1	0.6129	0.5694	0.4745
6	2	3	1	2	0.3947	0.3750	0.2631
7	3	1	3	2	0.4761	0.4571	0.4000
8	3	2	1	3	0.5263	0.6190	0.4186
9	3	3	2	1	0.5217	0.4634	0.4578

Figure 2: Experimentation on Universal Testing Machine

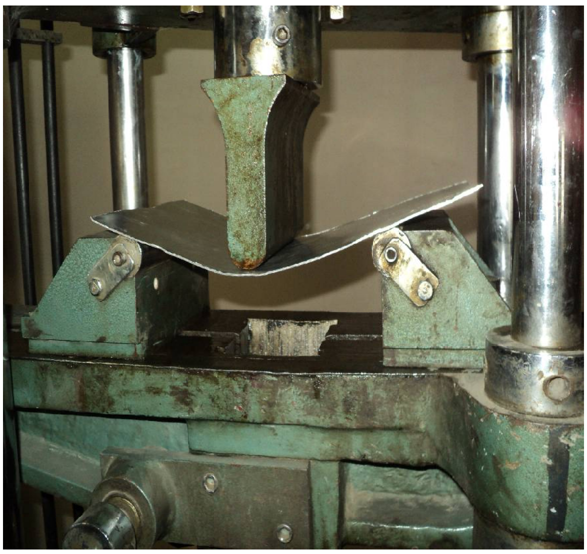


Figure 3: Aluminum Sheet After Deformation

RESULTS AND DISCUSSION

Taguchi experimental approach involves the use of orthogonal array and then the S/N ratio for analyzing the optimal result as shown in Tables 3 and 5. The analysis of S/N ratio and the level effect table, i.e., Table 4 establishes the relative significance of factors in terms of their rank in contribution to the response. The responses and level effect tables are used to identify the level giving best response value. The graphs for effect of different factors, i.e., gauges, temperature, orientation and forces having three levels on bending springback effect are shown in Figures 4 and 5.

Table 3: Signal to Noise (S/N) Ratio for Aluminum Sheets

Expt No.	Y_1	Y_2	Y_3	S/N Ratio (dB)
1	0.4166	0.3846	0.3500	8.2976
2	0.4500	0.2500	0.2800	9.4132
3	0.6285	0.6285	0.6600	3.8567
4	0.3636	0.3636	0.3000	9.2761
5	0.6129	0.5694	0.4745	5.1097
6	0.3947	0.3750	0.2631	9.1407
7	0.4761	0.4571	0.4000	7.0215
8	0.5263	0.6190	0.4186	5.5523
9	0.5217	0.4634	0.4578	6.3420

Table 4: Average Effect of Factors of Aluminum Sheets

Factors	S/N Ratio			Levels	Rank
	Level 1	Level 2	Level 3		
A	7.1891	7.8421	6.3052	1.5369	4
B	8.1984	6.6917	6.4464	1.7520	3
C	7.6635	8.3437	5.3293	3.0144	1
D	6.5831	8.5251	6.2283	2.2968	2

Table 5: Optimum Conditions of Aluminum Sheets

Factors	Levels	Level Description
A	2	18 gauge
B	1	8 kg
C	2	60 °C
D	1	20°

Figure 4: Effect Plot Graph for Means

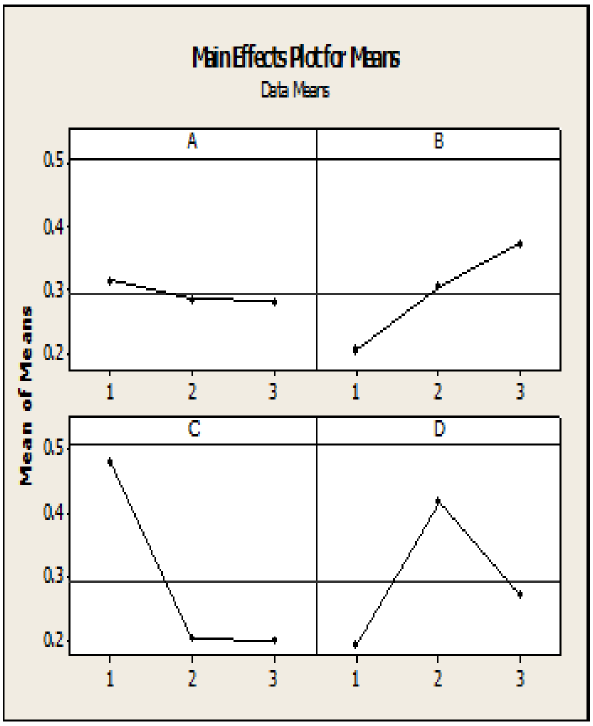
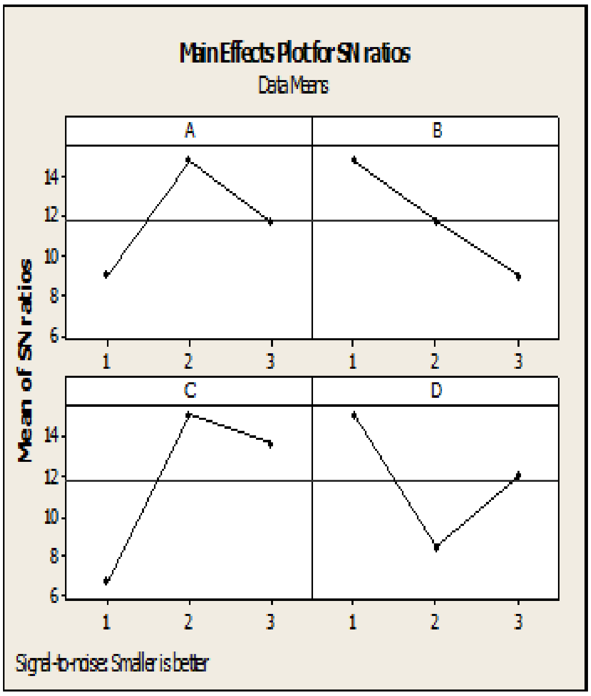


Figure 5: S/N Springback Ratio for Each Level



Tables 4 and 5 respectively shows that the temperature plays a major role in effecting the springback effects. The effect of orientation is predominant for springback effect minimization.

CONCLUSION

This paper utilized an efficient method for determining the optimum springback parameters for bending under varying noise conditions, through the use of the Taguchi design parameter process. Taguchi's Design of experiments is adapted for optimization of process parameters such as orientation, force, gauge, temperature on aluminum sheet. Result shows the temperature and orientation influences the springback mainly. Among these, the force and gauges have least effect on the springback behavior of the aluminum sheet.

Conclusions can be summed up with the following.

- The use of a modified L_9 orthogonal array, with four control parameters and one noise factor required only 27 work pieces to conduct the experimental portion.
- Temperature had the highest effect on springback, orientation had a moderate effect, and force and gauge had an insignificant effect. This would indicate that Temperature and Orientation might be included alone in future studies.

FUTURE SCOPE

- High and advanced high strength are finding wide acceptance in the automotive industry. One of the major problems in stamping automotive parts with high strength steel sheets is the increased level of springback. Effect of strength and process parameters on springback has been studied, now studied the anisotropy in future.
- The process parameters for bending springback studied include lower punch radius, die clearance, step height, and step distance (Zhao and In, 2011).
- To study several parameters have an effect on springback in bending operation like temperature and forming velocity, friction and blank profile.
- The development optimization of the bending process is connected with time consuming and costly. Therefore the finite element simulation of the process will be helpful tool for designer and quality assurance of the product.

- To study the springback influenced by many factors such as sheet metal thickness, elastic modulus, work hardening exponent.

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