Study Of Springback And Bend Force In V-Bending Process of Perforated Steel Sheets

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Abstract— **Bending is an important manufacturing process in sheet metal industry. Springback is a crucial issue in the sheet metal bending and it affects the precision of the product. Bend force is the force required to bend the sheet metal. The work aims to study the influence of factors such as number of holes, hole size, distance between holes and sheet thickness on springback and bend force in v-bending of perforated sheets. The study is based on Taguchi's design of experiments and the results show that the hole parameters and the thickness have a significant effect on springback and bend force.**

Index Terms—**Bend, Springback, V-Bending.**

I. INTRODUCTION

Perforated sheets are used in various applications such as load bearing structural components, heat transfer elements and decorative elements. V-bending is the most common type of bending process used in sheet metal shops today. In this process the work piece is bent to the required shape, with a v shaped punch and a die. After necessary bending operation, when the load on the sheet metal is removed, there is a change in the shape of the product due to elastic recovery. This phenomenon is known as springback. As the springback affects the tolerances for assembly, it is necessary to predict and compensate the springback to improve the product quality. Bend force, the force required to deform the work piece, is to be predicted for selecting the press for bending operation.

Researchers studied springback and bend force for the plain sheet metals extensively but the concentration on perforated sheets is less and in recent years, few researches are available. Farsi and Arezoo (2009) [1]studied the influence effect of punch radius and hole location on the spring-back of high-strength low-alloy sheet metal components with oblong holes on bending surfaces. It was found that the location of hole and the punch radius had an important effect on springback. Farsi and Arezoo (2011)[2] experimentally analysed the influence of the area of the holes, die angles, die widths and punch radius on bending force and spring-back in v-die bending of perforated sheet-metal components made of plain carbon steel and from the results, it was concluded that all these parameters affected the springback and bend force. Abdullah and Samad (2012) [3] investigated the spring-back of AA6061 aluminum alloy strip in V-bending process. The effects of length, thickness and bend angle had been studied and the results indicated that the thickness and bend angle had a significant effect on springback compared to the length of the workpiece. Venkatachalam et al. (2012) [4] modelled the V-bending process using finite element method and conducted numerical experiments to study the influence of hole size, hole shape, and hole pattern on spring back effect in perforated aluminium sheet metal. It has been found that all the hole size, shape and pattern influence the springback. The influence of hole size and shape on springback was much studied by the researchers. Since in a practical situation, the components contain many holes in the bending region instead of a single one and the distance between them are also different. This study includes these hole parameters and the influence of them are analysed by conducting the V bending experiments based on Taguchi's experimental design.

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II. TAGUCHI'S EXPERIMENTAL DESIGN

Taguchi method has been widely used in analyzing the complexity of manufacturing processes and uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments for obtaining information about the behavior of a given process [5]. The parameters considered in this work are number of holes, sheet thickness, diameter of holes and distance between the holes. L18 orthogonal array has been selected as it is more suited to design the 4 factor mixed level experiments. The factors and their levels are shown in Table 1 and the L18 OA is shown in Table 2.

III. EXPERIMENTAL WORK

The material used in the experiments was low carbon steel, a common material in the sheet metal industry. The perforated sheets were produced by drilling holes in the bending area. A 90^{o}V-die and punch were fabricated with EN8 steel and hardened. The bending experiments were conducted on a 40kN Universal testing machine (UTM) and the experimental setup is shown in Figure 1. The die was fixed on the platform and the punch was fixed above the die in the cross head of the UTM. The sheet was placed on the die and the punch was brought down at a constant speed and the component was bent. The bend angles before and after springback were measured by the method depicted in Srinivasan et al [6]. The maximum bend force was measured with a load cell and display arrangement. Three trials were conducted for each experiment and the average was taken for analysis.

95TABLE I FACTORS AND LEVELS

FACTORS	Notation	LEVEL- 1	LEVEL- 2	LEVEL- 3
Number of holes	N_h	2	3	
Sheet thickness (mm)	t_c	0.5	1	1.5
Diameter of the hole (mm)	d_h	2	5	8
Distance between the holes (mm)	D_h	2	5	8

TABLE II L18 ORTHOGONAL ARRAY

Expt.No	No. of holes	Sheet thickness (mm)	Diameter of hole (mm)	Distance between the holes (mm)
1	2	0.5	2	2
2	2	0.5	5	5
3	2	0.5	8	8
4	2	1	2	2
5	2	1	5	5
6	2	1	8	8
7	2	1.5	2	5
8	2	1.5	5	8
9	2	1.5	8	2
10	3	0.5	2	8
11	3	0.5	5	2
12	3	0.5	8	5
13	3	1	2	5
14	3	1	5	8
15	3	1	8	2
16	3	1.5	2	8
17	3	1.5	5	2
18	3	1.5	8	5

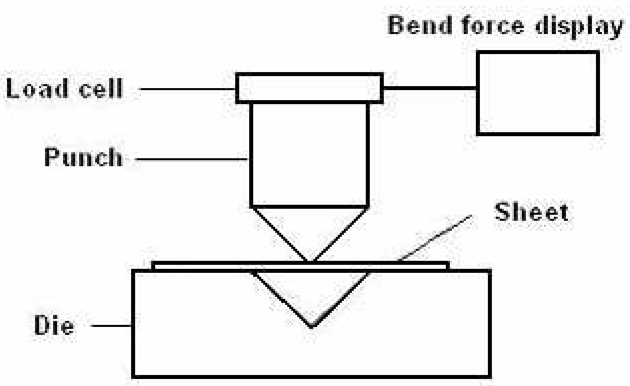

Fig. 1. Schematic of Experimental Setup

IV. RESULTS AND DISCUSSION

A. Analysis of the S/N ratio

Taguchi method employs signal to noise ratio (S/N ratio), ratio of the mean (signal) to the standard deviation (noise) as the quality characteristic. The S/N ratios normally used are lower the-better, larger-the-better, and nominal-the-best. As the responses considered are springback and bend force, the S/N ratio for these responses is smaller the better and is given by the equation,

$$S/N\,(dB) = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} Y_i^{2}\right) \qquad \text{Eq.1}$$

where i=1,2,3 … n and Y_i is the response value for an experimental condition repeated n times

TABLE III RESPONSE TABLE FOR SIGNAL TO NOISE RATIOS (SPRINGBACK)

Level	Number of holes	Sheet Thickness (mm)	Diameter of hole (mm)	Distance between holes (mm)
1	-13.01	-13.95	-14.72	-11.70
2	-12.21	-12.70	-12.85	-12.72
3		-11.18	-10.26	-13.40
Delta	0.80	2.76	4.46	1.69
Rank	4	2	1	3

TABLE III RESPONSE TABLE FOR SIGNAL TO NOISE RATIOS

(BEND FORCE)

Level	Number of holes	Sheet thickness mm)	Diameter of hole (mm)	Distance between holes(mm)
1	-40.62	-302.27	-42.38	-38.97
2	-37.80	-40.71	-39.62	-38.19
3		-44.66	-35.64	-40.47
Delta	2.82	12.39	6.74	2.27
Rank	3	1	2	4

The average S/N ratio for every level of each parameter was estimated and the values for the responses springback and bend force are listed in Table 3 and Table 4 respectively. From table 3 and table 4, based on their ranking the significance of factors for springback is in the order as diameter of the holes, sheet thickness, distance between holes, number of holes and for bend force, it is as sheet thickness, diameter of holes, number of holes, distance between holes.

B. Effect of factors on springback and bend force

Figures 2 and 3 show the variation of factors on the responses springback and bend force respectively. Springback decreases with increasing number of holes, increasing sheet thickness, increasing diameter of holes and decreasing distance between holes. Springback is induced by the elastic strain energy stored in the material. When number of holes or diameter of holes increases, the material available in the bending area for storing the strain energy decreases resulting in reduction of springback [1]. The increase in the distance between the holes increases the bending arm between holes, thereby increasing the bending moment. This increase in bending moment increases the springback. Bend force decreases with increasing number of holes, decreasing sheet thickness, increasing diameter of holes and decreasing the distance between the holes. The existence of holes decreases the bending zone area, thereby the force required for plastic deformation decreases. Hence increase in either size of hole or number of holes decreases the bend force.

C. Modelling By Regression Analysis

The mathematical models for springback and bend force are developed by regression analysis of the data collected using MINITAB 16 software.

Springback (Deg) = 7.83 - 0.370* Nh - 1.26* tc - 0.353* dh + 0.108* Dh

Bend force (N) = 70.2 – 19.1* Nh + 124* tc – 10.0* dh + 3.16* Dh

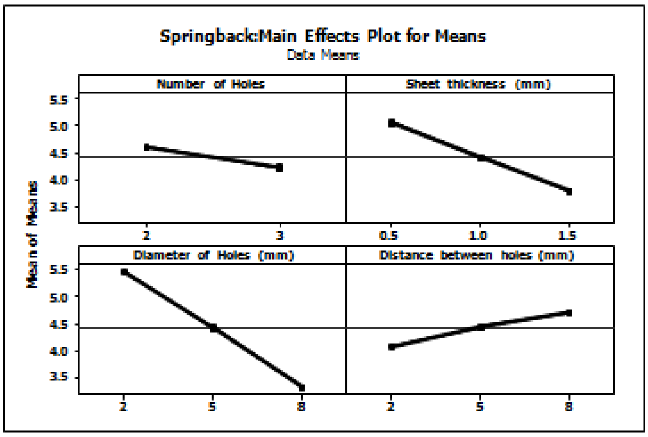

Fig. 2 Effect of factors on Springback

The results of the analysis of variance (ANOVA) of the proposed models are presented in Tables 5 and 6. The adequacy test of the proposed mathematical models has been performed by Fisher's variance ratio test (F-ratio test). As per this test, the calculated value of F ratio for the regression must be greater than its standard value for a desired level of confidence level. Since the estimated F value (939.78) is greater than the standard table value (3.18) for the springback model, it is assured that the springback model is adequate, at a confidence level of 95%, to represent the relationship between the springback and design parameters. In the case of the bend force model, as the estimated F value (15.699) is greater than the standard table value (3.18), it is certain that the bend force model is adequate at a confidence level of 95%. From the table 5 and table 6, the regression statistics values R2 and R2 are 0.9854 and 0.9752, respectively, for springback model and the values are 0.999 and 0.9985 respectively, for bend force

model. The R2 values are high and close to 1 for both response models and they are in close agreement with the respective R^2_{adj} values which are desirable.

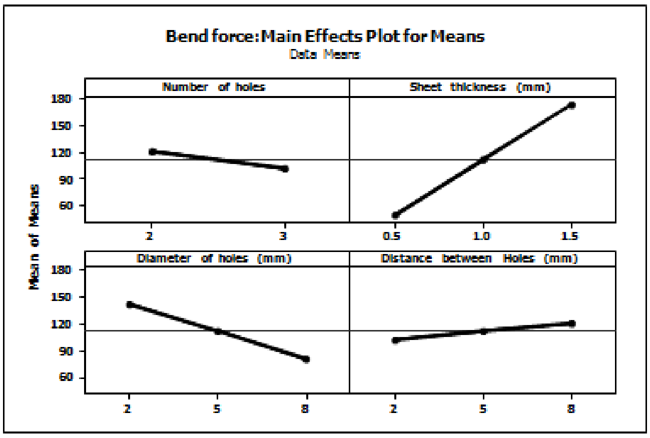

Fig. 3 Effect of factors on Bend Force

TABLE V
ANOVA FOR SPRINGBACK MODEL

Source	DF	SS	MS	F	P
Regression	4	20.1895	5.0474	939.78	0.000
Residual Error	13	0.0698	0.0054		
Total	17	20.2593			
R-Sq = 98.54%		R-Sq(adj) = 97.52%			

TABLE VI
ANOVA FOR BEND FORCE MODEL

Source	DF	SS	MS	F	P
Regression	4	59600	14900	15.699	0.000
Residual Error	13	12	1		
Total	17	59612			
R-Sq = 99.98%		R-Sq(adj) = 99.97%			

V. CONCLUSION

In this work, the effect of sheet thickness and hole parameters on springback and bend force is studied using Taguchi's method. The following conclusions are drawn from the study are:

- The increase in sheet thickness, diameter of holes, number of holes and decrease in distance between holes reduce the springback
- The decrease in sheet thickness and distance between holes reduces the bend force. The increase in number of holes and hole diameter decrease the bend force.
- Sheet thickness and hole diameter are the most significant factors influencing the springback and bend force.
- The regression models are developed and they are found to be adequate for predicting the springback and bend force.

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