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DESIGN PARAMETERS SELECTION OF SPRINGBACK EFFECT IN AIR-V BENDING USING TAGUCHI APPROACH ON ADVANCE HIGH STRENGTH STEEL-DP590

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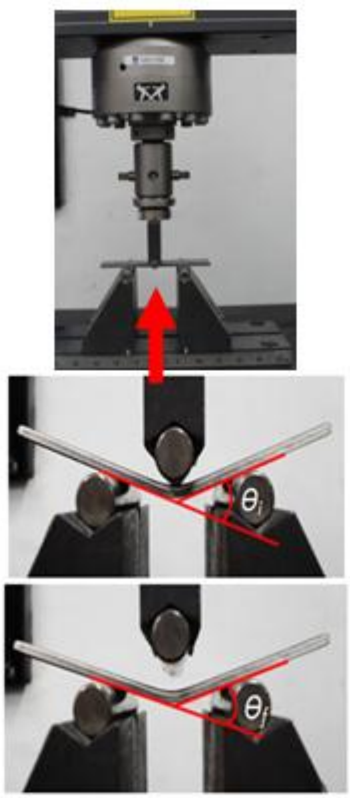
Graphical abstract



Abstract

Advanced High Strength Steels (AHSS) are increasingly utilized especially in automotive industry. However, forming of AHSS is challenging particularly in prediction of springback effect caused by material properties, tools and dies parameters, work material and bending technique factors. An air V-bending process was chosen as an evaluation problem because it showed larger springback effect. This paper presents an optimization to predict the influence of various parameters on springback of sheet metal in air V-bending process using Taguchi method (TM). The experimental study was conducted on DP590 sheets with plate thickness of 1 and 2 mm under different process parameters such as punch radius, die radius, die gap and punch travel. A significant level of springback parameters was further described by using the analysis of variance (ANOVA). It showed that the contribution percentage of each factor to springback was calculated to optimum level and the significant levels of entire factor were observed. The thickness of material, die width, punch travel and punch radius were found to be the most significant factor affecting springback while die radius is insignificant.

Keywords: Taguchi method, Springback, Air V Bending, Advance High Strength Steel-DP590

1.0 INTRODUCTION

Advanced High Strength Steels (AHSS) have a higher strength, high formability and have superior mechanical properties. These steels are characterized by improved formability and crash worthiness as compared to conventional steel grades [1]. In sheet metal forming process of automotive components, springback effect is a common phenomenon effecting dimensional inaccuracy, in particular for DP590 material [2]. Prediction of springback in bending of dual phase of different grades such as DP590 is becoming increasingly importance because this material is now widely used in automotive industries to decrease vehicle weight and structural parts of new vehicle with a good acceptance. Air bending technique [3] is used to improve flexibility and efficiency of the bending process to meet good quality output with shorter lead time. In air bending, a number of different bend angles can be produced using the same set of tools simply by controlling the punch travel [4].

Springback occurs in various forms like torsion, bending, twisting and is known to have many affecting factors such as sheet thickness, punch travel, punch radius, lubricating condition and orientation, etc. In recent years, design of experiment (DoE) is widely used in predicting the springback effect in research fields in order to optimize the input process parameters and the output variables that lead to the desired quality. Therefore, it is important to select the suitable process parameters for obtaining the minimized springback. Various industries have employed the Taguchi method [5] over the years to improve products or manufacturing processes. Narayan and Sawale [6], investigated the springback effect in aluminium sheet using Taguchi approach. M. S. Buang et al. [7] also implemented the DOE and Taguchi method to study effect of die gap and punch travel on springback in air v-bending process.

In this study, Taguchi's L_{32} (2^5) orthogonal array was applied and five controlling factors; thickness, die width, punch travel, die radius and punch radius with two level for each factor were selected into designing the experiments. Springback is selected as a response. The smaller the better signal-to-noise ratio analysis were implemented base on TM an optimal parameter setting was identified. A significant level of the springback parameters was further described by using analysis of variance (ANOVA).

2.0 EXPERIMENTAL

Advances High Strength Steel (AHSS) grade dual phase (DP590) steel sheets provided by OSI Sdn. Bhd. Shah Alam were cut to the required dimension of 120mm × 30mm × 1mm and 120mm × 30mm × 2 mm as work material for air-V bending. Hydraulic shear cutting machine was use to cut the material and the edges were cleaned to removed the burrs. The bending tool set consists of punch and lower dies which made of hardened steel. Two different radiuses of 5mm and 9 mm were fabricated for punch and lower dies radius, respectively. The air-V bending test was conducted on universal testing machine (UTM) with a maximum capacity of 100 kN Instron machine.

The tooling setup for the experiments is shown in Figure 1(a) where the specimens were placed on an Inston machine. The specimens were bent by moving the punch slowly to the required depth with velocity of 45 mm/min. The bending angle in air V bending process during loading (θ_i), and unloading (θ_f), are shown in Figure 1(b) and (c). Two methods were taken to measuring the springback angle before unloading and after unloading. Digital camera Canon D700 was used to capture the picture of the profile angle in position during loading for the first method. The picture was then converted into digitized images and imported to SolidWork2010 software. The line was drawn on the edges of the specimen images and angle line icon was selected to get the expected angle using the software. Meanwhile in the second method, Mitatoyo digital profile projector was used to measured the angle after unloading process.

(a)
(b)
(c)

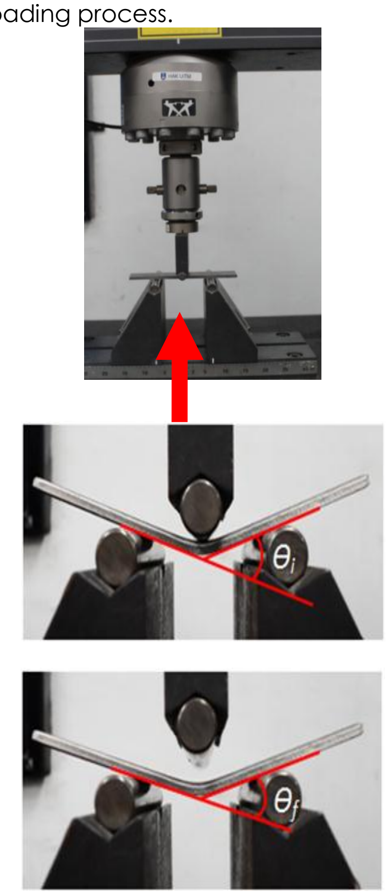


Figure 1 (a) Instron UTM setup with tooling (b) bending angle during loading, θ_i and (c) bending angle after unloading, θ_f

2.1 Taguchi Method

The Taguchi method defines three different forms of mean square deviations (i.e., signal-to noise ratios) including the nominal-the-better, the larger the-better and the smaller-the-better which depending on the objectives of the analysis. The signal-to-noise ratios can be considered as an average performance characteristic value for each experiment. As the objective of this paper was to minimize the springback angle ($\Delta\theta$) within the optimal levels of factor, the Taguchi method smaller-is-better for signal to noise (S/N) ratio was chosen based on equation below[8]:

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

where y_i is the process response or collected data through experiments, while n represent the number of experimental runs.

2.2 Design of Experiment approach.

The most important process of the DOE is determining the independent variable values at which a limited number of experiments will be conducted. DoE can broadly be classified into two categories; full factorial and fractional factorial designs so that the conducted experiments can produce more consistent results. Orthogonal arrays are a set of tables of numbers, each of which can be used to lay out experiments for a number of experimental situations. The DOE technique based on this approach makes use of these arrays to design experiments. The orthogonal arrays are determined by the number of factors and levels considered in the process. They are usually described in the form **$L_{32}(2^5)$**, where 32 denotes the number of fractional experiments, 2 is the number of levels, and 5 is the number of factors.

In the present work, experimental work has been design in a sequence of step to ensure data obtained in valid statistical inferences. 5 input parameters that affected springback were considered in the design of experiment and analysis. The process parameters with type two level design using L_{32} (2^5) orthogonal array were selected and presented. The value of the process parameter that affects the springback in bending process at the different level is tabulated in Table 1.

Table 1 Bending process parameters and their respective level of DOE

Number	Process Parameters	Unit	Level	
			Low (-1)	High (+1)
1	Die Radius (R_d)	mm	5	9
2	Punch Radius (R_p)	mm	5	9
3	Die Width (W_d)	mm	50	70
4	Punch Travel (T_p)	mm	15	20
5	Thickness (T)	mm	1	2

3.0 RESULTS AND DISCUSSION

3.1 Analysis of springback

The springback is calculated as the different between the bent angle after the removal load and during loading. Springback amount can be calculated by a springback angle ($\Delta\theta$), using the following equation:

$$\Delta\theta = \theta_i - \theta_f \qquad (2)$$

where (θ_i) angle during loading and (θ_f) angle after unloading. The commercial software MINITAB 16 was used to calculate the ANOVA to analyze the data and to find the mean values S/N ratio for springback angle. The experimental L_{32} (2^5) orthogonal array design and the S/N ratio results were calculated from Eq. (2). The results were analyzed by using main effect plot of S/N ratio, smaller-is-better of each parameter to springback values, response data in S/N ratio and ANOVA analyses.

3.2 Estimated effects and coefficients of model and their significance.

From the experimental, data were analyzed and effects and coefficients SN ratios were estimated and their *p*-values for springback are listed in Table 2. The coefficients of *p*-value less than 0.05 are considered as significant (95% confidence level). From Table 2 also, it is found that the coefficients of parameters that affect springback are thickness of the material, punch radius, die width and punch travel are significant with the *p*-values 0.000, 0.001, 0.000 and 0.000 respectively. Meanwhile, die radius is insignificant factor with p value is 0.777. Further, the regression statistics value R^2 and R^2 *(adj)* values are 0.975 and 0.970, respectively for springback model. The R^2 value is high and close to 1 and close agreement with R^2 *(adj)* values indicate that the model is highly significant.

3.3 ANOVA

The result of ANOVA and response result for S/N ratio smaller-is-better is represented in Table 3. Analyzing the percentage contribution of each factor on the springback can understand the relative importance of each factor. The percentage contribution of each factor to springback is calculated using Equation bellow:

$$P_i = (SS_i / SS_{total})*100 \tag{3}$$

where P_i is percentage contribution of each factors, SS_i is sum of square of each factors and SS_{total} is total sum of square. The model shown that the contribution of thickness of the material, punch radius, die radius, die width and punch travel to springback is 97.5 % of the total variation from 2.5 % residual error. The order of strong factors influencing springback is as follows with ranking: Thickness (*t*) (75.27%), follow W_d (15.34%), T_p (5.49%), R_p (1.37%) and lastly R_d (0.008%). Main effects plot for means, for each parameter to springback shown in Figure 2.

From the figure, it is clearly observed that the thickness of the material significantly affected springback angle as compared to another factor. The total mean of S/N ratio was calculated as -11 dB as shown by a straight line at the middle on the graphs. From this figure also shows the optimum levels for each input bending variable. It have been observed that the springback decrease with increasing the thickness. The optimum variable of thickness is 2 mm. The optimum level for punch radius, die width, punch travel and die radius are 5mm, 50mm, 15mm and 5mm, respectively.

Table 2 Estimated Effects and Coefficients SN ratios and their *p*-values for Springback

Term	Coefficient	SE Coef.	Term	*p value*
Constant	-21.9739	0.07525	-292.022	0.000
Thickness	-2.0933	0.07525	-27.819	0.000
Punch Radius	0.2806	0.07525	3.729	0.001
Die Radius	0.0216	0.07525	0.287	0.777
Die Gap	0.9447	0.07525	12.555	0.000
Punch Travel	0.5655	0.07525	7.515	0.000
S = 0.4257	R^2 = 97.5%	R^2 *(adj)* = 97.0%		

Table 3 ANOVA and response result for S/N ratio smaller is better

Factors	Deg. of Freedom	Sum of Seq	Mean of Seq	F	P	Contribution %	Mean S/N ratio (dB)		
							Level 1 -	Level 2 +	Rank
Thickness (*t*)	1	140.2	140.2	773.90	0.000	75.27	-24.07	-19.88*	1
Punch radius *(Rp)*	1	2.519	2.519	13.90	0.001	1.35	-21.69*	-22.25	4
Die radius *(Rd)*	1	0.015	0.015	0.08	0.777	0.008	-21.95*	-22.00	5
Die gap *(Wd)*	1	28.562	28.562	157.63	0.000	15.34	-21.03*	-22.92	2
Travel *(Tp)*	1	10.234	10.234	56.48	0.000	5.49	-21.41*	-22.54	3
Residual Error	26	4.711	0.181			2.5			
Total	31	186.26				100			

***Optimum level**

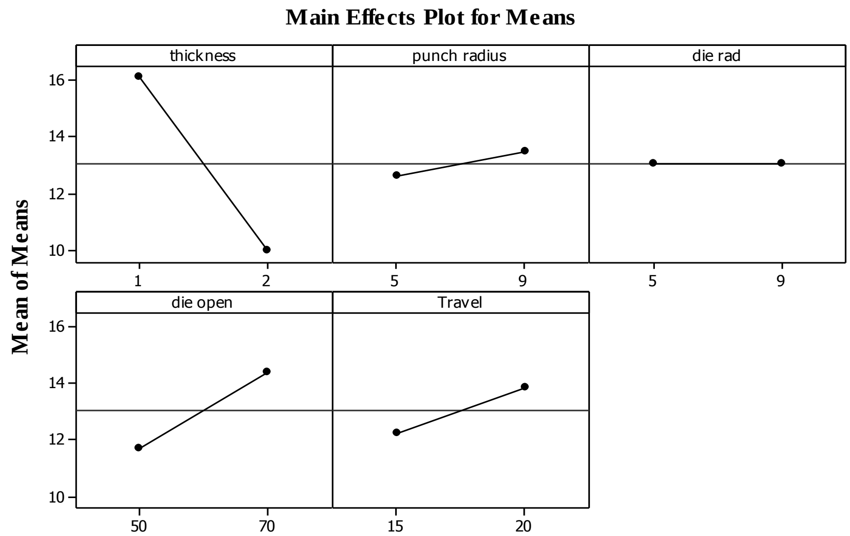


Figure 2 Main effects plot for Means of each parameter to springback

4.0 CONCLUSION

This paper discusses on the experimental results on the effect of thickness of the material, punch radius, die width, die radius and punch travel on springback in air V-die bending process for DP590 material sheet using Taguchi method based on L_{32} (2^5) Taguchi orthogonal array design. With these experiments, we upgraded our existing knowledge about the influence of the different process parameters on springback. With the Taguchi method, the optimum levels was obtained with the smallest value of springback and statistically significant level factors affecting springback have been determined.

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