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Optimization of Springback Prediction in U-Channel Process Using Response Surface Methodology

Muhamad Sani Buang, Shahrul Azam Abdullah, Juri Saedon

Abstract**—**There is not much effective guideline on development of design parameters selection on spring back for advanced high strength steel sheet metal in U-channel process during cold forming process. This paper presents the development of predictive model for spring back in U-channel process on advanced high strength steel sheet employing Response Surface Methodology (RSM). The experimental was performed on dual phase steel sheet, DP590 in U-channel forming process while design of experiment (DoE) approach was used to investigates the effects of four factors namely blank holder force (*BHF*), clearance (*C*) and punch travel (*Tp*) and rolling direction (*R*) were used as input parameters using two level values by applying Full Factorial design (2^4). From a statistical analysis of variant (ANOVA), result showed that blank holder force (*BHF*), clearance (*C*) and punch travel (*Tp*) displayed significant effect on spring back of flange angle (β_2) and wall opening angle (β_1), while rolling direction (*R*) factor is insignificant. The significant parameters are optimized in order to reduce the spring back behavior using Central Composite Design (CCD) in RSM and the optimum parameters were determined. A regression model for spring back was developed. The effect of individual parameters and their response was also evaluated. The results obtained from optimum model are in agreement with the experimental values.

Keywords**—**Advance high strength steel, U-channel process, Springback, Design of Experiment, Optimization, Response Surface Methodology (RSM).

I. Introduction

ADVANCE High Strength Steel (AHSS) have a higher strength, high formability and superior mechanical properties. AHSS steels are characterized by improved formability and crash worthiness as compared to conventional steel grades. Lightweight materials of AHSS such as Dual Phase steel of different grades such as DP590 is becoming increasingly importance because this material is now widely used in automotive industries to decrease the weight and structural parts of new vehicle with a good acceptance. AHSS are currently used in modern automotive structure due to their best combination of metallurgical and physical properties and it can be alternative material to replace other materials such as aluminum, high strength low alloy and mild steel to produce various structural body and parts of automotive.

The improvement of these steel can present higher strength to weight ratios for structure parts. AHSS by characterization have larger material yield stress where it requires higher force to form parts and tend to be anisotropic in nature. During the bending process, bend force is needed to deform the sheet metal to the required degree. Without sufficient formability qualities, defects such as wrinkling, fracturing, thinning and springback might occur, whether during loading or unloading tools set after sheet metal forming process.

One of the major issues with AHSS as stamped automotive structural members is the tendency to have large amount of Springback due to high yield strength and tensile strength. Springback is the phenomenon in which the material strip unbends itself after forming process. This is due to the elastic recovery of internal stresses during unloading where the formed part has a tendency to return to its original shape. The amount of Springback effect generally influenced by various factors namely material properties, die properties, process condition, bulk properties of work material and bending technique. It reduction is an important issue in sheet metal forming industry.

Over the last decades, many researchers have studied the influence of process parameters on springback to determine their controlling factors and ways to minimize it. N. Woellner et al. [1] studied the influence of blank holder force on the phenomenon springback of AHSS. It was reported that steel with higher mechanical strength showed large springback and higher blank holder force can reduce the problem of springback. Zhang and Lee [2] investigated the influence of blank holder force, blank thickness, strain hardening exponent and yield strength on the magnitude of the final springback strain in a part. Seo et al. [3] investigated the characteristics of springback for various process conditions included punch radius, die radius and temperature of the U-draw bending operation. Carden et al. [4] investigated the effect of die radius and thickness of blank sheet and propose greater R/t ratio to get smaller springback.

Some researcher also reported the use of FE simulation model to predict the springback effect. Cho et al. [5] investigated on spring-back and sidewall curl characteristics in sheet metal U-bending process using finite element. Samuel [6] proposed robust method of predicted springback and side wall curls in 2D operations under plane strain stretching, bending and unbending deformations. Chen et al. [7], Panthi et al. [8] and Chen et al. [9] found that simulation approach provides a rapid and accurate understanding of the influence of the random process variations on the springback variation of the formed part using FEA techniques eliminating the need for lengthy and costly physical experiments.

In order to compensate springback and to improve the shape accuracy of stamped parts, various optimization methods can be applied to define the desired output variables through

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development of mathematical models to specify the relationship between the input parameters and output variables. One of the optimization methods is Design of Experiment (DoE). To ensure that an experiment is conducted effectively, statistical experimental design is generally recommended where appropriate data can be recorded and statistically analyzed for valid conclusions to be drawn. Statistical technique such as factorial design, Response surface Methodology (RSM) and Taguchi Method (TM) can make the number of necessary experiments reduced and the significance of parameters can identified. In the recent years, RSM has been useful in modeling various prediction parameters influencing springback in sheet metal forming process. Srinivasan et al. [10] applied response surface methodology for predicting springback in air bending of electro galvanized steel sheets. Asgari et al. [11] used design of experiments and springback prediction for AHSS automotive components with complex geometry to study the sensitivity of the implicit and explicit numerical results with respect to certain arrays of user input parameters. Bahloul et al. [12] applied response surface methodology for optimization springback predicted by experimental and numerical approach. Therefore, it is understood that RSM can be very well used to model a particular sheet metal forming and bending processes.

In this work, the main objective is to find the optimum parameters and to develop prediction model for springback effect of AHSS namely DP590 in U-channel process which can improve the sheet metal forming processes and in particular sheet metal bending based on the use of experimental design and response surface techniques. It started with selecting of independent variables of the major effects that influencing the response through screening studies and choosing their upper and lower limits using (2^4) factorial design method as the first optimization step. At the second step of optimization, an experimental design is developed and according to the selected experimental matrix and the responses were recorded. The data will be analyzed which included regression analysis, model adequacy checking, conducting the confirmation experiments and the effect of process parameters on response [13]. In this investigation, MINITAB 16 software has been used for development of the RSM model.

II. Experimental Set-Up and Procedures

A. Experimental Set-up

The material used in this experimental is DP590 steel provided by JFE SHOJI Steel Malaysia Sdn. Bhd. The specimens dimension used in this experiment were (120 mm long x 30 mm wide) cut along the rolling direction and the edges were ground to remove the burrs. The sheet thickness of material used in this study was 2 mm. Sample for tensile test was cut in accordance to the required dimension of 50 mm gauge length and 12.5 mm wide based on standard test methods and definitions for mechanical testing of steel products according to the American Society for Testing and Materials (ASTM A370-12a). Tensile test were carried out using universal testing machine (UTM) with a maximum capacity of 100 kN Instron machine with stretching velocity 2 mm/min, and experiments data for mechanical properties were obtained by the automatic signal acquisition system. The mechanical properties and chemical composition of DP590 steel is shown in Table I.

TABLE I
MECHANICAL PROPERTIES AND CHEMICAL COMPOSITION OF DP 590

Percent composition (in wt.%)		Yield strength (MPa)	Tensile Strength (MPa)	Elastic Modulus, E (GPa)	% Elongation
C	0.09				
Si	0.28				
Mn	1.01	349	623	200	3.4
P	0.01				
S	0.01				
Cr	0.02				
Ni	<0.02				

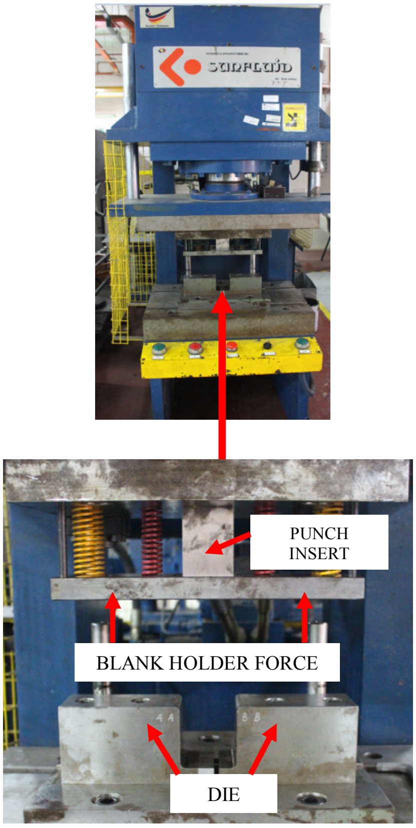
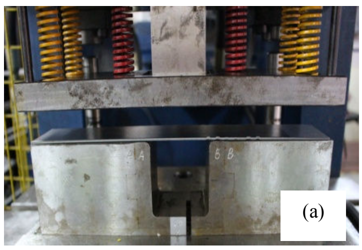


Fig. 1 Experimental stamping apparatus



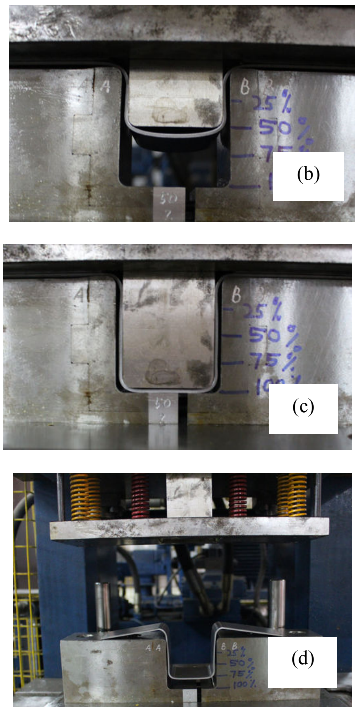


Fig. 2 The process sequence photographed during the experiments deep drawing process of Advance High Strength Steel (DP590): (a) Initial position, (b) intermediate phase, (c) bottoming position, (d) Specimen after springback

The experimental of U-channel bending process for the specimens was done using the Sunfluid hydraulic stamping machine with capacity 100 tonne. A specialized experimental apparatus was designed and constructed to experimentally investigate springback in DP590. The apparatus is shown in Fig. 1 which consists of a blank holder force, die and punch insert. DP590 steel sheet specimen is placed on the anvil of the die in correct position before load applied to punch insert to form of deep drawing forming process until it bent into the required depth. At the same time, blank holder force is lowered to hold the specimen. The amount of force applied on the blank holder is measured by spring pressure located at the top of the holder and the force in the blank holder is controlled by hydraulic pressure.

The punch automatically reversed and specimen with U-rail shape is removed from the die when punch insert traveled and reached at the specified stroke. The experiments deep drawing forming process of U-channel bending shape of specimen are illustrated in Fig. 2.

Measurements of springback angle were taken on the formed part using CAD software method. Digital camera was used to capture the picture of the profile angle after unloading. The picture was converted into digitized images. The digitized images were then imported to SolidWorks version 2010 software. The line was drawn on the edges of the specimen images and angle line icon was select to get the expected angle using the software. Mitatoyo Coordinate Measuring Machine (CMM) was also used to check the final measurements. The coordinates of the point for U-channel shape were taken and analyzed to calculate the springback parameters such as wall opening angle (θ_1), flange angle (θ_2) and sidewall curl radius (ρ).

B. Springback U-Channel Measuring Method

A schematic view of U-channel drawing test has been proposed as a springback benchmark test [14] as shown at Fig. 3. Figs. 3 (a) and (b) show details of the actual geometry investigated in the experimental analyses to measure springback.

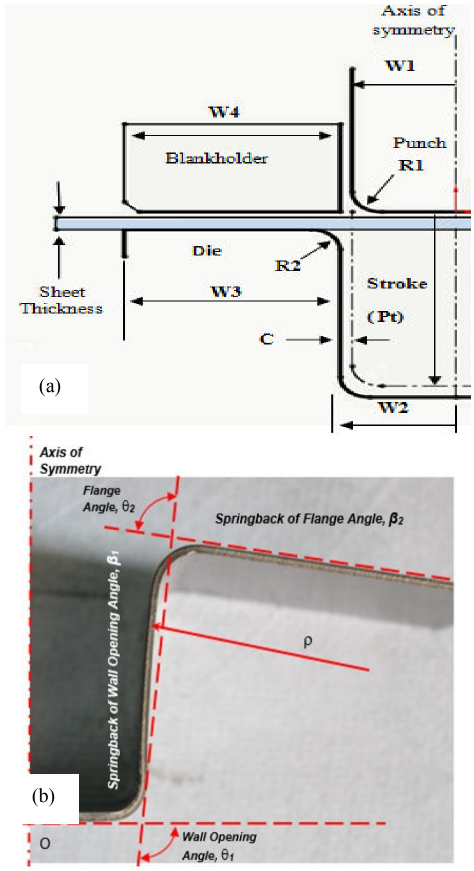


Fig. 3 (a) Schematic view of tools and (b) geometry to measure springback

TABLE II
DIMENSIONS FOR THE 2-D DRAW BNEDING TEST (UNIT IN MM)

Parameters	W1	W3	W4	R1	R2
Dimensions	25	125	100	5	5
Parameters	C	Stroke (Pt)	W2		
Dimensions	Variable	Variable	Variable		

Dimensions of the original 2-D draw bending test were accommodate to the variable values of parameters is shown in Table II. In this paper, only two measurements, namely the springback of wall opening angle (β1) and the springback of flange angle (β2), shown in Fig. 3 (b) were used to characterize the total springback considering only the crosssectional shape of formed parts obtained before and after the removal of punch tool. The equations needed for the calculation of the β_1 and β_2 is as in (1):

$$\beta_1 = \theta_1 - \theta_1^o$$

$$\beta_2 = \theta_2^o - \theta_2 \tag{1}$$

where the wall angle (θ_1^o) and flange angle (θ_2^o) before springback. Meanwhile the wall angle (θ_1) and flange angle (θ_2) after springback. Meanwhile, the sidewall culr radius (ρ) is not taken into account for the calculation of the springback effect in this paper.

C. Factorial Design of Important Factors

In general, factorial designs are most efficient design to prediction springback effect of two or more factors on a response. This study was done for screening medium components with respect to their main effects and not their interaction effects [15]. In order to conduct the experiment, the level of parameters must be known. The reason for finding 2 different levels for experimenting is followed by 2^k factorial design that requires each factor to have 2 levels. In this investigation on the predictive model for springback in U-channel process of AHSS DP590 steel sheet, four process parameters with two levels were used by applying Full Factorial design (2^4). The following four process parameters considered were: the rolling direction (anistropic) of material (*R*), blank holder force (*BHF*), clearance (*C*) and punch travel (*Tp*) within the low and high level presented in Table III. The low and high levels of these parameters are coded as -1 and +1 respectively.

D. Response Surface Methodology (RSM)

RSM is a collection of mathematical and statistical techniques useful for modeling and analysis of problems which provides a relationship between the response (*Y*) and the several input of variable (x_i) is given in (2):

$$Y = f(x_1, x_2, x_{3,....} x_n) + \varepsilon \tag{2}$$

If the expected response shown by;

$$(Y) = f(x_1, x_2) = \eta$$

Then the surface represented by

$$\eta = f(x_1, x_2 .... x_n) + \varepsilon \tag{3}$$

where η is the response, f is the unknown function of response, x_1, $x_2 .... x_n$ donate the independent variables, also call natural variables, n is the number of independent variables and finally ε represents an error observed in the response η.

The model used in RSM is generally a full quadratic equation which corresponds to the second order polynomial, which is adequate. The second order model can be written as:

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \Sigma \sum_{i<j} \beta_{ij} x_i x_j + \varepsilon \tag{4}$$

where β_0, β_i, β_{ii}, and β_{ij} are regression coefficients for intercept, linear, quadratic and interaction coefficients respectively, Y is dependent variable or the response, x_i and x_j are independent variables in coded unit. Commonly, the equation for coding is seen below:

$$X = \frac{x - (x_{high} + x_{low})/2}{(x_{high} - x_{low})/2} \tag{5}$$

where X is the coded value, x is the natural variable, while x_{high} and x_{low} are the high and low values of the natural variables respectively.

TABLE III
PARAMETERS AND LEVELS APPLIED IN 24 FACTORIAL DESIGN

Parameters	Symbols	Units	Level	
			-1	+1
Rolling direction	(R)	degree	22.5	67.5
Blank holder force	(*BHF*)	kN	10	20
Clearance	(*C*)	mm	2	3
Punch Travel	(*Tp*)	mm	45	55

III. RESULT AND DISCUSSION

A. Screening Using Factorial Design of Operating Parameters.

The design matrix and the result of four process parameters, 2 level values, (2^4) full factorial design or 16 run numbers specimen of test were performed to cover all possible combinations are given in Table IV. In this experimental design matrix, the springback of wall opening angle (β1), the springback of flange angle (β2), are the process responses. In order the conduct the experiment, MINITAB 16 software has been used. The ANOVA technique was also applied to illustrate the degree of significant of each process parameters that most influenced the springback in the U-channel process. The significance level of the factor refers to the statistical *p*-value. The *p* value for this case is at the 5% level of significance (95% confidence level). If *p* value is small (< 0.05), it indicates that the power level has statistically significant effect on the responses. The result of estimated effects and coefficients of *p* value from the analysis for springback are listed in Table IV. The significant effect for each parameter evaluated by a normal probability plot standardized effect to springback is shown in Figs. 4 and 5. From Figs. 4 and 5, it was observed that the parameters such as punch travel (A), blank holder force (B), clearance (C) and interaction punch travel and blank holder force (AB) are significance factors affecting to springback. These factors were selected for the second step of optimization. Meanwhile, the analysis shows that the rolling direction (D) is insignificance factor.

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B. Development of Experimental Design Matrix

Optimization of the significant parameters affecting the springback in U-channel process obtained from the screening medium using factorial experiment design was carried out using central composite design (CCD) and RSM. From the screening method, the rolling direction factor was not significant; therefor RSM was used to fit a second order polynomial model using (4). Meanwhile the actual and the coded values of design variable of the process parameters are obtained from the (5). Table V shown the parameters studied (-α, -1, 0, +1, α) in CCD, where levels -1 and +1 represent the low and high values, -α and α indicate the low and high extreme values, and 0 is the center value of each parameter. The value of Alpha (α) is given as 1.68179 for two levels full factorial from CCD.

The experimental design matrix used was 5 level, 2^3 full factorial design with 8 cube points (standard order 1 – 8), 6 axial points (standard order 9 – 14) and 6 replicates at the center point (standard order 15 – 20) with a total number of 20 experiments were conducted in the present study.

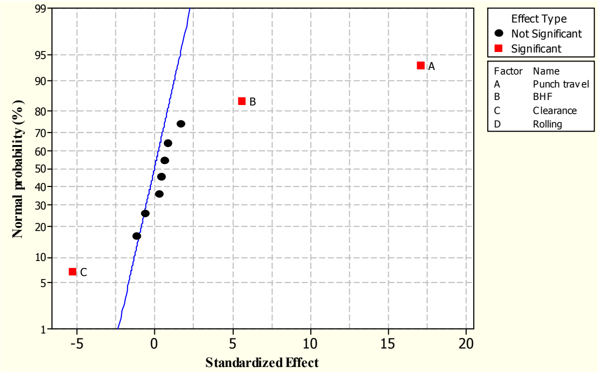


Fig. 4 Normal probability plot of standardized effect for springback angle of wall opening

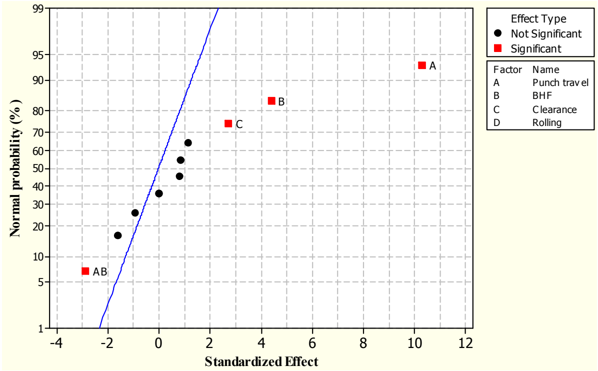


Fig. 5 Normal probability plot of standardized effect for springback angle of Flange

The experimental design matrix and results of CCD with 3 parameters and the responses is given in Table VI. This 20 experimental runs establish the mathematical relation of the response surface model for springback by estimating the linear, quadratic and interactive terms of the process variable.

TABLE IV
DESIGN MATRIX AND EXPERIMENTAL RESULTS OF RESPONSES

Standard Order	Run Order	Parameters				springback of wall opening angle	springback of flange angle
		A	B	C	D	β1(°)	β2(°)
2	1	10	2	55	22.5	3.2	3.36
3	2	20	2	45	22.5	2.3	2.6
4	3	20	2	55	22.5	3.5	3.1
16	4	20	3	55	67.5	3.44	3.7
13	5	10	3	45	67.5	1.5	2.3
5	6	10	3	45	22.5	1.6	2.1
7	7	20	3	45	22.5	1.9	2.75
11	8	20	2	45	67.5	2.35	2.5
10	9	10	2	55	67.5	3.33	3.3
15	10	20	3	45	67.5	2	2.9
8	11	20	3	55	22.5	3.3	3.6
1	12	10	2	45	22.5	1.9	1.5
12	13	20	2	55	67.5	3.53	3.9
6	14	10	3	55	22.5	2.9	3.4
9	15	10	2	45	67.5	2.1	1.4
14	16	10	3	55	67.5	2.5	3.5

A: blank holder force (kN); B: clearance (mm); C: punch travel (mm); D: rolling direction (°)

TABLE V
PARAMETERS AND LEVEL APPLIED IN CCD

Parameters	Symbols	Units	Level				
			-α	-1	0	+1	α
Blank holder force	*(BHF)*	kN	6.59	10	15	20	23.41
Clearance	*(C)*	mm	1.65	2	2.5	3	3.34
Punch Travel	*(Tp)*	mm	41.59	45	50	55	58.41

TABLE VI
DESIGN MATRIX AND EXPERIMENTAL RESULTS OF RESPONSES

Standard Order	Run Order	Parameters			Springback of wall opening angle	springback of flange angle
		A	B	C	β1(°)	β2(°)
6	1	20	2	55	3.24	4.37
10	2	23.41	2.5	50	2.65	4.00
16	3	15	2.5	50	3.03	3.25
7	4	10	3	55	3.68	3.77
20	5	15	2.5	50	3.02	3.26
17	6	15	2.5	50	3.04	3.27
8	7	20	3	55	3.17	4.59
18	8	15	2.5	50	3.02	3.25
4	9	20	3	45	2.29	3.05
19	10	15	2.5	50	3.01	3.26
2	11	20	2	45	2.37	2.11
15	12	15	2.5	50	3.00	3.28
12	13	15	3.34	50	2.95	3.34
1	14	10	2	45	2.48	2.1
9	15	6.59	2.5	50	3.15	2.50
3	16	10	3	45	2.40	2.38
5	17	10	2	55	3.70	3.54
11	18	15	1.65	50	3.22	2.93
14	19	15	2.5	58.41	3.34	4.7
13	20	15	2.5	41.59	1.82	1.8

C. Regression Model

The estimation coefficients (Coef) of each variable term in a regression model for springback of wall opening angle (β_1) and the springback of flange angle (β_2). The probability *(p)* values determined as 5% significant level from the analysis for springback are shown in Table VII. It was showed that the variable terms with $p<0.05$ are *A, B, C,* C^2 and A×C which are considered statistically significant for springback of wall opening angle (β1), while for the springback of flange angle (β2), the significant variable are A, B, C and A×C. This experimental result suggests that these variables strongly affect the springback. Therefore, a second–order model was built to describe the behavior of each response, followed by the optimization stage to find the best setting for ach factors. The final mathematical of second-order model for springback of wall opening angle (β_1) and the springback of flange angle (β_2) were subjected to analysis of variance with regression model given in term of factors are given in (6) and (7), respectively:

Springback of wall opening angle (β_1):

$$\begin{aligned} Y_1 &= 3.02025 - 0.18190A - 0.09165B \\ &+0.50791C - 0.03491A^2 + 0.04228B^2 \\ &-0.10975C^2 + 0.01208AB - 0.07042AC \\ &+0.03292BC \end{aligned} \tag{6}$$

Springback of flange angle (β_2):

$$\begin{aligned} Y_2 &= 3.26075 + 0.59731A + 0.28934B \\ &+1.41748C + 0.00688A^2 - 0.10979B^2 \\ &+0.00521C^2 + 0.23099AB + 0.34413AC \\ &-0.27106BC \end{aligned} \tag{7}$$

where A, B, and C are blank holder force, clearance and punch travel.

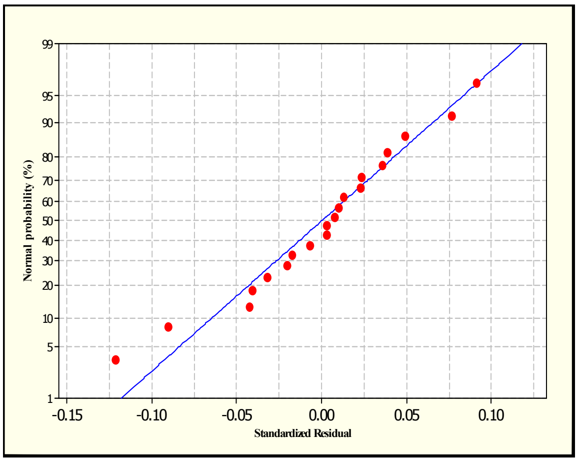
TABLE VII
ESTIMATED COEFFICIENTS OF THE REGRESSION MODEL FOR SPRINGBACK

Term	Coef	SDcoef	t-Start	P
Springback of wall opening angle β_1(°)				
Constant	3.02025	0.02751	109.773	0.000
A	-0.18190	0.01825	-9.965	0.000
B	-0.09165	0.01825	-5.021	0.001
C	0.50791	0.01825	27.824	0.000
AxA	-0.03491	0.01777	-1.965	0.078
BxB	0.04228	0.01777	2.379	0.039
CxC	-0.10975	0.01777	-6.176	0.000
AxB	0.01208	0.02385	0.507	0.623
AxC	-0.07042	0.02385	-2.952	0.014
BxC	0.03292	0.02385	1.380	0.198
Springback of flange angle β_2(°)				
Constant	3.26075	0.05232	62.325	0.000
A	0.59731	0.05838	10.232	0.000
B	0.28934	0.05838	4.956	0.001
C	1.41748	0.05838	24.281	0.000
AxA	0.00688	0.09558	0.072	0.944
BxB	-0.10979	0.09558	-1.149	0.277
CxC	0.00521	0.09558	0.055	0.958
AxB	0.23099	0.12828	1.801	0.102
AxC	0.34413	0.12828	2.683	0.023
BxC	-0.27106	0.12828	-2.113	0.061

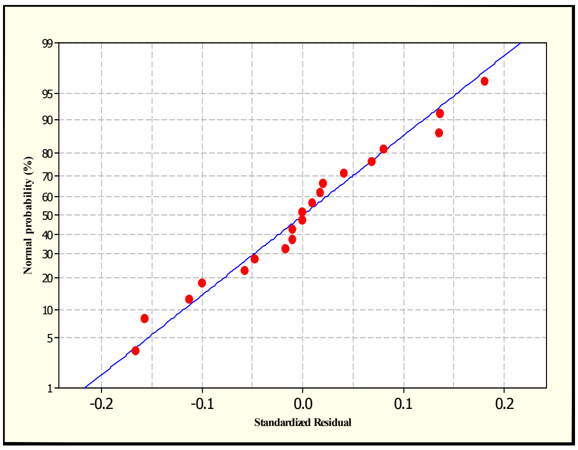
A: blank holder force (kN) B: clearance (mm) C: punch travel (mm)

D. Checking the Adequacy of the Developed Models

The adequacy of the model was checked using analysis of variance (ANOVA) and the results are shown in Table VIII. The regression model of springback for wall opening angle (β_1) (6) and the springback for flange angle (β_2) (7) were calculated using of MINITAB (Version16) software. To test the global fit of the model, the regression statistics values (R^2) were evaluated. The R^2 and R^2_{adj} values are 0.9897 and 0.9804, respectively, for springback of wall opening angle (β_1) and the values are 0.9866 and 0.9745, respectively, for springback of flange angle (β_2) model. The second-order model obtained for the springback of wall opening angle (β_1) and the springback of flange angle (β_2) are satisfied since the values of R^2 are high and close to 1 and it is close agreement with R^2_{adj}, which is desirable [16]. The adequacy of model was also examined from the normal probability plot of standardized residuals as shown in Figs. 6 (a), (b). From the figures, all points cluster along the straight line which indicates that the errors are distributed normally [17].



(a)



(b)

Fig. 6 Normal probability plot of standardized residuals: (a) springback of wall opening angle (β_1); (b) springback of flange angle (β_2)

TABLE VIII
ANOVA OF THE REGRESSION MODEL

Source	DF	Seq SS	F	P
Springback of wall opening angle				
Regression	9	4.36616	106.60	0.000
Linear	3	4.08972	299.56	0.000
Square	3	0.22693	16.62	0.000
Interaction	3	0.04950	3.63	0.053
Residual error	10	0.04551		
Lack-of-Fit	5	0.04483	65.60	0.000
Pure error	5	0.00068		
Total	19	4.41166		
R-sq 0.9897	R adjusted-sq 0.9804		R predicted-sq 0.9225	
Springback of flange angle				
Regression	9	12.0964	81.68	0.000
Linear	3	11.8284	239.60	0.000
Square	3	0.0227	0.46	0.717
Interaction	3	0.2453	4.97	0.023
Residual error	10	0.02		
Lack-of-Fit	5	0.1639	239.82	0.000
Pure error	5	0.00		
Total	19	12.2609		
R-sq 0.9866	R-sq adjusted 0.9745		R-sq predicted 0.8913	

DF= degree of freedom; Seq SS= sequential sum of squares; F= F values from Fisher's statistical test

E. Conducting the Confirmation Experiment

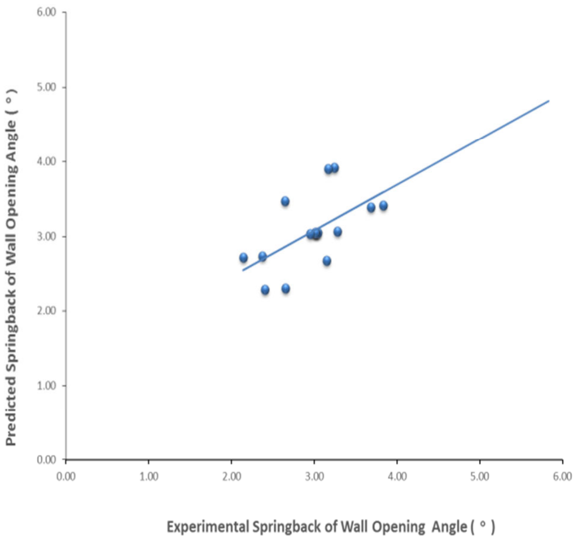
The legality of the model is further tested by drawing a scatter diagram as shown in Figs. 7 (a) and (b), which indicates the correlation between the experimental values and predicted values of springback of wall opening angle and springback of flange angle. There is a good relationship between the experimental and model results. Confirmations experimental were also conducted to identify the values of the process variables and the results were compared with the results of prediction models. The process parameters used to make comparison between experimental and predicted values are shown in Table IX. The error was calculated by:

$$Error(\%) = \left(\frac{X_{predict} - X_{\exp}}{X_{\exp}} \right) \times 100 \tag{8}$$

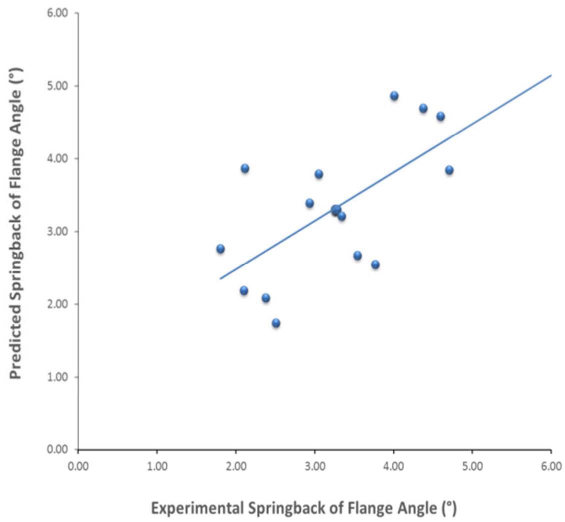
Another method used to check the adequacy of the model is response optimizer. Response optimizer was used to identify the combination of input variables that can give optimize a set of response for springback of wall opening and springback of flange angle.

TABLE IX
CONFIRMATION OF PREDICTED AND EXPERIMENTAL VALUE OF RESPONSES

Response	BHF (kN)	Clearance (mm)	Punch travel (mm)	Experimental (X exp)	Predicted (X predict)	Error (%)
Wall opening angle (°)	10	3	45	2.4	2.28	5
	15	2.5	50	3.03	3.05	0.6
	20	3	55	3.17	3.2	0.9
flange angle (°)	10	2	45	2.1	2.19	4.2
	15	2.5	50	3.25	3.31	1.8
	20	3	55	4.59	4.6	0.2



(a)



(b)

Fig. 7 Scatter diagram: (a) spring back of wall opening angle; (b) spring back of flange angle

From the analysis of response optimizer using all the parameters given, the predicted springback of wall opening angle (β_1) value was 1.8443 and springback of flange angle (β_2) value was 1.6249. The optimum parameters obtained in encoded units for blank holder force, clearance and punch travel are 6.59 kN, 2.5595 mm and 41.591 mm, respectively which give the highest composite desirability (0.43469) as shown in Fig. 8.

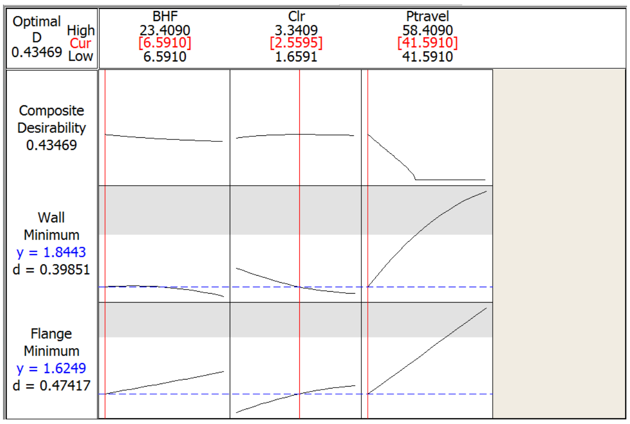


Fig. 8 Response optimization plot

IV. Conclusion

An experimental design was used to determine the effect of springback of wall opening angle and springback of flange angle on U-channel process with the variable parameters (rolling direction, blank holder force, clearance and punch travel). All the selected parameters except rolling direction affected the springback of wall opening and flange angle significantly and all the parameters which are significant were optimized using Central Composite Design (CCD) by RSM. The adequacy of the developed RSM models where validated statistically with normal probability plot of residuals, estimated coefficients of the regression model for springback and ANOVA of the regression model. The influences of various parameters on springback for wall opening angle and flange angle during U-channel process were studied based on the developed models. From the observation, with increasing blank holder force and clearance decreases the wall opening angle and increasing punch travel, blank holder force and clearance it will increases the flange angle. The punch travel is the most significant factor influencing the springback of wall opening angle and flange angle followed by clearance and blank holder force factor. The results from the developed models are found to have good agreement with the experimental results.

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