

Modelling of spring back in a laminated composite of SS304/PP/C80 under V-bending using integrating Taguchi, RSM .

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Abstract

In the forming operation, the dimensions of the sheet metal component change due to the spring-back effect. sheet metal made of composite materials is widely used in engineering applications, which necessitates the study of the relation of springback behaviour with design and geometrical parameters.

Modelling of spring back in a laminated composite of SS304/PP/C80 under V-bending using different methods and compare results with experimental method and find out optimal solution for minimise springback in a laminated composite of SS304/PP/C80 .

This work uses experimental and FEA analysis to study the effect of five factors, namely bending angle, sheet thickness, thickness ratio, and tool travel rate on the spring back of a laminated composite of SS304/PP/C80 materials.

Results obtained by FEA analysis are compared with Experimental results and relative errors are calculated. A maximum of 2.6% relative error occurred which is considerable. A set of 18 experiments are chosen using the experiment design using the integrating Taguchi method. Further, the regression model is developed using RSM. The RSM model is developed to minimise the spring back by optimisation of the selected five parameters. result obtained from regression analysis has been compared with the result obtained by the experimental method. and concluded material thickness, material thickness ratio and tool travel as the most influential parameters affecting spring back in laminated composite material.

Keywords: Laminated steel, Bending, RSM, Spring back, Integrated Taguchi.

1 INTRODUCTION

In the forming process sheet metal bending is a very crucial operation.

spring back after bending causes a change in the dimensions of the finished part. so minimising spring back and spring back prediction is essential. As we know composite materials are more design flexible and dimensionally stable, so the current study focused on spring back analysis of composite material made by laminated SS304/PP/C80.

The current paper aims to develop a CAD model for spring back analysis of a laminated sheet of SS304/PP/C80 By considering different process pa-

rameters of the bending process. numerical simulations were carried out and Results obtained by FEA

analysis were used to design the experiments using the Taguchi method. Results obtained by FEA analysis are used to validate the RSM model considering five-factor three levels. experimental testing is used to check the behaviours of the sandwich panel.

Wahid et. al[1] The study examined the effect of temperature, punch speed, and holding time on spring back. Comparing simulation and experimental results concluded that temperature is the most effective process parameter for minimising springback. Mo-

hammadi et. al[2] Proposed simulation and experimental methods to investigate the effect of different tool design parameters on spring back, and concluded that The spring back is predominantly affected by the die opening, which emerges as the strongest parameter, while the punch radius is identified as the minimal effective in influencing the spring back behaviour.. zhou et. al[3] examined different factors and cross sections of the different specimen by using RSM and concluded 20-53% panel deflection were occurred due to sandwich deformation.

Meddour et. al[4] used RSM, Artificial Neural Networks (ANN), and NSGA-II for the preparation of a prediction model of surface roughness and cutting forces. and concluded that RSM is the best method due to the involvement of each factor in response variation. Chatti et. al[5] developed a prediction model of spring back analysis for steel/pp/steel sandwich panels by using a mathematical model and concluded that the amount of spring back decreases by increasing foam thickness.

..Naceur et. al[6] designed sheet forming parameters with minimum spring back by using RSM and results are validated by using commercial codes STAMPACK and ABAQUS. and find out the optimal solution for minimising spring back.

Huang et. al[7] Investigated the Taguchi algorithm, BPNN, and RMS model to improve the quality of piston manufacturing processes to improve the process yield. The study concluded that all methods are skilled in identifying optimal settings for manufacturing parameters through experimental designs, resulting reduction in the number of required experiments

Haibo et. al[8]performed experimental and simulation methods to investigate the effect of a polymer layer on spring back. and they concluded that FEA analysis is a highly accurate method for spring-back prediction.

. Ali et. al[9]Analysed different factors affecting spring back using machine learning and linear regression approaches And concluded that The artificial neural network (ANN) approach is the best approach in identifying the spring back of the sandwich panel.

Pritima et. al[10] analysed the most significant factors affecting spring back by using RSM and ANOVA. and

concluded, that spring back increases with an increase in the width of the sheets. and spring back decreases with increasing holding time

Mrabti et. al[11] studied, ANN and RSM prediction models for spring back .After comparing both model results they concluded that the ANN results are more accurate than the RSM results. Lepadatu et. al[12]studied the optimization of the bending process using FEA analysis, RSM and gradient optimization algorithm. it included factors like die corner radius and punch die clearance for simulation and found out optimal solution for springback reduction. Lepadatu et. al[12] Outlined a method for optimizing spring back in sheet metal bending by integrating finite element analysis, response surface methodology, and a gradient optimization algorithm. The simulation focused on key variables such as die corner radius and punch-die clearance, ultimately identifying an optimal solution for reducing spring back. Narayanasamy et.al [13] Utilized RSM to predict bend force in the air-bending process for interstitial-free steel sheets. Utilising five factors, the study aimed to determine the optimal solution for springback. The conclusion highlighted that punch travel is considered as the primary factor influencing bending force. Parsa et.al [14] numerical simulations and experiments were carried out to find The impact of punch radius on the spring back during the bending process for Al/PP/Al sheets. It was observed that spring back was reduced by enlarging the thickness of the sandwich sheet. varsha et.al [15] investigated the spring back of SS304 and C80 using FEA analysis and prepared a spring back prediction model using the Taguchi method and ANN model and concluded that spring back is affected by material stiffness.

In this paper spring back of a laminated composite sheet of SS304/PP/C80 is analysed by using the Integrated Taguchi, RSM method. the main objective of this study is to find out the effect of different bending parameters on the spring back of the laminated sheet of SS304/PP/C80 and find out the optimal solution to reduce spring back.in this work RSM model is trained by using results obtained by FEA analysis. and the optimal solution is finalised by comparing results obtained by the experimental method. the process parameters with their levels are given in Table no 1.

Table 1 Process parameters and their respective levels.

Process parameter	Levels		
	Level1	Level2	Level3
Material yield strength (N/mm ²)	230	290	-
Angle(Degree)	80	100	120
Sheet thickness(mm)	0.8	1	1.2
Thickness ratio(mm)	1	2	3
Tool travel rate (mmms ⁻¹)	1	2	3

2. PROBLEM STATEMENT

To investigate the effect of different material factors and tool design factors on the spring back of laminated composite of SS304/PP/C80 material under the bending process. material factor consists of material yield strength having two levels and tool design factor consists of sheet thickness, thickness ratio, bending angle, and tool travel rate each with three levels. Furthermore, each factor is considered to find out its effect on spring back while performing experiments.

FEA analysis of the cad model is discussed in section 3, The experimental setup for the bending operation is discussed in section 3.2 and the design the experiments using Taguchi method and the result obtained by RSM is discussed in section 4. Discussion and conclusions are discussed in sections 5 and 6.

3. METHODOLOGY

To examine the impact of different input variables on responses and to find out the optimal value of spring back in a laminated composite of SS304/PP/C80 under the V bending process. ANSA software is used to prepare Punch, die, and laminated sheets of composite material of SS304/PP/C80 using material properties as shown in Table no .2. L.S.Dyna software is used as a solver and Hyperview software is used for validation of results.

Table 2.Specimen properties (SS304/PP/C80)

Sr No	Part	T ₁ (mm)	Material name
1	Specimen	0.8,1,1.2	Laminated
2	Die	NA	SS304/PP/C80
3	Punch	NA	NA

The mesh size for both the punch and die was chosen as 10 mm, while the mesh size for the metal sheet plate was set at 2 mm. The analysis model is developed based on the following assumptions

- 1.The die is immobile.
2. The punch is permitted to move solely along the Z-axis.
3. The material exhibits no residual stress before loading.
4. The punch and die demonstrate rigidity, while the sheet metal is deformable. The input data supplied in the L.S. Dyna software are outlined as follows:

Design of experiment is prepared by using taguchi method, total five factors are used from that material factor have two layers and remaining all four factors having three layers. L18 Orthogonal array (Taguchi mixed level design) is used to prepare iteration as shown in Table 3.

Table 3. Set of iteration for laminated SS304/PP/C80 materials

Sr No	MATERIAL	TH	ANGLE	TH RATIO	TOOL TRAVEL
1	230	0.8	80	1	1
2	230	0.8	100	2	2
3	230	0.8	120	3	3
4	230	1	80	1	2
5	230	1	100	2	3
6	230	1	120	3	1
7	230	1.2	80	2	1
8	230	1.2	100	3	2
9	230	1.2	120	1	3
10	290	0.8	80	3	3
11	290	0.8	100	1	1
12	290	0.8	120	2	2
13	290	1	80	2	3
14	290	1	100	3	1
15	290	1	120	1	2
16	290	1.2	80	3	2
17	290	1.2	100	1	3
18	290	1.2	120	2	1

In the above table Thickness ratios are indicated with numbers 1,2 and 3, where 1 number indicates the thickness ratio of the polypropylene sheet and metal sheet is 1:0.5 (means when the thickness of the PP sheet=0.8mm then the thickness of a metal sheet of SSS304 and C80=0.4mm) similarly 2 number indicate thickness ratio of polypropylene sheet and metal sheet are as 0.5:1 (means when thickness of PP sheet=0.4mm then thickness of metal sheet of SSS304 and C80=0.8mm) and 3 number indicate thickness ratio of polypropylene sheet and metal sheet are as 1:1 (means when thickness of PP sheet=0.8 mm then thickness of metal sheet of

SSS304 and C80=0.8mm respectively. Similarly, for tool travel 1 number indicates the tool travel rate is 2 mm/mili sec, for tool travel 2 numbers indicate the tool travel rate is 4 mm/mili sec, and for tool travel 3 numbers indicate the tool travel rate is 6 mm/mili sec.

3.1 Properties of the material and boundary conditions

Constraints to X, Y, and Z axes are applied to die displacement similarly constraints to X and Y axes are applied to punch displacement as shown in fig 1 and 2 respectively.

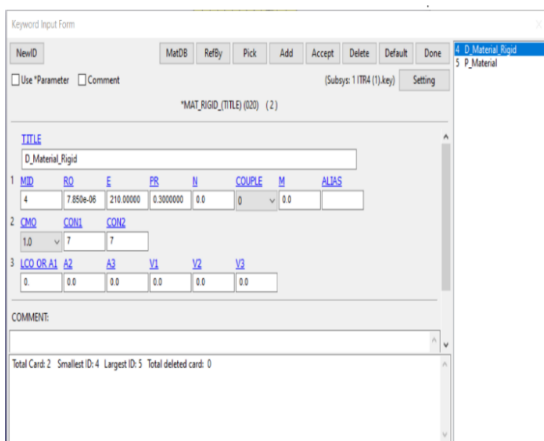


Figure 1 Material characteristics for the die.

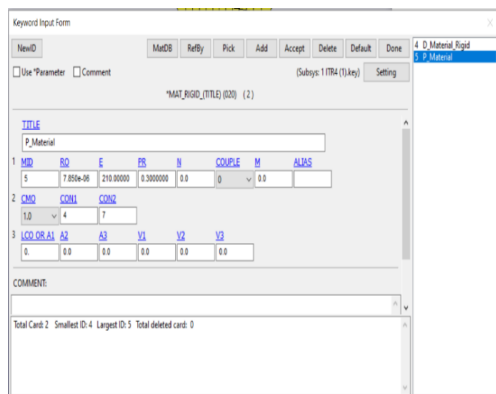


Figure 2 Material characteristics for the Punch

3.2 Experimental set-up

Press brake CNC Bending machine adapted for experimental set-up as shown in Fig no 3, it is a 19"3D touch screen graphical controller with a simple and easy-to-use interface. By using this machine we can able to observe a 3D graphical representation of the workpiece. and this machine

Executes the air-bending process for securing the die on the machine table. Following the preparation of the necessary sheet, the punch is brought down to bend the laminated metal sheet to 80 Degrees, 100 Degrees, 120 Degrees.



Figure 3 CNC Bending Machine

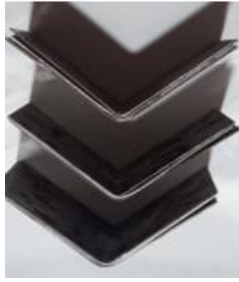
By adjusting respective bending angle and tool travel rate bending operations are performed for all experimental sets as shown in Fig.4(a), Fig.4(b) Fig.4(c) and Fig 5 (a), Fig 5 (b) Fig 5(c).



a)80 Degrees bending angle



b)100 Degrees bending angle



c)120 Degrees bending angle

Figure 4 . Sample of SS304/PP/C80 Workpiece after bending



a)80 Degrees bending angle



b)100 Degrees bending angle



c)120 Degrees bending angle

Figure 5. Sample of C80/PP/SS304 Workpiece after

bending

4. Results and Discussion

4.1 FEM Model Validation



Figure 6 Bevel Protector

After unloading the specimen bending angle was measured by using an optical bevel protector, and the spring back was calculated. As shown in Fig no 6 and the results are mentioned in table no.4.

Table 4. Springback provided by FEAsimulation and experiments.

Sr No	Springback by FEA simulation	Springback by Experiments	Relative Err or,%
1	0.96	0.98	2.04082
2	4.1	4.02	1.99005
3	2.8	2.81	0.35587
4	0.43	0.44	2.27273
5	2.7	2.71	0.369
6	1.8	1.79	0.558659
7	0.49	0.48	2.083333
8	2.5	2.51	0.39841
9	1.9	1.88	1.06383
10	0.57	0.58	1.72414
11	5.4	5.4	0
12	2.3	2.29	0.436681
13	0.38	0.39	2.5641
14	4.7	4.8	2.08333
15	2	1.99	0.502513
16	0.23	0.23	0
17	3.7	3.8	2.63158
18	2	1.99	0.502513

4.2 Spring Back Analysis Using Response Surface Methodology (RSM)

FEA Analysis results are used to train the RSM model by providing different response variables and various input variables.RSM is used for to prediction and optimization of results.

4.3 Development of the regression equation

Analysis of Variance (ANOVA) technique is used to check The acceptability of the model. Utilization of the which is employed to assess the model's ability to

predict spring back accurately. The outcomes are presented in Table 5.

Table 5. Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	15	39.3668	2.6245	3.30	0.257
MATERIAL	1	0.0016	0.0016	0.00	0.968
ANGLE	1	1.8628	1.8628	2.34	0.265
TH	1	0.9389	0.9389	1.18	0.391
TH RATIO	1	11.6956	11.6956	14.72	0.062
TOOL TRAVEL	1	0.2925	0.2925	0.37	0.606
MATERIAL*ANGLE	1	1.9721	1.9721	2.48	0.256
MATERIAL*TH	1	0.6615	0.6615	0.83	0.458
MATERIAL*TH RATIO	1	10.3360	10.3360	13.01	0.069
MATERIAL*TOOL TRAVEL	1	15.1425	15.1425	19.06	0.049
ANGLE*TH	1	0.0352	0.0352	0.04	0.853
ANGLE*TH RATIO	1	1.4988	1.4988	1.89	0.303
ANGLE*TOOL TRAVEL	1	0.0340	0.0340	0.04	0.855
TH*TH RATIO	1	1.9836	1.9836	2.50	0.255
TH*TOOL TRAVEL	1	1.9811	1.9811	2.49	0.255
TH RATIO*TOOL TRAVEL	1	0.1048	0.1048	0.13	0.751
Error	2	1.5891	0.7945		
Total	17	40.9558			

To examine all conceivable combinations, a complete factorial design is utilized with five process parameters, each set at three distinct levels, as summarized in Table 3. Minitab-18 is used to establish the correlation of spring back (ΔY_p) and the input variables.

$$\begin{aligned}
 SB = & -91.48 + 0.1664 \text{ MATERIAL} + 1.350 \text{ ANGLE} - \\
 & 0.07262 \text{ TH} + 4.817 \text{ TH RATIO} \\
 & + 0.5828 \text{ TOOL TRAVEL} - 0.006098 \\
 & \text{ANGLE*ANGLE} + 0.5208 \text{ TH*TH} - 0.2775 \\
 & \text{TH RATIO*TH RATIO} \\
 & - 0.5204 \text{ TOOL TRAVEL*TOOL TRAVEL} - \\
 & 0.001055 \text{ MATERIAL*ANGLE} - 0.005679 \\
 & \text{MATERIAL*TH} \\
 & - 0.008609 \text{ MATERIAL*TH RATIO} - 0.009944 \\
 & \text{MATERIAL*TOOL TRAVEL} + 0.05930 \\
 & \text{ANGLE*TH} \\
 & + 0.01850 \text{ ANGLE*TH RATIO} + 0.03236 \\
 & \text{ANGLE*TOOL TRAVEL} - 3.568 \text{ TH*TH} \\
 & \text{RATIO}
 \end{aligned}$$

a statistically significant contribution to the response is fulfilled by the response having p value less than 0.06. Table 5 shows that the

variables material*tool travel are considered statistically significant parameters. Table 6 presents the FEA analysis and regression model predicted values of springback. impact and interplay of different input parameters on springback are assessed by The Design of Experiments (DOE) as a statistical approach .metal thickness is the most significant influence on spring back among these factors, As shown in Figure 6, it is proved that variations in metal thickness have a noticeable effect. as shown in fig 7 all results are grafically represented and noted that the maximum error is 16.06%, well within the acceptable range. demonstrating close concordance between the

outcomes derived from FEA and Regression analysis.

Table 6. FEA Analysis and regression model predicted values of spring back

Sr No	Material	TOOL TRAVEL			Springback by FEA simulation	Springback by the regression model	Error (%)	
		ANGLE	TH	TH RATIO				
1	230	80	0.8	1	0.96	0.92739	3.51632	
2	230	100	0.8	2	4.1	4.0581	1.032503	
3	230	120	0.8	3	2.8	2.74901	1.85485	
4	230	80	1	1	2	0.43	0.3976	8.148893
5	230	100	1	2	3	2.7	2.65831	1.56829
6	230	120	1	3	1	1.8	1.74858	2.940672
7	230	80	1.2	2	1	0.498	0.465744	6.925693
8	230	100	1.2	3	2	2.5	2.458654	1.681652
9	230	120	1.2	1	3	1.9	1.848274	2.798611
10	290	80	0.8	3	3	0.579	0.546078	6.028809
11	290	100	0.8	1	1	5.4	5.355818	0.824935
12	290	120	0.8	2	2	2.3	2.246148	2.397527
13	290	80	1	2	3	0.386	0.35277	9.419735
14	290	100	1	3	1	4.7	4.65658	0.932444
15	290	120	1	1	2	2	1.94584	2.783374
16	290	80	1.2	3	2	0.238	0.205066	16.0602
17	290	100	1.2	1	3	3.78	3.736326	1.168902
18	290	120	1.2	2	1	2	1.945936	2.778303

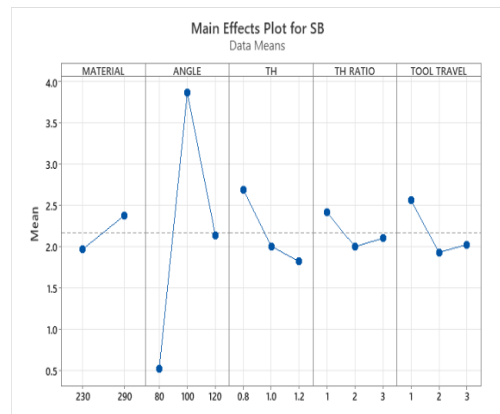


Fig 6 Main Effect Plot for Springback

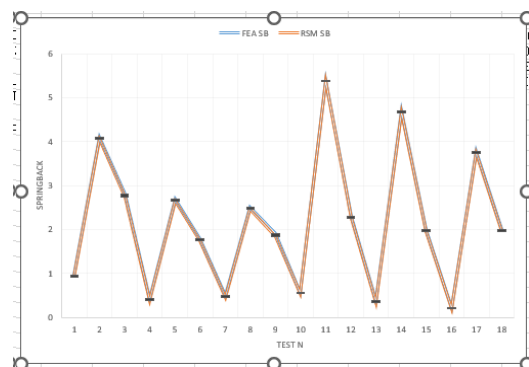


Fig 7 Comparative Analysis of Springback Values between FEA and Regression

MINITAB-18 software is used to generate surface plots. surface plots are used to represent the impact of different variables on the response.

Figure 8 illustrates Response surface plots, representing that material yield has a negligible effect on springback, as springback increases with an increase in material yield. Springback decreases by increasing material thickness, material thickness ratio and tool travel.

parameters(material, thickness, thickness ratio, bend angle, and tool travel) is represented by using contour plots as shown in Fig 9. The observations show that an increase in panel thickness significantly reduces the spring back, and an increase in bending angle increases the spring back. importantly, the thickness ratio exerts an obvious impact on the spring back.

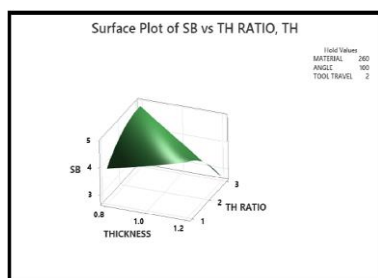
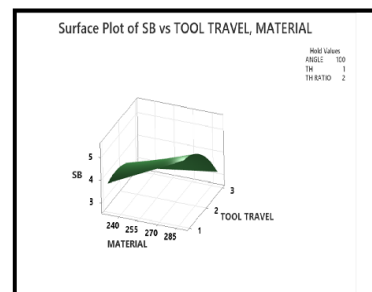
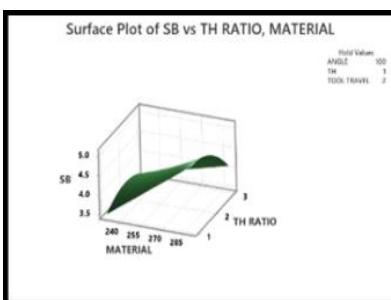
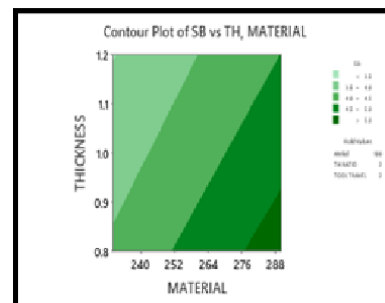
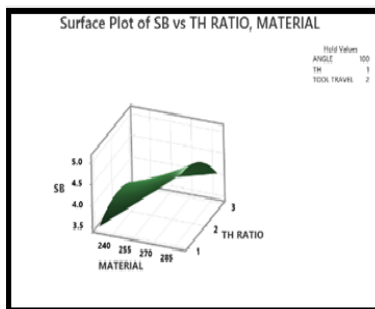
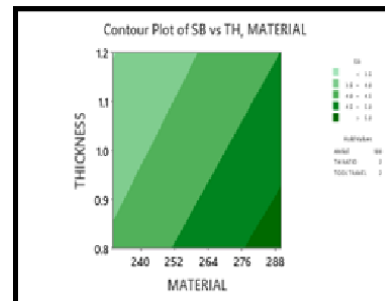
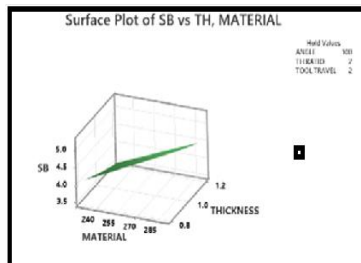


Fig. 8 Response surfaces relationship between spring back and five input

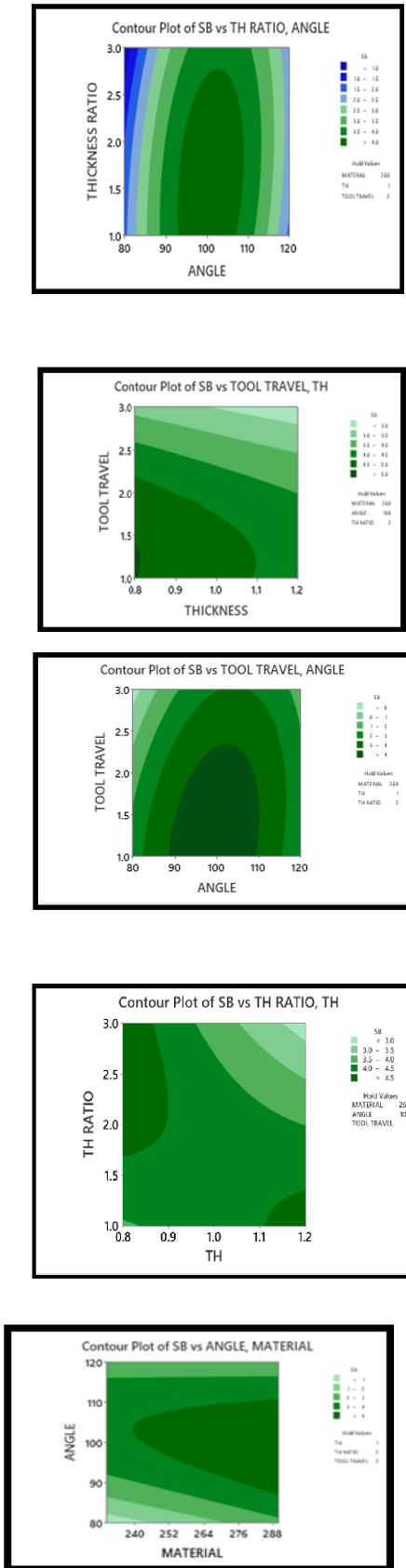


Fig. 9 Contour Plots

5. CONCLUSION

During the air bending process spring back analysis of the laminated composite of SS304/PP/C80 sheet were done by FEA analysis, Integrated Taguchi and RSM and experimental techniques. FEA analysis results are in good argument with Experimental results. Results obtained by FEA analysis are used to train RSM. Results obtained by mathematical model are listed below.

The FEA modelling of spring back for laminated composite material was established. The relative percentage error varies from 0 to 2.63, which is reasonable and in an acceptable range.

A regression equation for the spring back prediction was developed. The results obtained by the regression equation are validated with FEA model results.

The Analysis of the Variance Model (ANOVA) identifies material thickness, material thickness ratio and tool travel as the most influential parameters affecting spring back in laminated composite material.

By examining 2D contour plots and surface plots generated by RSM, it is evident that an improvement in material yield correlates with a reduction in spring back. However, spring back tends to decrease with an increase in "material thickness/material thickness ratio" and "tool travel."

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Disclosure statement

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