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STUDIES ON SPRING BACK CHARACTERISITCS OF METAL-POLYMER-METAL LAMIANTE USING STATISTICAL DESIGN OF EXPERIMENTS

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ABSTRACT

Spring back is one of the parameter which affects the accuracy and success of the bending process. In the present work, the spring back behavior of the aluminum polymer laminate is studied by the three point bending process by varying three parameters viz. core to skin thickness ratio (Tc/Ts), the speed of bending (N) and punch radius (rp). Amount of spring back and peak bending load was measured with each combination of process parameters Tc/Ts, N and rp. The experimental work has been carried out on the Tensometer having load measurement capacity as two tone. The levels of the input parameters are decided by performing screening experiment. The experimental results have been analyzed using full factorial statistical experimental design technique.

Key words: *Metal-polymer-metal laminate, Spring back, Statistical design of experiment, Full-factorial design.*

1. Introduction

Metal-polymer-metal laminate (MPML), as studied in this work, is a sheet metal product that consists of two metal sheets with a relatively thin polymer layer between them. It has been developed for applications requiring sound and vibration damping. MPML is being in used from quite some time in automobile sector [1]. Number of researchers in recent past had put efforts to study various aspects like mechanical performance of laminates, three point bending, strength and failure of laminates, spring back and wrinkling of laminates, inter laminar stresses in the layer composites.

Asundi et.al, [2] made study on the fiber metal laminates including their applications, characteristics, and behavior. Khalili et.al,[3] compared the mechanical properties of steel/aluminum/GRP laminate by with each other and with monolithic metals or fiber composite laminates in order to study the feasibility of their replacement in aerospace industry. They made standard FML samples prepared from various lay ups of glass fiber/epoxy laminates with steel and/or aluminum sheets and tested them by three distinct test i.e. Tensile test, Three point bend test and Charpy impact test according to the ASTM standards.

Hino et.al, [4] investigated the spring back of two-ply sheet metal laminates by draw-bending process. The experiments were conducted for two-ply laminates consisting of pure aluminum (JIS A1100) and ferritic stainless steel (JIS SUS430) to measure residual curvatures after spring back of the laminates.

Kim et.al, [5] investigated the effect of tool design and process parameters on the spring-back of Glare in the brake forming process. The parameters studies were punch radius, punch speed, forming load, and forming temperature. Scanning electron microscopy (SEM) was also carried out for the observation of delamination or cracking in the bent zone.

Compston et.al, [6] presented some preliminary results from stamp-forming aluminum-thermoplastic sandwich material. They compared the permanent strain on the surface of a channel-formed aluminum-polypropylene laminate to monolithic aluminum. Channel sections were stamped in an open die.

Roebroeks [7] made the study of the fiber metal laminates, their recent advances and their applications. The fatigue crack initiation behavior and fatigue crack growth behavior of laminates in joints under realistic loading conditions were also studied and compared to those of aluminum alloys.

Weiss et.al, [8] investigated the influence of temperature on forming behavior of an aluminum/polypropylene/ aluminum (APA) sandwich sheet. Shear and tensile tests were performed to determine the mechanical properties of the laminate and the component materials as a function of process temperature. The forming limit diagram (FLD) of the laminate was established for two different temperatures, and its spring back behavior was examined in four-point

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bend and channel bend tests. They also performed cup forming tests at various test temperatures to determine the limiting drawing ratio (LDR) and the tendency for wrinkling at these temperatures.

Homan [9] investigated the fatigue initiation in the fiber metal laminate. He carried out the fatigue tests on Glare 3-3/2-0.3, Glare 4B-3/2-0.3 and monolithic aluminum 2024-T3 based on the assumption that fatigue crack initiation in Fibre Metal Laminates was determined by the stress cycles in the metal layers only, further followed by if the stress cycles in the metal layers were known, the fatigue initiation life could be established using S–N data available for the given metal alloy.

Kim and Tong-Xi Yu [10] studied formability and fracture resistance of coated and laminated sheets and sandwiches during forming and in service. Major failure were also studied in the laminated sheet during forming and in sandwiched sheets subjected to static and dynamic loading.

Cheng et.al, [11] investigated the wrinkling behavior of laminated steel sheets. Buckling test and wedge strip test of laminated steel were also conducted. The information regarding local strains, buckling heights and global wrinkling patterns were obtained to provide verification data for numerical predictions.

Wang [12] investigated the analytical approach to predict spring back and sidewall curl of laminates due to wiper die bending. Based on the integration of a straight beam and a curved beam models, the spring back factor K_s was calculated. Application of the integrated model to minimize the spring back and side wall curl was demonstrated.

The objective of the present study concerns investigation on spring back characteristic of aluminum-epoxy-aluminum laminate in three point bending operation. The punch speed(S), polymer core thickness (Tc), and the punch radius (r_p) are found to be most influencing parameters on spring back as per the literature . Hence in the present work an attempt is made to study their influence on spring back using statistical design of experiment.

2. Experimentation

In the present work, the behavior of the aluminum polymer laminate is examined in the three point bending process by varying three parameters named as core to sheet skin thickness ratio(depicted by **Tc/Ts**), feed rate(the speed of bending in mm/min depicted by **N**) and punch radius (depicted by r_p). Fig. 1 shows schematic of three point bending process. The specimens were prepared using the core material as

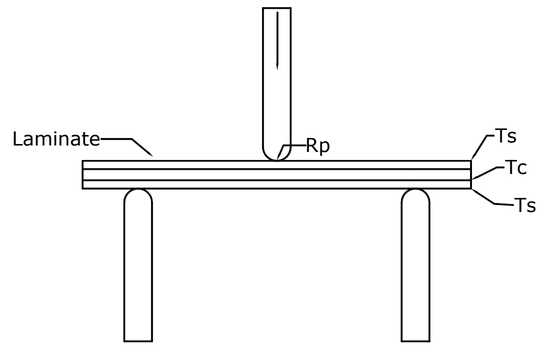

Fig. 1 Schematic of Three Point Bending Process

epoxy having various thickness values 1.0, 0.8, 0.6, 0.4 & 0.2 permitting ±5% variation in the core thickness.

The dimension of the aluminum strip was 150x18 mm with 1 mm thickness. Specimens were prepared by depositing epoxy on the aluminum strip and pressing the other one with due care to maintained required core thickness at room temperature. Table 1 indicates one such set of the parameters considered during the screening experiment.

Table 1: Process Parameters and their Levels for Screening Experiment

Sr. No.	**Punch Speed (N)** (mm/min)	**Punch radius (r_p)** (mm)	**Ratio of core to sheet thickness (Tc/Ts)**
1	1	6	0.2
2	2	7	0.4
3	3	8	0.6
4	4	9	0.8
5	5	10	1.0

During screening experiments two sets (with N = 1 mm/min, r_p = 6 mm, and T_c/T_s = 0.2 and with N = 5 mm/min, r_p = 10 mm, and T_c/T_s = 1.0) were found to have early de-bonding and hence rest of the three set were considered for further detail study related to spring back effect . The de-bonded laminate specimen is shown in Fig.-2. As, a result three levels of each parameter that is punch speed (2mm/min, 3mm/min, 4mm/min), punch radius (7mm, 8mm, 9mm), and ratio of core to sheet thickness (0.4, 0.6, 0.8) were considered.

Total 27 specimens were tested with each combination of punch speed, punch radius and ratio of core to sheet thickness. The experiments were conducted

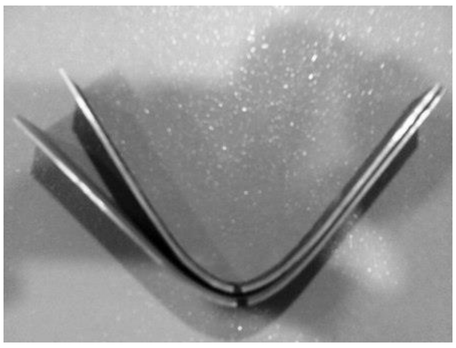

Fig. 2 Aluminum Epoxy Laminate after 3 Point Bending Showing Delamination (with N = 5 mm/min, r_p = 10 mm, T_c/T_s = 1.0)

with one replication (total 27 x 2 tests) for each run in a random order to avoid any bias in the results. The specimen was not clamped and was free to slide with increasing angle of bend. The included angle under load (before spring back) was measured based on geometrical data and the same was measured after spring back using a bevel protractor with the accuracy of 0.5 degree. The difference between the two angles was used to determine spring back of the included angle. Spring back for each set of experiments was measured at the time when room temperature varied in a narrow range (22 ± 2°C). The photographic view of tested specimens is shown in Fig. 2.

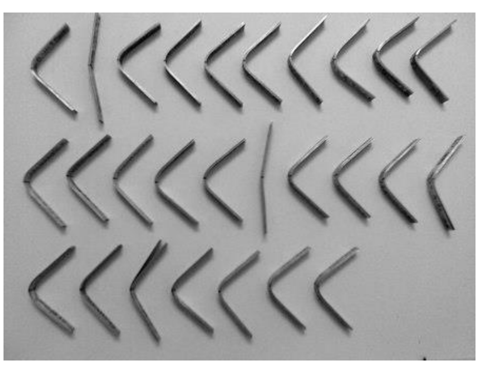

Fig. 3 Specimens after Three Point Bending

Spring back characteristic is then analyzed for all 27×2 specimens using 3-level factorial design, the plan is highlighted in Table 3.

3. Design of Experiments

Factorial designs are widely used in experiments involving several factors (process parameters) where it is necessary to study the joint effect of the factors on a response (process outcome) [13].

Table 3: Three Factor Experimentation Plan

Sl. No.	A (mm/min)	B (mm)	C	S_b Set-I (°)	S_b Set-II (°)
1	2	7.0	0.4	0.7	0.8
2	2	7.0	0.6	1.6	1.5
3	2	7.0	0.8	1.7	1.6
4	2	8.0	0.4	2.1	2.2
5	2	8.0	0.6	2.7	2.6
6	2	8.0	0.8	3.7	3.6
7	2	9.0	0.4	3.9	4.0
8	2	9.0	0.6	5.0	5.1
9	2	9.0	0.8	5.3	5.2
10	3	7.0	0.4	5.3	5.4
11	3	7.0	0.6	5.5	5.4
12	3	7.0	0.8	5.5	5.3
13	3	8.0	0.4	5.9	6.0
14	3	8.0	0.6	6.0	6.3
15	3	8.0	0.8	6.2	6.4
16	3	9.0	0.4	6.4	6.2
17	3	9.0	0.6	6.6	6.6
18	3	9.0	0.8	6.7	6.8
19	4	7.0	0.4	8.9	9.0
20	4	7.0	0.6	9.3	9.2
21	4	7.0	0.8	10.1	10.2
22	4	8.0	0.4	10.2	10.1
23	4	8.0	0.6	10.5	10.6
24	4	8.0	0.8	11.1	11.4
25	4	9.0	0.4	13.9	14.0
26	4	9.0	0.6	27.2	27.1
27	4	9.0	0.8	29.4	28.0

3.1 Three-level factorial design

Three-level factorial design includes the study of process parameters which are at 3-levels. In 3^3 a regression model relating the response to the factor levels, is mentioned below as equation-1;

$$Y = \beta_0 + \beta_1 A + \beta_2 B + \beta_3 C + \beta_{12} AB + \text{........} \quad (1)$$

Where, β_0 is the coefficient associated with factor n, and the letters, A, B, C, represent the factors in the model. Combinations of factors (such as AB) represent an interaction between the individual factors in that term. This design facilities following study of the process parameters on the response:

i) Zero Intercept
ii) Main effects: A, B, C, D...
iii) 2-factor interactions (2FI) - AB, AC, BC, AD, ...
iv) 3-factor interactions (3FI) - ABC, ABD, ACD, ..

The treatment combination in a 33 design is depicted in Fig. 4.

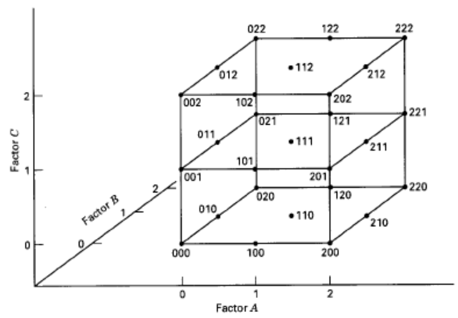

Fig. 4 Treatment Combinations in a 3^3 Design

4. Results and Discussion

The data collected from the experiments (performed as per 3^3 factorial design) was analyzed to evaluate main effect, two factor and three factor interactions effect of input process parameters (Punch speed, Punch radius, Sheet skin to core ratio) on spring back characteristic.

4.1 Main effects due to parameters and interactions

The effect of a factor is defined to the change in response produced by a change in the level of the factor. This is known as a main effect because it refers to the primary factors of interest in the experiment.

Figs. 5, 6 & 7 depicts main effects plots for punch speed, punch radius and core to skin thickness ratio.

In order to confirm the main effects due to punch speed, punch radius and core to thickness ratio on spring back Analysis of Variance (ANOVA) is used. From the ANOVA it reveals punch radius and core to sheet thickness ratio is more significant than the punch speed.

Table 4 shows the ANOVA result for main effects of process parameters. In above table the model. values of “Prob > F” less than 0.0500 indicate model terms are significant.

In this case punch radius and sheet core to thickness ratio are significant from spring back point of view. Values greater than 0.10 indicate that model terms are not significant, so punch speed has less significant on spring back.

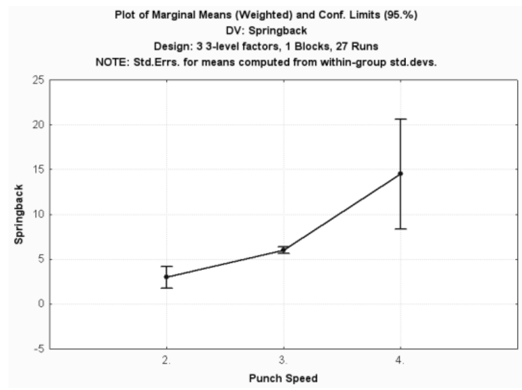

Fig. 5 Main Effects Plot for Punch Speed (N) Vs Mean Spring-Back

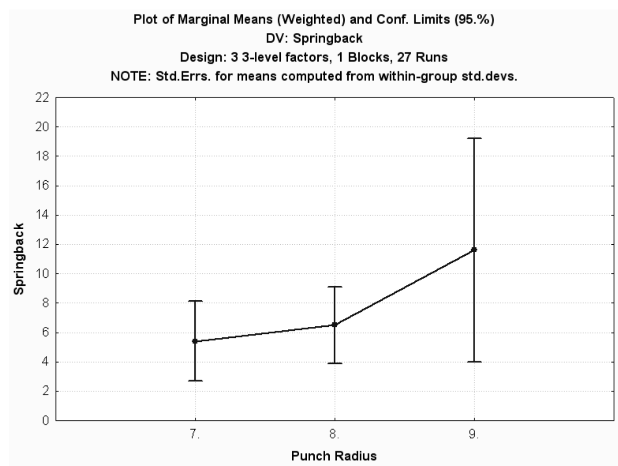

Fig. 6 Main Effects Plot for Punch Radius (r_p) Vs Mean Spring-Back

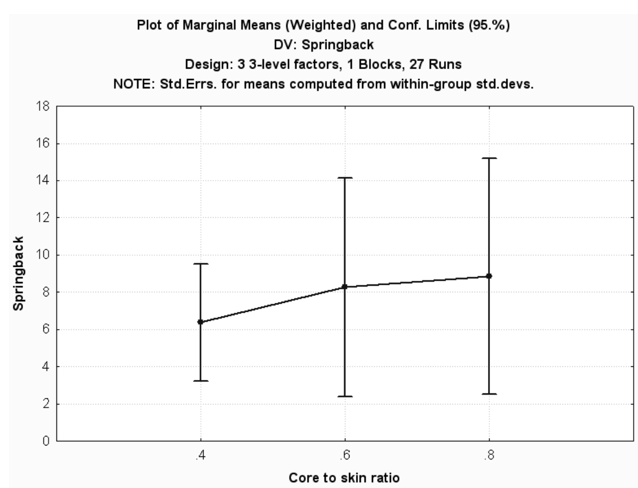

Fig. 7 Main Effects Plot for Core to Skin Ratio (Tc/Ts) Vs Mean Spring-Back

To identify the interaction effects of punch speed, punch radius and core to skin thickness ratio on spring back normality of the data is checked by plotting normal probability plot as shown in Fig. 8. The effects that are negligible are normally distributed, with mean zero and σ^2 variance and will tend to fall along a straight line on this plot, whereas significant effects will have nonzero means and will not lie along the straight line.

Table 4: ANOVA Table for Main Effects of Punch Speed (A), Punch Radius (B), Core to Skin Ratio (C)

Source	Sum of squares	DOF	MS	F Value	p-Value Prob > F
Model	872.08	6	145.35	9.62	< 0.0001
A	30.45	2	15.23	1.01	0.3829
B	197.25	2	98.62	6.53	0.0066
C	644.38	2	322.19	21.32	< 0.0001
Residual	302.24	20	15.11		
Cor Total	1174.32	26			

Fig. 9 confirms that interaction effects of punch speed, punch radius on spring back is not negligible, because most of the data points are fall away from the straight line. Fig. 10 to 11 shows the interaction effects of, punch radius and core to skin thickness ratio on spring back. And Punch speed& core to skin ration on spring back. To confirm the interaction effects on spring back ANOVA is carried out.

ANOVA table is described as Table 5 for 2-factor interactions effects of AB, BC and AC. From the table the Model F-Value of 9.0 indicates that the model is significant and values of "Prob > F" less than 0.0500 indicates the significance of punch radius, core to thickness ratio and BC (interactions of punch radius and core to thickness ratio) on spring back.

There is no significant interaction effects noticed for all three factors on spring back. From the study of ANOVA it reveals that the punch radius and epoxy core to sheet skin thickness ratio has more significant effects on spring back

5. Conclusion

Based on analysis of experimental result using three level factorial experiment designs, the following conclusions can be drawn:

i) The core to thickness (Tc/Ts) and punch radius (r_p) are highly dominant among all three parameters affecting spring back in aluminum-epoxy-aluminum laminate.

ii) Among Tc/Ts and r_p; Tc/Ts is found comparatively more significant with 95% confidence interval.

iii) Effect of punch speed on spring back is found less significant.

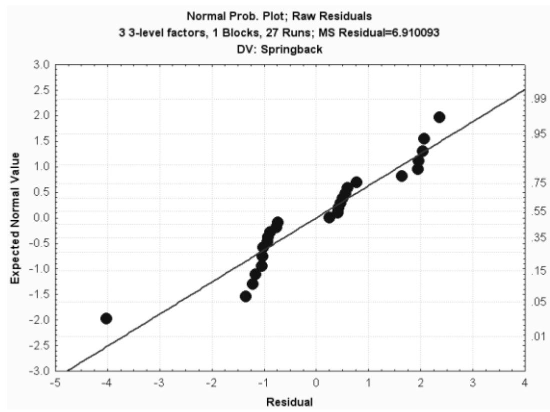

Fig. 8 Plot for Normal Probability Vs Residual

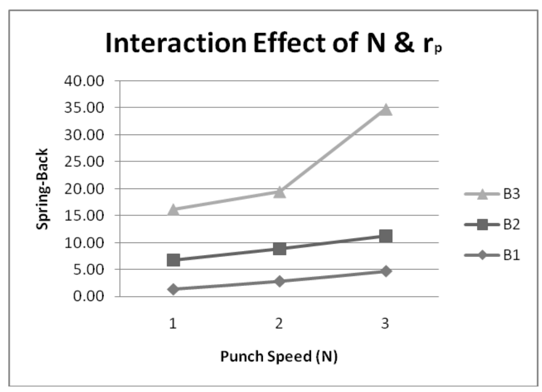

Fig. 9 Interaction Effects of Punch Speed Vs Punch Radius

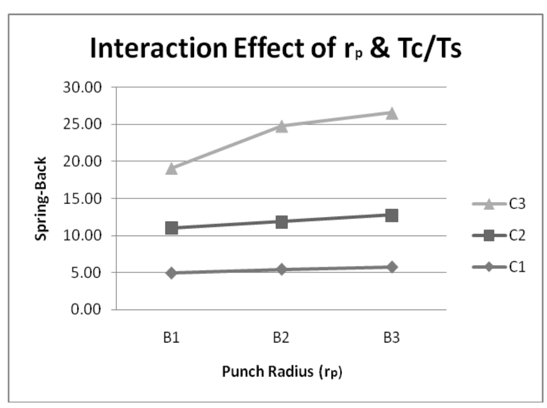

Fig. 10 Interaction Effects of Punch Radius Vs Core to Skin Thickness Ratio

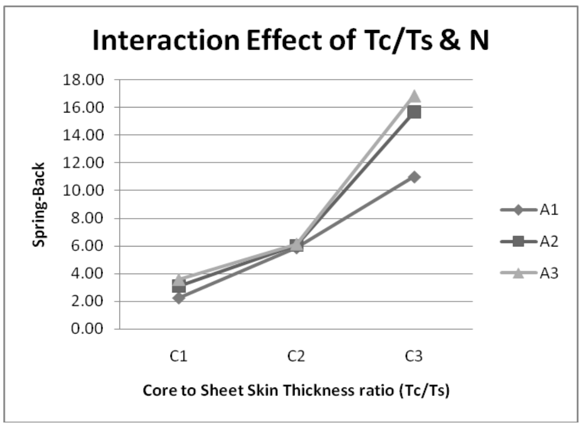

Fig. 11 Interaction Effects of Core to Skin Thickness Ratio Vs Punch Speed

Table 5: ANOVA Table for Interaction Effects of Punch Speed (A), Punch Radius (B), Core to Skin Ratio (C)

Source	**Sum of squares**	**DOF**	**MS**	**F Value**	**p-Value Prob > F**
Model	1119.04	18	62.17	9.00	0.0018
A	30.45	2	15.23	2.20	0.1728
B	197.25	2	98.62	14.27	0.0023
C	644.382	2	322.19	46.63	< 0.0001
AB	29.17	4	7.29	1.06	0.4372
BC	30.04	4	7.51	1.09	0.4245
AC	187.74	4	46.94	6.79	0.0110
Residual	55.28	8	6.91		
Cor Total	1174.32	26			

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Nomenclature

Symbol	**Meaning**	**Unit**
N	Punch Speed	mm/min
r_p	Punch Radius	mm
Tc/Ts	Core to sheet skin thickness ratio	-