Experimental Investigation for Minimization of Spring back in L bending using Taguchi Design of Experiments

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Abstract

Spring back is a main defect occurred in the sheet-metal forming processes. In press working where sheet metal is given the required shape by using press, it is very much required to consider the variation in dimension after removal of the applied force. This work deals with analysis of spring back occurring in L- bending process of aluminium alloy. Comparison is made by varying various parameters like material thickness, rate of feed and settle time after bending. Various quality control tools like Taguchi analysis, ANOVA are applied to find most significant parameter affecting spring back obtained in L-bending process. Reverse bending technique is useful for minimization of spring back obtained in L bending. Efforts are made towards reducing the spring back using Reverse bending approach. The aim of the work is to identify various design parameters on which spring back depends and mainly focuses on experimental investigation of factors related to material and process parameters related to L-bending process using Aluminium (HE 9) which is commonly used for L-bending. These parameters include thickness, rate of feeding and time for which punch is kept in contact with specimen. Efforts are made towards minimisation of spring back using reverse bending tool.
Keywords: L Bending, Reverse Bending, Design of experimentation, Taguchi method, Annova

I. INTRODUCTION

Manufacturing industries are very much dependent on highly precise sheet metal component. Various electronics industries, automobile industries rely on fabrication of complex parts for production of wide range of items. Sheet metal L-bending is one of the commonly used processes. Accurate calculations of various material variables such as stress, strain is required for metal forming process. Elastic properties of materials play vital role in prediction of final geometries of deformed parts. Hence accurate prediction of factors like spring back becomes essential to obtain final geometry of deformed part. Accuracy of deformed parts is heavily dependent on tool geometry. Over the years research has been made in investigations of process parameters for design of spring back. When the force used to create the bend is removed, the recovery of the elastic region results in the occurrence of spring back. Spring back is the partial recovery of the work from the bend to its geometry before the bending force was applied. When bending is done, the residual stresses cause the material to spring back towards the original position, so the sheet must be over-bent to achieve the proper bend angle. The amount of spring back is dependent on the material and the type of forming. The magnitude of spring back depends largely on the modulus of elasticity and the yield strength of the material. Typically the results of spring back will only act to increase the bend angle by a few degrees; however, all sheet metal bending processes must consider the factor of spring back. In the present study, a reverse bend approach is proposed to reduce the spring back in the L bending of sheet-metal. In the reverse bend approach, the sheet-metal is first bent locally to an opposite direction of the desired bend into a hemispherical bend shape and then is bent at the bend location by the punch to the desired shape. The reverse bend is located at the desired bending position, and the dimensions of the reverse bend are characterized by band width (b) and bend height (h). S.Chatti et al (2012) proposed model and evaluated the variation in the elastic modulus of metallic materials due to both damage & dislocations rearrangement leading to nonlinear recovery. The L-bending test is also simulated and the proposed model allows obtaining more accurate spring back prediction. Predicted spring back angle is improved as compared to experimentation [1]. Fuh-Kuo Chen, Shen-Fu Ko (2006) investigated the effect of reverse bending on the obtained spring back in specimens by Finite Element Analysis. They suggested that springback can be reduced by reverse bending approach. [2]. Sutasn Thipprakmas (2012) stated the use of coined bead technique. According to his findings the conventional coined-bead technique could only prevent the spring-back. In contrast, the sided coined-bead could prevent both the spring-back and the spring-go by setting a suitable geometry and position. [3]. Sutasn Thipprakmas (2012) has given the effect of process parameters on the springback. According to him the degree of importance of process parameters in V-bending process depended on the spring-back and spring-go. The material thickness has a major influence on the spring-back. In contrast, in the case of spring-go, the bending angle has a major influence and closely followed by the material thickness. V. Nasrollah et al (2011) have given the effect of various process parameters and the variation of work piece shape on the spring back. [5]. Jenn-Terng Gaul et al have suggested a new model for springback based on isotropic and kinematic models. The method proposed incorporates the capabilities of the isotropic and kinematic hardening models, but the new model is capable of modelling the material's physical phenomenon through the M and CM values. The proposed method for modelling the Bauschinger effect gives better results than those obtained using the isotropic and kinematic hardening models and Mroz multiple surfaces model [6]. Peng Chen et al (2008) have given the experimental investigation of spring back variation in forming of high strength steels. According to them the thicker the blank is, the less the spring back variation. The application of lubricant helps to reduce spring back variation, although it actually increases the spring back itself. The more uniform the friction condition, the less the spring back variation [7]. M. T. Braga et al (2010) have given the spring back analysis of thin bent sheets on elastomeric die. Some models for predicting spring back in conventional bending are available but in non-conventional bending using poly urethane die and the process is treated on trial and error basis, implying in product discharge. Theoretical model for predicting the spring back is given. Model validation is done by experimental results [8]. Deniz Bekar et al (2012) have investigated robust spring back optimization of a DP600 dual phase steel seven flange die assembly composed of different flange designs. [9]. X Jing-jing et al (2004) worked out on a new model to improve the precision of spring back prediction in sheet metal forming by combining the finite element method (FEM) with the data mining technique [10]. Y.L. Liu et al (2012) have given the concept to improve the spring back prediction precision by considering the variation in the Young's modulus with plastic deformation for 3A21 material by repeated loading and unloading experiment. [11]. As 'spring back' is giving variation in dimension after removal of applied forces, it is required to get controlled. Many authors have studied Spring back for forming operations like U bending, Edge bending. Very few authors have considered spring back in V bending process. Most of the authors have used finite element analysis for getting precise values of Spring back. Some have identified the critical parameters for analyzing the spring back.

II. METHODOLOGY

A. Taguchi Method:

A full factorial design of experiments considers all possible combinations for selected factors. If the numbers of parameters considered are more this is the case in many practical examples, a full factorial design results in a large number of experiments. Taguchi methodology can be used to reduce this large number of experiments to a practical level. It is done by selecting a small set of experiments from all possible experiments. The method of selecting a limited number of experiments, which produces the maximum information, is known as a partial fraction experiment [13]. Taguchi analysis provides guidelines for factorial experiments to improve its accuracy. It investigates how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning [12]. The experimental design by Taguchi method involves orthogonal arrays to arrange the parameters affecting the process and the levels in which they should be varied. It determines the contribution of each factor that affect the process and their optimum values for required response with minimum number of experimentation thus saving efforts, time and resources. Taguchi developed a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only. The experimental results are then transformed into a signal-to-noise (S/N) ratio. It uses the S/N ratio as a measure of quality characteristics deviating from or nearing to the desired values. There are three categories of quality characteristics in the analysis of the S/N ratio, i.e. the lower the better, the higher the better, and the nominal the better.

B. Fabrication:

Aluminium HE9 was selected to carry out experimentation on L bending. Aluminium HE9 is widely used in bending applications especially when there is light weight requirement. The detailed schematic of the actual set up is also shown in figure 2 which gives a complete idea about the practical set up used. The punches and dies are made up of Mild Steel. As the punches and dies are made up of Mild Steel, they were hardened by using induction hardening. The punches and dies are manufactured using shaping machine. Die and punch required for L-bending are designed as per mounting requirement of the Universal testing machine. Covering plate used as holder which serves the purpose of keeping specimen in stationary position. Design of die shown in figure1 is as per the requirement of Aluminium HE9 sheet having 3 mm thickness. For L-bending of sheets of thickness 4 mm and 5 mm, minute changes are made accordingly. The schematic for L-bending shown in figure 1 is designed using AUTOCAD Inventor software.

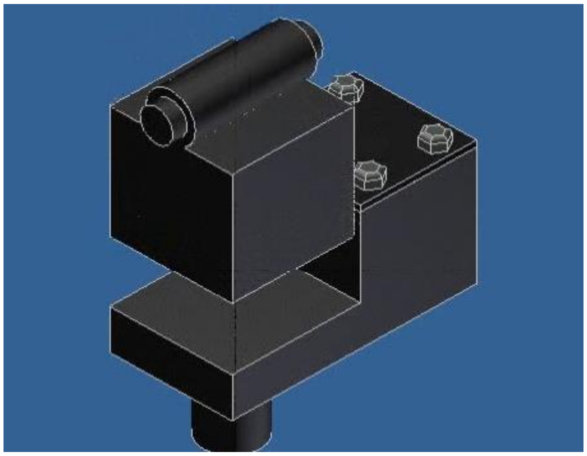

Fig. 1: Schematic for L bending

Fig. 2: Actual L-bending set up

The critical parameters affecting Spring back; chosen for experimentation through available literature are: material thickness, rate of feeding and settling time after bending The experiments were conducted by deciding appropriate levels of the these critical parameters as given in table 1.

Table - 1
Levels of critical parameters affecting spring back in L bending

	Material Thickness (mm)	*Rate of feeding (cm/min)*	*Settling Time (min)*
Level 1	3	0.6	15
Level 2	4	1.5	30
Level 3	5	2.4	45

C. Experimentation:

This section discusses the details of the experiments carried out for finding spring back after L bending of Aluminium HE9. The experiments for L-bending were conducted by making suitable attachments to mount the punches and dies on universal testing machine. A universal testing machine (UTM), also known as universal tester, material testing machine, material test frame, is used to test tensile stress and the compressive strength of the materials. It is named after fact that can perform many standard tensile and compression test on materials, components and structures. The specimen is placed in the machine between the grips and an extensive meter if required can automatically record the change in a gauge length during the test. If an extensive meter is not fitted, the machine itself can record the displacement between its cross head on which the specimen is held. However, this method not only records the change in the length of specimen but also all other extending/elastic components of the testing machine and its drive system including any slipping of the specimen in the grips. Once the machine is started it begins to apply an increasing load on specimen. The machine is hydraulically operated, vertical, floor mounted, designed for testing metals and other materials under tension, compression, bending/ transverse load. The 60 ton universal tensile testing machine (Lloyd Instruments Ltd) was used for L- bending experiments. Aluminium HE9 sheets of 30 mm width, 60 mm length and 3 mm, 4 mm and 5mm thickness were used as a work piece. The experiments are designed and conducted by taking the combination of levels of all critical parameters; Taguchi's orthogonal array L9 is used for the same. The levels of the critical parameters as shown in table 1. The specimens used for L bending in Aluminium HE9 are shown in figure 4, 5 and 6.

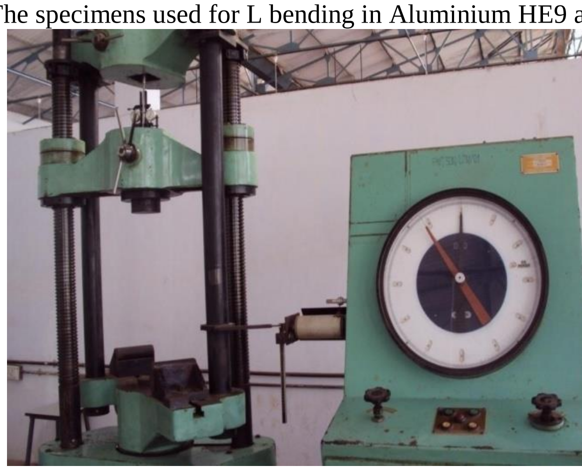

Fig. 3: 60 ton Universal testing machine

Fig. 4: Specimen after L bending (5mm)

Table - 2
L9 Orthogonal array for selected levels of critical parameters

Experiment No.	*Material Thickness (mm)*	*Rate of feeding (cm/min)*	*Settling Time (min)*
1	*3*	*0.6*	*15*
2	*3*	*1.5*	*30*
3	*3*	*2.4*	*45*
4	*4*	*0.6*	*30*
5	*4*	*1.5*	*45*
6	*4*	*2.4*	*15*
7	*5*	*0.6*	*45*
8	*5*	*1.5*	*15*
9	*5*	*2.4*	*30*

Fig. 5: Specimen after L bending (3mm)

Fig. 6: Specimen after L bending (4mm)

D. Measurement of Angle:

The variation in the angle, spring back is taken as response. The spring back was examined in terms of angle using the Optical Profile projector of AURA make having a least count of 5´ (5 minutes). The values of angles of Spring back for Aluminium HE9 measured using the Optical profile projector shown in figure 7; are listed in table 5. Profile projector is also known as optical comparator, or even called as shadow graph, a profile projector is an optical instrument that can be used for measuring. It is a useful item in small parts machine shop or production line for quality control inspection team. The projector magnifies the profile of specimen, and displays this on the built in projection screen. On this screen there is typically a grid that can be rotated 360 degrees so the X-Y axis of the screen can be aligned with a straight edge of machine part to examine/ measure. This projection screen displays the profile of the specimen and is magnified for better ease of calculating linear measurements. An edge of specimen to examine may be lined up with the grid on the screen. Figure 7 shows profile projector used for measurement of values of spring back obtained after L bending and reverse bending.

Fig. 7: Profile projector

Fig. 8: Die and punch for reverse bending

E. Reverse Bending:

Minitab software is used for detailed analysis of spring back obtained after L bending. Best possible combination of critical parameters is found out and specimen with such combination of critical parameters is selected for reverse bending approach. The punch and die used for reverse bending are made up of Mild Steel. As the punch and die are made up of Mild Steel, they were hardened by using induction hardening. The punch and die is manufactured using shaping machine.

Fig. 9: Specimen after reverse bending and half straightening

III. RESULTS AND ANALYSIS

Taguchi's design of experiments was used to design the experiments. The three factors viz. material thickness, rate of feeding and settling time after bending were considered as the critical factors affecting the Spring back in L bending and 3 levels of each factor were taken. Hence L9 orthogonal array was selected for experimentation and total 9 experimental runs were conducted. After performing experimentation on 9 plates Spring back was measured for each plate using a profile projector. The spring back obtained is in degrees as given in the table 3 given on last page.

Table - 3
Factors and response

Runs	*Material Thickness (mm) (factor1)*	*Rate of feeding (cm/min) (factor2)*	*Settling Time (min) (factor 3)*	*Spring back (min)*	*Spring back (response) (degree)*
1	*3*	*0.6*	*15*	*30*	*0.5*
2	*3*	*1.5*	*30*	*35*	*0.583*
3	*3*	*2.4*	*45*	*35*	*0.583*
4	*4*	*0.6*	*30*	*30*	*0.5*
5	*4*	*1.5*	*45*	*35*	*0.583*
6	*4*	*2.4*	*15*	*40*	*0.667*
7	*5*	*0.6*	*45*	*45*	*0.75*
8	*5*	*1.5*	*15*	*40*	*0.667*
9	*5*	*2.4*	*30*	*45*	*0.75*

Table - 4
S/N ratio given by MINITAB for spring back as response

Runs	*Material Thickness (mm) (factor1)*	*Rate of feeding (cm/min) (factor2)*	*Settling Time (min) (factor 3)*	*Spring back (response) (degree)*	*S / N Ratio*
1	*3*	*0.6*	*15*	*0.5*	*6.02060*
2	*3*	*1.5*	*30*	*0.583*	*4.68663*
3	*3*	*2.4*	*45*	*0.583*	*4.68663*
4	*4*	*0.6*	*30*	*0.5*	*6.02060*
5	*4*	*1.5*	*45*	*0.583*	*4.68663*
6	*4*	*2.4*	*15*	*0.667*	*3.51748*
7	*5*	*0.6*	*45*	*0.75*	*2.49887*
8	*5*	*1.5*	*15*	*0.667*	*3.51748*
9	*5*	*2.4*	*30*	*0.75*	*2.49887*

The data is analysed using signal to noise ratio (SN ratio). Smaller the better criterion is used as the Spring back (response) is desired to be minimum. Every value in the response table for S/N ratio gives average of S/N ratio for a parameter for each level. For example, the first value in a table 5 is 5.131 which is an average of three values of S/N ratios for thickness for first level i. e. 3 mm. Similarly all average values for S/N ratios are given in a table 5.

Table - 5
Delta values for S/N ratio

Level	*Thickness*	*Feed Rate*	*Settling Time*
1	*5.131*	*4.847*	*4.352*
2	*4.742*	*4.297*	*4.402*
3	*2.838*	*3.568*	*3.957*
Delta	*2.293*	*1.279*	*0.445*
Rank	*1*	*2*	*3*

Delta value given in the table 5 gives the variations in S/N ratio within the levels, more the variation more is the delta value and hence more is the contribution of that factor in the response. The rank for each control factor given in a table 5 gives the order in which every factor is contributing in a particular response and it is decided on the value of delta. From higher to lower value of delta ranks of all factors are decided. It can be seen from the table 5 that for a Spring back delta value of settling time is maximum followed by rate of feeding and material thickness. Hence in the same order rank is given to the control factors. The delta value of the material thickness in table 5 is highest and rank 1 is given to it, hence it is considered as the most affecting parameter for Spring back in Aluminium HE9. According to the effect of each parameter, the ranks are given. Rate of feeding is given rank 2 and settling time is given the rank 3 as it is the least affecting parameter. It can be easily seen that the variation of the material thickness is greater as compared to the variation of the other two factors. Hence, material thickness is the most affecting parameter for Spring back in Aluminium HE9. The main effects plot graphically represents the effect of factors on the response which helps to compare the effect of each level of the control factor on the response under study. The reference line drawn is showing the average S/N ratio for overall response. From the main effect plot it is clear that the spring back will be minimum at 5 mm material thickness, 2.4 cm/min feed rate and 45 min settling time. The main effect plot obtained from MINITAB software is shown in Fig 10.

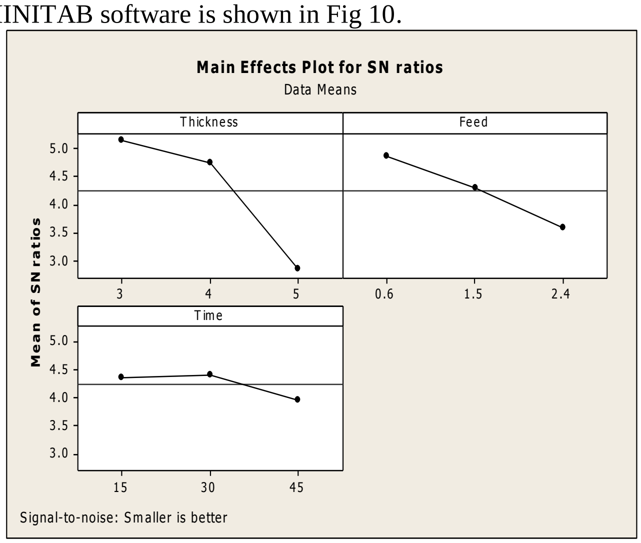

Fig. 10: Main effects plot for S/N ratios

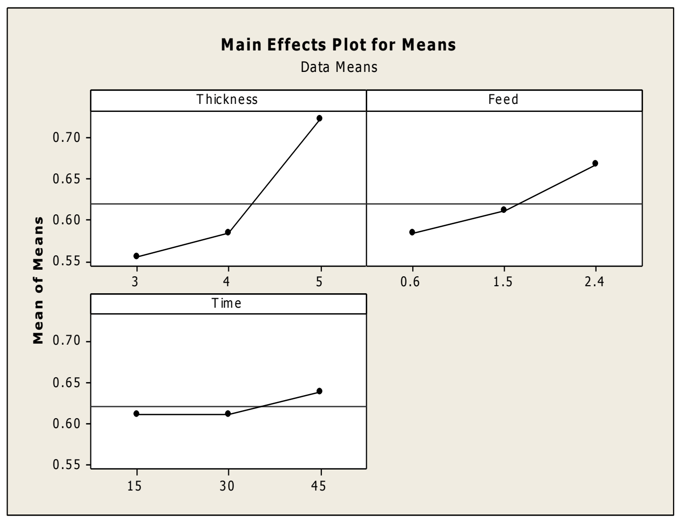

Fig. 11: Main effects plot for means

Table - 6
Delta values for means

Level	*Thickness*	*Feed Rate*	*Settling Time*
1	*0.5533*	*0.5833*	*0.6113*
2	*0.5833*	*0.6110*	*0.6110*
3	*0.7223*	*0.6667*	*0.6387*
Delta	*0.1670*	*0.0833*	*0.0277*
Rank	*1*	*2*	*3*

In table 6, 0.5533 indicates mean of spring back values for first level of parameter thickness i.e. 3 mm. 0.5833 indicates mean of spring back values for second level of parameter thickness i.e. 4 mm. Similarly all mean values of spring back for all levels of other factors are calculated. Delta value is maximum deviation in mean values of same parameter. It can be seen that delta value for material thickness is greater than that of other two parameters and it is given rank 1. Hence, the material thickness is found to be the most affecting parameter for spring back in L bending process for Aluminium HE9. The analysis of variances of the differences in parameters was also calculated. One-way ANOVA was done to find the significance of each process parameter on the Spring back. The ANOVA results of material thickness versus spring back for Aluminium HE9 are shown in table 7. From table 7, the ANOVA results show that, as the value of F for the material thickness is greater than that of other factors; hence material thickness is significant factor as far as Spring back in Aluminium HE9 is concerned. The rate of feeding and settling time are the insignificant factors and can make significance only due to chance. The optimum levels of controlling parameters found out by using S/N ratio. The rank has given the order in which each factor is contributing to the response. Applying analysis of variance, ANOVA it can be done. The ANOVA for spring back is shown in Table 5.8. The percent contribution is a function of sum of squares of each control factor. It is shown in the table 5.8. As L9 array which is chosen for analysis, total degrees of freedom available are 9-1= 8. The percentage contribution of each factor is shown graphically in Figure 12.

Table - 7
ANOVA for spring back

Sr.No.	*Factor*	*SS*	*DOF*	*MSS*	*% contribution*
1	*Thickness*	*0.0479*	*2*	*0.0239*	*67.48%*
2	*Feed rate*	*0.0108*	*2*	*0.0054*	*15.20%*
3	*Settling time*	*0.0108*	*2*	*0.0054*	*15.20%*
4	*Error*	*0.0015*	*2*	*0.0007*	*2.13%*

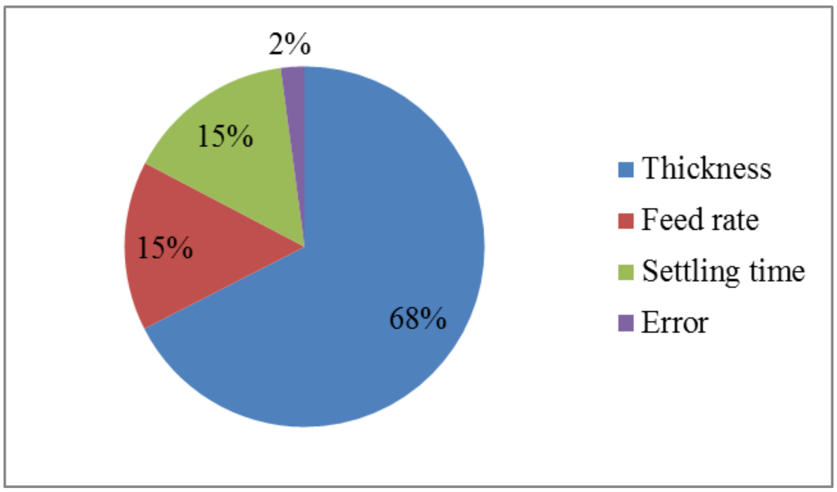

Fig. 12: Percent contribution in spring back

From ANOVA study it is clear that material thickness contributes more towards the spring back than remaining two factors i.e. rate of feeding and settling time after bending.

IV. CONFIRMATION EXPERIMENT

A confirmation experiment is performed by conducting a test using a specific combination of factors and levels previously evaluated. The purpose of the confirmation experiments is to validate the conclusions drawn during the analysis phase. The confirmation experiments are conducted by using the combination of factor levels which are obtained after the analysis and are identical to those used in the initial experiments. The predicted result is only a point estimate based on the averages of the results obtained from the experiments. While performing the confirmation experiment it is better to have a range of value than having exact value of predicted results within which the observed values should fall with some confidence. This range is called as confidence interval (C.I.). It has a maximum and minimum value between which the observed value should fall. It can be calculated by statistical way by using following expression,

$$\text{C. I.} = \pm\sqrt{(F(1, n_2) \times V_e)/N_e}$$

Where F (1, n_2) is the F value from F table at a required confidence level at DOF 1 and error DOF n_2.

$$N_e = \text{Effective number of replications} = \frac{\text{Total number of results}}{\text{DOF of mean} + \text{DOF of all factors}}$$

Using these equations confidence interval for all three responses is calculated which is shown in table 8. The F value is taken for 95% of confidence.

Table - 8
Confidence interval

Sr. No.	*Response*	*No. of samples*	*Mean*	*Standard Deviation*	*C.I.*
1	*Spring back*	*3*	*0.472*	*0.084*	*± 0.1*

From table 8, confidence interval comes out to be ± 0.1; hence values of spring back for confirmation experimental runs should fall within the range 0.472 ± 0.1 i.e. 0.38 to 0.57.

Table - 9
Spring back obtained in confirmation experiment

Runs	*Material Thickness (mm) (factor1)*	*Rate of feeding (cm/min) (factor2)*	*Settling Time (min) (factor 3)*	*Spring back (degree)*	*Mean Spring back (degree)*
1	*3*	*0.6*	*15*	*0.416*	*0.472*
2	*3*	*0.6*	*15*	*0.5*	
3	*3*	*0.6*	*15*	*0.5*	

As per feedback given by Minitab 16 software, optimum combination of levels of all three factors was selected for confirmation experiments. Table 9 indicates value of spring back obtained after L bending which is minimum value of spring back. For the confirmation experiment, same combination i.e. 3 mm thickness, 0.6 cm/min rate of feeding and 15 minutes of settling time was tested three times for spring back and then mean spring back is calculated. It was discovered that this combination of levels gives minimum spring back than all other eight combinations. It is clear that the observed results are falling within the confidence interval of results hene the confirmation experiment has validated the results.

V. CONCLUSION

The experiments were conducted on 60 ton Universal Testing machine (UTM) to apply L bending on material Aluminium (HE9). Profile Projector is used for obtaining values of spring back. The further experiments are conducted on the same machine for L bending to find the effect of process parameters on Spring back using material- Aluminium (HE 9) which is used for L bending in different applications. The L9 Orthogonal Array was used to minimize the experimental runs. The experimental results are analyzed using ANOVA. The percentage contribution of each parameter causing spring back is calculated. At the end the confirmation experiments are carried out. Reverse bending approach is adopted to minimize the spring back in L bending. The influence of each process parameter on the spring-back, together with their calculated percentage contributions was effectively illustrated with ANOVA results. The material thickness was found as the most significant parameter affecting spring back with a contribution of 67.48 % causing spring back in L bending of Aluminium HE9. Hence in order to minimize the spring back, this parameter needs to be effectively controlled

Hence, there is strong significance of the design of process parameters in L-bending process. Taguchi method along with the ANOVA technique was an effective tool to predict the amount of significance of the process parameters in the L-bending process through the designed experiments. Spring back was found to be reduced to significant extent after the application of reverse bending approach before L bending. Hence, there is strong significance of the design of process parameters in L-bending process. Taguchi method along with the ANOVA technique was an effective tool to predict the amount of significance of the process parameters in the L-bending process through the designed experiments. Spring back was found to be reduced to significant extent after the application of reverse bending approach before L bending.

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