International Journal of Mechanical Engineering (IJME)
ISSN(P): 2319-2240; ISSN(E): 2319-2259
Vol. 4 Issue 3, Apr - May 2015; 129-136

International Academy of Science, Engineering and Technology
Connecting Researchers; Nurturing Innovations

AN EXPERIMENTAL STUDY ON THE V- BENDING OF AA 6061 SHEET MATERIAL

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ABSTRACT

Bending is the uniform straining of material, usually flat sheet or strip metal, around a straight axis, which lies in the neutral plane and normal to the lengthwise direction of the sheet or strip with little or no change in the surface area. Springback is an undesirable feature associated with bending particularly with materials of high strength to weight ratio. It is a function of material properties and process parameters. AA 6061 is a material that has wide acceptance in Automobile industries for body panels in which the sheet material undergoes extensive bending. Therefore in this investigation, an attempt has been made to determine the optimum combination of the selected process parameters that minimize the springback in the V bending process..

KEYWORDS: Bending, AA 6061 Sheet Material, Optimization, Response Surface Methodology

INTRODUCTION

Sheet metal bending is one of the most widely applied sheet metal forming operations. The fabrication of sheet metal bending is widely used in automobile and aircraft industrial processes with the trial-and-error method being employed to bend the sheet to the required angle. The accuracy and success of the bending process depends upon the operating parameters as well as the material properties [1]. The spring-back effect is the main defect of both U and V shaped parts, exhibiting significant modifications of the bend angles, especially for materials with higher strength-to-modulus ratios like Aluminium and high strength steel [2]. AA 6061 is a material that has wide acceptance in Automobile industries for body panels in which the sheet material undergoes extensive bending. Therefore in this investigation, an attempt has been made to determine the optimum combination of the selected parameters that minimize the spring back.

SELECTION OF PARAMETERS

In bending process (Figure 1), deformations occur in the bent-up region of the work piece depending on the dimensions of the work piece, bend angle, and bend radius. As the strength of the work piece is limited, the deformations should be restrained in some limits [3]. In this study, the effect of dominant parameters [3-7] such as Bend radius (BR), Bend angle (BA), and Orientation of the sheet blank to the rolling direction (OR) on the spring back has been studied.

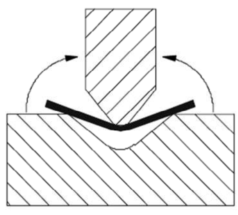

Figure 1: V Bending

Bend Radius (BR)

Bend radius or die radius is one of the most important parameter, which considerably affects all bending operations of sheet metals. The bend radius in bending operations always pertains to the inside radius of the bend. When the bending radius is too small, the strain level on the outer layers is too high, and usually the outer layer will undergo severe plastic deformation or cracking. Whereas a large bend radius results in large amount of elastic strain that leads to higher springback. Therefore the maximum radius considered for the study is limited to ten times the thickness.

Bend Angle (BA)

Bend angle is another crucial factor in bending operations. The area of localized plastic deformation decreases as the bend angle increases. To study the effect of bend angle on springback, three angles were considered, an acute angle, 45^0, a right angle, 90^0 and an obtuse angle, 135^0.

Orientation of the Blank to the Rolling Direction (OR)

Anisotropy in blank sheets is usually the result of a large deformation during initial processing operations such a rolling, extrusion, etc. In bending processes, in order to achieve the desired perfect bending profile, stress–strain distributions are very important. The strain is related to crystallographic texture in sheet [7]. This anisotropy prevalent in the pre-processed sheet segment influences subsequent deformation. The orientation of the blank sheet to the rolling direction has significant influence on the deformation behavior. [6, 8-9]. To evaluate this effect on springback, the blanks are cut in three different orientations, parallel, perpendicular and forty-five degrees to the rolling direction that represent the three vectors of the planar anisotropy.

Thus, the three parameters namely Bend radius (BR), Bend angle (BA), and Orientation of the sheet blank to the rolling direction (OR) were considered for this study. The parameters selected were varied with three levels. Table 1 exhibits the different levels of the chosen parameters.

Table 1: Parameters and their Levels

Parameter	Symbol	Levels		
		-1	0	1
Bend radius, mm	BR	2	5	8
Bend angle, (^{0})	BA	45	90	135
Orientation, (^{0}) to the rolling direction	OR	0	45	90

RESPONSE

Spring back is a growing concern as manufacturers increasingly rely on materials with higher strength to modulus ratio. Springback can be minimized by using suitable die designs, but cannot be eliminated. One of the most important problems in the die design is to minimize the spring back [10]. Springback is often expressed in terms of angular springback error defined as the difference between θ_1 and θ_2. where θ_1 and θ_2 are the bend angles respectively before and after the bending load is removed.

Table 2: Design Matrix in Coded and Actual Values

Exp. Run	Coded value			Actual value		
	BR	BA	OR	BR	BA	OR
1	-1	-1	1	45	2	90
2	0	0	0	90	5	45

Table 2: Contd.,						
3	1	-1	-1	135	2	0
4	0	0	0	90	5	45
5	0	-1	0	90	2	45
6	1	1	-1	135	8	0
7	-1	0	0	45	5	45
8	-1	1	-1	45	8	0
9	0	0	0	90	5	45
10	0	0	1	90	5	90
11	0	0	0	90	5	45
12	0	0	0	90	5	45
13	0	1	0	90	8	45
14	-1	1	1	45	8	90
15	1	1	1	135	8	90
16	0	0	-1	90	5	0
17	1	0	0	135	5	45
18	-1	-1	-1	45	2	0
19	1	-1	1	135	2	90
20	0	0	0	90	5	45

EXPERIMENTAL PLAN

Design of Experiment and Response Surface Methodology (RSM)

In this study, the Response surface methodology (RSM) and Analysis of variance (ANOVA) techniques were used to examine the effects of the parameters -bend radius, bend angle and orientation on spring-back and the parameters are optimized for minimum springback. The upper limit of a factor was coded as +1, and the lower limit was coded as –1. Table 2 shows the design matrix in coded and actual values. Using the design of experiments and applying regression analysis the modeling of the response to the selected independent input variables are gained.

Experimentation

Punch and Die Inserts

V bend dies and punches were designed and build to install on the Hydraulic press. Nine sets of V bend dies and punches with three bend radii (2 mm, 5 mm & 8 mm) and three bend angles (45^0, 90^0 and 135^0) were fabricated. Photograph of the dies is shown in Figure 2. A hydraulic press with a maximum load capacity of 150 tons was used to conduct the deep drawing experiments. The length and width of the specimen are 50 mm and 25 mm respectively [11]. Each experiment was carried out in duplicate. According to the experimental direction, ten blanks were cut perpendicular to the rolling direction and twenty blanks were cut forty five degrees to the rolling direction.

Figure 2: V Dies and Punches

Punch and die were mounted on the hydraulic press and the twenty experiments were carried out according to the designed experimental scheme. Each experiment was carried out in duplicate. The photograph of the formed blanks is shown in Figure 3. The average springback values are shown in the Table 3.

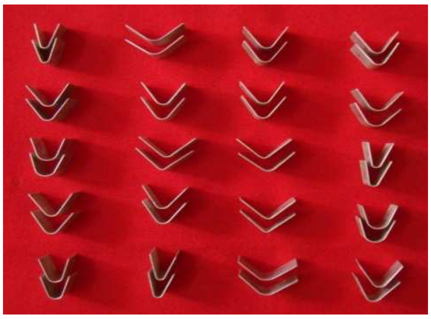

Figure 3: Blanks After V Bending

Table 3: Measured Springback Values

Exp. Run	Springback (^{0})	Exp. Run	Springback (^{0})
1	2.02	11	3.1
2	3.1	12	3.12
3	2.74	13	4.5
4	3.1	14	4.26
5	1.78	15	6.32
6	6.02	16	3.62
7	2.64	17	3.98
8	4.16	18	2.2
9	3.08	19	2.9
10	3.72	20	3.16

MATHEMATICAL MODELING OF SPRINGBACK

From Table 4, The P value for the regression model (0.000) is lower than 0.05 (α = 0.05, or 95% confidence) which indicates that the model is considered to be statistically significant. Also The P value for the model terms BA, BR and OR are lower than 0.05. It demonstrates that the terms have significant effect on springback. The result of the test for the significance of the parameters is given in Table 4 from which it can be concluded that all model terms representing the response variables except the square effect of BR are significant.

Table 4: ANOVA Table for the Quadratic Model of Springback

Source	Degree of Freedom	Sum of Squares	Mean Sum of Squares	F-Value	P-Value
Regression	9	25.6276	2.84751	1158.25	0.000
Linear	3	22.7738	0.2567	104.42	0.000
BA	1	4.4622	0.03186	12.96	0.005
BR	1	18.279	0.08384	34.1	0.000
OR	1	0.0325	0.64118	260.81	0.000
Square	3	2.0141	0.67136	273.08	0.000
BA*BA	1	1.0718	0.04845	19.71	0.001
BR*BR	1	0.1471	0.00045	0.18	0.679
OR*OR	1	0.7952	0.79516	323.44	0.000
Interaction	3	0.8398	0.27992	113.86	0.000
BA*BR	1	0.7813	0.78125	317.78	0.000

Table 4: Contd.,					
BA*OR	1	0.0364	0.03645	14.83	0.003
BR*OR	1	0.0221	0.02205	8.97	0.013
Residual Error	10	0.0246	0.00246		
Lack-of-Fit	5	0.0169	0.00337	2.18	0.206
Pure Error	5	0.0077	0.00155		
Total	**19**	**25.6522**			

The quadratic model for springback is fitted with the significant terms and the model is given in Eq.1. The calculated value of R^2 for this model is over 0.95 (i.e. 97.90%), close to unity, which is acceptable. The adjusted R^2 is 97.82%, indicates that the quadratic model is adequate to represent the variability of the springback as a function of BA, BR and OR. The lack of fit is insignificant (0.206) as desired.

Springback = 1.87273- 0.01003 BA+ 0.21069 BR-0.02758 OR+ 0.00007 BA*BA+

0.00141 BR*BR+ 0.00027 OR*OR+ 0.00231 BA*BR+ 0.00003

BA*OR+ 0.00039 BR*OR (7.1)

RESULTS AND DISCUSSIONS

Based on Eq.1, developed through experimental observations and response surface methodology, studies were carried out to analyze the effects of the variables on the springback.

The Effect of Bend Radius and Orientation on Springback

From Figure 4, it is observed that springback increases almost linearly with bend radius.The stress over the punch corner is the most significant factor that governs the magnitude of springback. At smaller bending radii, the sheet is deformed more locally and severely, resulting in the increased plastic strain. But for the larger die radius comparatively small bending stress locked into the sheet at the punch corner. However there is a little effect of orientation on springback. This is due to the variation in strength of the sheet material for different orientation.

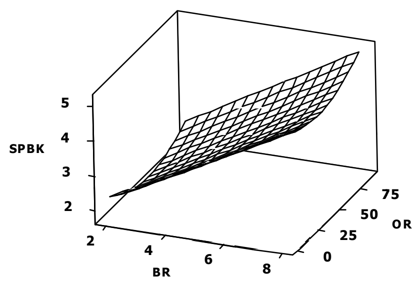

Figure 4: Influence of Bend Radius and Orientation on Springback

The Effect of Bend Angle and Orientation on Springback

It is noted from Figure 5 that increase in bend angle increases the springback gradually. When the bend angle increases the amount of material that undergoes deformation under the punch nose also increases. The increased volume of material is not severely deformed and hence the springback increases. This effect when combined with the higher strength of the sheet that is cut in orientation perpendicular with the rolling direction becomes more predominant. Therefore a comparatively higher value of springback is observed for higher orientation angle.

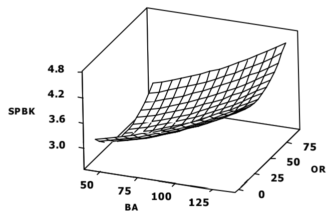

Figure 5: Influence of Bend Angle and Orientation on Springback

The Effect of Bend Angle and Bend Radius on Springback

It is noted from Figure 6. As the sheet is bent over a very sharp radius, the material will stretch more on the outside, which means that the neutral axis will lie closer to the inside of the bend. As a result smaller volume of material at the inside of the sheet is heavily deformed and stressed beyond the yield strength. It, thereby does not allow the edges of the V to springback. For lower bend angle and lower bend radius, the material is plastically deformed almost the entire thickness. Therefore the springback is least at this condition.And the springback is maximum when both are high.

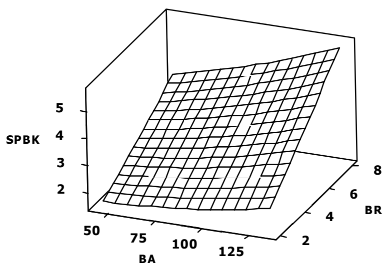

Figure 6: Influence of Bend Angle and Bend Radius on Springback

Optimization

Based on the developed second order response surface equations for correlating the selected parameters Bend radius (BR), Bend angle (BA), and Orientation of the sheet blank to the rolling direction (OR) on the response springback, optimality search can be carried out.. The objective of the optimization was to minimize the springback. The input parameter setting for the target value of the response is shown graphically in Figure 7. The parameter setting for which springback is predicted as 1.5871, are bend radius 2.0 mm, bend angle 45^0, and orientation of the sheet blank is 47.27^0 to the rolling direction (OR).

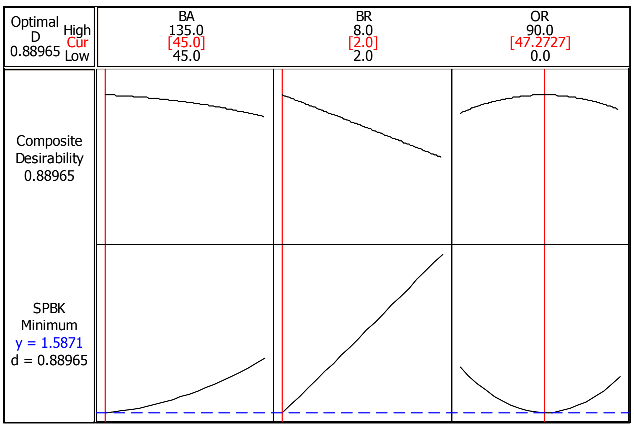

Figure 7: Optimization Plot for Springback

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