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Effect of Die and Punch Geometry on Spring Back in Air Bending of Electrogalvanized CR4 Steel

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Abstract

This paper presents a study of spring back in air bending process. It is a sensitive feature of sheet metal forming due to elastic recovery upon load removal. The main objective of this study is to analyze the effects of the die and punch radius on spring back of galvanized and nongalvanized CR4 steel. Different galvanizing thickness, punch travel, die radii and punch radii were used with one parameter at a time approach in air bending. The universal testing machine was used keeping a constant speed. The orientation of steel sheet was kept same. Graphics and optical profile projector were used for the measurement of angles. A Graphical method was used for analyzation. An increase of spring back was observed with the increase of punch radii and die radii as well, in both galvanized and ungalvanized steel sheet. The findings will be useful for metal forming industry.

Keywords: Spring back; CR4 steel; electro-galvanizing; die and punch; geometry; sheet metal forming; air bending

INTRODUCTION

As a classical and traditional method of metal working process of manufacturing, sheet metal forming is widely used due to fast production, high precision, and low wastage, an easy realization of automation is an added benefit. Aeronautics, automotive, electrical, home appliances are some of the well-known industries employing sheet metal forming process for manufacturing. Sheet metal forming process makes use of the theory of plasticity. Plastic deformation is always followed by elastic recovery upon load removal. This elastic recovery is known as spring back [1]. Every material has a finite modulus of elasticity, so spring back is also finite, but due to different methods of forming it varies. Bending is a basic metal forming process generally used to stiffen the part by increasing the moment of inertia by providing flanges, curls, seams, and corrugations in sheet metal product. This process is of three types, namely, air bending, wipe die bending and v-die bending. Air bending, a traditional method of bending, has been considered for this study. This process makes use of flexible tooling and different bend angles can be made by changing the punch travel without changing the die and punch. In this process sheet metal is supported by die at two edges of die opening and the punch touches on the top surface of the sheet metal and applies a load. An angle is made by punch travel and the bottom radius is made by punch profile. Since in this process sheet metal does not get support below at the end of the operation, so accurate punch travel is required. This process is commonly used for batch production, part production and prototype build. In bending, spring back appears in the form of reduction of bend angle. If θi is the initial bend angle before load removal and θf is the final bend angle after load removal, then spring back, Δθ can be calculated by the equation (1)

$$\Delta\theta = \theta i - \theta f \qquad (1)$$

Spring back in an elastic - perfectly plastic metal is given by equation (2) [2]

$$\Delta\theta = -3\left(\frac{Ri}{T}\right)\left(\frac{Y}{E}\right)\theta i \qquad (2)$$

Here, Ri is the initial bent angle, T is steel sheet thickness, Y is yield stress and E is the modulus of elasticity.

Galvanizing is a process of applying protective coating of zinc on the surface of the steel. The zinc layer prevents the corrosive substances from reaching the beneath surface of steel by sacrificing itself. Zinc works as a sacrificial anode, so as if zinc coating is scratched, even then, the exposed surface will be protected by remaining zinc. Shackelford states zinc being more anodic than steel, in the presence of corrosive elements, losing itself slowly, it provides galvanic protection to steel, even if the coating is removed and steel is exposed in some area [3]. There are several ways of galvanizing, in this investigation electro galvanizing is considered, since it is commonly used in the automobile sector, where the additional decorating coating of paint is required.

RELATED WORKS

H. Hayashi and T. Nakagawa [4] said that shape fixability is the main indices to access the sheet formability. The degree of fixation of size and shape of the formed part after bending, load removal and elastic recovery is called shape fixability. This causes a change in shape referred as spring back. It is a measure of fixability of shape in bending.

C. C. Chen and C. P. Jiang [5] studied the effect of grain size on spring forward, spring back and punch force in the micro v-bending process of thin metal sheets.

M. Kadkhodayan and I. Zafarparandeh [6] investigated the process of sheet draw bending for the relation of spring back and equivalent plastic strain.

C. C. Chen [7] analyzed the effects of punch speed, punch radius and grain size on micro v-bending and observed punch speed, punch radius and grain size has a vital role in spring back control in the micro v- bending process of thin metal sheets.

J. A. Schey and G.M. Dalton [8] found that minor variation in surface finish modifies the friction significantly and the submicroscopic features of electro galvanized sheet helped in retention of lubricants.

J. Z. Gronostajski [9] studied the forming process of coated steel sheets and their behavior. He observed that zinc is softer and behaves as a solid lubricant since it has the lower shear strength than steel

D. Fei and P. Hodgson [10] identified the major parameter affecting the spring back behavior, in air v bending, of cold rolled transformation induced plasticity (TRIP) steels.

M.L. Garcia-Romeu, J. Ciurana and I. Ferrer [11] conducted experiments in air bending of aluminum and stainless-steel sheets for obtaining spring back values for different angles, presented those values graphically and evaluated the effect of parameters.

R. Narayanasamy and P. Padmanabhan [12] presented an experimental investigation on air bending process of I. F. steel sheets for studying the important parameters affecting the spring back.

D. Vasudevan, R. Srinivasan and P. Padmanabhan [13] conducted the experiment on air bending to study the spring back behavior of electro-galvanized steel sheets and analyzed the influence of various process parameters. In this study, initial bend angle was measured by taking an impression and then evaluating the same by Auto CAD.

T.R. Gupta and H. S. Payal [14] investigated bending process of electro galvanized steel for spring back. Measurement of initial bend angle was done by the method described in [13]

A. K. Gupta and D. R. Kumar [15] conducted experiments and compared the formability of ungalvanized and galvanized steel and observed formability is marginally higher in the case of ungalvanized interstitial-free steel sheets in comparison of hot dip galvanized interstitial-free steel sheets.

T. Meinders, A.W. A. Konterl, S.E. Meijers, E.H. Atzema and H. Kappert [16] analyzed the sensitivity of spring back and observed that the spring back was reduced due to the decrease of friction coefficient.

M. S. Baung, S. A. Abdullah and J. Saedon [17] investigated the influence of tool geometry on spring back in air bending of stainless steel sheet.

S. Kurra, S. D. Bagade and S. P. Regalla [18] compared the behavior of extra deep drawing steel analytically using LS-DYNA software and experimentally in single point incremental forming and found a good correlation in the obtained data. After incremental forming a grain refinement was observed in the steel sheet.

T.R. Gupta and H. S. Payal [19] studied the effect of Die and punch geometry, bending speed and sheet orientation on bending force in air bending of CR4 steel and found the increase of die width is the main source of force reduction, die radius is having the marginal impact. They found bending force obeys 2^{nd} order polynomial equation.

H. Khalatbari, A. Iqbal, X. Shi, L. Gao, G. Hussain and M. Hashemipour [20] studied high speed incremental forming process and found forming at the speed of 5000 mm/min is viable with satisfactory sheet formability.

M. Salahshoor, A. Gorji, and M. B. Jooybari [21] studied the effects of tool and process parameters in hydroforming.

F. A. Khadra and A.W. El-Morsy [22] predicted spring back using kriging metamodel in the process of air bending.

T.R. Gupta and H. S. Payal [23] investigated the effect of electro galvanization on spring back in CR4 steel. In this study measurement of initial bend angle was computed using a graphical method by drawing enclosure parameters like die width, die radius, punch radius and punch travel and observed spring back was increased due to galvanization as compared to a nongalvanized sheet, it increases due to increase of galvanizing thickness also. An increase of bending speed has also increased the spring back.

RESEARCH AIM AND OBJECTIVES

Now a day use of nongalvanized and galvanized CR4 steel has increased due to its properties and it is evident from the above literature that very limited research is carried out for spring back of CR4 steel and the effect of galvanizing thickness. Spring back and geometry of die and punch are major players for governing the quality in the forming process. Therefore, the objective of the present study is to analyze the effect of galvanizing thickness, geometry of die and punch on spring back in air bending. This study will help the development engineers for enhancing the quality and reducing the development time of metal forming products.

METHODOLOGY

The steel sheet used in this experimental investigation was CR4, an aluminum killed grade of 1mm thickness. Chemical composition and mechanical properties were tested and found to be as per specifications, the results obtained are shown in Table I. and Table II respectively.

TABLE I.

Test Data of CR4 Steel (Chemical Composition)						
C%	*Mn%*	*P%*	*S%*	*Al%*	*L%*	*Si%*
0.057	0.189	0.018	0.013	0.043	< 0.004	< 0.017

TABLE II.

Test Data of CR4 Steel (Mechanical Properties)					
Orientation	*Yield stress*	*Tensile strength*	*Elongation %*	*Modulus of elasticity*	*Hardness*
	(MPa)	*(MPa)*	*Lo=50*	*(GPa)*	*HV5*
0°	181.2	318.7	45	202	95
90°	190.6	318.7	43.8	206	
45°	193.4	335.5	37	207	
Average*	189.65	327.1	40.7	205.5	

* $X_{average} = X_0 + 2X_{45} + X_{90}$ *(X stands for property)*

A. Specimen Preparation

The samples were cut to 35x150, keeping 150 along rolling direction. Electro galvanizing was done using an alkaline cyanide - free zinc plating system. The galvanizing thickness of 4 µm; 7 µm; and 10 µm was controlled by varying the duration of plating. The thickness of galvanizing was measured using coating thickness gauge.

B. Experimentation

Table III gives the account of various parameters used for the experimentation Same punch speeds were used for all the experiments on twin column universal testing machine. This machine was equipped with servo control drive to control the speed and distance. It was having a computer interface for chart recording and analysis. Different punch travels were used to see the effect of spring back at different angles. Fig. 1 shows the experimental setup.

C. Measurements

Initial bend angle θi was computed by drawing the different enjoinment parameters such as Wd = 60 mm; Rd = 5 mm; Rp = 8 mm and different punch travels using AutoCAD. Similarly, for other combinations of die and punch radii, θi was computed [23]. Measurement of final bend angle θf was done by using PJ2505 profile projector, manufactured by Mitutoyo. Spring Back Δθ was calculated by using the equation (1).

TABLE III.

Parameters Used in Experiment		
Constant parameters		
Work blank width	Ws (mm)	**35**
Work blank length	Ls (mm)	**150**
Work blank thickness	Ts (mm)	**1**
Orientation of sheet	(°)	**0**
Punch speed	Vp (mm/sec)	**0.4**
Die width	Wd (mm)	**60**
Variable parameters		
Punch radius	Rp (mm)	**8**, 12, 16
Die radius	Rd (mm)	3, **5**, 8
Punch travel	(mm)	5, 10, 15, 20, 25
Coating thickness	(µm)	0, 4, 7, 10

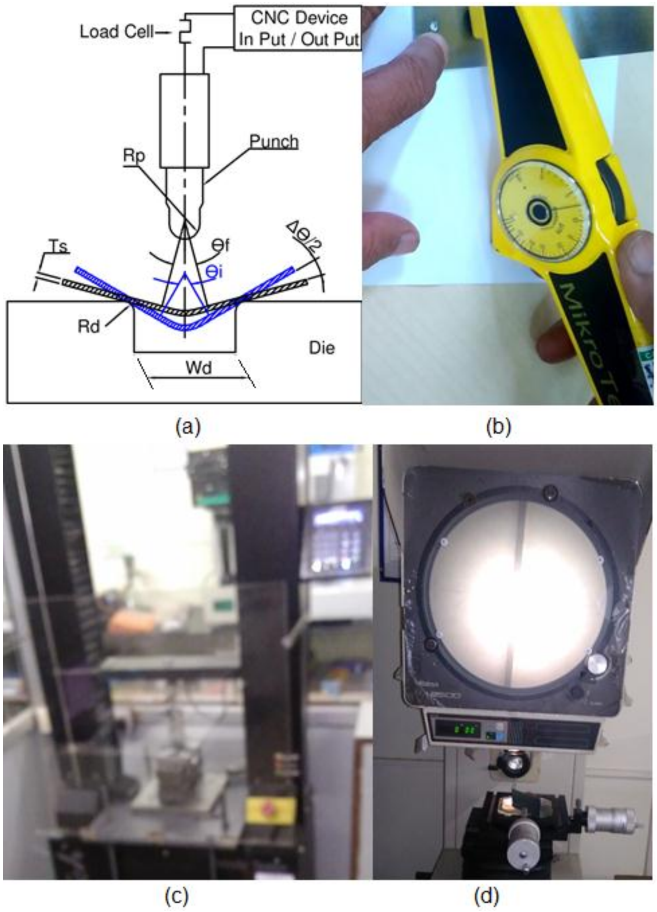


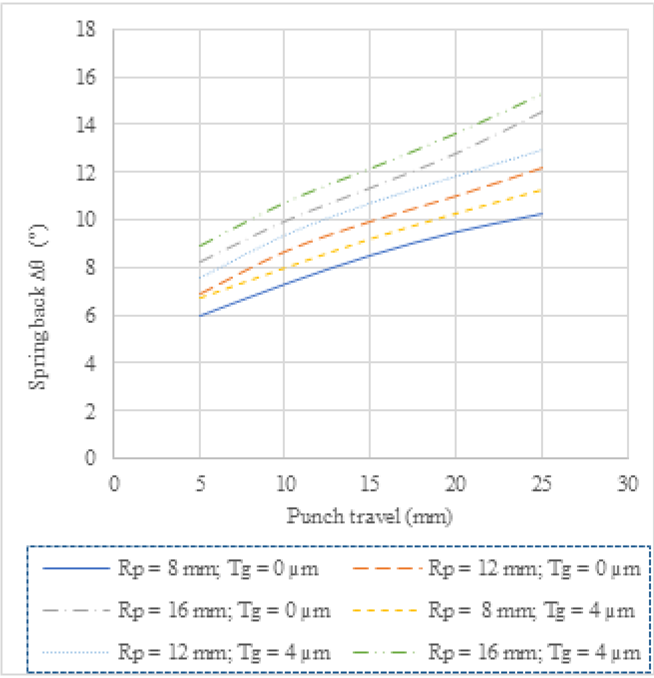
Figure 1. Experimental setup (a) schematic diagram of air bending and spring back (b) measuring the galvanizing thickness (c) bending setup on universal testing machine (d) profile projector for measurement of final bent angle.

RESULTS AND ANALYSIS

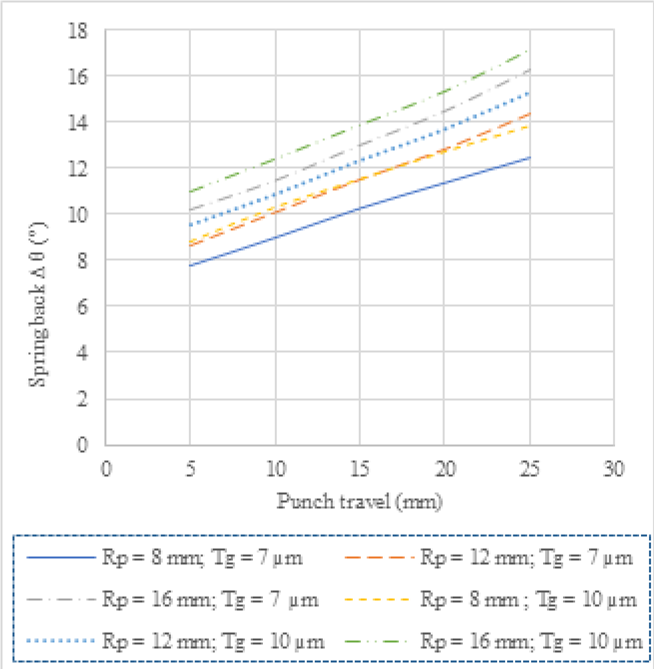
Experiments were conducted using different galvanizing thickness; punch radii and die radii, keeping constant punch speed, die width and work blank. Effect of the various parameters on spring back was plotted at various punch travels on scattered smooth line graph and illustrated.

A. Effects of Punch Radius

Fig. 2 (a) and 2 (b) shows the effect of punch radius on spring back. It was observed that with the increase of punch travel bend angle increases and spring back also increases. Spring back increases with the increase of galvanizing thickness. It was observed that with the increase of punch radius, spring back was increased for each punch travel in case of ungalvanized as well as galvanized sheet of each galvanizing thickness. Increasing of punch radius increases warp around zone curvature and thereby spring back. Equation (2) is also in agreement with it. It was seen that the effect of punch radius was less on spring back for low ranges of punch travel since contact area of punch does not increase much and became stronger at larger punch travel.



(a)

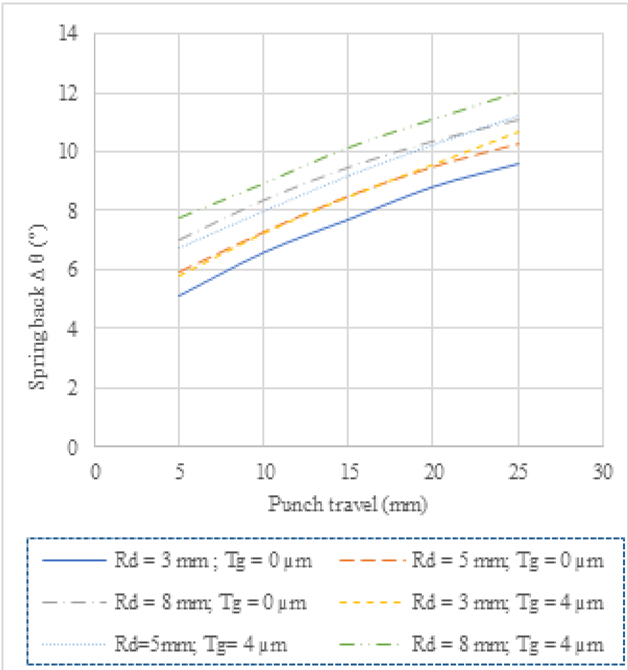


(b)

Figure 2. Effect of punch radius on spring back

B. Effects of Die Radius

Fig. 3 (a) and 3 (b) shows the effect of die radius on spring back.



(a)

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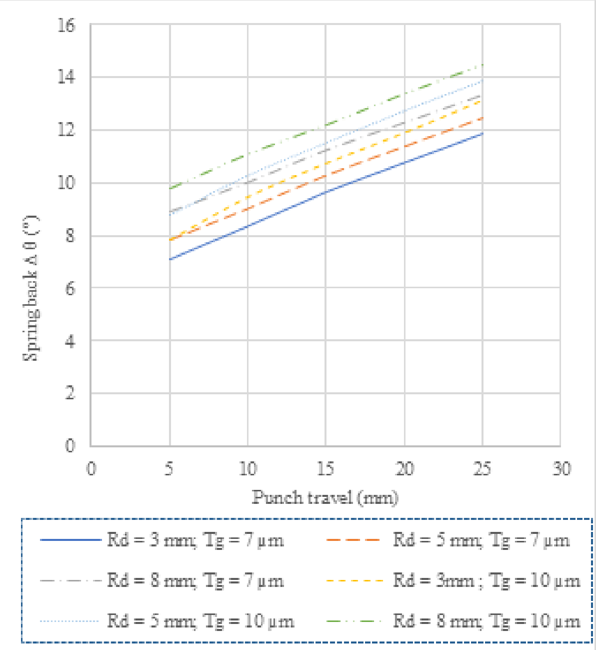

(b)

Figure 3. Effect of die radius on spring back

It was observed that with the increase of die radius spring back was increased for each punch travel in case of ungalvanized as well as galvanized sheet of each galvanizing thickness. It was seen that the effect of die radius was more prominent on spring back for low ranges of punch travel since the free bending length was increased and became weaker at larger punch travel.

CONCLUSION

Based on the investigations of this experimental study following conclusions are drawn

- With the increase of punch travel, bend angle increases and spring back also increases for galvanized as well as the un-galvanized sheet.
- Spring back is more in the case of galvanized sheet as compared to a ungalvanized sheet. Spring back increases with the increase of galvanizing thickness.
- With the increase of punch radius spring back increases for both galvanized as well as the ungalvanized sheet. It increases with the increase of galvanizing thickness. The effect is stronger at higher punch travel
- With the increase of die radius spring back increases for both galvanized as well as the ungalvanized sheet. It increases with the increase of galvanizing thickness. The increase is more prominent in the low range of punch travel.

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