

Investigation of Spring Back in Air Bending of Electrogalvanized CR4 Steel

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Abstract

Objectives: To analyze the effects of galvanizing thickness and punch speed on spring back of CR4 steel. **Methods:** Galvanizing is done by electro-deposition method using an alkaline cyanide-free zinc plating system and different thickness of deposition was achieved by changing the time. Galvanizing thickness was measured by coating thickness gauge. Experiments were conducted on a universal testing machine, using various combinations of punch travel, punch speed, and sheet orientation, using the same tooling and size of the specimen. An approach to change one parameter at a time was applied. Measurement of angles was done with the help of graphics and optical profile projector. Spring back was analyzed graphically. **Findings:** It was observed that spring back increases with the increase of punch travel and punch speed both. With the increase of galvanizing thickness increase of spring back was observed. **Application/Improvements:** These results will be useful for design engineers and manufacturing engineers since the use of galvanized steel sheets has increased and the methods of initial bent angle and galvanizing used is as per industry's current practice.

Keywords: Air Bending, CR4 Steel, Electro-galvanizing, Metal Forming, Punch Speed, Spring Back

1. Introduction

Today in the global market, demand is for fast production, high precision, and low wastage. Sheet metal forming process meets all these requirements, an easy realization of automation is an added benefit. Sheet metal products have a wide range of applications in the field of aeronautics, automotive, electrical, home appliances etc. Bending is a simple metal forming process, making use of the theory of plasticity. In this process, the metal sheet is shaped by straining the metal around a straight axis. During this operation, internal side is compressed and external side is stretched. It is used to impart stiffness by increasing the

moment of inertia by providing flanges, curls, seams, and corrugations in sheet metal product. Bending process is of three types those are air bending, v-die bending and wipe die bending. Air bending has been considered for this study. It is known as free bending also. This process makes use of flexible tooling. In this process sheet metal is supported by die at two edges of its opening and punch touches on the top surface of the sheet metal and applies a load. Since die does not support the sheet metal at the bottom, an angle is made and controlled by adjusting the punch travel. Bottom radius is made by punch profile. So, accurate punch travel is important in air bending.

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Different angles can be made with the same tool set by changing the punch travel, whereas in v-die bending different die and punch are required for different angles. So, air bending is used for small batch production, prototype development, and part production. Every material has a finite modulus of elasticity. Plastic deformation is always followed by elastic recovery upon load removal. In bending, this recovery is known as spring back⁴. If θ_i is the initial bend angle before load removal and θ_f is the final bend angle after load removal, then spring back, $\Delta\theta$ is given by the equation (1)

$$\Delta\theta = \theta_i - \theta_f \quad (1)$$

Spring back in an elastic, perfectly plastic metal is given by equation (2)²

$$\Delta\theta = -3(R_i / T) \cdot (Y / E) \theta_i \quad (2)$$

Here, R_i / T is bend ratio and (Y / E) is the ratio of yield stress to the modulus of elasticity.

Spring back has been a topic of interest for researchers. Shape fixability is one of 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 shape discrepancy referred as spring back. Spring back is a measure of shape fixability in bending³. Change in young modulus due to plastic deformation should be taken into consideration for estimation of spring back in air bending in cold rolled transformation induced plasticity (TRIP)⁴. Experiments were conducted for aluminum and stainless steel sheets to obtain spring back values for different angles. The spring back values were presented graphically⁵. Influence of tool geometry on spring back in air bending of stainless steel sheet was studied⁶. Experimental investigation on air bending process of interstitial free steel sheets was conducted to study important parameters affecting the spring back⁷. The effect of grain size on punch force, spring forward and spring back in the micro v- bending process of thin metal sheets were analysed⁸. Effect of bending speed, steel sheet orientation and die and punch geometry on bending force in bending

were studied for CR4 steel and it was found that bending force follows polynomial equation of 2nd order and that die width is the main source having an impact on bending force, whereas die radius has a marginal effect. Bending force was found to be more in the case of cross rolling direction, in comparison of rolling direction. The increase of bending force was observed with the increase of punch radius, the effect was less for the smaller angle but it was prominent for higher bend angles⁹.

Investigation of the process of draw bending was conducted for the relation of spring back and equivalent plastic strain¹⁰. The kriging metamodel was used for predicting the spring back in the process of air bending. The study was conducted on a training exercise¹¹. In the study of effects of punch speed, punch radius and grain size on micro v-bending it was found that punch speed, punch radius and grain size has a vital role in spring back control in the micro v- bending process of thin metal sheets¹². During the comparison of the behavior of extra deep drawing steel experimentally and analytically using LS-DYNA software in single point incremental forming it was found that a good correlation exists in the obtained data and after incremental forming a grain refinement was observed in the steel sheet¹³. During the studies of the high speed incremental forming process it was found that forming speed of 5000 mm/min is perfectly viable with satisfactory sheet formability¹⁴. Process of hydro-forming was studied for the formability due to the effects of tool and process parameters¹⁵.

Galvanizing is a process of depositing zinc over the surface of the steel. Minor variation in surface finish modifies the friction significantly and the submicroscopic features of electro galvanized sheet helped in retention of lubricants¹⁶. 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 area¹⁷. When exposed to the atmosphere, the pure zinc reacts with oxygen (O_2) to form a very thin tenacious layer of zinc oxide (ZnO), with water it forms zinc hydroxide. This hydroxide reacts with carbon dioxide (CO_2) to form zinc carbonate ($ZnCO_3$), a strong dull gray material that stops further corrosion in many enjoyment environments and

protect the steel below from the corrosive elements. There are numerous methods of galvanizing, in this investigation electro galvanizing is considered. Experiments were conducted for electro-galvanized steel and measurement of initial bent angle was done by taking an impression on paper supported by cardboard and data were presented graphically¹⁸. The forming process of coated steel sheets and their behavior was studied and observed that zinc has the lower shear strength than steel, it is softer and behaves as a solid lubricant¹⁹. Formability is marginally higher in the case of ungalvanized interstitial-free steel sheets as compare to hot dip galvanized interstitial-free steel sheets²⁰. During a study of the sensitivity of spring back it was observed that due to the decrease of friction coefficient spring back was reduced²¹. Investigation of electro galvanized CR4 steel for air bending process and spring back was done using a similar method of impression¹⁸ for measurement of initial bent angle and data were presented graphically²².

A limited research is carried out for spring back of CR4 steel and the effect of galvanizing thickness.. The objective of the present study is to analyze the effect of galvanizing thickness and process parameters, such as punch speed

and sheet orientation. In this study, the initial bent angle is measured by drawing the enjoinment parameters, i.e., die width, die radius, punch radius and punch travel of the individual experiment using AutoCAD, a method commonly used by design engineers in the industry. Electro galvanization is done using an alkaline cyanide-free zinc plating system currently used in the auto sector. This study will help the development engineers in enhancing the quality and reducing the development time of metal forming products.

2. Materials and Methods

2.1 Materials

The steel sheet used in this experimental investigation was CR4, an aluminum killed grade of one mm thickness. Chemical composition was analyzed using emission spectrometry as per ASTM-E415-2014 and a tensile test was conducted as per IS 1608:2005 and found to be as per specifications, results obtained are shown in Table 1. In India, it is manufactured as per IS 513:2008

Table 1. Test data of CR4 steel

Chemical composition						
C%	Mn%	S%	P%	Al%	Si%	N%
0.057	0.189	0.013	0.018	0.043	< 0.017	< 0.004
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		

2.2 Preparation of Samples

Steel sheet was cut to 35x150 size, keeping length along the rolling direction for (0°) orientation, and across the rolling direction for (90°) orientation. These samples were electro galvanized using alkaline cyanide free zinc plating system, Millenium NCZ 511 of ArtekSurfin chemicals Ltd., for different thickness of 4 μm ; 7 μm ; and 10 μm . The thickness of plating was controlled by timing and measured using coating thickness gauge 'Micro-test', manufactured by Electro Physik, Germany.

2.3 Experimentation

Experiments were conducted using different parameters given in Table 2. For (0°) orientation samples bending was done across the rolling direction and for (90°) orientation samples bending was done in the rolling direction. Different punch speeds were used to see the effect of same on twin column universal testing machine, HT-U 1605-HS. This machine was equipped with an electrical servo control programmable drive to control speed and distance, having 1 mm/min to 500 mm/min variable cross

Table 2. Overview of tool parameter used in experiment

Type	Parameter		
Constant	Work blank width	Ws (mm)	35
	Work blank length	Ls (mm)	150
	Work blank thickness	Ts (mm)	1
	Die width	Wd (mm)	60
	Punch radius	Rp (mm)	8
	Die radius	Rd (mm)	5
Variables	Punch travel	(mm)	5, 10, 15, 20, 25
	Orientation of sheet	(°)	0, 90
	Galvanizing thickness	(μm)	0, 4, 7, 10
	Punch speed	Vp (mm/sec)	0.4, 0.6, 0.8

head speed and 500Kg load cell. It was having a computer interface for analysis and chart recording. Different punch travels were used to see the effect of spring back at different angles. Various parameters used for the experimentation is given in Table 2.

2.4 Measurement of Spring Back

Initial bend angle θ_i was computed by drawing the enjoinment parameters that is $W_d = 60$ mm; $R_d = 5$ mm; $R_p = 8$ mm and different punch travels using AutoCAD. Measurement of final bend angle θ_f was done by using

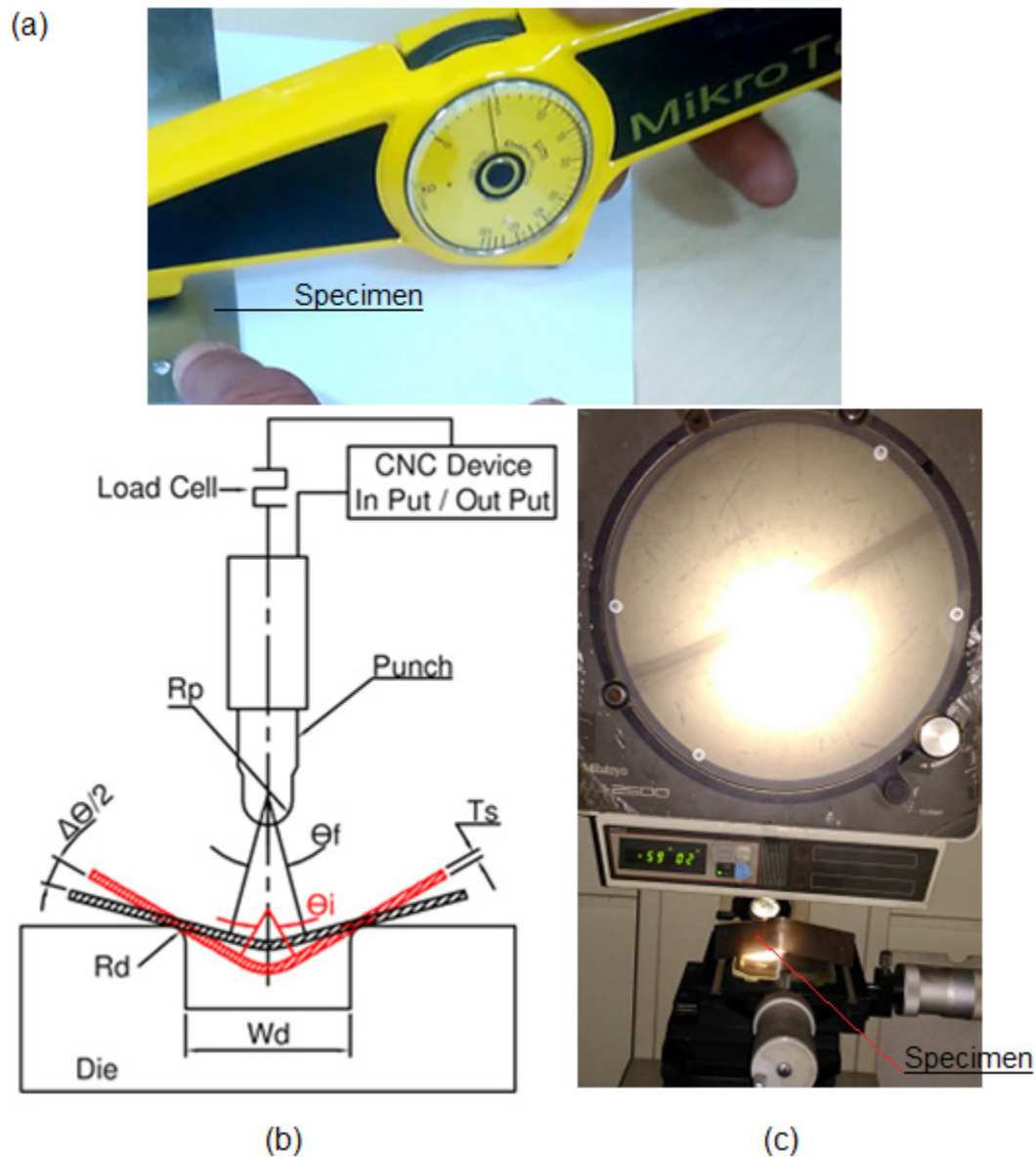


Figure 1. Experimental setup (a) measuring coating thickness (b) schematic diagram of air bending and spring back (c) profile projector for measurement of final bent angle.

PJ2505 profile projector, manufactured by Mitutoyo. Spring Back $\Delta\theta$ was calculated by using the equation (1). The experimental setup is shown in Figure 1.

3. Results and Discussion

Effect of the various parameters on spring back was plotted at various punch travel on the graph and illustrated.

3.1 Effect of Punch Travel on Initial Bent Angle

Figure 2 shows the angle θ_i subtended by the different punch travels in the association of the enjoinment parameters, using AutoCAD. It shows a linear correlation having the value of the coefficient of correlation, R^2 as 0.9983.

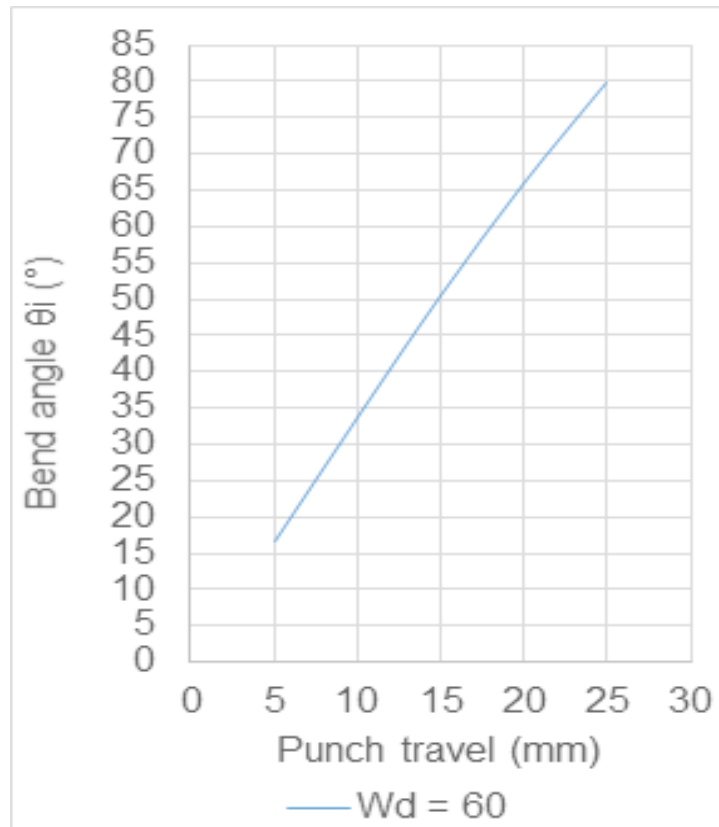


Figure 2. Initial bend angle subtended by different punch travel.

3.2 Effect of Galvanizing

Figure 3 shows the effect of punch travel and galvanizing thickness on spring back. It was observed with the increase of punch travel; spring back was increasing for all galvanizing thicknesses. It was also observed with the increase of galvanizing thickness spring back was increasing for all punch travels. Zinc being softer it can be related to friction, zinc presence changes the friction when it meets punch and die. Since zinc has the lower shear strength than steel, it is softer and behaves as a solid lubricant. Therefore, spring back angle is likely to increase. The increasing galvanizing thickness further reduces friction and so the spring back angle is found to increase with the increase of thickness.

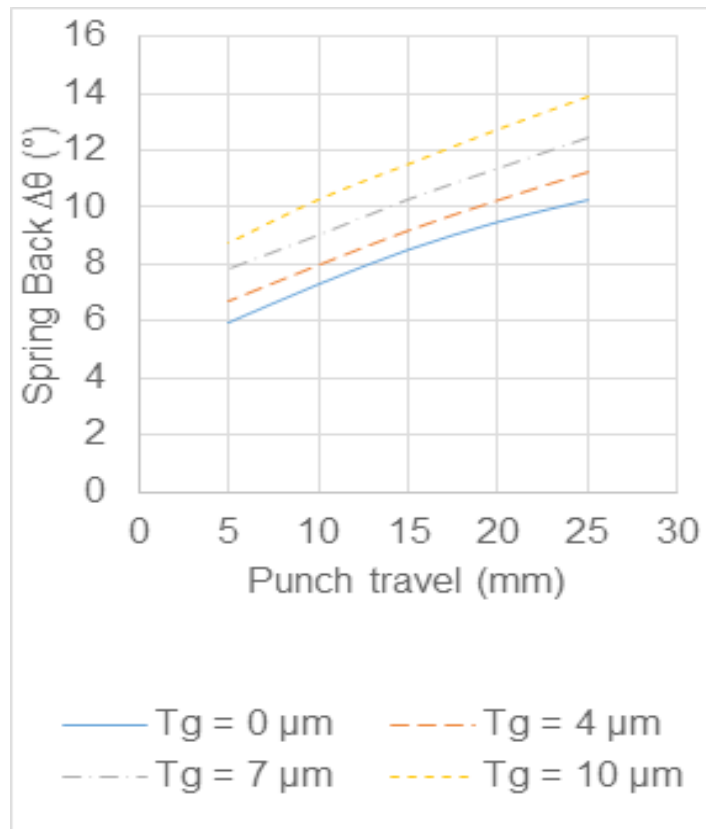


Figure 3. Effect of punch travel on spring back with varying galvanizing thickness.

3.3 Effect of Orientation

Figure 4 shows the spring back angles for ungalvanized and galvanized both sheets at 0° and 90° orientations. It was observed with the increase of punch travel, spring back was increasing in ungalvanized, galvanized, 0° orientation and 90° orientation. It was observed for both ungalvanized and galvanized, at 90° orientation the spring back was more as compared to 0° orientation. Since spring back angle is a function of the ratio of yield strength to the modulus of elasticity and the same is higher for 90° orientation.

3.4 Effect of Punch Speed

Figure 5(a) and Figure 5(b) shows the effect of punch speed on spring back. It was observed that with the increase of punch speed spring back was increased for each punch travel in case of ungalvanized as well as galvanized sheet of each galvanizing thickness. It was due to the decrease of friction coefficient, since higher speed decreases friction coefficient and spring back increases with the decrease of friction. It was also observed that the effect of punch speed was more effective in the case of galvanized sheet as compared to an ungalvanized sheet.

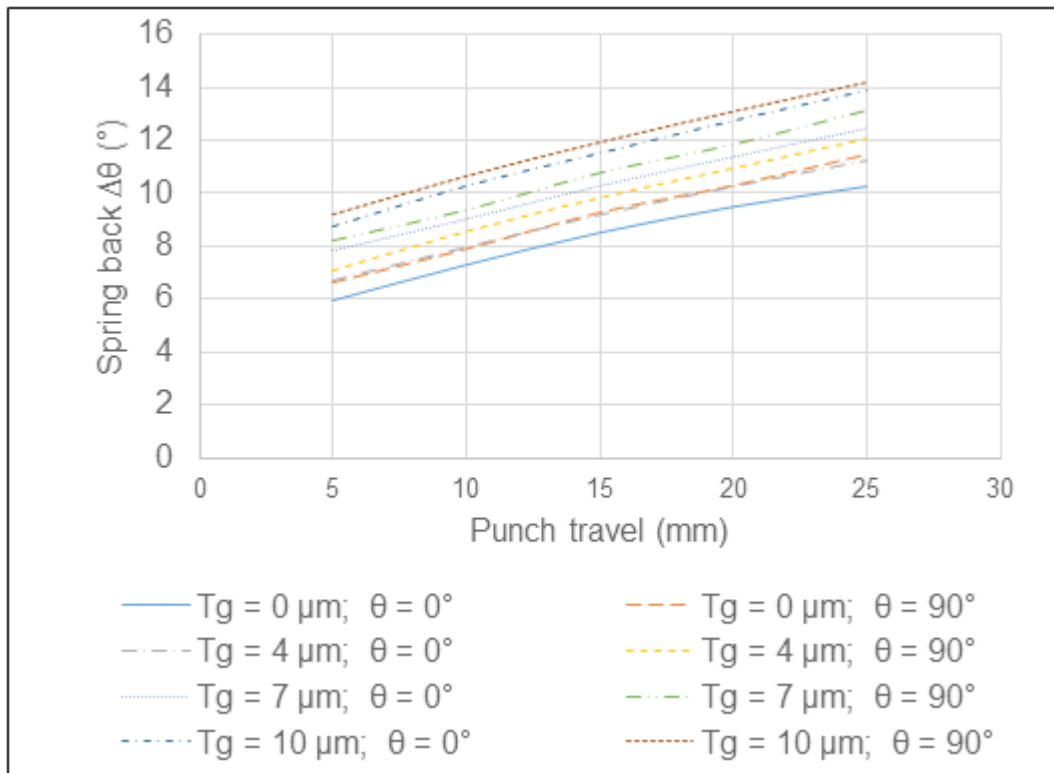
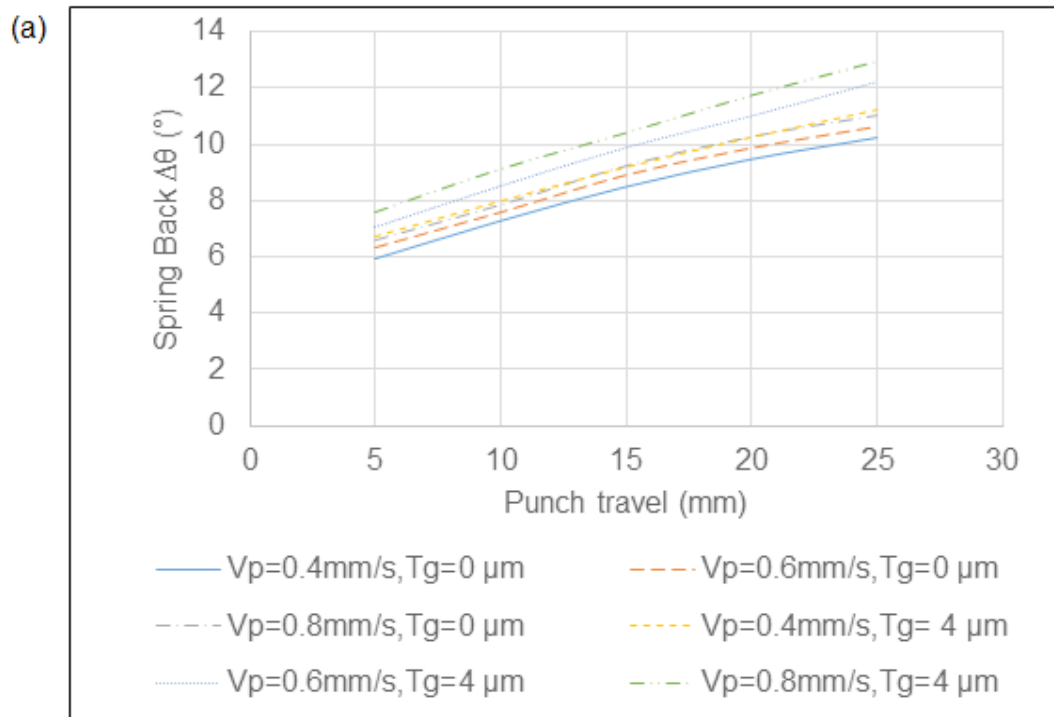


Figure 4. Effect of different orientations on spring back.



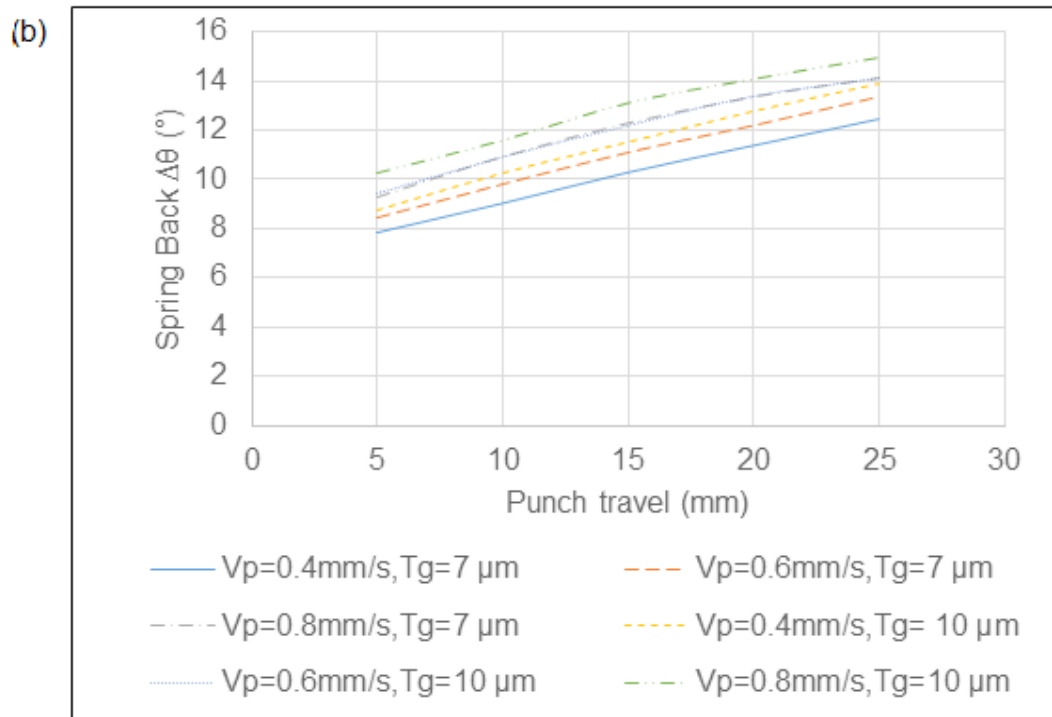


Figure 5. Effect of punch speed on spring back for (a) 0 μm and 4 μm galvanizing thickness (b) 7 μm and 10 μm galvanizing thickness.

4. Conclusion

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

- With the increase of punch travel, bend angle increases, and with the increase of bend angle, spring back increases for galvanized as well as the un-galvanized sheet.
- In the case of bending along rolling direction, 90° orientation, spring back is more for galvanized as well as ungalvanized sheet for each punch travel or bend angle, as compare to bending across rolling direction, 0° orientation.
- Spring back is more in the case of galvanized sheet as compare to the ungalvanized sheet. Spring back

increases with the increase of galvanizing thickness.

- With the increase of punch speed spring back increases for both galvanized as well as the ungalvanized sheet. It is substantially higher in the case of galvanized sheet as compared to an ungalvanized sheet. Spring back increases with the increase of galvanizing thickness.

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6. References

1. Kalpakjian, Serope, Schmid, Steven R. *Manufacturing Processes for Engineering Materials*. 5th ed. New Delhi: Pearson Publisher; 2013. PMCid:PMC3767008
2. Marciniak Z, Duncan JL, Hu SJ. *Mechanics of sheet metal forming*. 2nd ed. Butterworth-Heinemann, Linacre House, Jordan Hill, Oxford; 2002. p. 93–4. PMCid:PMC2214105
3. Hayashi H, Nakagawa T. Recent trends in sheet metals and their formability in manufacturing automotive panels. *Journal of Materials Processing Technology*. 1994; 46(3-4):455–87. [https://doi.org/10.1016/0924-0136\(94\)90128-7](https://doi.org/10.1016/0924-0136(94)90128-7)
4. Fei D, Hodgson P. Experimental and numerical studies of spring back in air v-bending process for cold rolled TRIP steels. *Nuclear Engineering and Design*. 2006; 236(18):1847–51. CrossRef.
5. Gracia-Romeu ML, Ciurana J, Ferrer I. Spring back determination of sheet metals in air bending process based on an experimental work. *Journal of Materials Processing Technology*. 2007; 191(1-3):174–7. CrossRef.
6. Baung MS, Abdullah SA, Saedon J. Effect of die and punch radius on spring back of stainless steel sheet metal in the air bending process. *Journal of Mechanical Engineering and Science*. 2015; 8:1322–31. CrossRef.
7. Narayanasamy R, Padmanabhan P. Effects of material orientation on air bending of interstitial free steel sheet. *Journal of Manufacturing Engineering*. 2008; 3(3):163–9.
8. Chen CC, Jiang CP. Grain size effect in the micro v-bending process of thin metal sheets. *Materials and Manufacturing Processes*. 2011; 26(1):78–83. CrossRef.
9. Gupta TR, Payal HS. Effect of Tooling Parameters on Bending Force in Air Bending of CR4 steel. *International Journal of Theoretical and Applied Mechanics*. 2017; 12(3):375-388.
10. Kadkhodayan M, Zafarparandeh I. On the relation of equivalent plastic strain and spring back in sheet draw bending. *International Journal of Material Forming*. 2008; 1(S1):141–4. CrossRef.
11. Khadra FA, El-Morsy AW. Prediction of spring back in the air bending process using a krigingmetamodel. *Engineering, Technology & Applied Science Research*. 2016; 6(5):1200–6.
12. Chen CC. Experimental study on punch radius and grain size effects on v-bending process. *Materials and Manufacturing Processes*. 2014; 29(4):461–5. CrossRef.
13. Kurra S, Bagade SD, Regalla SP. Deformation behavior of extra deep drawing steel in single-point incremental forming. *Materials and Manufacturing Processes*. 2015; 30(10):1202–9. CrossRef. <https://doi.org/10.1080/10426914.2014.994755>
14. Khalatbari H, Iqbal A, Shi X, Gao L, Hussain G, Hashemipour M. High speed incremental forming process: a trade-off between formability and time efficiency. *Materials and Manufacturing Processes*. 2015; 30(11):1354–63. CrossRef.
15. Salahshoor M, Gorji A, Jooybari MB. Analysis of the effects of tool and process parameters in hydroforming process. *Proceedings of the 4th International Conference on Electrical, Computer, Mechanical and Mechatronics Engineering (ICE2016)*, Dubai: Emirates; 2016 Feb. p. 4–5.
16. Schey JA, Dalton GM. Lubrication mechanisms in the forming of galvanized steel sheet. *Journal of Material Process Technology*. 1990; 24:365–74. CrossRef.
17. Shackelford JF. *Introduction to Materials Science for Engineers*. 3rd ed. USA: MacMillan Publishing Company; 1992.
18. Vasudevan D, Durairaj, Srinivasan, Rajumani, Padmanabhan, Palani. Effect of process parameters on spring back behavior during air bending of electro galvanized steel sheet. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*. 2011 Mar; 12(3):183–9.
19. Gronostajski JZ. Behavior of coated steel sheets in forming processes. *Journal of Materials Processing Technology*. 1995; 53(1-2):167–76. CrossRef.
20. Gupta AK, Kumar DR. Formability of galvanized interstitial-free steel sheets. *Journal of Materials Processing Technology*. 2006; 172(2):225–37. CrossRef.
21. Meinders T, Konterl AWA, Meijers SE, Atzema EH, Kappert H. A sensitivity analysis on the spring back behavior of the unconstrained bending problem. *International Journal of Forming Processes*. 2006; 9(3):365–402. CrossRef.
22. Gupta TR, Payal HS. Investigative study on bending and spring back of electro galvanized steel. *Proceedings of the 5th International Symposium on Fusion of Science & Technology*, New Delhi, India: 2016 Jan. p. 461-465. PMCid:PMC4771870