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Effect of process parameters on springback behaviour during air bending of electrogalvanised steel sheet

Durairaj VASUDEVAN[1], Rajumani SRINIVASAN[‡2], Palani PADMANABHAN[3]
(*[1]Department of Mechanical Engineering, PSNA College of Engineering and Technology, Dindigul 624622, Tamil Nadu, India*)
(*[2]Department of Mechanical Engineering, RVS College of Engineering and Technology, Dindigul 624005, Tamil Nadu, India*)
(*[3]Bharath Niketan Engineering College, Andipatti 625536, Tamil Nadu, India*)
E-mail: drdvasudevan@gmail.com; sriparam_2000@yahoo.com; ajaypalani@yahoo.co.in

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Abstract: This work aims to study the springback behaviour of electrogalvanised (EG) steel sheets during the air bending process. Experiments have been conducted to analyse the influence of various parameters such as coating thickness, orientation of the sheet, punch radius, die radius, die opening, punch velocity, and punch travel on springback behaviour. It is established that the springback increases with increasing coating thickness, punch radius, punch travel, die radius, die opening, and punch velocity. The 90° orientation exhibits higher springback than 0° orientation.

Key words: Springback, Electrogalvanised (EG) steel, Air bending
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1 Introduction

Bending is a widely used metal forming process in various sheet metal products such as automobile panels, supermarket shelves, and housing utensils. In small-batch-part sheet metal manufacturing, a bending process that is flexible, effective and efficient is required to meet the higher accuracy demands and shorter lead time. In such an environment, air bending (de Vin, 2000; 2001; Kurtaran, 2008; Narayanasamy and Padmanabhan, 2009) is more flexible than its counterpart, closed die bending. Different bend angles are achieved by changing the tooling in the closed die bending process. In air bending, as the punch displacement decides the bend angles, the tool changes required to achieve different bend angles are reduced. Therefore, air bending is commonly used in automotive manufacturing and other fabrication industries.

In the automotive industry, there is a wide use of steel sheets for manufacturing various parts, but the susceptibility to corrosion is a natural weakness of steel products. The necessity to protect the steel products from corrosion has demanded the widespread use of coated steels instead of uncoated ones. The most frequently used coating material is zinc. The zinc coating protects the steel in two ways. It acts as a permanent physical barrier, preventing the atmosphere from contacting the steel surface, and inhibits corrosion. Since zinc is anodic relative to steel, it provides galvanic protection losing slowly in the presence of corrosive elements, even the coating is removed in some areas and the steel becomes exposed. (Shackelford, 1992). The zinc-coated steels are known as galvanised steels including hot dipped and electrogalvanised (EG) steels. Besides corrosion resistance, the coated sheet steels used in automobiles must also satisfy other requirements such as formability and surface quality. Even though hot dipped galvanised steel sheets have effective corrosion resistance, they have poor formability and inadequate

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‡ Corresponding author

surface quality. Since the EG steel sheets have better formability (Gronostajski, 1995; Jiang *et al.*, 2004) and surface finish, EG steel sheets are much preferred as a substitute for uncoated cold rolled steel sheets in automotive manufacturing and applications including panels, fenders, hoods, and gas tanks.

The evaluation of forming performance is a great necessity when large-sized complex parts such as automobile panels are press formed, for controlling the forming defects to get precise parts. Shape fixability is one of the main indices to assess the sheet formability (Hayashi and Nakagawa, 1994). Shape fixability is defined as the fixation degree of size and shape of the formed part. During bending, the load is applied to bend the part in the expected shape. After bending, when the load is being removed, the total strain on the work part is reduced due to elastic recovery. This causes a shape discrepancy in the work part referred to as springback. Springback is a measure of shape fixability in bending. Information on springback is vital for a designer to provide allowances for springback in die design to meet the objective of an accurate product and its ease of assembly. Since air bending is a major sheet bending process employed in the manufacturing of auto panels, the control of springback is important.

In recent years, investigations on springback during air bending have received significant attention, and some important investigations are reviewed. Inamdar *et al.* (2002) investigated the influence of various parameters on springback for five different sheet metals during air bending. The parameters affecting springback are identified as punch radius, die radius, die gap, sheet thickness, and angle of bend. Bruni *et al.* (2006) conducted warm and hot air bending experiments on AZ31 magnesium alloy to study the parameters influencing the springback. The results showed that major parameters influencing the springback are punch radius and temperature. Fei and Hodgson (2006) identified the major parameters affecting the springback behaviour of cold rolled transformation induced plasticity (TRIP) steels in air v-bending process. Garcia-Romeu *et al.* (2007) conducted experiments in air bending of aluminium and stainless steel sheets to obtain springback values for different bend angles. The springback values were presented graphically, and the effect of parameters on springback were evaluated. Narayanasamy and Padmanabhan (2008a; 2008b) presented experimental investigations on air bending process of interstitial free steel sheets to study important parameters affecting the springback. However, only a few studies are available on the forming and springback behaviour of coated steel sheets. The application of coated sheet metals used in auto body parts, problems on forming these materials, and various forming techniques were reported by Hayashi *et al.* (1994). The coating layer damage and the change in frictional behaviour were the two major issues observed in forming coated steel sheets. The forming performance of coated, laminated, and sandwiched sheet metals was extensively reviewed by Kim and Yu (1997). It was concluded that it was important to select the proper bonding techniques of coating over substrate and the tooling for better performance, and the importance of further experimental and analytical investigations for studying the behaviour was emphasized. Chan and Wang (2001) investigated the effect of nickel coating on springback for integrated circuit lead frames made of steel and copper alloys. The major conclusion was that coating thickness influenced springback significantly.

The substitution of EG steel for uncoated steel presents challenges in understanding the springback behaviour. The springback behaviour for EG steel sheet is commonly restricted by the same phenomena as in the bare steel sheet, but coating modifies the springback behaviour of EG steel sheets. Hence, the understanding of springback behaviour is essential for controlling the process and in the design of dies. It is evident that the springback behaviour of the EG sheet in the air bending process has not been attempted, and on the basis of this, the present investigation was carried out.

Springback behaviour (Gotzinger *et al.*, 2001) depends on the properties of materials such as yield strength, Young's modulus, strain hardening exponent, and plastic strain ratio. During rolling, the material gets deformed in the rolling direction, and the grains rotate and orient themselves in a particular direction. This preferred orientation causes a variation of properties with direction, known as anisotropy. Since the properties vary with orientation of the sheet, the orientation can influence the tensile properties, and hence the springback behaviour. Various investigations on bending show that the process parameters such as punch radius, die radius, die opening, and punch velocity have considerable influence on springback. Hence, the parameters considered in this study are coating thickness, orientation of the sheet, punch radius, die radius, die opening, and punch velocity.

2 Experimental

The substrate used in this investigation is aluminium killed draw quality (AKDQ) steel sheet with 1 mm thickness. The chemical composition of the uncoated steel sheet was discovered using spectroscopy, and the major elements are given in Table 1. The tensile tests were conducted to determine the mechanical properties of the uncoated steel sheet (ASTM Standard E8, 2008). The measurements were taken for the two orientations 0° (along the rolling direction) and 90° (perpendicular to the rolling direction) (Table 2).

Table 1 Chemical composition of uncoated sheet

Element	Composition (%, w/w)	Element	Composition (%, w/w)
C	0.079	S	0.015
Si	0.025	Al	0.031
Mn	0.332	Fe	~99.502
P	0.016		

The steel sheet was electrogalvanised for various coating thicknesses such as 4, 7, and 10 μm. The coating was obtained by zinc chloride electrolyte, and pure zinc is used as the anode. The pH value was adjusted to 4.8 at 30 °C. The pretreatments were necessary to get rid of the impurities before electrogalvanising. The pretreatments and deposition process is shown in Fig. 1.

The blanks from the coated and uncoated steel sheets were prepared to a size of 120 mm×40 mm. A 400 kN capacity hydraulic type universal testing machine (UTM) (Krystal Elmec, Maharashtra, India) was used for conducting the experiments. The tooling included a die and a punch made of hardened steel. The experimental setup is shown in Fig. 2. In UTM, the punch was fixed in the cross head, and the die was positioned on the table. The steel blank was placed on the die. Necessary care was taken for positioning the steel blank. The punch travelled to the required depth for bending the sheet, and the digital meter attached to the UTM was used to measure the punch travel. The longer edge of the bent sample was coated with black ink and the impression of the profile was taken carefully on a thick white paper supported by a board. Two impressions were taken before unloading and after unloading. The impressions of the sheet were scanned, and converted into digitized images. The digitized images were imported to AutoCAD R2008 (Autodesk Inc., USA), and the lines were drawn on the edges of the legs of images using software. The necessary angles were measured using CAD software (Narayanasamy and Padmanabhan, 2008a). The difference between bend angle during loading (θ_i) and after unloading (θ_f) gives the springback angle ($\Delta\theta$). The sheets were bent to different depths such as 5, 10, 15, 20, and 25 mm by controlling punch travel. Three trials were conducted for each punch travel and the average values of measurements were taken. Table 3 shows the tool and process parameters used in the experiments.

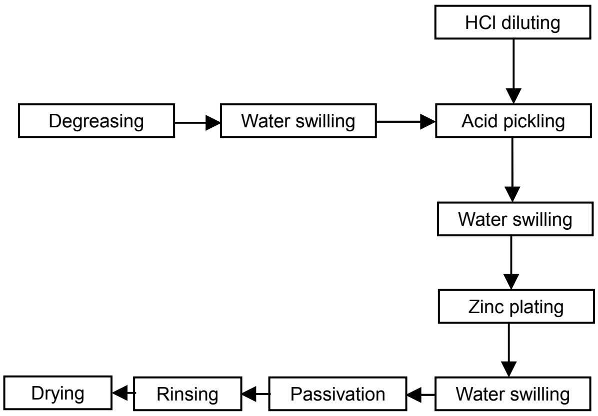

Fig. 1 Zinc coating process

Table 2 Mechanical properties of uncoated sheet

Orientation related to the rolling direction	Yield strength (MPa)	Ultimate strength (MPa)	Young's modulus (GPa)	Strain hardening exponent	Strength coefficient (MPa)
0°	208.6	345.3	206	0.211	413.4
90°	214.3	335.2	206	0.227	436.1

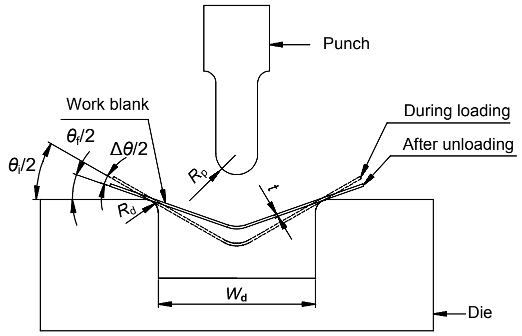

Fig. 2 Schematic diagram of experimental setup

R_p: punch radius; R_d: die radius; W_d: die opening; t: sheet thickness; θ_i: bend angle (during loading); θ_f: bend angle (after unloading); $\Delta\theta$: springback angle

Table 3 Tool and process parameters

Parameter	Dimension
Work blank, $L_s \times W_s \times t_s$ (mm)	120×40×1
Coating thickness, t_c (μm)	4, 7, 10
Punch radius, R_p (mm)	8, 12, 16
Die radius, R_d (mm)	3, 5, 8
Die opening, W_d (mm)	40, 60, 80
Punch travel, d_p (mm)	5, 10, 15, 20, 25
Punch velocity, V_p (mm/s)	0.4, 0.6, 0.8

L_s, W_s, and t_s are the length, width of the sheet, and the thickness of the sheet without coating, respectively

3 Results and discussion

Experiments were conducted with a combination of process variables, and springback angles were measured accurately. The parameters considered were coating thickness, orientation of sheet, punch radius, die opening, die radius, and punch velocity. The effect of various parameters on springback angles was illustrated graphically. The graphs of springback angles were plotted against punch travel.

3.1 Influence of coating thickness on springback

The relationship between the springback angle and coating thickness is shown in Fig. 3. The springback angle increases with increasing punch travel. This behaviour is found similar for both uncoated and zinc-coated steel sheets. It is clear that the springback angle increases with increasing coating thickness for the same punch travel. It can be related to the frictional properties of the coating. The presence of zinc changes the friction experienced by the sheet when it comes in contact with tooling. Since zinc has lower shear strength compared to steel (Gronostajski, 1995), the coating is softer, and behaves as a solid lubricant. This lowers the friction, and the reduction in friction causes different strain behaviours in the zinc-coated sheet. Therefore, the springback angle is likely to increase (Samuel, 2000). The increasing coating thickness further reduces the coefficient of friction (Kim and Thomson, 1990; Gupta and Kumar, 2006; Kadkhodayan and Zafarparandeh, 2008) thereby lowering the friction, and hence the springback angle is found to increase with increasing coating thickness.

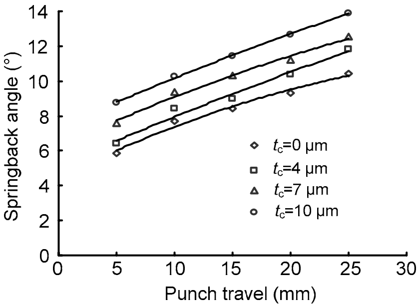

Fig. 3 Variation of springback angles with respect to punch travel for different coating thicknesses

R_p=8 mm, R_d=5 mm, W_d=60 mm, θ=0°, V_p=0.4 mm/s, and W_s=40 mm

3.2 Influence of orientation on springback

Fig. 4 shows the springback angles for uncoated and coated steels in both 0° and 90° orientations. It is observed that for both uncoated and coated sheets, the orientation has a great influence on springback, and the work blank along the 90° orientation exhibits greater springback than the blank of 0° orientation. It is understood that the springback angle is a function of yield strength to modulus of elasticity ratio (σ_y/E) (Samuel, 2000; Narayanasamy and Padmanabhan, 2008a), which is higher for transverse direction than rolling direction.

3.3 Influence of punch radius on springback

The influence of punch radius on springback angles is depicted in Figs. 5a and 5b. It is found that the springback angle increases with increasing punch radii for both coated and uncoated sheets. Springback is sensitive to the effective clearance between the punch and the die (Inamdar *et al.*, 2002). The effective clearance is the distance between the point of sheet contacting with the die and the point where the sheet leaves contacting with the punch nose radius. When the punch radius is larger, the effective clearance would be smaller compared to a smaller radius. Hence, the increase in the punch radius increases springback. Moreover, smaller punch radii cause higher local straining level and larger plastic deformation (Kim *et al.*, 2007), and therefore, springback is reduced.

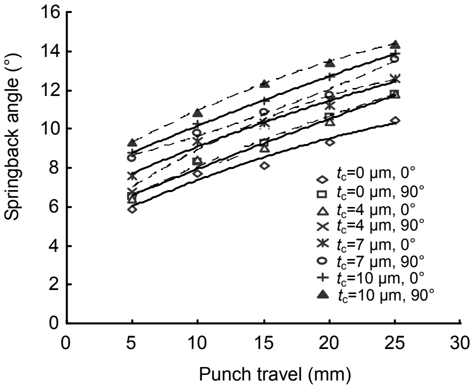

Fig. 4 Variation of springback angles for different orientations

R_p=8 mm, R_d=5 mm, W_d=60 mm, V_p=0.4 mm/s, and W_s=40 mm

3.4 Influence of die opening on springback

Note that the increase in die opening increases the springback angles for both uncoated and coated steels (Figs. 6a and 6b). It is evident that a large die opening increases the bending moment, and hence the springback. Moreover, when the die opening is larger, there is a larger elastic displacement and rotation (Garcia-Romeu *et al.*, 2007). Therefore, an increase in die opening increases the springback angle.

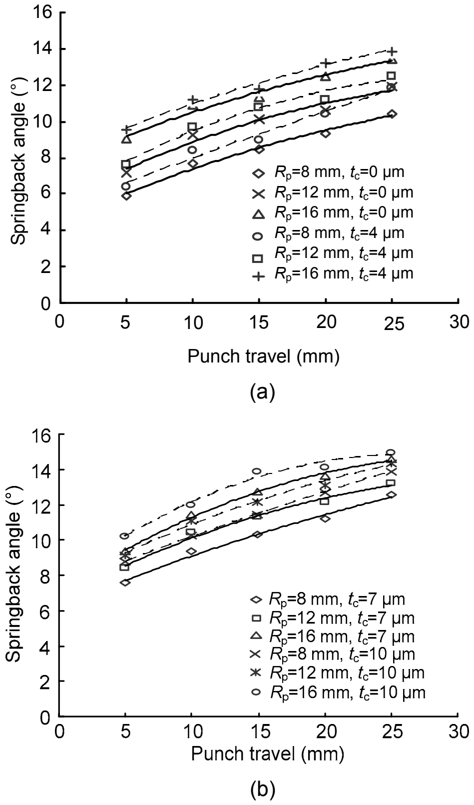

Fig. 5 Variation of springback angles for different punch radii

(a) t_c=0, 4 μm; (b) t_c=7, 10 μm. R_d=5 mm, W_d=60 mm, θ=0°, V_p=0.4 mm/s, and W_s=40 mm

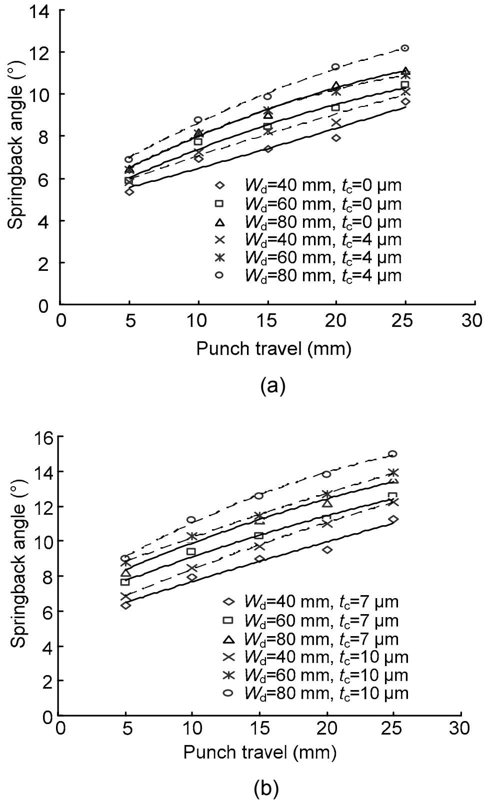

Fig. 6 Variation of springback angles for different die openings

(a) t_c=0, 4 μm; (b) t_c=7, 10 μm. R_p=8 mm, R_d=5 mm, θ=0°, V_p=0.4 mm/s, and W_s=40 mm

3.5 Influence of die radius on springback

As shown in Figs. 7a and 7b, the increase in die radius increases the springback angle for both uncoated and coated steels. It can be explained that an increase in die radius is similar to an effective increase in die opening in a restricted sense. In this case, the points of contact between the sheet and the tool are spaced further apart. This increases the moment arm and hence the bending moment (Garcia-Romeu *et al.*, 2007). Therefore, an increase in die radius for a given die opening increases the springback angle.

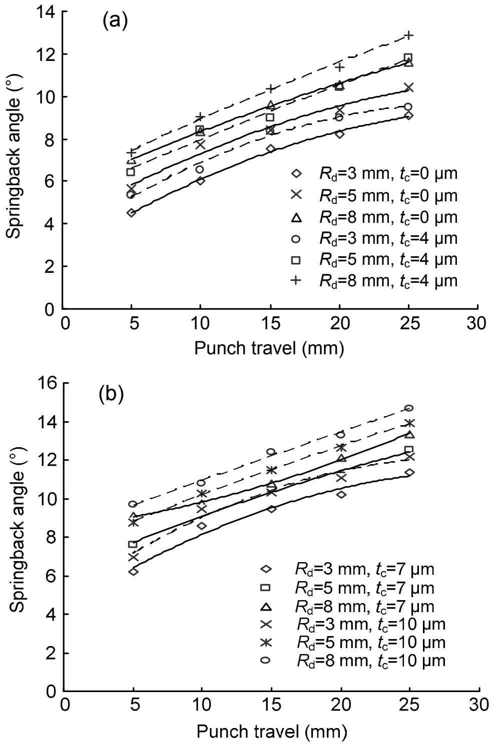

Fig. 7 Variation of springback angles for different die radii

(a) t_c=0, 4 μm; (b) t_c=7, 10 μm. R_p=8 mm, W_d=60 mm, θ=0°, V_p=0.4 mm/s, and W_s=40 mm

3.6 Influence of punch velocity on springback

The influence of punch velocity on springback angles is illustrated in Figs. 8a and 8b. The springback angle is increased with an increase in punch velocity for both uncoated and coated steel sheets. The reason may be the variation of the friction coefficient with velocity. The values of the friction coefficient decrease as the velocity increases (Matuszak, 2000). Since the decrease in the coefficient of friction reduces the friction, the springback increases accordingly (Meinders *et al.*, 2006). However, as shown in Fig. 8a, the difference in springback value for EG sheet is greater compared to that for the uncoated sheet. It is identified that the effect of velocity on springback is more dominant in EG steel than in uncoated sheet.

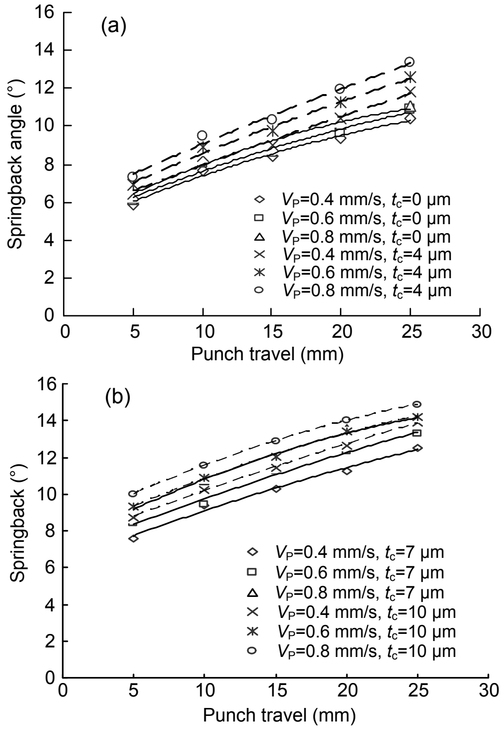

Fig. 8 Variation of springback angles for different punch velocities

(a) t_c=0, 4 μm; (b) t_c=7, 10 μm. R_p=8 mm, R_d=5 mm, W_d=60 mm, θ=0°, and W_s=40 mm

4 Conclusions

In this study, the influence of process parameters on springback behaviour for EG steel in air bending was analyzed, including coating thickness, orientation, punch radius, die opening, die radius, and punch velocity. The main conclusions have been drawn as follows:

1. The coating thickness has a strong influence on springback, and springback increases with increasing coating thickness. This is due to the frictional effect of the coating during the bending process.

2. Orientation interacts with springback, and springback is larger for 90° orientation compared to 0° orientation as strength ratio influences the springback.

3. Since the increase of punch travel increases the bend angle, the springback increases with increasing punch travel.

4. The springback angle is smaller for smaller punch radius, and larger for larger punch radius, and this effect is due to larger effective clearance and higher plastic deformation along the thickness for a smaller punch radius.

5. The die parameters such as die opening and die radius influence springback greatly. Increasing die opening and die radius increase the bending moment, which increases the springback.

6. Punch velocity influences springback significantly. The effect is more significant in the case of EG steel than in uncoated steel.

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