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TECHNICAL PAPER

Influence of friction parameters on springback and bend force in air bending of electrogalvanised steel sheet: an experimental study

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Abstract This investigation analyses the effect of friction which is influenced by the parameters including type of lubricant, surface roughness of the sheet, die geometry and punch velocity on springback and bend force of electrogalvanised steel sheet in air-bending process experimentally. It is observed that the decrease in friction increases the springback and reduces the bend force. This effect is evident in case of high-viscosity lubricant, low surface roughness, larger die radius and higher punch velocity.

Keywords Friction parameters · Air bending · Electrogalvanised steel · Springback · Bend force

List of symbols

d_p	Punch travel, mm
E	Young's modulus, GPa
L_s	Length of the sheet, mm
R_a	Surface roughness, µm
R_d	Die radius, mm
R_p	Punch radius, mm
T	Sheet thickness, mm
t_c	Coating thickness, µm
V_p	Punch velocity, mm/s
W_d	Die opening, mm
W_s	Width of the sheet, mm

Greek symbols

σ_y	Yield strength, MPa
σ_u	Ultimate tensile strength, MPa
θ_i	Bend angle (during loading), °
θ_f	Bend angle (after unloading), °
$\Delta\theta$	Springback angle, °

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1 Introduction

Sheet metal forming is a major sector of manufacturing in automotive industries to produce various components. Press brake bending is one of the important sheet metal forming processes where a flat sheet is placed over the die and the punch is lowered onto the sheet to form the bend. Air bending [1] is a technique employed to increase the flexibility of press brake bending. In air bending, the required bend angle is produced on the workpiece by adjusting the punch travel into the die opening and hence it is possible to produce different bend angles with a single set of tooling. Electrogalvanised (EG) steel sheets are one of the promising materials for automotive industry used in various applications such as panels, fenders, hoods and gas tanks because of their excellent corrosion resistance, good formability, weldability and paintability [5].

An important issue in sheet metal bending is the springback, the geometric variability between the loaded and unloaded condition. Bend force is the force required to deform the sheet metal to produce the required bend angle. The information on springback and bend force provides a base for designing the tooling and choosing the appropriate presses [2]. The change in strain distribution [6] and membrane forces [3] influence the springback and bend force, respectively. The strain distribution and membrane forces are very sensitive to the magnitude and distribution of friction [14, 19]. The friction in sheet metal forming process has been studied by a number of researchers and important investigations are reviewed. The influence of various stamping parameters on interfacial friction was examined by Lovell and Deng [9] for electrogalvanised and lead-coated sheet steel with oil and grease lubricants. Liu et al. [8] employed a strip drawing test to investigate the effects of rolling direction of aluminium alloy sheet and lubricant on the friction behaviour in sheet metal forming. The results indicated that the kind and amount of lubricant have great influence on friction. Schey and Dalton [15] carried out bead-drawing experiments with bare, hot-dipped, electrogalvanised and galvannealed steel sheets using paraffinic base oils with various additives. It was found that minor variation in surface finish modifies the friction significantly and the sub-microscopic features of electrogalvanised sheet helped in the retention of lubricants. Skarpelos and Morris [18] conducted experiments in the draw bead simulator to study the result of surface parameters on friction during forming of electrogalvanised steel sheet. It was understood that friction was determined by the combination of two parameters: the arithmetic average roughness and mean wavelength of the roughness. Lee et al. [7] developed a friction model considering lubricant viscosity and surface roughness for using in the finite element analysis of sheet metal-forming processes. Saha and Wilson [14] investigated the relationship between friction and process variables including sliding velocity, angle of wrap and strain rate in the boundary lubrication regime for electrogalvanised and aluminium sheets. It was found that friction tended to decrease with plastic strain under three different experimental conditions. Matuszak [10] studied the influence of factors including material orientation, lubricant, velocity, plastic strain and contact pressure on friction and developed a regression model for friction for steel sheet/steel tool, using experimental data. Wang et al. [19] used the test and analytical procedure to investigate the frictional behaviour of four types of sheet alloys. The coefficient of friction as a function of tool radius, punch speed, lubricant and material was measured and analysed. From the literature, it is understood that the frictional conditions in sheet metal forming is determined by various process variables including type of lubricant, surface conditions of the sheet, tool geometry and forming velocity. But the effect of friction and lubrication on springback is studied by very few researchers [6, 11, 12].

During bending of EG steel sheets, zinc acts as a solid lubricant because of its low shear strength. Yet, the coating can be damaged catastrophically by shear separation [15]. Besides, the interfacial friction between the tooling and the workpiece surface increases the required forces to form the part. To avoid the damage of the coating and to reduce the friction forces, lubrication becomes essential [16] in sheet metal bending. Since the parameters influencing friction including lubricant modify the friction conditions, they modify the springback and bend force behaviour of EG steel sheets. It is evident from the literature that the study on influence of friction variables including lubricants, surface roughness of the sheet, die radius and punch velocity on springback and bend force behaviours of EG steel sheet in air-bending process has not been attempted and on the basis of this the present investigation was carried out.

2 Experimental details

2.1 Material and lubricants

The uncoated sheet used in this study is aluminium killed draw quality (AKDQ) steel of 1 mm thickness. The chemical composition of the uncoated steel sheet was discovered using spectroscopy and the tensile tests were conducted as per ASTM E8 standard to determine the tensile properties of the uncoated steel sheet. The chemical composition and the tensile properties of the steel sheet are listed in Table 1.

Steel sheets of two different surface roughnesses were electrogalvanised uniformly on both sides with a coating thickness of 10 µm. The coating was obtained with zinc chloride electrolyte and pure zinc was 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

Table 1 Chemical composition and mechanical properties of uncoated sheet

Chemical composition (%)	
C	0.079
Si	0.025
Mn	0.332
P	0.016
S	0.015
Al	0.031
Fe	Rest
Mechanical properties	
Yield strength (σ_y) MPa	208.6
Ultimate strength (σ_u) MPa	335.2
Young's modulus (E) GPa	206

Table 2 Properties of the lubricant

Type of lubricant	Specific gravity	Kinematic viscosity at 40° C, (m^2/s)	Dynamic viscosity at 40° C (Pa s)
Mineral oil 1 (Paraffin oil)	0.85	15×10^{-6}	0.013
Mineral oil 2 (SAE 20-40 oil)	0.8521	155×10^{-6}	0.1321
White grease	1.052	345×10^{-6}	0.363

electrogalvanising. The mean surface roughness values of the sheets after the coating process were measured using Mitutoyo surface roughness tester and the average roughness values were 1.25 and 1.65 µm. The test blanks were prepared to the dimension of 120 mm × 40 mm.

Three lubricants were used in the experimental work and among these, two were commercial mineral oil and the other commercial grease. The main properties of the lubricants given by manufacturers are stated in Table 2.

2.2 Experimental procedure

The experiments were conducted in a universal testing machine (UTM) and the experimental setup is shown in Fig. 1. The punch and dies used were made of hardened steel. The punch was mounted in the upper arm of UTM and the die was placed on the lower platform. The sheet blanks were positioned on the die with necessary care. 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 lubricant was applied on both punch and die. The larger 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 and after unloading. The impressions of the sheet were scanned and converted into digitised images. The digitised images were imported to CAD software and the necessary bend angles were measured using CAD software [11]. The difference between bend angle during loading (θ_i) and after unloading (θ_f) gives the springback angle ($\Delta\theta$). The bend force was measured by the digital display of load cell arrangement. 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. After every experiment, the lubricant was wiped off and the tooling surfaces were degreased with acetone. Fresh lubricant was applied for every experiment. Experiments were conducted with a combination of parameters, and the tooling geometries and the process parameters used in this work are given in Table 3.

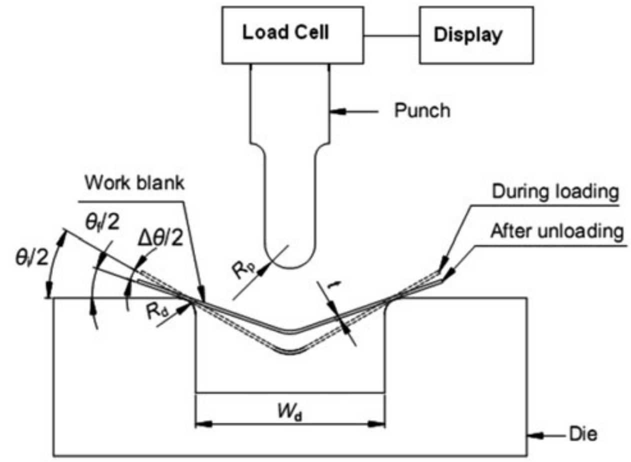

Fig. 1 Schematic diagram of experimental setup. R_p punch radius, R_d die radius, W_d die opening, t sheet thickness, θ_i bend angle (during loading), θ_f bend angle (after unloading); $\Delta\theta$ springback angle

Table 3 Tooling geometries and process parameters

Work blank ($L_s \times W_s \times t_s$) in mm	120 × 40 × 1
Coating thickness (t_c) in µm	10
Surface roughness (R_a) µm	1.25, 1.65
Punch radius (R_p) in mm	8
Die radius (R_d) in mm	5, 8
Die opening (W_d) in mm	60
Punch travel (d_p) in mm	5, 10, 15, 20, 25
Punch velocity (V_p) in mm/s	0.4, 0.8
Dynamic viscosity of lubricants in Pas	0.013, 0.1321, 0.363

3 Results and discussion

The springback and bend force values were measured accurately. The bend force values were converted for unit metre width. The effects of various parameters on springback/bend force were illustrated by plotting graphs between punch travel and springback/bend force.

3.1 Effect of lubricant

The effect of lubricant on springback and bend force is shown in Fig. 2a, b. It is noted that the type of lubricant plays a significant role in springback and bend force behaviour. The decrease in friction increases the springback and decreases the bend force. In dry condition, due to the absence of lubricant, the interaction between the tool and sheet is dominated by frictional adhesion [9]. This causes an increase in friction, thereby reducing the springback and increasing the bend force. When low-viscosity mineral oil is used, as the cohesive force is low [7] the lubricating film is easily destroyed. There is a boundary contact between sheet and tooling and hence the friction increases. This decreases the

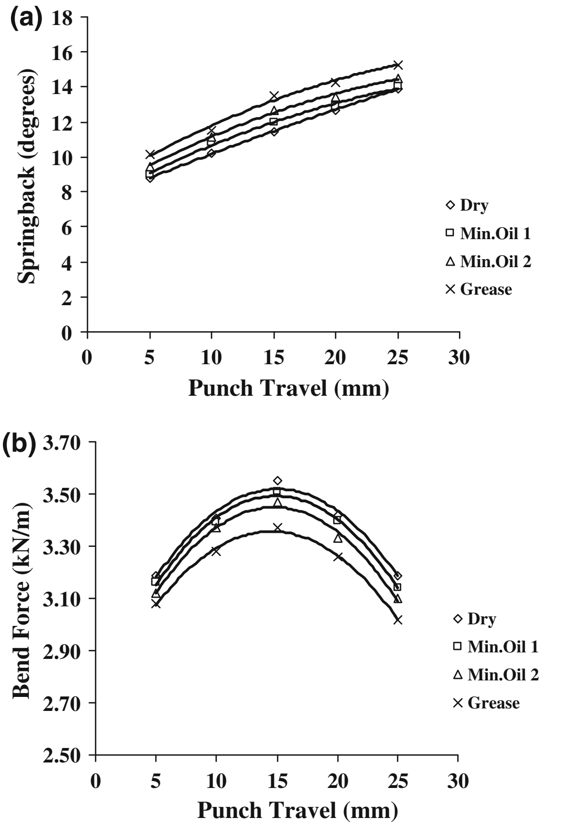

Fig. 2 a–b Variation of springback and bend force with respect to punch travel for different lubricants ($R_a = 1.25$ µm, $R_p = 8$ mm, $R_d = 5$ mm, $W_d = 60$ mm, $V_p = 0.4$ mm/s, $W_s = 40$ mm)

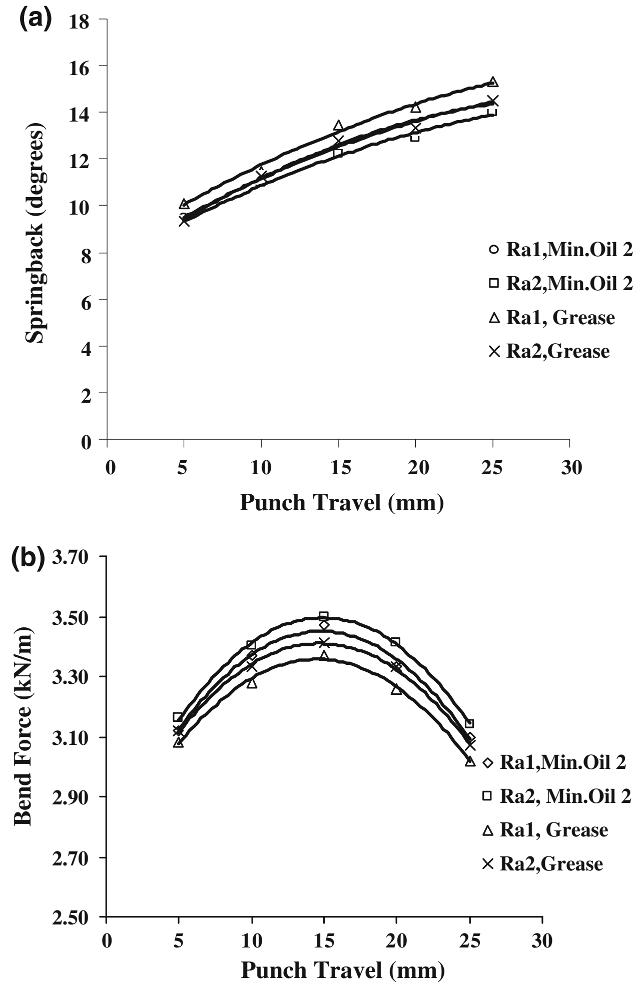

Fig. 3 a–b Variation of springback and bend force with respect to punch travel for different surface roughness of sheets ($R_p = 8$ mm, $R_d = 5$ mm, $W_d = 60$ mm, $V_p = 0.4$ mm/s, $W_s = 40$ mm)

springback and increases the bend force compared to other lubricants. Since the high-viscosity mineral oil forms a thicker film [15] and has a higher cohesive force than low-viscosity mineral oil, it is able to keep the boundary lubrication and reduces the friction. Hence in this case, the springback increases and bend force decreases further. When the grease lubricant is applied, the high-viscosity film provides a small amount of hydrodynamic lift on the tooling [9]. This reduces the asperity interaction and causes a reduction in friction. This is the reason for higher springback and lower bend force in this case.

4 Effect of surface roughness of sheet

From Fig. 3a, b, it is observed that the springback decreases and bend force increases as the surface roughness increases. There is an increase in the number of oil pockets when surface roughness increases [7], but the asperity interaction is more between the sheet and tool. Hence, there is an increase in plastic deformation of asperities and easy destruction of the lubrication film. This increases the surface friction causing decrease in springback and increase in bend force.

5 Effect of die radius

The effect of die radius on the springback and bend force is indicated in Fig. 4a, b. The 5 mm die radius exhibits lower springback and higher bend force values compared to the 8 mm die radius. It is due to the reason that the friction increases as die radius decreases [4]. Since the contact area between the sheet and die decreases with smaller die radius, it increases the contact pressure [10] considerably. As a result of this higher contact pressure, there is a possibility of more asperity interaction resulting in a higher friction [9].

6 Effect of punch velocity

The effect of punch velocity on springback and bend force is shown in Fig. 5a, b. Springback increases and bend force decreases with an increase in punch velocity. The reason

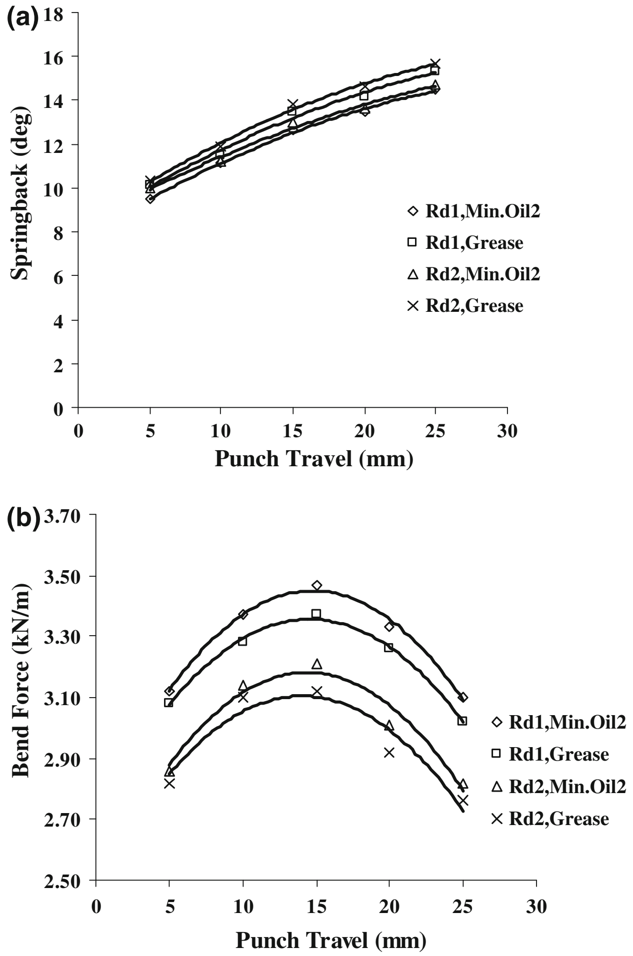

Fig. 4 **a**–**b** Variation of springback and bend force with respect to punch travel for different die radii ($R_a = 1.25$ µm, $R_p = 8$ mm, $W_d = 60$ mm, $V_p = 0.4$ mm/s, $W_s = 40$ mm)

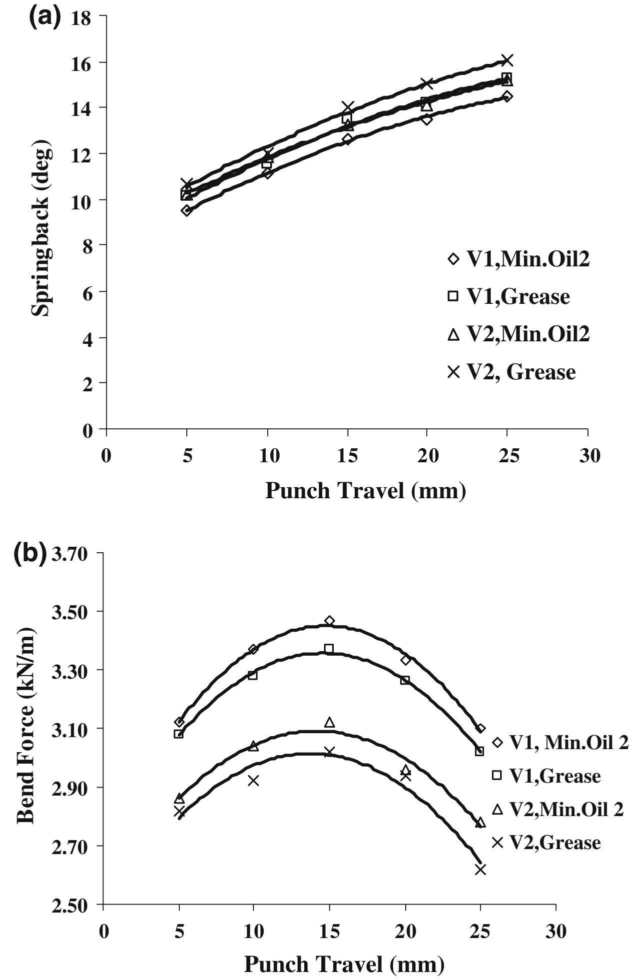

Fig. 5 **a**–**b** Variation of springback and bend force with respect to punch travel for different velocities ($R_a = 1.25$ µm, $R_p = 8$ mm, $R_d = 5$ mm, $W_d = 60$ mm, $W_s = 40$ mm)

may be the variation of friction coefficient with sliding velocity of the sheet which is proportional to the punch velocity [19]. The values of the friction coefficient decrease as the sliding velocity increases [13]. Since the decrease in coefficient of friction reduces the friction, the springback increases and bend force decreases accordingly. The coefficient of friction declines with increasing Sommerfeld parameter, which depends on the product of dynamic viscosity and sliding velocity [17]. As the dynamic viscosity of grease is higher than that of mineral oil 2, the velocity effects are more prominent in the case of grease than in mineral oil.

7 Conclusions

Earlier, the friction in sheet metal forming has been studied by a number of researchers, but the effect of friction on the bending process has not been concentrated much. In this study, the effect of friction-related process variables including lubricant viscosity, surface roughness of the sheet, die radius and punch velocity on springback and bend force of electrogalvanised steel sheet during air bending is evaluated and the following conclusions are derived.

- Friction plays a role in springback/bend force and the reduction in friction increases the springback and decreases the bend force.
- Viscosity of the lubricant determines the film thickness of lubricant and hence influences the friction. As the viscosity increases, the springback increases and the bend force decreases.
- Since the sheets of high surface roughness have more friction due to increased asperity interaction, they exhibit lower springback and higher bend force for all lubricants.
- Air bending with smaller die radius increases the contact pressure and asperity interaction, thereby

increasing friction. This reduces the springback and increases the bend force.

- Increase in punch velocity increases the springback and decreases the bend force and this effect is significant in the case of grease lubricant.
- The die radius and punch velocity play a dominant role in friction compared to surface roughness and viscosity of the lubricant.
- Experimental results show that it is important to consider the friction-related parameters while predicting the springback and bend force for designing the tools and selecting the press in industrial applications.

References

1. De Vin LJ (2000) Curvature prediction in air bending of metal sheet. J Mater Process Technol 100:257–261
2. Farsi MA, Arezoo B (2011) Bending force and spring-back in V-die bending of perforated sheet- metal components. J Braz Soc Mech Sci Eng 23:45–51
3. Hamouda AMS, Abu Khadra F, Hamadan MM, Inhemed RM, Mehdi E (2004) Springback in V-bending : a finite element approach. Int J Mater Prod Technol 21(1–3):124–136
4. Han SS (1997) The influence of tool geometry on friction behavior in sheet metal forming. J Mater Process Technol 63:129–133
5. Jiang HM, Chen XP, Wu H, Li CH (2004) Forming characteristics and mechanical parameter sensitivity study on pre-phosphated electro-galvanized sheet steel. J Mater Process Technol 151:248–254
6. Kim JK, Thomson PF (1990) Friction and stress distribution in coated steel sheet during forming. J Mater Process Technol 21:29–42
7. Lee BH, Keum YT, Wagoner RH (2002) Modelling of the friction caused by lubrication and surface roughness in sheet metal forming. J Mater Process Technol 130–131:60–63
8. Liu X, Liewald M, Becker D (2009) Effects of rolling direction and lubricant on friction in sheet metal forming. J Tribol Trans ASME 131(042101):1–8
9. Lovell MR, Deng Z (2002) Characterization of interfacial friction in coated sheet steels: influence of stamping process parameters and wear mechanisms. Tribol Int 35:85–95
10. Matuszak A (2000) Factors influencing friction in steel sheet forming. J Mater Process Technol 106:250–253
11. Narayanasamy R, Padmanabhan P (2010) Influence of lubrication on springback in air bending process of interstitial free steel sheet. J Mater Eng Perform 19(2):246–251
12. Ragai L, Lazim D, Nemes JA (2005) Anisotropy and springback in draw bending of stainless steel 410: experimental and numerical study. J Mater Process Technol 166:116–127
13. Ramezani M, Mohd Ripin Z, Ahmad R (2010) Modelling of kinetic friction in V-bending of ultra-high-strength steel sheets. Int J Adv Manuf Technol 46(1–4):101–110
14. Saha PK, Wilson WRD (1994) Influence of plastic strain on friction in sheet metal forming. Wear 172:167–173
15. Schey JA, Dalton GM (1990) Lubrication mechanisms in the forming of galvanized steel sheet. J Mater Process Technol 24:365–374
16. Schey JA (1983) Tribology in metal working, friction, lubrication and wear. ASM International, New York
17. Schey JA (1996) Speed effects in drawbead simulation. J Mater Process Technol 57:146–154
18. Skarpelos P, Morris JW Jr (1997) The effect of surface morphology on friction during forming of electrogalvanized sheet steel. Wear 212:165–172
19. Wang W, Wagoner RH, Wang XJ (1996) Measurement of friction under sheet forming conditions. Metal Mater Trans A 27A:3971–3981