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Experimental study on bending behaviour of aluminium-copper clad sheets in V-bending process

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Abstract. The bimetallic sheets are used in the industrial sheet metal products to meet the demands of multi-functionality. The bending behaviour of bimetallic sheet is contributed by individual layers of the sheet and it is entirely different from the monolithic material. In this study, V-bending experiments are carried out to understand the springback, bend force and thickness change of Al-Cu clad sheets. The effect of different parameters such as sheet thickness, sheet setting condition, die angle, die opening and punch radius have been investigated. The results indicated that springback is more for smaller die angle, wider die opening and larger punch radius. Increase in die angle, increase in die opening or decrease in punch radius decreases the bend force. The clad sheet thickens at Al/Cu setting condition whereas it thins at Cu/Al setting condition. This thinning or thickening of the sheet influences the springback and bend force.

Keywords: V-bending / Al-Cu clad sheet / springback / bend force / change in thickness

1 Introduction

In manufacturing of sheet metal components, press brake bending is one of the widely used processes. The V-bending process is the commonly used bending process for making different angular bends in which a V-shaped punch presses the sheet metal into a V-shaped die until the metal contacts the sides of the die. The process occurs in two stages: during the first stage the air bending occurs and sheet continuously bends. When the bent sheet reaches a position tangent to the sides of the die, the second stage named coining begins. In this stage, the sheet metal conforms to the shape of the die-punch pair. After the operation, the punch is unloaded from the die and this causes a shape discrepancy in the bent part due to elastic recovery. This phenomenon is known as springback which affects the accuracy of bent parts, particularly the bent angle. Hence it becomes a practical issue to predict the springback and to provide necessary compensation in the tooling to compensate for springback. The springback depends on various parameters such as geometry and tensile properties of sheet, tooling and process. The springback in V-bending process has been studied by many researchers. Esat et al. [1] analysed the springback of different aluminium materials using commercially available finite element analysis software. It was observed that the springback increases with increasing yield strength. Tekaslan et al. [2] conducted experiments with modular V-bending die to determine the springback of stainless sheet metals. They established that the springback increases with increasing thickness and bend angle whereas the springback can be reduced by holding the punch longer on the sheet. Leu and Hsieh [3] developed an analytical model to find the springback reduction as a function of anisotropy, strain-hardening exponent, thickness to punch radius ratio, die width to thickness ratio, friction coefficient and semi bent angle. Thipprakmas and Phanitwong [4] identified the degree of importance of V-bending parameters on springback using FEM, Taguchi and analysis of variance and it has been found that material thickness has a major influence. Leu [5] conducted finite element simulations to study the effect of process parameters on position deviation and springback in asymmetric V-bending process and validated the results with experimental results. Bend force is the force needed to deform the sheet plastically to achieve the required shape during bending process. The selection of tooling and press depends on the bend force data. Very few researchers studied the bend force behaviour during V-bending process. Huang and Leu [6] investigated experimentally and numerically the effects of various parameters on bend force in V-bending process. It was identified that there is an increase in punch load with decrease in strain hardening exponent, increase in punch radius and punch speed. Hamouda et al. [7] investigated using finite element analysis, the bend force characteristics of various types of

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Table 1. Composition and properties of component materials of clad sheet.

Composition and properties	Al1050–H14 (Aluminium) [17]	C11000 (Copper) [18]	Al-Cu clad sheet
Composition (wt.%)	99.44 Al, 0.406 Fe, 0.121 Si, 0.033 Cu	Cu 99.9, Bi 0.002, Sb 0.002, Pb 0.005, As 0.002, S 0.005, O 0.06	60% Al and 40% Cu
Yield strength (MPa)	103	195	120.4
Ultimate strength (MPa)	110	250	123.5
Young's Modulus (GPa)	69	117	76

stainless steel. It was found that the initial effective stress and coefficient of friction increase the bend force. Narayanasamy and Padmanabhan [8] employed response surface methodology for predicting the bend force in air V-bending of interstitial free steel sheets. The study showed that bend force is influenced to a greater extent by punch travel followed by punch radius and punch velocity. Farsi and Arezoo [9] studied the bend force in V-bending of perforated sheets and found that increasing die width and decreasing punch radius decrease the bend force. Srinivasan et al. [10] conducted air V-bending experiments on electrogalvanised steel sheets to investigate the effect of various parameters on bend force behaviour. The results indicate that the bend force is smaller for thicker coating thickness, smaller punch radius, wider die opening, larger die radius and slower punch velocity.

Laminated or clad metal sheets consist of two or more layers of dissimilar metals of different thicknesses and are formed by different joining methods like roll bonding. They combine the mechanical, physical and chemical properties possessed by the base materials. The laminated sheets are developed as multifunctional materials to provide new functions that individual metallic sheets could not. Now-a-days, there is a rising need of laminated sheets having special properties, including light weight, better mechanical and thermal properties, high corrosion and wear resistance, and they have been increasingly common in many industrial applications such as automobile, electrical, ship, food and construction [11]. The bending behaviour of laminated sheets is altered because of different mechanical properties of the base materials. In recent years, limited research efforts have been focused towards the bending studies of laminates. Yilamu et al. [12] investigated the bending behaviour of aluminium-stainless steel clad sheet in air V-bending process. Springback and thickness variation have been studied and the results showed that the bending behaviour is highly influenced by the sheet-set condition. Kagzi et al. [13] derived an analytical model to predict springback and thickness variation in bimetallic sheet. The results were validated with the experimental results obtained by the previous authors. Ganesh and Mukesh [14] developed a bending model for bilayer laminated sheet to determine the change in relative thickness as a function of bending curvature. The results of the model indicated that the relative thickness of the sheet after bending is influenced by the location and thickness of the softer material of the clad. The results were validated with results of FE models and experiments using steel-aluminium laminates.

Aluminium-Copper clad sheets are widely used as electric elements such as power connectors, tapes, battery casings, condenser casings and as heat conductive elements in heat exchangers because of its higher magnetic shielding, heat conductivity, corrosion resistance, lighter weight and lower price than pure copper or copper alloys [15,16]. The research on the study of bending behaviour of Al-Cu bimetallic sheet has not been extensively studied yet. This paper investigates the effect of various parameters on the bending behaviour such as springback, bend force and thickness variation of Al-Cu clad sheet in V-bending process.

2 Materials and experimental method

The material used in this investigation is Aluminium-Copper clad sheets of 1 mm and 2 mm thicknesses. The Al-Cu clad sheets consist of layers of aluminium and copper in 85:15 by volume and 60:40 by weight composition. The composition and properties of component materials of the clad sheet are shown in Table 1.

The different V-dies were fabricated with die angles 60°, 90° and120° and die openings 24, 32 and 40 mm. The punches have different punch radii such as 2, 4 and 6 mm. The dies and punches were fabricated with EN8 steel and hardened. The die and punch sets are shown in Figure 1.

The equipment used for the experiments was a universal testing machine (UTM) of 40 kN capacity. The experimental setup could record the force using a load cell and a digital display. The displacement was measured in the displacement meter. The experimental setup is shown in Figure 2. The sheets were cut by wire electro discharge machining to a size of 80 mm × 20 mm. The die and punch were clamped in the UTM and the sheet was kept on the die with proper alignment. The punch was brought down to bend the sheet metal workpiece. The displacement of the punch was observed using the digital displacement meter. During bending, the maximum bend force had been measured with the load cell and display arrangement. The bent sheet profiles were taken as impressions before and after unloading the punch. They were scanned to convert as digitized and imported to CAD software. The initial bend angle (θ_i) and final bend angle (θ_f) were measured from the digitized images and the difference

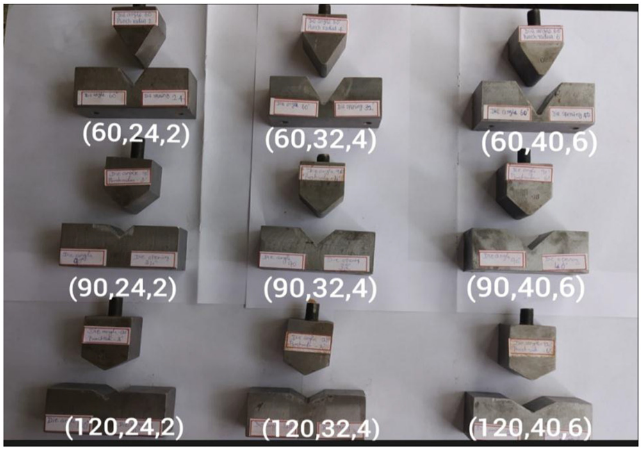

Fig. 1. Punch and die sets.

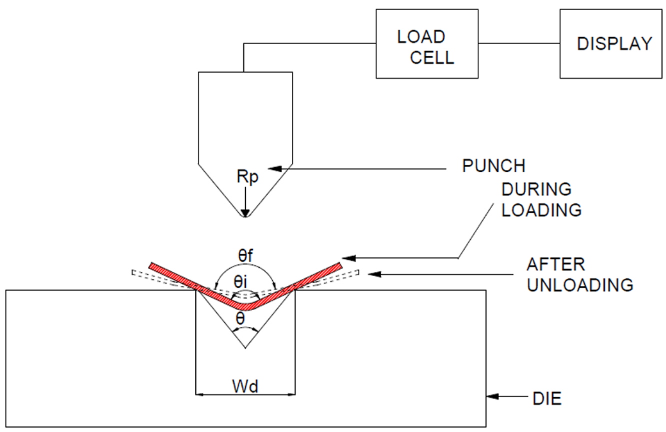

Fig. 2. Experimental setup (W_d – die opening, R_p – punch radius, θ – die angle, θ_i – initial bend angle, θ_f – final bend angle).

between them is springback angle. The thickness of the bent sheet was measured using a profile projector. The difference between initial thickness and the bent sheet thickness gives the total thickness variation. After measuring the total thickness variation, the copper layer of the clad sheet was dissolved in the concentric nitric acid and only the aluminium layer was present. The thickness of the aluminium layer was measured and from this, the thickness variations of individual layers were obtained.

The experiments were conducted for various sheet thicknesses, sheet positions, die angles, die openings and punch radii to study the springback, maximum bend force and the thickness variation of the sheet. Table 2 shows the parameters of the experiments.

3 Results and discussion

The experimental studies were conducted to study the effect of process parameters on springback and bend force of clad sheets. The change in thickness is also discussed in this section. The results were depicted graphically.

Table 2. Process parameters.

Parameters	Dimensions
Sheet thickness (mm)	1, 2
Sheet position	Al/Cu, Cu/Al
Die angle (°)	60, 90, 120
Die opening (mm)	24, 32, 40
Punch radius (mm)	2, 4, 6

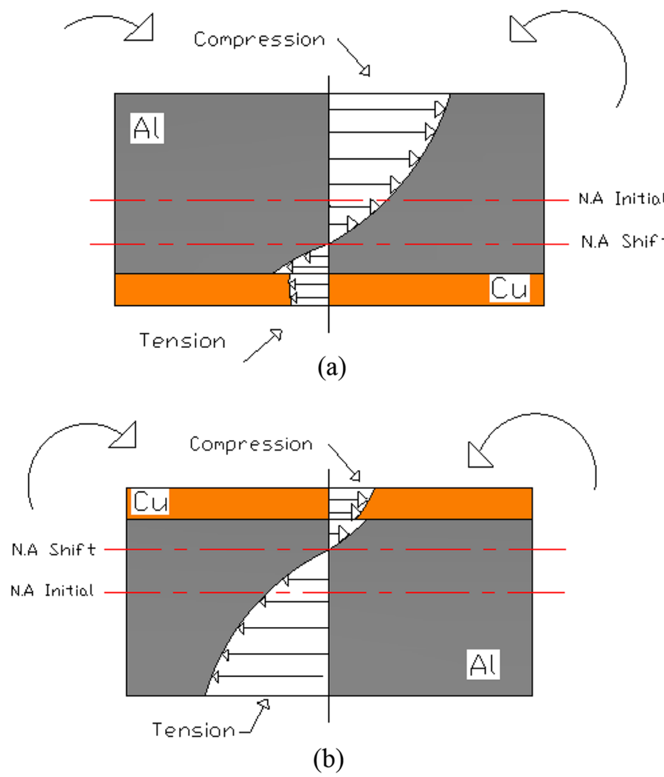

Fig. 3. Stresses acting on layers (a) Al/Cu set condition (b) Cu/Al set condition.

3.1 Thickness change in clad sheet

In clad sheets, as the properties of the two layers differ, thickening or thinning of the sheet could occur depending on the position of the sheet. The bending action results in both tension and compression in the sheet metal. The outer radius of the sheet is subjected to tension and the inner radius experiences compression. The tensile and compressive stresses decrease towards the centre of the sheet and at a particular boundary line, both the stresses are absent. This is known as neutral axis. When the clad sheet is subjected to bending in Al/Cu setting condition, the weaker layer (aluminium) faces the punch, it undergoes compression and thickens; the stronger layer (copper) is in tension and undergoes thinning. During bending, neutral axis moves towards the stronger layer. Since the stronger layer is in the outer side, the neutral axis is towards the outer radius that is on the tension side. Hence large portion of aluminium layer is subjected to compression and thickens resulting in increase in total thickness of the clad

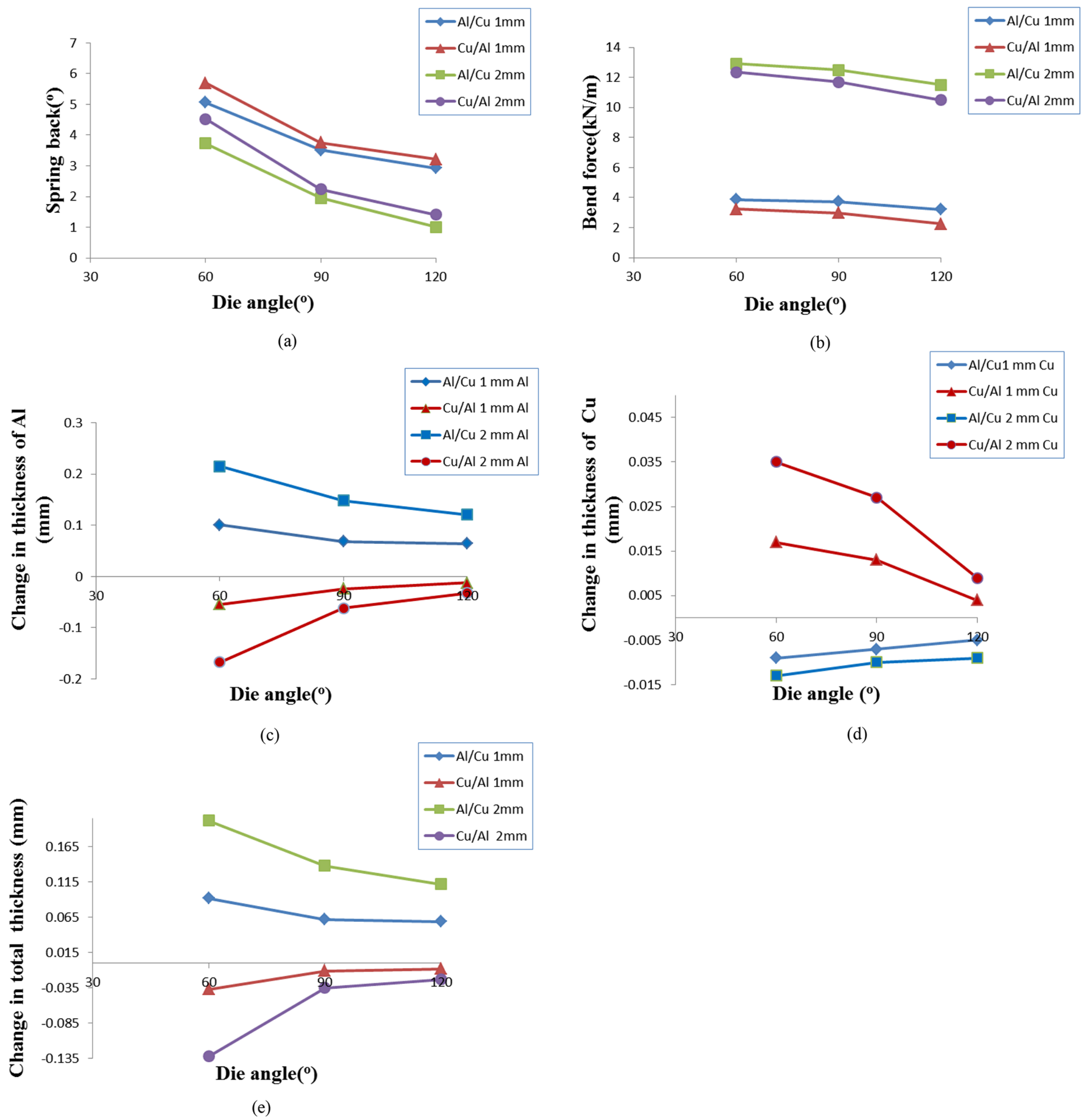

Fig. 4. Effect of die angle on (a) springback, (b) bend force, (c) change in thickness of Al layer, (d) change in thickness of Cu layer, (e) change in total thickness of clad sheet ($W_d = 32$ mm, $R_p = 4$ mm).

sheet. Conversely, in Cu/Al setting condition, as the stronger layer (copper) is in the inner surface of the bend, the neutral layer is moved towards inner radius. The weaker aluminium layer is at the outer surface and undergoes tension (Fig. 3) [13].

3.2 Effect of die angle

Figure 4a shows the variation of springback with die angle. The springback decreases with increase in die angle. For the same die opening, the punch has to travel a longer distance in smaller die angle than the larger one. The increase in punch travel increases the bending moment which in turn increases the springback [19]. When the sheet thickness increases from 1 mm to 2 mm, the springback reduces. As the thickness increases, the bending stiffness which resists the springback increases, causing reduction in springback [12].

Figure 4b illustrates the change in maximum bend force with die angle. For larger die angle, the bending arm length is longer and the contact pressure reduces [20]. This reduces the maximum bend force with increasing die angle. While bending a narrow angle the strain level in the bending region is more which increases the bend force [21]. This is the reason for higher bend force for 60° and it decreases with increasing bend angle.

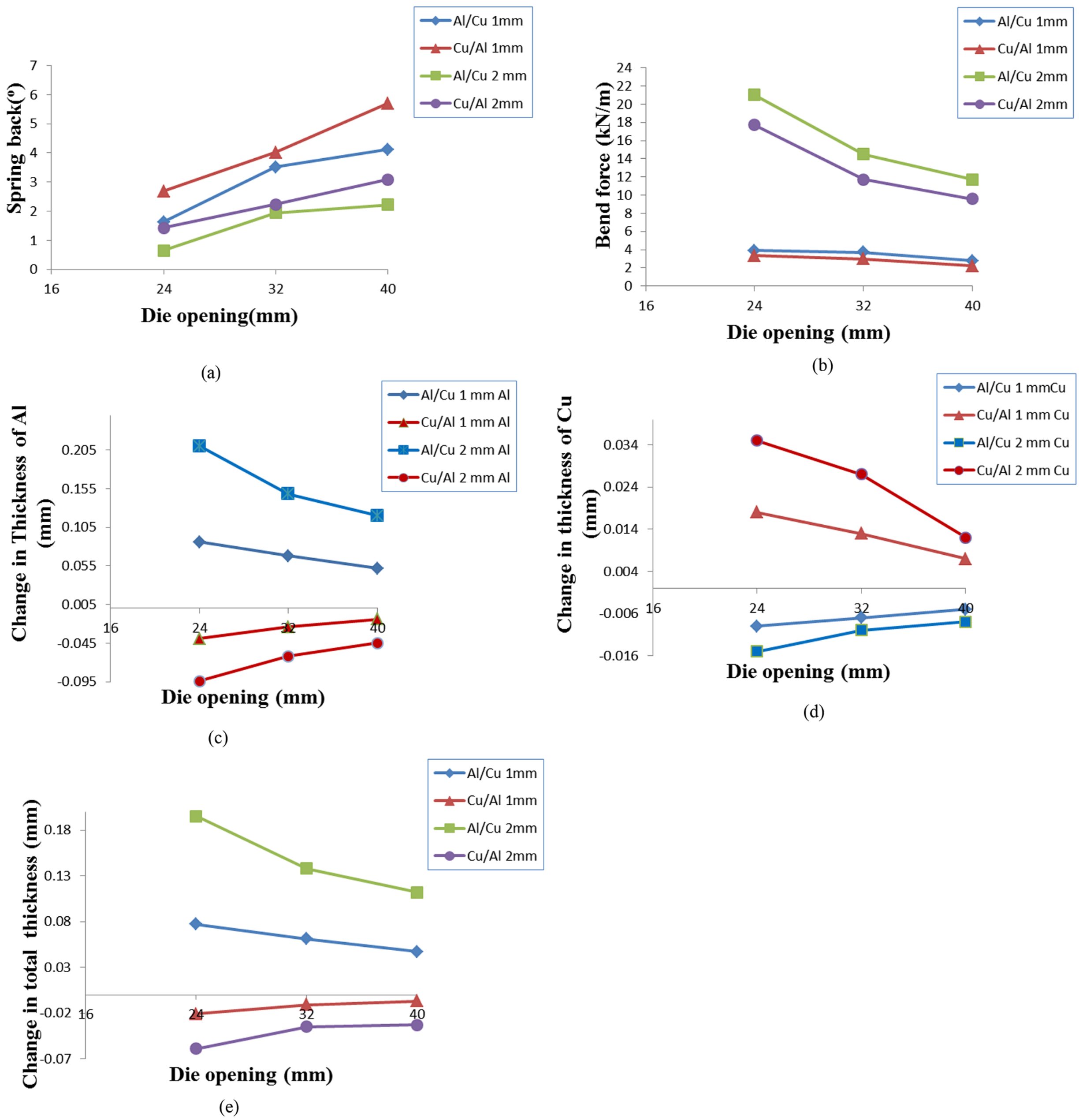

Fig. 5. Effect of die opening on (a) springback, (b) bend force, (c) change in thickness of Al layer, (d) change in thickness of Cu layer, (e) change in total thickness of clad sheet ($\theta_d = 90°$, $R_p = 4$ mm).

The changes in thickness of individual layers and total thickness of the clad sheet are depicted in Figure 4c–e for different set condition. The increase in thickness is indicated as positive and decrease in thickness as negative. The thickness variation of the soft and strong layers is dependent on the strengths of aluminium and copper, respectively. The weaker aluminium deforms to a larger extent compared to copper and also the aluminium layer subjected to deformation is thicker than copper. Hence the thickening or thinning of aluminium is more than the copper. Moreover, aluminium undergoes higher strain in compression when it is on the inner curve (Al/Cu setting condition) compared to it in tension when it is on the outer curve (Cu/Al setting condition). The total thickness variation depends on the thickness ratio of layers [14]. As the thickness ratio between aluminium and copper is 17/3, the total thickness change in the clad sheet is decided by the change in thickness of aluminium layer. It is revealed from Figure 4e, both for 1 mm and 2 mm sheets, the total thickness of the sheet increases for Al/Cu set condition and decreases for Cu/Al set condition. With an increase in bend angle, the thickness changes in individual layers and clad sheet decrease as the strain level decreases with increasing bend angle. The thinning or thickening of sheet so contributes to the springback and bend force. Since the thickening of clad sheet increases the bending stiffness resisting the springback,

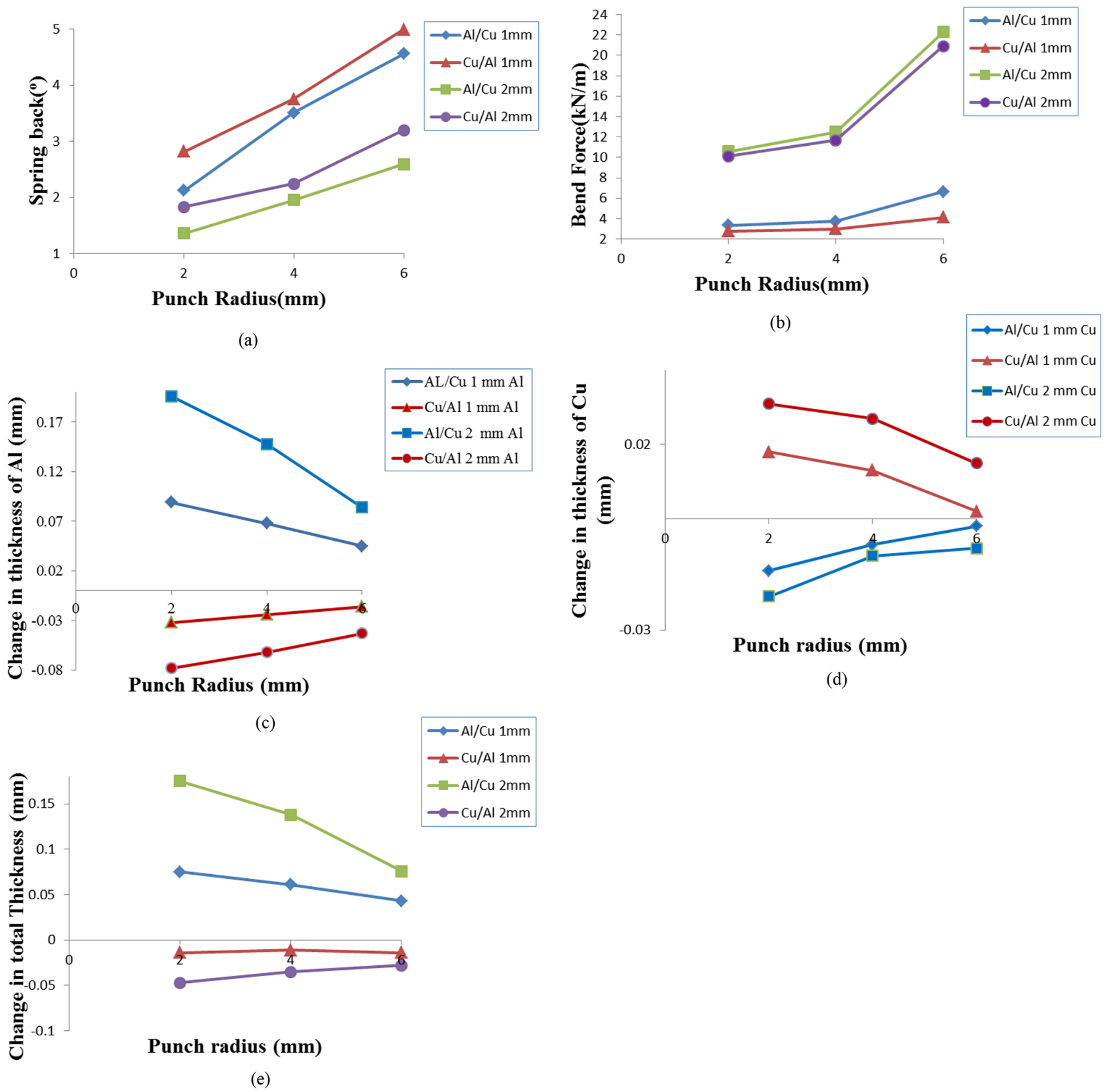

Fig. 6. Effect of punch radius on (a) springback, (b) bend force, (c) change in thickness of Al layer, (d) change in thickness of Cu layer, (e) change in total thickness of clad sheet ($\theta_d = 90°$, $W_d = 32$ mm).

the springback of Al/Cu condition is comparatively smaller than the Cu/Al condition. Similarly, the maximum bend force of Al/Cu condition is lower than Cu/Al condition.

3.3 Effect of die opening

Figure 5a depicts the effect of die opening on the springback. With increase in die opening the springback increases. For a wider opening, the length of the sheet subjected to bending and hence the bending moment increases [22]. As a result, the springback increases. The effect of die opening on maximum bend force is shown in Figure 5b. The figure indicates that bend force decreases with increasing die opening. The increase in die opening increases the lever arm which is utilized to transfer the bend force into bending moment [23]. Since the lever arm is shorter in the case of narrow die opening, a larger bend force is required to provide the bending moment. As the increase in sheet thickness requires higher bending moment and hence higher bending force to bend the sheet. This is the reason for higher bend force for 2 mm sheet than 1 mm sheet.

When the die opening increases, the change in thickness of individual layers and clad sheet decreases and this is shown in Figure 5c–e. It is evident that increase in die opening reduces the severity of bending [24]. Hence the compressive or tensile stresses causing the deformation on individual layers decreases with increase in die opening. This is the reason for lesser thickness variation for wider die opening. As in the previous case, the springback and bend force values are lower for Al/Cu set condition than Cu/Al set condition.

3.4 Effect of punch radius

Figure 6a–e depicts the effect of different punch radii on springback, bend force and thickness variation of clad sheet. For a smaller punch radius, the punch–sheet contact curve is small. It increases the contact pressure which increases the transverse stresses. Hence the stress is localized and concentrated in a narrow region causing a localized plastic deformation [24]. This decreases the size of the elastic zone and therefore springback is reduced. Moreover, the localized deformation causes more thinning or thickening of individual layers and clad sheet. When punch radius increases the sheet comes into contact with the sides of punch tip and the contact region extends. This reduces the contact pressure and the stresses are distributed for a larger area. This widens the elastic zone which increases the springback. The strains in the wrap around zone decrease which reduce the thinning or thickening of layers and sheet. Moreover, the increase in punch radius shortens the actual lever arm which increases the bend force [25,20]. It is also revealed that the springback and bend force behaviour of different set conditions are similar to the previous cases.

4 Conclusions

– The experiments are conducted to study the springback, bend force and change in thickness of the Al-Cu clad sheet in V-bending. The springback and bend force decrease with increasing die angle. When die opening increases, springback increases and the bend force decreases. The increasing punch radii increase the springback and bend force. When the sheet thickness increases there is a reduction in springback and increase in bend force.
– When the individual layers either Cu or Al in the inner radius of the bend, they thicken and are in the outer layer they thinned. The thickening in compressive stress is comparatively more than the thinning in tensile stress for either case.
– When considering the total thickness variation, the sheet thickens at Al/Cu set condition and thins at Cu/Al set condition. This results in reduction in springback and increase in bend force in the clad sheet for Al/Cu set condition and vice versa for Cu/Al set condition.
– With increase in die angle, the thickening or thinning of both layer decreases and also the change in total thickness. For wider die opening, the change in thickness of individual layers and total thickness is lesser than the narrow one. The smaller punch radius causes more thinning or thickening of individual layers and hence the total thickness variation is more in that case.

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