INFLUENCE OF ADHESIVE ON THE SPRING-BACK OF ADHESIVE BONDED SHEETS

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Abstract

Usage of adhesives in joining thin metal sheets of high strength increases its scope in automotive and aerospace industries as it reduces weight and material cost.The current investigation is aimed at investigating the spring-back of adhesive bonded sheetsduring V-bending by varying the adhesive properties. The effect of hardener to resin ratio of adhesive, with and without shim, wire reinforcement, and adhesive thickness, was determined. It has been demonstrated that the spring-back of base sheet can be reduced to a larger extent with the help of adhesives. The influence of H/R ratio on spring-back is considerable of about 8-20° reduction depending on the presence or absence of shim. But the other two parameters, adhesive thickness and wire reinforcement, show almost insignificant effect, with wire reinforcement the least.

Keywords:Spring-back, V-bending,Adhesive properties, Deformation

1 Introduction

Adhesive bonding is a cheap, fast and robust joining technique. Availability of several high strength adhesives has led to wide spread use in structural applications of metallic and composite materials, in the automotive, aerospace, and electronic industries. Adhesive bonding has many advantages over other joining process like welding, diffusion bonding and riveting. For example, dissimilar materials can be easily joined and there is no need to care about thermal strain produced due to welding or protrusions produced due to riveting. Use of adhesives in joining thin metal sheets of high strength reduces weight and material cost. Also the adhesive layer can play the role of vibration damping.In the sheet metal industries, press formed sheet metal elements are usually adhesive bonded at the end of the assembly process. Instead if we could inverse it by adhesive bonding first and press forming at final stage, it would be an excellent technique from the view point of high productivity.Many research works have been pursued to study the mechanical behaviour and formability of adhesive bonded sheets and also on the various factors affecting the strength of adhesive bond.

The effect of surface roughness on the bonding strength of adhesive was studied by Ueharaand Sakurai(2002) for adhesives like epoxy and cyanoacrylate. It was found that the optimum value of roughness is in the range of 3-6 μm for tensile strength of adhesion. There is no clear relationship observed between the peel strength and the surface roughness for different types of adhesives.Pereira et al. (2010)studied the effect of surface treatment and adhesive thickness on the shear strength behaviour of aluminium alloy adhesive lap joints, with the aim of optimizing shear strength. The adhesive used was a high strength epoxy. The surface treatments using sodium dichromate–sulphuric acid etch and abrasive polishing resulted in improved joint shear strength, when compared to caustic etch, with Tucker's reagent etch. The decrease in surface roughness was found to increase the shear strength of single lap joints. An increase in base sheet thickness and overlap length was found to increase shear strength indicating the influence of joint rigidity. Through Kahraman et al. (2008)work it is found from experiments and finite element analysis that adhesion strength decreases as the thickness of the adhesive increases. It is observed that the shear stresses in the adhesive increase as the bond thickness increases, which is responsible for reduction in adhesion strength.

Ravi Kant and Narayanan (2012) studied the influence of bonding width, adhesive thickness, and blank surface roughness on the tensile behaviour of adhesively bonded blanks. It is found that the engineering stress attained in forming the bonded blank for the same amount of strain is greater if the surface roughness is greater. The extension of the bonded blank at the break point is less for higher surface roughness base materials. With an increase in the adhesive thickness, there was no effect due to adhesive thickness on the elongation at failure. The engineeringstress required decreases with the bonding width and the extension at the breaking point of the bonded blank is greater in the case of the bonded blank with a higher bonding width. Satheeshkumar and Narayanan(2014)studiedthe influence of adhesive properties on the formability of adhesive-bonded steel sheets made of dissimilar steel sheets. The adhesive properties were varied by changing the hardener to resin ratios. The epoxy and acrylic adhesives show improved elongation with increase in hardener to resin ratio. This is because of changeover of resin-rich formulation to hardener-rich formulation, making the sample more ductile. With increase in hardener to resin ratio of both the adhesives, the elongation and limit strains of individual sheets has improved.

Zadpoor et al. (2009, 2010) investigated the mechanical behaviour of adhesively bonded tailor made blanks of similarand dissimilar material. For similar materials, it is found that if the in-plane straining is mainly in parallel with the transition line, the formability is restricted by the ductility of the applied adhesive. If the in-plane straining is normal to the transition line, the formability is controlled by the fracture energy of the adhesive.The simulations showed that for dissimilar material combination, due to the lower ductility of base sheet in comparison to the upper sheet there is a competition between two failure mechanisms like delamination and metal failure. Lower levels of tensile strain at the transition line and localization of the strain in the imperfection zone of base material are the prominent reasons of base metal failure occurring before delamination. Takiguchiand Yoshida (2001) studiedplastic bending of adhesive bonded sheets by performing V-bending experiment. It is proposed by them that the ‘gull-wing bend’ can be removed with an increase of forming speed. This is mainly due to the reduction of bending moment action on each face metal withincreasing shear strain rate of the adhesive.

Controlling spring-back is crucial from sheet forming view point, and minimizing spring-back by changing adhesive properties will be discussed in the present work.In the present work, the effect of adhesive properties on the spring-back during V-bending of adhesive bonded sheets made of same base material is studied.The various parameters considered for modifications in adhesive properties are, hardener to resin ratio(withshim and without shim), adhesive thickness, and wire reinforcement. The spring-back angle was measuredimmediately after load was removed. The failure pattern was also analysed.

2 Experimental work

Deep drawing quality(DDQ) cold rolled steel sheet of 0.4mm thickness was used to fabricate adhesive bondedsheets. The nominal chemical composition (in wt %) of deep drawing quality steel is: C%-0.1, Mn%-0.6, Si%-0.12, S%-0.035, P-0.045%, Fe-remaining.Commercially available two part epoxy adhesive was used to bond the sheet materials. For wire bonded adhesive sheets, aluminium wire of 0.3mm diameter was considered. The dimensions of die and punch used for V-bending experiments are shown in Figure 1.The base material mechanical properties were evaluated by performing tensile tests of Deep Drawing Quality steel on INSTRON machine at 1mm/min cross-head speed. The sample was made according to ASTM standard. Three samples each of 0°, 45°, 90° rolling directions were tested and the data recorded was used to evaluate engineering stress-strain, and true stress-strain data. The plastic strain ratio(*R*)was found in accordance to E517 ASTM standard. The base material properties thus evaluated are shown in table 1.For wire reinforcement, the wires were first tested on INSTRON machine at 1mm/min cross-head speed to determine the ductility and load carrying capacity of the wire. Three wires of gauge length 125mm were tested and it was found that the average total extension of the wire was 40mm, and it could support an average maximum load of 10 N.

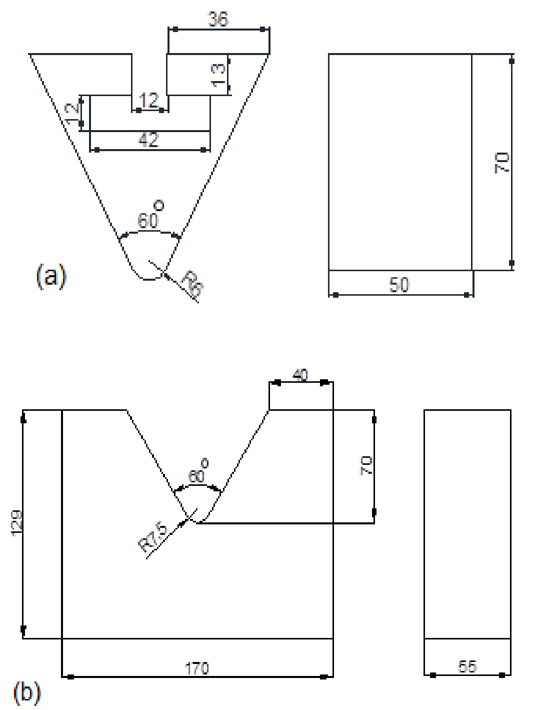

Figure 1 Schematic of V-bending setup, (a) Punch, (b) Die. All dimensions in mm and not to scale.

Table 1Material properties of DDQ steel

Rolling direction	Yield strength, MPa	Ultimate tensile strength, MPa	Uniform elongation, %	Total elongation, %	Strain hardening exponent	Strength co-efficient, MPa	Plastic strain ratio
0°	224	372	27.6	33.5	0.23	647	1.12
45°	216	360	26.3	33.6	0.23	633	1.37
90°	201	344	25.3	32.3	0.24	608	1.47

DDQ steel sheets of size170 mm ×50mm were cut 0° rolling direction for adhesive bonding.The sheets were first cleaned in soap solution and later with acetone to remove impurities in order to have good bonding between adhesive and the two part epoxy containing resin and hardener was mixed and stirred for 15-20 min till it becomes semi-solid. The adhesive was spread in between the base sheets and placed in an oven maintained at 25°C to prevent any moisture from seeping.The curing time for adhesive is about 48 hours before testing it for spring back. Four sets of samples were fabricated for spring-back tests:(a)samples made by using shims at the extreme ends located between the top and bottom sheets with the help of Feviquick glue (commercially available). The main aim of using shim was to maintain uniform thickness of adhesive layer during bonding, (b) samples made without usingshims, just to determine the effect of only epoxy adhesive. These two samples were made at varying hardener to resin (H/R) ratios, (c) samples having different adhesive thicknesses, but at constant H/R ratio of 1:1, (d) samples with wire reinforcement. In this, the length for single wire strand was maintained at 160 mm and the wires were placed at distance of 2mm form each other. The quantity of wires was increased in an increment of five, keeping the minimum numbers at 5 and maximum at 25. The hardener to resin ratio was maintained at 1:1, while varying the number of wires. Three trials were performed in each case for checking the repeatability of results.

All the samples prepared were tested for their thickness at five different locations and average of all values was taken to be the final thickness of the sample. V-bending experiments were done on a universal testing machine.At the beginning three rectangular samples of DDQ were tested to determine the spring-back of base sheet, and later adhesive bonded samples were tested. The punch stroke was maintained at 68 mm and the cross-head speed was maintained at 1mm/min. After V-bending, the spring-back angle of the samples was measured under profile projector. Angles were measured at three different locations and the average of all the angles was considered as the final spring-back angle. During bendingdelamination of sheet occurs, hence spring-back of upper sheet and bottom sheet are measured separately.All spring-back measurements were done within 24 hours, after completion of experiment. The various parameters involved in the experimental study are given in Table 2.

Table 2Parameters and levels used for experiments

Experimental parameters	Level 1	Level 2	Level 3	Level 4	Level 5
H/R ratio with shim	0.6:1	0.7:1	0.8:1	0.9:1	1:1
H/R ratio without shim	0.6:1	0.7:1	0.8:1	0.9:1	1:1
Adhesive thickness (mm)	1	1.2	1.4	1.6	1.8
No. of wires	5	10	15	20	25

3 Results and discussions

The die angle in the V-bending setup is 60° (Fig. 1b) and any deviation from the die angle after bending is due to the influence of spring-back. In the case of DDQ steel base material, the spring-back angle is found to be 74°. Figure 2 and 3 show the influence of H/R ratio on the spring-back of adhesive bonded sheets made with shim located by quickfix at the bottom and at the top.In the case of Fig. 2, due to transverse shear deformation the delamination of the bonded sheet occurs at the location of shim (at the extreme ends). The delamination occurs between the upper sheet and the shim during V-bending, since the quickfixadhesive between the shim and the bottom sheet has more joint strength than epoxy. Because of the delamination, the upper sheet bends separately as compared to bottom sheet and adhesive. Hence after load removal, the spring-back of the upper sheet is very different from that of bottom sheet and adhesive. In fact, it is expected that the upper sheet will bend like base material, but it is seen from Fig. 2 that the spring-back of upper sheet (i) is much lesser than that of bottom sheet and adhesive, and (ii) is almost same as that of die angle of 60° indicating no spring-back. Even then, the spring-back increases with the increase in H/R ratio for both the upper and bottom sheets. There is cohesive (adhesive) failure at the point of application of load,mainly because of the limited ductility of adhesive at 0.6:1 H/R ratio, while no adhesive failure is witnessed with increase in H/R ratio, specifically at 1:1 H/R ratio.

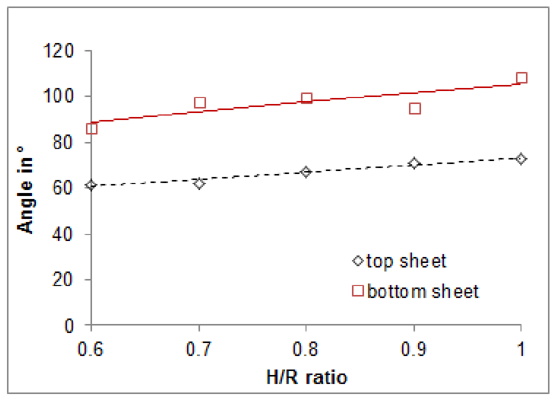

Figure 2 Influence of H/R ratio on the spring-back of bonded sheets made with shim located by quickfix glue at the bottom (Average deviation: 4°)

In the second case (Fig. 3), when quick fix is placed between the upper sheet and shim during bending, the delamination occurs at the bottom side between the adhesive and the bottom sheet. Now the upper sheet and adhesive deform together, while the bottom sheet deforms separately. As a result, two different spring-back angles are expected. But the spring-back of detached bottom sheet is restricted by the die and punch, and the upper sheet, resulting in almost the same spring-back behaviour as that of upper sheet/adhesive. Even in this case, the spring-back increases with increase in H/R ratio. Moreover in the first case (Fig. 2), the spring-back of DDQ un-bonded base material is in between that of bottom sheet and upper sheet constituting adhesive bonded sheets. While in the second case (Fig. 3), the adhesive bonded sheets exhibit a reduced spring-back (55° to 69°) as compared to DDQ base sheet, which could be due to the combined effect of increase in overall thickness and decrease in strength of the adhesive sample as compared to base material. Figure 4 shows the influence of H/R ratio on the spring-back of adhesive bonded sheets without shim. Due to presence of shims in the previous cases, there was competition between epoxy adhesive and quickfix adhesive as a result of which there was huge difference in spring-back of upper sheet and bottom sheet. To determine the effect of only epoxy adhesive, the shims were removed and V-bending was done. It was found that delamination occurred between the bottom sheet and adhesive due to transverse shear and there was no delamination between upper sheet and adhesive. There was adhesive breakage at the point where the punch load was applied, which is due to the reduction in ductility of adhesive as compared to the base metal. The spring-back of both the upper sheet and lower sheet have slightly decreased (by about 7°) with increase in H/R ratio.

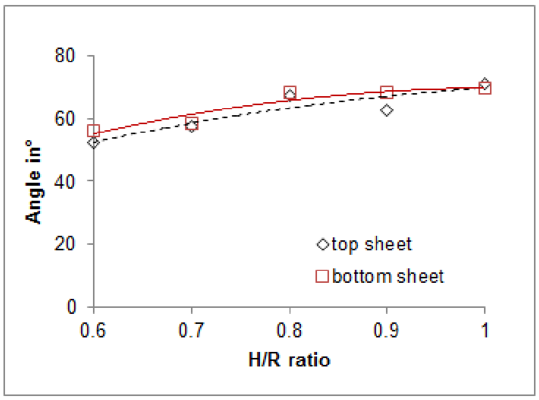

Figure 3 Influence of H/R ratio on the spring-back of adhesive bonded sheets made with shim located by quickfix glue at the top (Average deviation: 1.5°)

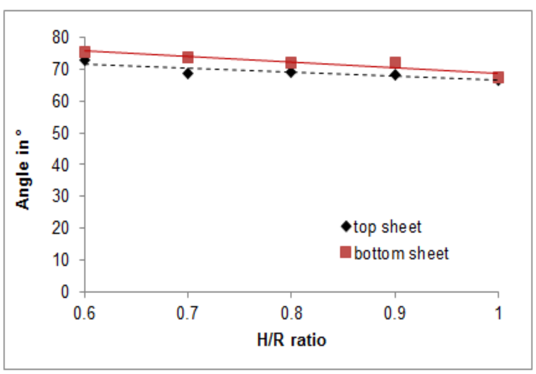

Figure 4 Influence of H/R ratio on the spring-back of adhesive bonded sheets without shim (Average deviation: 2.3°)

In this case, the spring-back of adhesive bonded sheet is governed by change in Young's modulus, tensile strength, and ductility of adhesive, when H/R ratio is increased. It is observed from our earlier attempts (Satheeshkumar and Narayanan, 2014)that the Young's modulus of adhesive decreases, tensile strength decreases, and ductility increases, with increase in H/R ratio. The modifications in such mechanical properties will affect the overall mechanical properties of the bonded sheets in a direct manner.It is seen from available literature that with (i) decrease in elastic modulus, the spring-back increases; (ii) decrease in tensile strength, spring-back decreases, and (ii) increase in adhesive bonded sheet ductility, spring-back increases because of more elastic recovery. The combined effect of all this is to reduce the spring-back of adhesive bonded sheet slightly (Fig. 4), with increase in H/R ratio.

The influence of adhesive thickness was studied at a constant hardener to resin ratio of 1:1. Since the spring-back of upper and bottom sheets were same, the spring-back ofupper sheet was considered (Fig. 5). It is observed that on increasing the thickness of adhesive layer, the spring-back effect has reduced. This agrees with the available results obtained for un-bonded sheet metal where spring back is inversely proportional to the thickness of the metal sheet, and directly proportional to the overall strength. From the earlier attempts, it was observed that with increase in H/R ratio, the overall strength of the adhesive bonded sheets has decreased. Hence the combined effect of increase in sample thickness and decrease in overall strength is to reduce the net spring-back of adhesive bonded sheets (Fig. 5).From the Fig. 6 it is observed that with the increase in number of wires of reinforcement, the spring back increases by about 3°. This variation is negligible as compared to the spring-back error deviation among different trials. Initially delamination of sheet occurs due to transverse shear deformation, but no adhesive failure was observed since H/R ratio used was 1:1 which has more ductility as compared to other hardener to resin values. It is also observed that the spring back for wire reinforced sheet with 1:1 H/R ratio, the maximum among five different ratios, is about 64°, which is slightly less than the case without wire reinforcement, which is 67°.

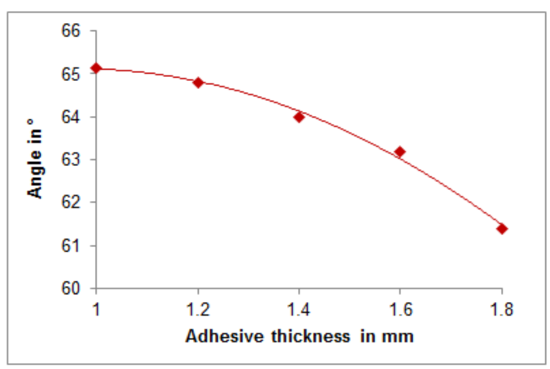

Figure 5 Influence of adhesive thickness on the spring-back of adhesive bonded sheets (H/R = 1:1) (Average deviation: 2°)

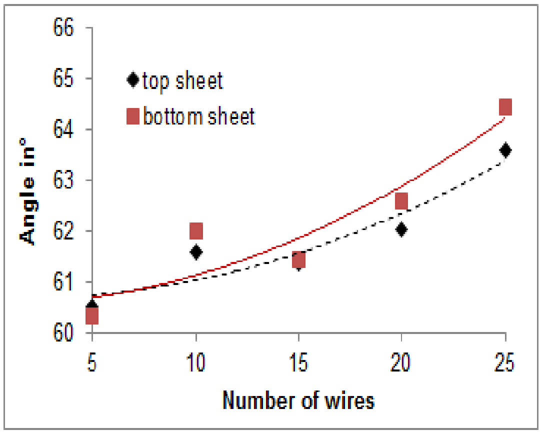

Figure 6 Influence of number of wires on the spring-back of adhesive bonded sheets (H/R = 1:1) (Average deviation: 2.4°)

4 Conclusions

The following conclusions are drawn from the present work.

(i) It has been demonstrated from the present work that the spring-back of steel sheets can be modified significantly with the help of adhesives, by changing the adhesive mechanical properties. Just by changing the hardener to resin ratio, adhesive thickness, and by wire reinforcement, the spring-back of bonded sheets have shown a drastic reduction as compared to DDQ base material.

(ii) The use of shim to maintain uniform adhesive thickness plays a vital role in deciding the spring-back of adhesive bonded sheets, by changing the delamination location, i.e., between the upper sheet and adhesive, and between adhesive and lower sheet.

(iii) When shim is not present, the effect of H/R ratio is to slightly reduce the spring-back.

(iv) The influence of adhesive thickness for a constant H/R ratio is to reduce the spring-back by about 4-5°, and the influence of wire reinforcement is found to be negligible.

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