International Journal of Engineering and Applied Sciences (IJEAS)
ISSN: 2394-3661, Volume-4, Issue-4, April 2017

Experimental analyses of springback variation in wipe bending

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Abstract— **In an effort to reduce the weight of vehicles, automotive companies are used the CRS, HRS and Aluminium 6061. These materials are used widely in the automobile industry for car panels. Springback is an important issue in sheet metal forming. It arises from the elastic recovery, mainly due to bending, permanent softening of metallic sheet and transient behavior subjected to reverse loading. The hardening parameters related to the Bauschinger effect, permanent softening and transient behavior are optimized from the springback profiles of wipe bending tests. Here an approach is proposed to measure the Bauschinger effect In general, the influence of the Bauschinger effect must be considered for obtaining accurate springback predictions. Springback is the elastically driven change of shape that occurs following a sheet forming separation when the forming loads are removed from the work piece. It is commonly undesirable, causing problems such as increased tolerances and variability in the subsequent forming operations such as in assembly and in the final part. Most sheet metal elements undergo complicated deformations during forming process. An efficient and low cost wipe bending experiment has been designed to investigate the influence of the Bauschinger effect on spring back in sheet metal forming. From these experiments, it can be concluded that the influence of the Bauschinger effect on springback is more significant in AL6061.**

Index Terms— **Springback, Bauschinger effect, wipe bending.**

I. INTRODUCTION

In sheet metal forming bending operation is one of the most widely used operation. In the manufacturing of automobile components, panel's of electronic components, panels used in vehicles, drums etc. Despite being the most inaccurate of all the bending operations, wipe bending is still widely used throughout the industry. Because of simple tool construction and possibly multiply flanges can be formed for more than one part. During wipe bending, the punch slides down, coming first to a contact with the material to follow along, until finally bottoming on the wipe shape of the die.During forming, most of the sheet metal undergoes a complicated deformation process that may comprise a sequence of stretching, bending, unbending and reverse bending processes. When a sheet flows through round bead or square, its observation in deformation includes of stretching and BRB (bending, reverse-bending, bending) processes. When a sheet metal flows through a die shoulder into the cavity involves to an additional sequence of unbending, bending and unbending. For such a complicated deformation, the overall strain method will not predict springback accurately because of the Bauschinger effect.

"springback" in the present topic to the elastically driven change of shape due to the forming loads are removed from the work piece during sheet forming operation. This phenomenon causing problems such as variability in the subsequent forming operations and increased tolerances such as in assembly and in the final part. This effect leads to change in the quality of the products and appearance ding manufactured. The essential need of this work in sheet metal forming is to investigate the influence of the Bauschinger effect on springback. For prediction of the Bauschinger effect in the springback , an analytical model can be developed it includes the Bauschinger effect in the springback prediction. Once accuracy in simulation of the sheet metal forming process can be obtained, then the punch opening as close as possible to move draw beads by the designer and the area of addenda can also be decreased. And thus the size of the blank sheet can be reduced. Tryout times of both hard tool and soft tool can be reduced by more accurate simulations, material savings are an additional benefit.

1.1 Deformation Mechanism

It is very clear to understand that the occurrences of permanent deformation due to the changes in the material structure exceeded the maximum elastic limit. However, this is not considering the final deformation. Because after releasing of the applied load or pressure, the material try to move back to its initial position, called as springback. This effect is also called as Bauschinger effect.

So the total deformation is equal to the sum of the elastic and the plastic deformation of the operation. i.e.

$D_{Total} = D_{EL} + D_{PL}$

Here in the total deformation, the sum of the elastic deformation (D_{EL}) is easily recoverable by the material. Whereas sum of the plastic deformation of the material. It is cleared that in the total deformation only the plastic deformation is responsible for the exact size and shape of the components.

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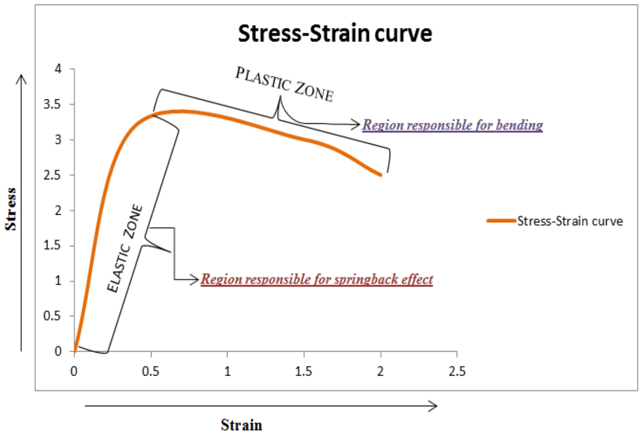


Graph showing the Elastic and Plastic zones in the stress-strain curve

1.2 Deformation in forming

There are two types of deformation can be observed in all forming process. One is localized and another one is affecting whole part.

1. Equal deforming: it is observed fairly even and by its mean values free from excessive deviation and not affected by axial orientation.
2. Unequal deformation: Here unequal changes are observed from the formed parts in the size and shape. Possibility of development of additional stresses, beneficial or detrimental. The main causes for the occurrence of localized stresses within the material during the unequal deformations are :
   a) In between the forming tool and the part of the component experienced by unequal friction.
   b) The component of the part also experienced by unequal temperature distribution.
   c) Due to the geometry of the product is too complex.
   d) Due to chemical differences within the material.
   e) Due to mechanical properties of the material.
   f)

1.3 springback effect

It can be observed during tension-compression conditions and is associated with decrease of the yield stress when the loading direction is revered. Such behavior may have different origins. For instance, if due to residual macroscopic stresses, it is not a true springback. Macroscopic residual stresses may result from heat treatment or from cold work during manufacture.

Two other causes exist. One of them, the principal cause, is related to the dislocation structure in the work-hardened metal. As deformation occurs, the dislocations accumulate at barriers (precipitates, grain boundaries) and from dislocation pile-ups and tangles. Two types of mechanisms are used to explain springback/Bauschinger effect. First, local back stresses, which oppose the applied stress on the slip plane, are produced by discolorations pile-ups on slip planes at barriers. Back stresses assist the movement of dislocations in the reverse direction and the yield strength of the metal is lowered. Secondly, when the slip direction is reversed, dislocations of opposite sign may be created at the same source that produced the slip-causing dislocations in the initial direction. Since dislocations of opposite sig attract and annihilate each other, the net effect is a further softening of the lattice.

Springback is the major problem in bending process. Material properties and process are the major causes for springback. This is the amount of elastic distortion os a material has to go through before it become permanently deformed. In ductile or annealed metal, to some extent the amount of elastic tolerance may present in it. It is observed that the springback in ductile material is much lower than hard metals. And also mainly depends on the modulus of elasticity of the material. Due to the greater yield strength or tendency of the material's strain-hardening increases the amount of springback. Due to heat treatment and cold working may also increase the amount of springback. The springback of low-strength steel material will be always smaller than that of high strength steel. Comparably the amount of springback in aluminium will be two or three times higher than the previous case.

1.4 Springback removal

Several methods to remove the springback in bending including either over-bending or coining. Most widely adopted technique is the over-bending; where the sheet is bending beyond the required dimension. The sheet returns to required dimension due to springback effect. The amount of over-bend by the trial and error method is further verified with the support of simulation software. Coining is one of the methods to avoid springback. Here either the edges of the punch or the surface undergo coining. In some cases the edges of the punch or die, or the both edges may subject to coining.

II. Literature Review

Reviews of certain aspects of the Bauschinger effect have been made by Jeen -Terng Gau (1) conclude that the influence of the Bauschinger effect on HS, AKDQ and BK steels specimen is not very significant. Sowerby and Uko (2) and Bate and Wilson (3).Cyclic torsion tests and uniaxial tension/compression are the most common experimental methods for determining the Bauschinger effect. For example, Rolfe et al (4) select specimens from bent plates with various orientations, including both longitudinal and transversal directions and the compressed the specimens. The fact that the yield stress in compression illustrate the Bauschinger effect that yield the stress in compression was comparatively lower than the yield stress in tension by almost 30%..Even though, to use the cyclical compression-tension tests for determining the Bauschinger effect is not so easy in sheet metal because the fact that the sheet metal buckle under compression. For this special fixtures have to be created. For example, Tan et al (5) designed a fixture that eliminate buckling without the friction between the specimens and the supports and as the axial load applied without any restraint to lateral expansion of the specimens. From their experimental data the Bauschinger effect can be observed. In same manner, Kuwabara et al (6) in the sheet metal, in-plane compressive flow stresses can be measured by the comb-shaped die. After that they used this pre-compressed specimen for a tensile test (CT-test), and an in-plane compressive flow stress of uni-axially pre-stretched specimens (TC-test) and an uniaxial re-tensile flow stress of TC-test specimens (TCT-test). AK steel and A5182-o were used as specimens in their experiments.

In order to avoid the buckling problem in the tension/compression tests, Weinmann et al (7) and Jiang(8) carried out the experiments in pure bending and reverse bending tests. From their experimental data the Bauschinger effect can be directly observed except the direct relationship of stress and strain can't directly obtained. .by Jiang's (8) experiment in bending movement and movement relations' are used to observed the Bauschinger effect.

To test the Bauschinger effect in the sheet metal, shear tests have also been used. To investigate the Bauschinger effect in both aluminum and steel sheets by Miyauchi (9,10) developed test of simple shear. By comparing the torsion test this method is better because it cannot apply directly to sheet metal. But anyhow, the most common approaches to determine the Bauschinger effect is the cyclical torsion test. For instance, to investigate the Bauschinger effect, Takahashi et al (11) used cyclical torsion test in aluminum pipe specimens just like White et al (12). D.W.A.Rees (13), Takshi and Shiono (14) and Lindholam et al (15) also used the torsion test approach to investigate the Bauschinger effect.

It is observed from this experimental result, it is clearly shows that two identical sheet metal specimens can have the same final total strains but have distinctly different amount of springback. Because in the strain space the deformation histories are different. The deformation history in the strain space and the type of material is the main depended variables in the Bauschinger effect on springback predictions. In this paper clearly indicats the Bauschinger effect on springback of the high strength materials like HSLA and AHSS sheet metals. The results can be used to verify analytical models developed to include the Bauschinger effect on the springback predication. If the analytical modeled can be used for the process, the designer can courgiesely move draw beads as close as possible to reduce the addenda area and to the punch opening, that is why, the sheet blank size can be reduced to save material and bothe hard tool and soft tool tryout times becomes reduced.

Experiment tooling, lubricant, materials and procedures

The specimen materials, tooling setup and procedures for this simple and low cost multiple bend experiment are shown in Fig.1. WD – 40 was used as the lubricant.

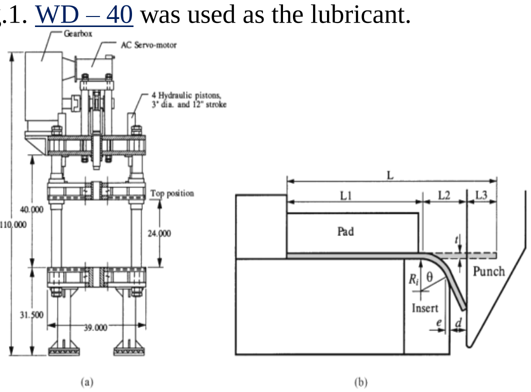


Fig.1. (a) Thirty tons ERC linkage press, and (b) the tooling setup

Three different inserts were used, and their radii (Ri) in Fig.1(b) are ½,3/8 and 3/16in. HRS, CRS and Aluminium 6061 steel were studied. Their thicknesses and properties are summarized in Table 1, where K refers the strength coefficient, n refers the hardening exponent and r refers the anisotropy factor. On conducting the experiment, the gap, d means that the distance between the insert and the punch was fixed. As shown in the table 1, all metallic sheets have different thicknesses. The clearance is nothing but the difference between the metal thickness, t and the gap, d as shown in fig.1 (b). For the three types of metal sheet, the above said t and d are differ. The dimensions of all of the test specimens were 5 in. x 1 in.

For each metal sheet type and insert, four different types of deformation processes were performed. T observe the repeatability of the test, three specimens for each type were tested. The summarization of the experimental procedure as following:

- B: The specimen was fixed by the pad, and then bent by the punch when it moved down as shown in Fig.2.
- BR: After the specimen was deformed in pure bending, it was turned over and bent in the reverse direction. The deformation sequence of the BR process is the combination of Figs. 2 and 3.
- BRB: The specimen was then turned over again and bent in the original direction.
- BRBR: The specimen was again turned over and the bending process was repeated for a sequence of bending, reverse-bending, bending and reverse bending.

III. Measurement methods

There are two approaches are adopted here so as to measure the bending angles of the metal sheet for both before and after the deformation of this experiment.

3.1. Bending angle before springback

During the deformation process it was not convenient/not possible. So that to measure the bending angle a simple numerical approach was used. Nothing but a simple equation (eq.(1))based on a purely membrane assumption and geometrical assumption is used. Because usually the bending angle lies between 0^0 to 90^0 for this experiment. Before springback the bending angle can be computed from the geometry of the setup as

$$L2\,(1 - \cos\Theta) - L3\cos\Theta + (R_i + 1/2t)\,\Theta\cos\Theta - R_i \sin\Theta = 0 \quad (1)$$

Where R_i refers the tooling bending radius, Θ refers the bending angle, t refers the metal sheet thickness and the definitions of L_2 and L_3 as shown in Fig. 1.

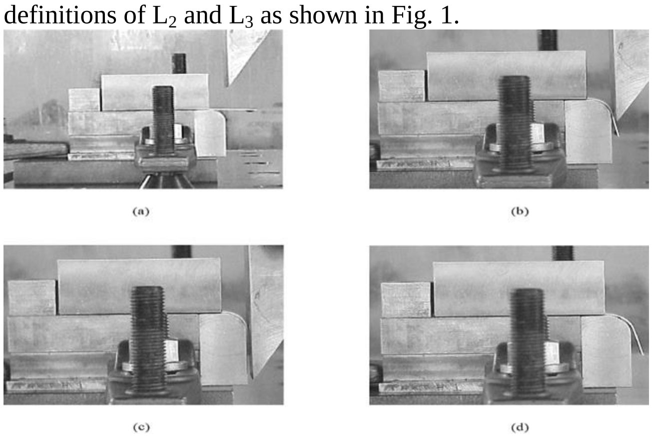


Fig.2. The deformation sequence of bending process: (a) undeformed sheet, (b) intermediate bend, (c) final bend, and (d) springback

3.2. Bending angle after springback

The measurements of the cross-section of an AHSS specimen after springback, with data points measured using a coordinate measuring machine (CMM). These points were measured around the middle of the specimen, and the distance between points is based on the profile curvatures. This means the distance between points would be greater if the curvature is small. Based on the cross-section of the specimen, the bending angle after springback can be computed by the following procedure:

1. Extract the inner portion of the cross-section.
2. Use two linear equations to fit the two straight parts of the specimen.
3. Utilize these two equations to calculate the bending angle of this specimen after springback.

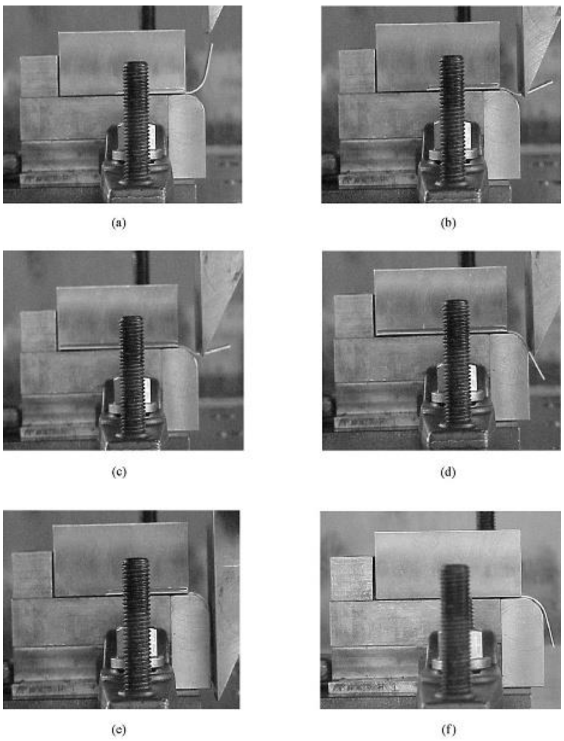


Fig.3. The deformation sequence of reverse bending process: (a) before reverse-bend, (b) intermediate unbebd, (c) intermediate unbend Contd., (d) intermediate reverse – bend, (e) final reverse bend. And (i) springback

Measuring of the angle after springback and difference between depth of specimen before springback and depth of specimen after springback was measured. Due to difficulty of using conventional methods, measuring in MATLAB was used. It could by conclude that springbacks of angle can be calculated and evaluated accurately using MATLAB measuring method. Photos of real experiment were loaded in the MATLAB and then five points on the each arm of specimen was selected. After points were selected, linear regression was used to reach equation of straight line for each arm of specimen. Then based on equations of straight lines, angle between two straight lines was computed.

IV. Experiment Results

The average bending angles after springback for all experiments can be seen in table. The abbreviations used in this table are given below.

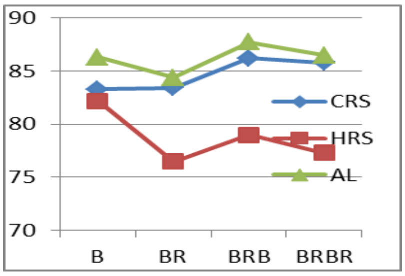
Insert 1 R12	Process	CRS	HRS	AL6061
	B	83 ° 3'	82° 2'	86° 3'
	BR	83° 4'	76° 5'	85° 4'
	BRB	86° 2'	79° 0'	84° 7'
	BRBR	85° 8'	77° 3'	83° 5'
Insert 2 R9	B	82° 3'	76° 2'	84° 3'
	BR	81° 6'	75° 3'	83° 4'
	BRB	82° 5'	77° 4'	82° 6'
	BRBR	84° 4'	75° 6'	81° 6'
Insert 3 R6	B	86° 2'	81° 5'	88° 5'
	BR	85° 0'	79° 6'	87° 4'
	BRB	85° 2'	81° 4'	86° 6'

Table – 2 The experimental results for all experiments

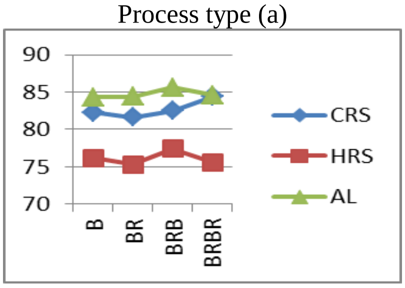
On the first column of table indicates the insert radius, second column indicates the process types and the third to fifth column shows the three materials springback values

V. Discussion and Conclusions

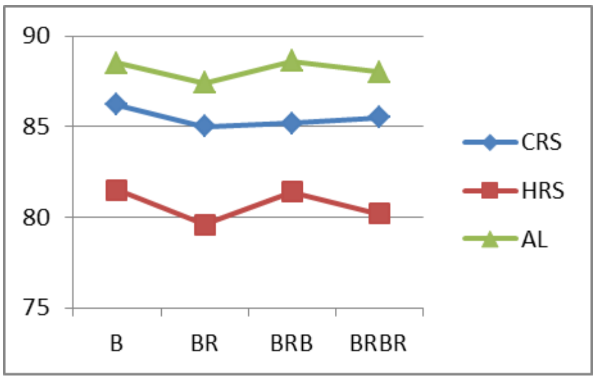
This study is an attempt to obtain the optimum sheet thickness (for HRS steel) for minimum springback angle. This is one of the several methods (discussed previously) to minimize the springback effect. This study also concludes that springback effect depends on the sheet thickness and efficient selection of sheet thickness plays an important role in reducing the springback effect.



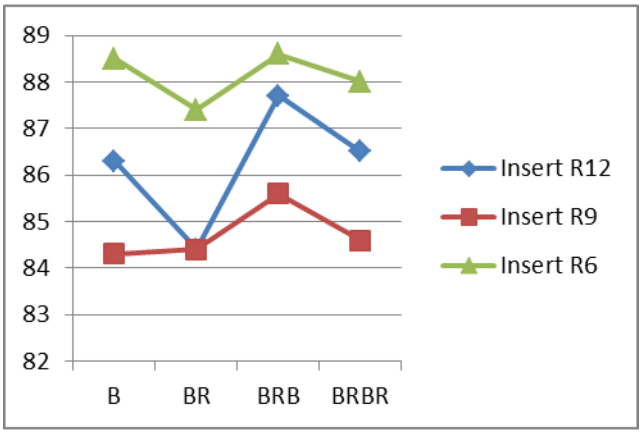
Process type (a)



process type (b)



Process type (c)



process type (d)

Fig. 4. The experimental results of three different inserts (a) R12 insert, (b) R9 insert, (c) R6 insert and the result of AL 6061

From the experimental results CRS, HRS and AL6061 steels, the springback variance between the B and BRB processes are insignificant that is, the final total strain method can be utilized for these steels to determine the springback, and the error would be still acceptable. On the other hand, the influence of the springback prediction for this grade of aluminum is very significant, and its influence would be cumulative, e.g., as with aluminium here. It can be found that these results are consistent regardless of the tooling geometry and clearance between punch and die. A comparison of the results of B with BRB of indicates a springback difference of $2^0$7'. Furthermore, the difference for BR and BRBR. Based on this observation, it is apparent that the total strain method would not accurately predict the springback amounts for the aluminium sheet metal when it undergoes a cyclical deformation process. This is one reason that it is difficult to predict the springback in aluminium. Never the less, aluminium is widely used in the forming industry because of its high strength and low density. Therefore, to save costs and die tryout times, springback must be accurately predicted. It can be concluded that the Bauschinger effect must be considered in the internal stress calculation when aluminum sheet metal undergoes complicated cyclical deformations. The influence of the Bauschinger effect on the steel sheet metals studied is not very significant, e.g., HRS and CRS steels. For these materials, the total strain method can be used to predict springback amounts. The advantage of the total strain method is its computational efficiency.

The experimental data also can be used to derive the material parameters for sheet metal after reverse yield (cyclical loading), and these parameters can be utilized for more precise springback predictions when the sheet metal undergoes complicated deformation processes.

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