Finite Element Analysis of Springback in L-Bending of Sheet Metal

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Abstract: The finite element code ABAQUS was employed to investigate the deformation mechanics of the springback phenomenon in the L-bending of sheet-metals. The axial stress distribution in the bent sheet was classified into three zones: the bending zone under the punch corner (zone I), unbending zone next to the bending zone (zone II), and the stress-free zone (zone III). The effects of the stress distributions in these three zones on the springback were examined in details, and it was found that the stress distribution in zone 2 plays an important role in reducing the springback. A reverse bend approach was also proposed to reduce the springback in the L-bending process. The efficiency of the proposed approach was demonstrated by the finite element simulations, and was validated as well by the experiments conducted in the present study.

Keywords: ABAQUS, springback, L-bending, reverse bend approach, experimental validation

1. Introduction

Springback is a main defect occurred in the sheet-metal forming processes and has been thoroughly studied by researchers. Among them, quite a few efforts have been made to obtain a deep understanding of the springback phenomenon. The beam theory has been applied to formulate the curvature before and after loading by some researchers [1-3]. Hill [4] also presented a general theory for the elastic-plastic pure bending under the plane strain condition. The springback occurring in the bending of high strength steels was discussed by Davies [5], and Chu [6]. Nader [7] examined the effects of process parameters on the springback in the V-bending process by developing theoretical models. In addition to various theories on prediction of springback, efforts were also made to reduce the springback. Liu [8] demonstrated an efficient method that dramatically reduced the springback using the double-bend technique. A bending-restriking process was proposed by Nagai [9] to reduce springback. Wang [10] showed by conducting experiments that the springback could be reduced by the over-bend approach.

In the present study, the L-bending process of aluminum alloy AA5052-H34, as shown in Fig. 1, was studied. The effects of the process parameters on the springback occurring in the L-bending process were first examined by both the finite element analysis and experiments. In addition, the deformation mechanics of the springback phenomenon was investigated in detail by the finite
element analysis. A reverse bend approach was then proposed to reduce the springback in the L-bending process. The proposed approach was demonstrated to be very efficient by the finite element analysis and was validated by experiments conducted in the present study.

The finite element code ABAQUS was adopted to conduct all the simulations, and the L-bending process was assumed under the plane strain deformation. The material properties of AA5052-H34 obtained from the tension tests conducted in the present study, as shown in Fig. 2, were used for the finite element simulations.
2. Finite Element Model

In the present study, the sheet-metal was assumed to be very wide and the L-bending could be simplified to a 2-D problem. The sheet-metal was first clamped between the blank-holder and the die surface and then the punch moved down to bend the sheet-metal into an L-shape. The tooling used in the bending process was modeled as rigid bodies, including punch, die and blank-holder. As for the sheet-metal, the 4-node plane-stress element was adopted to construct the mesh. Since the number of elements in the thickness direction has significant effect on the accuracy of the simulation, the convergence tests were performed to determine a suitable number of elements to be used in the thickness direction. In the present study, 6 layers of elements in the thickness direction were used in most of the simulations. The finite element model constructed for the simulations are shown in Fig. 3. After the sheet-metal being bent into an L-shape, the punch and blank-holder were removed and the springback was measured by comparing the difference of the bent angle before and after the tooling was removed, as shown in Fig. 4. In each simulation, the Coulomb friction coefficient was used to describe the interface friction condition between the tooling and sheet-blank.

![Figure 3. The L-bending process](image)

![Figure 4. The shapes before and after tooling removal](image)
3. **Deformation Mechanics In L-Bending**

Most previous theories for L-bending have only analyzed the deformation at bend area right around the die corner. The major difference among the various theories lies essentially in the choice of material models. However, a close investigation of L-bending reveals that the springback results from the deformation not only at the die corner but also at the neighboring area next to the die corner, i.e. the sheet-metal under the blank-holder and the side wall adjacent to the die corner area. F In order to examine the deformation mechanics along the whole sheet after bending, the 2-D plane-strain finite element simulations were performed using aluminum alloy AA5052-H34 sheet as specimen. Since springback is mainly due to the elastic recovery of the stress distribution along the axial direction, the stress distributions in the bent sheet obtained from the finite element simulations were transformed into the axial direction accordingly, and the stress distribution mentioned hereinafter is associated with axial direction. Figure 5 shows the stress distribution in the bent sheet along the axial direction at the end of bending process before the punch is removed. Based on the stress distribution patterns, the bent sheet is classified into three zones: flat zone under the blank-holder, bending zone at the die corner and unbending zone at side wall, which are marked by I, II, and III, respectively, in Fig.5, and the stress distributions in zone I and zone II are displayed in Fig. 6. Since the stress distribution in the flat zone is nearly uniform compression, it is obvious that the springback is independent of the flat zone, i.e., zone I, and is mainly attributed to the stress distributions in zone II and zone III.

![Figure 5. Stress distribution in the bent sheet before tooling removal](image)

![Figure 6. Stress distribution in zone II](image)
The stress distribution in zone II, as shown in Fig. 6, follows the bending theory that the sheet is compressed inside and stretched outside. The elastic recovery of the sheet in this zone, equivalent to an application of an opposite moment, makes the sheet to bend outward, resulting in a positive springback. While the stress in zone III, as shown in Fig. 5, has an opposite distribution pattern to that in zone II, i.e., tension inside and compression outside. The elastic recovery of the sheet in this zone therefore creates a negative springback. Consequently, the total springback is determined by the combined effects contributed by both zone II and zone III. The bent sheet has a positive springback after the punch is removed, if the springback phenomenon is dominated by the stress distribution in zone II. On the other hand, the L-bending process results in a less amount of springback, if the stress distribution in zone III is predominant. It implies that the deformation of sheet-metal other than the die corner area also contributes to the springback.

To further illustrate the effects of the stress distributions in zone II and zone III on springback, the finite element analysis was performed to examine the stress distributions in the L-bending of 0.5 mm thick AA5052-H34 sheet with different die corner radii ranging from 0.1 mm to 3 mm. The finite element simulation results indicate that the larger the die corner radius, the more significant is the springback, as shown in Fig. 7. The stress distributions in zone III for the L-bending with different die corner radii are shown in Fig. 8. It is noted in Fig. 8 that the area of non-uniform stress distribution in III becomes small when the die corner radius increases, resulting a smaller negative springback created by the stress distribution in zone III. In consequence, the stress distribution in zone II dominates the springback and the amount of springback increases, as shown in Fig. 7.

![Figure 7. The effect of die radius ($R_d$) on springback](image-url)
The above stress analysis clearly explains the deformation mechanics of the springback phenomenon that occurs in the L-bending process, especially the formation of negative springback in zone III. Since the springback is inevitable in the L-bending process, in order to reduce the total springback, an optimum process design is required to make the stress distribution in zone III more significant to balance the springback caused by the elastic recovery of the stress distribution in zone II. However, over-adjustment will result in a negative springback and should be avoided.

4. Effects Of Process Parameters On Springback

In addition to the material properties, the springback is also affected by the process parameters, such as die corner radius, punch radius, blank-holder force, and friction condition in the L-bending process. In order to determine the predominant ones among these process parameters, the finite element analysis was performed using the AA5052-H34 sheet as specimen. One process parameter was examined at a time, while the other process parameters were remained the same. The effect of the die corner radius on the springback has already been discussed and shown in Fig. 7. The effect of punch radius on the springback is shown in Fig. 9. It is observed in Fig. 9 that the springback increases as the punch radius increases for the punch radii smaller than 1.2 mm, and then the springback decreases as the punch radius further increases. It implies that there is an optimum punch radius in the L-bending process to reduce the springback. However, the optimum punch radius is quite small and the effect of the punch radius on springback is not so obvious, hence, it is not practical to reduce the springback by changing the punch radius. Figure 10 shows the effect of die gap on the springback. As seen in Fig. 10, the die gap has a significant effect on springback, and the larger the die gap, the more significant is the springback. Since the sheet-metal is less
constrained around the die corner when the die gap becomes large, the effect of zone III on producing negative springback becomes insignificant, resulting in larger positive springback. The effect of friction on the springback is illustrated in Fig. 11. It is clearly seen that the friction does not influence the springback so much. The effect of blank-holder force also is small on the springback, as demonstrated in Fig. 12. However, it is noted in Fig. 12 that the springback is large when the blank-holder force is quite small. It is because that the sheet-metal is not completely confined between the blank-holder and the die surface when the blank-holder force is not large enough, and the effect of zone II dominates the deformation.

Figure 9. Springback versus punch radius($r_p$)

Figure 10. Springback versus die gap($g$)

Figure 11. Springback versus coefficient of friction($\mu$)
The L-bending experiments were also performed in the present study with AA5052-H34 sheet as specimen to validate the finite element analysis. The sheet thickness is 0.6 mm, and dies and punches with various corner radii were machined to perform the tests. The angles of deformed specimens were measured with a CMM and the springback is calculated by the difference between the right angle (90°) and the measured angle. The experimental data and the finite element simulation results are then compared with each other. The finite element simulation results agree well with the experimental data, though the finite element simulations underestimate the springback in an insignificant amount. The agreement confirms the validity of the finite element analysis and the effects of the process parameters on the springback as well.

It can be concluded that the springback is affected mostly by the die corner radius and die gap in the L-bending process, while the punch radius, friction condition and blank-holder force do not contribute more to the springback. Hence, in order to reduce the springback, smaller die radius and die gap should be used in the L-bending process.

5. Reverse Bend Approach

The practical approach commonly adopted in the sheet-metal industry to reduce the springback is to compensate the springback by bending the sheet inward. However, it is not possible to do this if the draft angle for the punch is negative. As mentioned in Introduction, in order to eliminate the springback, Liu [8] proposed the double-bend technique, and Nagai [9] developed the bending-restriking method for the U-bending process. The finite element analysis was performed in the present study to study the deformation mechanics of the double-bend technique. The simulation results indicate that the reduction of springback in the double-bend process is also mainly due to the change of the stress distribution in zone III.

In the present study, a reverse bend approach was proposed to reduce the springback in the L-bending of sheet-metal. In the reverse bend approach, the sheet-metal is first bent locally to an opposite direction of the desired bend into a hemispherical bead shape and then is bent at the bead
location by the punch to the desired shape, as shown in Fig. 13. The reverse bend is located at the
desired bending position, and the dimensions of the reverse bend are characterized by bend width
(b) and bend height (h), as shown in Fig. 14. The complete bending process, including reverse
bend, is illustrated in Fig. 15. The main purpose of adding a reverse bend to the V-bending process
is to change the deformation mechanics in the stress distributions in both zone II and zone III. The
stress distribution in zone III is much improved when the reverse bend approach is applied to the
L-bending process, as shown in Fig. 16. As seen in Fig. 16, the area of the non-uniform stress
distribution increases and produces significant negative springback to reduce the total springback.
However, the reverse bend may cause uneven surface at the die corner area, as shown in Fig. 17.
Hence, the use of reverse bend approach must be cautious if high surface quality is required.

![Figure 13. Reverse bend approach in L-bending](image)

![Figure 14. Dimensions of the reverse bend](image)
Figure 15. L-bending using reverse bend approach
The efficiency of the reverse bend approach proposed in the present study was demonstrated by the finite element analysis, and was validated by the L-bending experimental data as well. Both the finite element simulation results and the experimental data indicate that a larger reverse bend height yields a significant effect on the reduction of springback. The proposed reverse bend approach provides an alternative to reduce the springback in the L-bending process of sheets.
6. Concluding Remarks

The deformation mechanics of springback phenomenon in the L-bending of sheet-metals was investigated by the finite element analysis. The axial stress distribution in the bent sheet was classified into three zones: the flat zone under the blank-holder (zone I), bending zone around the die corner (zone II), unbending zone next to the bending zone (zone III). The stress distribution in zone I is quite uniform and hence has little influence on the springback. While the stress distribution in zone II results in a positive springback, whereas the stress distribution in zone III produces a negative springback. The total springback therefore depends on the combined effect of those produced by zone II and zone III. The finite element analysis also indicates that the smaller die radius and die gap will reduce the springback in the L-bending process.

A reverse bend approach was also proposed in the present study to reduce the springback in the L-bending process. The finite element analysis was performed to study the stress distribution pattern with various dimensions of reverse bend, and the results indicate that the larger the bend height, the more efficient is the reverse bend approach. However, the reverse bend approach may cause uneven surface around the die corner. Hence, the use of the reverse bend approach must be cautious if the surface quality is required.

The finite element analysis performed in the present study was validated by experiments as well. The good agreement between the finite element simulation results and the experimental data confirm the efficiency in using the finite element analysis in the L-bending process of sheet-metals.

Acknowledgements

The authors wish to thank The National Science Council of The Republic of China for the financial support under Contract No. NSC 91-2212-E-002-063, which makes the experimental work possible.

References