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Deformation analysis of springback in L-bending of sheet metal

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ABSTRACT

Purpose: In the present study, the deformation mechanics of the springback phenomenon in the L-bending of sheet-metal was examined and a new method that could efficiently reduce springback in the L-bending of sheet-metal was proposed.

Design/methodology/approach: Both the finite element analysis and experiments were performed to analyze the deformation mechanics and the effects of process parameters on the formation of springback.

Findings: The axial stress distribution in the bent sheet obtained by the finite element simulations 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). It is found that 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. A reverse bend approach that can efficiently reduce springback was also proposed to reduce the springback in the L-bending process. The finite element analysis performed in the present study was validated by experiments as well.

Research limitations/implications: Although the reverse bend approach can reduce springback efficiently, it may cause uneven surface at the die corner area. Hence, the use of reverse bend approach must be cautious if high surface quality is required.

Practical implications: The proposed reverse bend approach provides the die design engineer with a novel idea to reduce the springback occurred in the L-bending of sheet metals.

Originality/value: In addition to the reverse bend approach, the analysis of defomation mechanics of springback performed in the present study also provides researchers with a better understanding of the formation of springback.

Keywords: Plastic forming; Springback; L-bending; Reverse bend approach

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. Chan and Wang [11] have proposed a strain-hardening plane-stress bending model to predict the deformation behavior and springback of narrow strips. A computer aided design method for straight flanging using finite element method was presented by Livatyali and Altan [12], they also investigated flanging with coining as a method to eliminate springback and to improve part quality. The finite element simulation and experimental approach were also employed by researchers [13-15] to study the springback and side-wall curl in the sheet metal forming.

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.

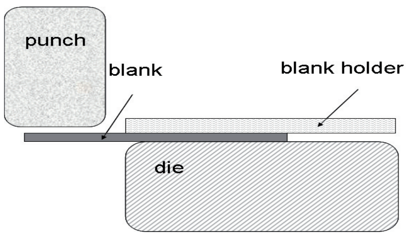

Fig. 1. A sketch of L-bending

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 plane-strain problem. The tooling used in the bending process was modeled as rigid bodies. 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. 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. 2. In each simulation, the Coulomb friction coefficient was used to describe the interface friction condition between the tooling and sheet-blank.

The finite element code ABAQUS was adopted to conduct all the simulations, and the material properties of AA5052-H34 obtained from the tension tests conducted in the present study were used for the finite element simulations.

3. Deformation mechanics in

In order to examine the deformation mechanics along the whole sheet after bending, the 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 3 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. 3, and the stress distributions in zone I and zone III are displayed in Fig. 3 as well. While Fig. 4 displys the stress distribution in zone II. 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.

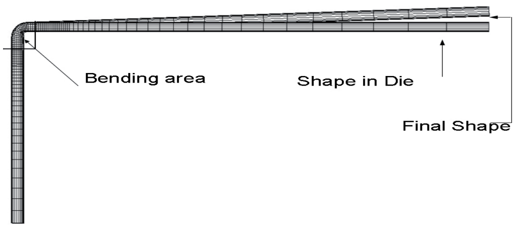

Fig. 2 The shapes before and after tooling removal

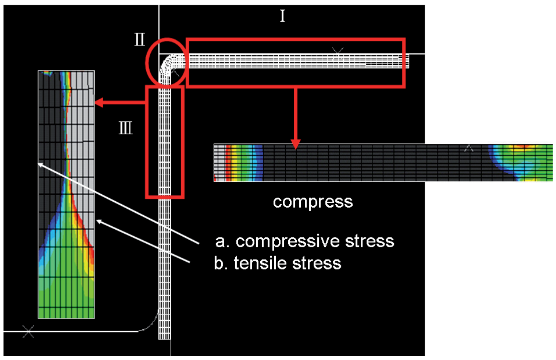

Fig. 3. Stress distribution in the bent sheet before tooling removal

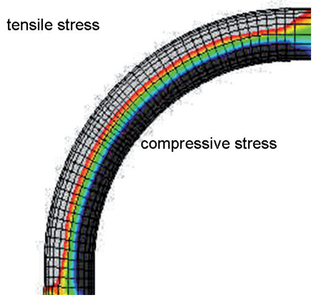

Fig. 4. Stress distribution in zone II

The stress distribution in zone II, as shown in Fig. 4, 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. 3, 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 0.1mm to 3 mm. The finite element simulation results indicate that the larger the die corner radius, the more significant is the springback. The stress distributions in zone III for the L-bending with different die corner radii are shown in Fig. 5. It is noted in Fig. 5 that the area of non-uniform stress distribution in zone III becomes small when the die corner radius increases, resulting in 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.

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.

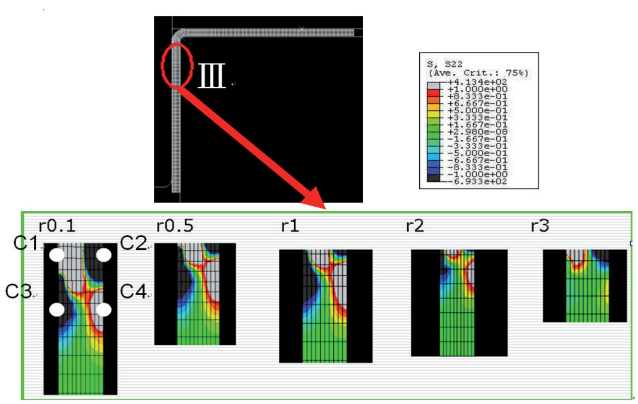

Fig. 5. The stress distributions in zone III for different die radii

4. 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. 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. 6. 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. 7. 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. 8. As seen in Fig. 8, the area of the non-uniform stress distribution increases and produces significant negative springback to reduce the total springack. However, the reverse bend may cause uneven surface at the die corner area, as shown in Fig. 9. Hence, the use of reverse bend approach must be cautious if high surface quality is required.

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.

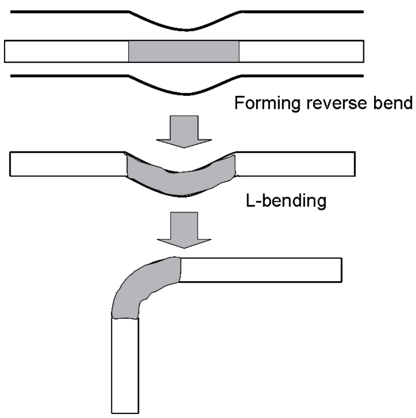

Fig. 6. Reverse bend approach in L – bending

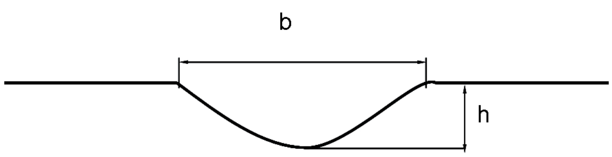

Fig. 7. Dimensions of the reverse bend

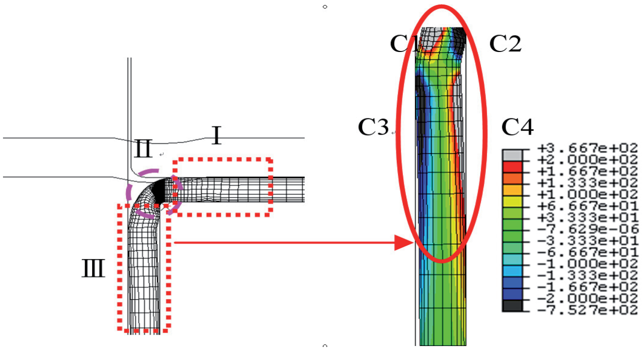

Fig. 8. The axial stress distribution after L-bending with reverse bend

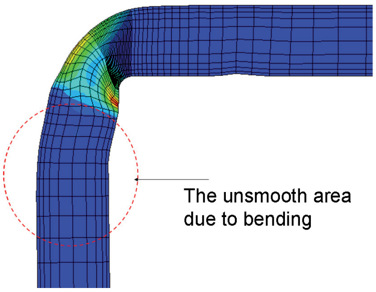

Fig. 9. The unsmooth area after L-bending with reverse bend.

5. 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 reveals that the stress distribution pattern varies with the use of the reverse bend approach, resulting in a significant reduction of springback. 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.

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