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A novel technology to eliminate U-bending springback of high strength steel sheet by using additional bending with counter punch

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Abstract

The aim of this paper is to present a new technology to eliminate springback of HSS sheets in U-bending process, where the bottom plate is additionally bent with a counter punch at the final stage of U-bending process. The U-bending process consists of four steps starting with clamping of a sheet between a punch and a counter punch, then U-bending with constant clamping force followed by bottom pushing-up by the counter punch, and final unloading process. From the experiment on 980Y HSS sheet, an appropriate combination of the clamping force and the final bottom pushing-up force that eliminates springback entirely was found. From the FE simulation of the process, it was found that the major mechanism of the springback elimination is ‘spring-go’ by releasing negative bending moment which has been generated by bottom pushing-up.

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1. Introduction

High strength steel (HSS) sheets are extensively used nowadays, particularly in automotive industry. They are applied to several structure components to improve crashworthiness without increasing body weight. The most serious problem in press forming of HSS sheets is their extremely large springback, therefore new technology to eliminate springback is a major concern in the stamping industry. The most effective way to suppress springback is the reduction of bending moment which is the driving force of springback. Yamano and Iwaya [1] proposed a sequential bending-unbending technology by using a specially designed punch. Ogawa and Yoshida [2] investigated the effect of die-corner bottoming. One of the present authors [3] have recently proposed a new process of U-bending followed by bottoming, where a sheet is firmly clamped throughout the process. Springback compensation with the appropriate die design is the alternative approach. For example, Saches [4] employed a rounded-head punch together with a counter punch (so called ‘arc bottoming’). Liu [5] proposed to operate two stage of restrike (so called ‘double-bend technique’). Although there are several methods for springback control and compensation, as mentioned above, it is still difficult for engineering to design appropriate forming process by which spring-back can be eliminated. In this paper, to eliminate U-bending springback, a new forming technology that includes additional bending with a counter punch is proposed.

2. U-bend experiment

The U-bending apparatus consists of a die, a punch and a movable counter punch, as schematically illustrated in Fig. 1. Newly proposed U-bending process has four-steps (including unloading stage), as shown in Fig. 1., where (a) clamping of a sheet between a punch and a counter punch (clamping force: $F_1$), (b) U-bending keeping the clamping force constant, (c) bottom pushing-up with the counter punch (pushing-up force: $F_2$) and (d) removing the sheet from the die. The dimensions of the tools are depicted in Fig. 2. The flat headed punch (47.4 mm wide) has a shallow hollow on the punch head (three different hollow depths, $D_h = 0.5, 1.0$ and $1.5$ mm). The punch-corner radius was $1.2$ mm and die-corner radius was $2.96$ mm. The width of the counter punch was $39.4$ mm.

In order to examine the shape of the final product, springback angle $\theta$ defined in Fig. 1(d) were measured. A dual phase 980MPa level HSS sheet (hereafter denoted by ‘980Y’) of $1.22$ mm thick was used in this work. The workpiece was rectangular shape with dimension of $45 \times 160$ mm.

The effects of the following process parameters on the elimination of springback, as well as other geometrical imperfections, were investigated.
- clamping force, $F_1$, and bottom pushing-up force, $F_2$,
- depth of the hollow on the punch head, $D_h$.

![Fig. 1. Schematic illustrations of U-bending with bottom pushing-up.](image)
3. Results and discussions.

3.1. Comparison between experimental and analytical results of springback.

Figure 3 shows the comparison of the calculated results of springback angles of 980Y sheet with the corresponding experimental data for various bottom pushing-up forces $F_2$ under a constant clamping force $F_1 = 2$ kN, when using the punch with hollow depth $D_h = 1.5$ mm. In the calculation, two types of material models were employed, i.e., a classical model of isotropic hardening that neglects the description of the Bauschinger effect, and the Y-U model (refer to [6], [9] and [10]) that describes it accurately. From this figure, it is found that the Y-U model predicts the springback angles fairly well, whereas the IH model apparently underestimates it. This is because the Y-U model describes the plastic strain dependent Young’s modulus and the Bauschinger effect which affects springback of HSS sheets. In the following discussions, therefore, only the analytical results with the Y-U model are used.

![Fig. 2. Dimensions of tools.](image_url)

![Fig. 3. Comparison of springback angles calculated by Y-U model and the IH model for 980Y sheet with corresponding experimental data for various bottom pushing-up forces $F_2$ under constant clamping force $F_1 = 2$ kN.](image_url)
3.2. Effects of clamping force and bottom pushing-up on springback.

The experimental data of springback angle of 980Y sheet for various clamping forces and bottom pushing-up forces, when using the punch of $D_h = 1.5$ mm, are shown in Fig. 4. From these results, it is found that the springback angle decreases with increasing bottom pushing-up force $F_2$ under any clamping force $F_1$. Springback also decreases with increasing clamping force $F_1$ when the final bottom pushig-up was not applied ($F_2 = 0$). On the other hand, springback get larger with increasing clamping force when large bottom pushing-up force was applied.

![Comparison of springback angles of 980Y sheet for various clamping forces $F_1$ and bottom pushing-up forces $F_2$ when using the punch of $D_h = 1.5$ mm.](image)

Fig. 4. Comparison of springback angles of 980Y sheet for various clamping forces $F_1$ and bottom pushing-up forces $F_2$ when using the punch of $D_h = 1.5$ mm.

Fig. 5 summarizes the experimentally obtained geometries of 980Y sheet after U-bending for various combinations of clamping forces $F_1$ and bottom pushing-up forces $F_2$. From these results, it is found that:
- the application of clamping force $F_1$ is essential to have a flat bottom, and
- springback decreases with increasing bottom pushing-up force $F_2$.

![Experimentally obtained geometries of 980Y sheets after U-bending for various clamping forces $F_1$ and various bottom pushing-up forces $F_2$ when using the punch of $D_h = 1.5$ mm and the counter punch of $W_{cp} = 39.4$ mm.](image)

Fig. 5. Experimentally obtained geometries of 980Y sheets after U-bending for various clamping forces $F_1$ and various bottom pushing-up forces $F_2$ when using the punch of $D_h = 1.5$ mm and the counter punch of $W_{cp} = 39.4$ mm.
For U-shaped channel, a precise bent angle (no springback) is essential, and furthermore, most of the cases flatness of the bottom plate and sharp bent corner are required. To satisfy these requirements, an optimum combination of clamping force $F_1$ and pushing-up forces $F_2$ should be determined. In the case of bending without clamping force ($F_1 = 0 \text{ kN}$) combined with bottom pushing-up force $F_2 = 10 \text{ kN}$, it was found that, springback angle $\theta$ is almost zero. However, the bottom part of the U-bent sheet is slightly curved and the bent corner radius is much larger than the punch corner radius because of springback (see Fig. 5(b)). In the case of larger $F_2$ (up to 15 and 20 kN), the bottom sheet is still curved, and the negative springback (so-called ‘spring-go’) of the sidewall appears (see Fig. 5(c) and (d)). The very best result of the springback angle (almost 0 degree), together with the flat bottom and sharp bent corner, was obtained at the clamping force of 2 kN and the bottom pushing-up force of 20 kN (see Fig. 5(h)). Furthermore, Fig. 6 illustrates the major stress (membrane stress) distributions when applying the bottom pushing-up force (before springback, see in Fig. 1(c)). $F_1$ and $F_2$ conditions of Fig. 6. (a)-(c) correspond to those of the experimental results shown in Fig. 5(d), (f) and (h), respectively. When applying a large bottom pushing-up force ($F_2 = 20 \text{ kN}$) with an appropriate clamping force ($F_1 = 2 \text{ kN}$), the large compressive stress appears at the end of rounded corner (see Fig. 6(c)). It also reduces springback (see Fig. 5(h)).

![Fig. 5(b)](image)

Fig. 5. (b) Calculated bending moment acting on a cross-section near the curved corner of the bent sheet, when applying various amount of bottom pushing-up load $F_2$. The bending moment decreases markedly with increasing bottom pushing-up load $F_2$, and it turns to have a negative value at $F_2 = 20 \text{ kN}$.
4. Concluding remarks

A new technology to eliminate U-bending springback by applying bottom pushing-up with a counter punch has been proposed. The reduction of springback in the present process is attributed to the negative bending moment generated at the bent-corner part of the sheet, which is the driving force of ‘spring-go’. It was verified from experiments on 980Y HSS sheet and the corresponding numerical simulations. The present findings are summarized as follows:

1. In the process of bottom pushing-up without clamping force, springback angle can be reduced to zero, but the geometrical imperfections will appear at the bottom part and the bent corner, i.e. the bottom is not flat enough and the corner radius is too large.
2. Clamping of sheet plays an important role to improve the flatness of the bottom part of a U-bent product. An appropriate combination of the sheet clamping and the bottom pushing-up force is able to eliminate springback entirely and remove the geometrical imperfections.
3. As for tool design, it is important to have a deep enough hollow on the punch head.
4. For accurate simulation of springback, selection of material models is of vital importance. Y-U model well captures springback behavior of the present process, whereas the conventional IH model poorly predicts springback.

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