Numerical Analysis and Investigation on the Drawbending Springback and Fracture

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Abstract. In this paper, the effect of process parameters on the drawing springback and fracture mechanism of high strength steel in drawbending process was investigated. The fracture behaviour and fracture morphology were observed and analyzed using Scanning Electron Microscope (SEM). The process parameters studied in this paper includes drawing speed, roll radius, drawing force and roll radius. The springback angle measurement method for drawing springback was also introduced and applied. The conclusions were drawn from the results. The drawbending springback angle increases with the increase of drawing velocity. The springback decreases with the increase of the round roll. The large bending angle leads to the large springback. The large tension force can decrease the springback angle. The springback increases with the increase of the drawing distance. The fracture with the plane angle of 60 indicates a shear fracture and the dominated brittleness mode, which is induced by a large radius against thickness value. The fracture vertical to straight side indicates the ductility tension fracture, which is induced by a small radius against thickness value.

Keywords: Springback, high strength steel, fracture, drawing, fracture.

1. Introduction
In recent years, the high strength steel has become more and more popular due to the lightweight trend. The springback affects the application of high strength steel, so a lot of attention has been paid to the springback of high strength steel. Gray et al. [1] analyzed the influence of material properties on the high strength steel. At the same time, the formability of the high strength steel was studied in consideration of the Bauschinger effect. Several materials were studied. Ma et al. [2] studied the springback of high strength steel using the finite element (FE) method and experiments. An automotive part made of high strength steel was stamped. The response surface method was also employed to analyze the effect of process parameters on the springback of high strength steel. Kinzel et al. [3] analyzed the springback behavior of several kinds of steel, such as BK steel and HS steel. The Bauschinger effect of material was considered in the study, which can be useful for improving the accuracy of FE prediction. The Bauschinger effect of material can be considered to improve the predictability [4]. Ma et al. [5] also studied the springback in consideration of Bauschinger effect for high strength steel. A longitudinal beam was employed to for the related study. The simulation results can be corresponding to the experiments well. Chongthairungruang et al. [6] used the finite element
simulation method and experiments to analyze the springback of steel. The effect of different material models on formability was also studied, including Yoshida-Uemori model and Barlat-Lian’s 1989.

In this study, a drawing springback machine was employed to study the springback behavior in drawing mode. First, the drawing machine was introduced. Second, the experimental details were given. Third, the results were analyzed. Fourth, the fracture morphology and mechanism were analyzed. The process parameters studied in this paper includes drawing speed, roll radius, drawing force and roll radius. The fracture mode was also analyzed. The Scanning Electron Microscope was used for fracture morphology. At the same time the springback angle measurement method was also introduced.

2. Experimental

In this study, a drawing springback machine was employed to study the drawing springback behavior of high strength steel. The machine has several parts, mainly including drawing part; tension part and roll. In the following figure, the part b is the drawing part. The end of the blank was clamped in part b, and drawn during the experiments. The part b provides the constant velocity. The part a is the tension end. The part provides the force to drag the blank. The tension is generally constant. The part R is the roll to support the blank. The blank flows through the roll. The material used in the experiments includes DP590, DP780 and DP980.

![Figure 1. The drawing tool machine for high strength steel.](image)

The drawing tool machine is shown in the figure, where end a is the tension terminal side and b is the drawing terminal side and R is the round rod for the drawing blank. After the drawing springback experiment, the part was taken from the machine and the springback can be measured. The springback was mainly measured by calculated the angle shown in the following figure.

![Figure 2. The springback angle for the test part.](image)

The experimental process includes fixing the blank, setting the control parameters, and drawing the blank. In the above figure, the end a is the tension terminal to drag the blank with a set force. And the end b is the drawing terminal to draw the blank from the round rod with a set velocity. After the springback process, the part was taken from the machine and the springback angle was measured, as shown in the figure. The one side was put in a horizontal line and the springback angle was measured
between the other side and the straight line. The angle for the springback value is shown in the figure as $\alpha$.

The experiments were conducted to study the process parameters on the drawing springback. These process parameters have drawing speed, drawing force, drawing distance, drawing distance and roll radius. At the same time, the fracture during the drawing process was also studied. Two fracture modes were analyzed. The design of the experiment measuring the effect of process parameters on drawing springback is shown in the Table 1.

Table 1. The design of the experiment for high strength steel drawing.

| No. | Process parameters | Value 1 | Value 2 | Value 3 |
|-----|--------------------|---------|---------|---------|
| 1   | Drawing force      | 6.24    | 12.48   | 18.72   |
| 2   | Drawing speed      | 5       | 20      | 40      |
| 3   | Drawing distance   | 25.4    | 76.2    | 127     |
| 4   | Roll radius        | 9.5     | 12.6    | 25.4    |

In terms of the fracture analysis, the design of the test was shown in the Table 2. The tension side was fixed. At the same time, the roller was also fixed.

Table 2. The drawing conditions and results for the drawing fracture tests.

| No. | Material | Specification | Velocity | Tension force | Roller radius | R/t | Fracture mode                                      |
|-----|----------|---------------|----------|---------------|---------------|-----|---------------------------------------------------|
| 1   | DP590    | 660*50*0.8    | V1=40;V2=0; | Fixed tension side | 25.6         | 32  | Plane angle of 60°,Shear fracture Britteness mode dominated |
| 2   | DP590    | 660*50*1.35   | V1=40;V2=0; | Fixed tension side | 3.2           | 2.37| Vertical to straight side, ductility tension fracture |

3. Results and Discussion

The effect of the drawing velocity, round roll radius, tension force and drawing distance on the springback was investigated. The results were shown in the following figures.
Figure 3. The effect of process parameters including (a) drawing force; (b) drawing speed; (c) drawing distance; (d) roll radius on the drawing springback.

It can be seen from the figure that the springback increases with the drawing velocity. Because the high velocity leads to the inadequate plastic deformation and the high velocity would draw more material to pass the round roll due to the inertia, the springback would increase to a large value. The springback would decrease with the increase of the round roll, because the large round roll causes the large bending angle. The large bending angle would lead to the large springback. The large tension force would decrease the springback angle. The large tension force would cause the more material to plastic deformation, so the adequate plastic deformation would occur. Then the springback would decrease. The springback would increase with increasing the drawing distance. Because more material was drawn to deformation, more material would be involved into the springback behavior, which results in large springback value.

The drawing experiments for fracture were studied and the crack parts were shown. The drawing conditions and results for the drawing fracture tests were shown in the table. Two different and dominated fracture modes are shown. One part has the fracture plane angle of 60°; the other part has the fracture vertical to the drawing direction.

Figure 4. The drawing part in the drawing fracture experiments: (a) fracture plane angle of 60°; (b) fracture vertical to the drawing direction.

After the drawing test, the end of the fracture was cut and the fracture morphology was observed using SEM. There are two typical test parts. The cutting mode is electronic line cutting. The following figure is the result of the part 1.
Figure 5. The fracture morphology for the specimen 1: (a) small magnification; (b) middle magnification; (c) large magnification.

It can be observed from the results that there are obvious cleavage planes in the fracture morphology. The number of ductile dimples is less. The cleavage planes leans to a side. The observed result indicates the specimen was parted by shear stress. The mode of fracture is brittle fracture dominated. The direction of the fracture has an angle with the tensile direction. In this experiment, the angle between the tensile force and fracture direction is about 60°.

The following figure shows the fracture morphology for the fracture vertical to the tension direction, which is the result of part 2.

Figure 6. The fracture morphology for specimen 2: (a) small magnification; (b) middle magnification; (c) large magnification.

It can be seen from the above figures that the fracture morphology of part 2 has more ductile dimples compared to that of part 1. The dimples have different sizes and depths. The obvious dimples indicate the ductile fracture. At the same time, some dimples are very large, which should be induced by the inclusions. The concentration of the stress causes the small dimple. With the increase of stress, the small dimple increases to the larger one. The coalescence of nearly dimples leads to the larger one and final fracture.

It can be concluded that the fracture with the plane angle of 60° indicates a shear fracture Brittleness mode dominated, which is induced by a large radius against thickness value. The fracture Vertical to straight side indicates the ductility tension fracture, which is induced by a small radius against thickness value.

4. Conclusion
1) The drawbending process parameters affect the springback angle significantly. The drawbending springback angle of high strength steel increases with the increase of drawing velocity. The drawbending springback of high strength steel decreases with the increase of the round roll. The springback angle increases with the increase of the drawing distance. The large bending angle leads to the large springback. The large tension force results in the decrease of the springback angle.
2) There are two dominated fracture mode for the drawbending parts. The fracture with a plane angle of 60° indicates a shear fracture of brittleness mode dominated, which is induced by a large radius against thickness value. The fracture with the vertical direction to straight side indicates the ductility tension fracture, which is induced by a small radius against thickness value.
References

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