Springback Behaviour due to Die Deflection during Bending

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Abstract. The material strength of rolled steel sheet for car bodies is increasing considerably. It has been experientially known that the die deflection affects the springback, but there are few experimental verification cases. In this study, two bending dies with different rigidity but the same shape were manufactured. The springback of panels bended by each die was compared in detail. Using 590MPa class and 980MPa class steel sheets, the deformation of the dies due to bending also measured. The springback and deflection of the die were clearly large using the low rigidity die. From these results, it was suggested that it is necessary to consider the die deflection for accurate springback prediction of bending.

1. Introduction

In order to reduce the weight of automobile bodies, the use of high strength steel sheets is increasing, and recently, materials with strength of 1.2 GPa or higher may be coldworked. One of the biggest problems in applying high strength steel sheets is springback. In the study of accurate springback prediction of high strength steel sheet, Yoshida et al [1] discovered that it is important to take into account the Bauschinger effect and the elastic modulus of unloading. On the other hand, when the difference between simulation results and experiment results is discussed, it may be suggested that the deflection of the die or elastic die deformation affect the springback.

There are several works on calculation method considering die deflection. Del Pozo et al. [2] proposed the calculation method of the elastic die deformation to modify the die tooling data for manufacturing. Rosochwski [3] has proposed a tool design considering die elastic deformation and springback in the forging process. Pilthamar et al. [4] showed a calculation example of forming the door inner panel of an automobile with elastic dies. Müller et al. [5] measured the elastic deformation of whole press machine not only the dies in order to investigate the boundary conditions. Authors have published two papers on the die deflection and springback in Japanese. The first [6] is a study focusing on the deflection of blank holder for draw forming. By the simulations with the die rigid body model and with elastic die model and experiments, it was shown that deflection of blank holder affected forming condition, as a result, there was a large difference in springback of a cross section and twist of the formed panel. The second paper [7] also focused on the deflection of blank holder for draw forming and proposed an efficient simulation method considering the die deflection. In both papers, the springback calculation results were almost the same as the experimental results when the die deflection was taken into account. However, both examples only considered the deformation of the blank holders for draw forming, the other forming types did not describe at all.

In this work, the bending die deflection in bend forming has been focused on. Two bending dies with completely different rigidity but the same surface shape were used for the comparison of springback. The elastic deformation of the bending die was experimentally investigated by non-contact measuring instrument.
2. Dies configuration
The model in this work has a hat shape with a height of 50 mm and opening angle of 10° considering application for the automobile body parts, and only one side of the target shape was used due to space. The blank is placed on the lower die, then the pad is placed on the blank, and they are eventually fixed by bolts as shown in left side of Figure 1 or 2. The bending die or upper die fixed on the upper die set forms the blank to the one side of hat shape, as shown in right side of Figure 1 or 2. This process is not simple bending, we call it “draw bending” in this work because the flange part and the wall part are formed by bending die at the same time. Two types of upper dies were manufactured, DIE 1 was solid steel and DIE 2 was made by cutting to a thickness of about 10 mm. These material and surface shape are completely the same. The rigidity and structure of those dies were intentionally changed significantly. Figure 1 shows the general shape of Die set No. 1 including DIE 1. Figure 2 is also general shape of Die set No. 2 including DIE 2. The left side of Figure 1 or 2 is the upper dead point, right side of the Figure 1 or 2 is lower dead point.

![Figure 1. General shape of Die set No. 1.](image1)

![Figure 2. General shape of Die set No. 2.](image2)

SKD11 was used as the material of the die where the die contacted the blank, S45C was used for the others. The blank size was 120 mm × 100 mm. The 100 mm direction of the blank is used as the depth direction of Figure 1 or 2, the thickness of the virgin material is 1.2 mm.
3. Test material of the blank
Dual phase high strength steel sheets of tensile strength (UTS) classes 590 MPa and 980 MPa were used for the forming test. Both material thicknesses are 1.2 mm. Table 1 and 2 show the material properties including $r$ and $n$-value in three directions.

**Table 1. Material property of 590 MPa UTS.**

| 590MPa class steel sheet | Degree from rolling direction | Yield Stress / MPa (0.2% proof) | Tensile Strength / MPa | $r$   | $n$   |
|--------------------------|-------------------------------|----------------------------------|------------------------|-------|-------|
|                          | $0^\circ$                     | 173.78                           | 638.70                 | 0.827 | 0.157 |
|                          | $45^\circ$                    | 172.18                           | 631.03                 | 0.967 | 0.154 |
|                          | $90^\circ$                    | 104.81                           | 650.16                 | 1.277 | 0.152 |

**Table 2. Material property of 980 MPa UTS.**

| 980MPa class steel sheet | Degree from rolling direction | Yield Stress / MPa (0.2% proof) | Tensile Strength / MPa | $r$   | $n$   |
|--------------------------|-------------------------------|----------------------------------|------------------------|-------|-------|
|                          | $0^\circ$                     | 198.32                           | 1069.09                | 0.627 | 0.088 |
|                          | $45^\circ$                    | 165.65                           | 1033.86                | 0.970 | 0.088 |
|                          | $90^\circ$                    | 245.86                           | 1079.34                | 0.773 | 0.082 |

4. Experiments
Figure 3 shows the press machine used for the experiments, which is Komatsu AC servo press S1F50. The stroke per minutes (SPM), which deeply concerned the velocity of the bending die, was 11 min$^{-1}$. The blank set state or position and how to fix the pad and the blank are shown in Figure 4. The blank was strictly fixed by the bolts with pad. No movement of the fixed part of the blank due to forming was observed. Two kinds of material were respectively processed to two panels by two types of the die. Totally, 8 panels were created for springback measurements.

![Figure 3. Komatsu AC Servo Press machine S1F50.](image1)

![Figure 4. Blank set state.](image2)
5. Measurement of panels
Panel measurement was performed by a primitive method. After scanning and printing the panel to the actual size, auxiliary lines were drawn using the shape of the outside of the panel as shown in Figure 5, therefore \( \theta, X \) and \( Y \) were obtained. Since the opening angle \( \text{DIE} \) was 10°, \( x \) displacement \( \text{DIE}_x \) was obtained by equation (1). The springback angle \( \text{SB} \) and the springback displacement \( \text{SB}_x \) were two evaluation values for springback. Here, \( \text{SB} \) is defined by equation (2), and \( \text{SB}_x \) is also defined by equation (3).

\[
\begin{align*}
\text{DIE}_x &= Y \cdot \tan(10^\circ) \\
\text{SB} &= \theta - \text{DIE} \\
\text{SB}_x &= X - \text{DIE}_x
\end{align*}
\]

\[\text{Figure 5. Definition of } X, Y \text{ and } \theta \text{ for panel measurement.}\]

\( \text{SB} \) values of experimental results are shown in Figure 6, \( \text{SB}_x \) values of experimental results are shown in Figure 7. The horizontal axes represent the nominal material strength in both figures. Using \( \text{DIE}_2 \) increases \( \text{SB} \) and \( \text{SB}_x \) values of 590 MPa and 980 MPa materials. Especially for 980MPa class, the values using \( \text{DIE}_2 \) are clearly larger than using \( \text{DIE}_1 \).

\[\text{Figure 6. Results of springback } \text{SB}.\]

\[\text{Figure 7. Results of springback } \text{SB}_x.\]
These indicate that the springback is large when the resilient bending die is used. The comparison photos for material strength 590 MPa using DIE 1 and DIE 2 are shown in Figure 8. The same comparison for material strength 980 MPa can be found in Figure 9. There are clear differences visually in both figures.

6. Measurement of die deflection
The die deflection was measured using the no-contact 3D measurement system GOM-ARAMIS. Dot stickers were attached to the dies and were used for these measurements. The displacement in the X direction was measured. Here, X direction is defined the horizontal, and right side is positive. Figure 10 shows the measurement positions of DIE 1 and lower die, and Figure 11 shows the measurement positions of DIE 2 and lower die from P1 to P9. The displacement of marked points on the die for material strength 590 MPa with DIE 1 are shown in Figure 12. The results using DIE 2 are ensured in Figure 13. Using DIE 1, the maximum value of X displacement was less than 0.2 mm, and the maximum value exceeded 0.4 mm with DIE 2. The displacement values at the positions from P7 to P9 of DIE 2 were higher than the values at other points. For the material strength 980 MPa, Figure 14 shows the displacement measurement results with DIE 1 and Figure 15 shows that of for DIE 2. The maximum value of X displacement with DIE 2 higher than 0.6 mm. The die deflection increased as the die rigidity decreased and increased as the material strength increased. The differences of the deflection due to the die rigidity were less than the differences of springback due to the die rigidity. This suggests that the die deflection affects the forming state or forming condition.
Figure 12. Pointwise deflection of DIE 1 for material strength of 590 MPa.

Figure 13. Pointwise deflection of DIE 2 for material strength of 590 MPa.

Figure 14. Pointwise deflection of DIE 1 for material strength of 980 MPa.

Figure 15. Pointwise deflection of DIE 2 for material strength of 980 MPa.
7. Conclusion
Springback behaviour due to die deflection was experimentally investigated in bending. Two bending dies with different rigidity were manufactured and high strength steel sheets of material strength 590 MPa and 980 MPa were used. The observed difference of springback due to the die rigidity was larger than the difference due to the difference in material strength. Die deflection and springback increased with the increased resilience of bending dies. This is also the case when higher strength steel was used. It is therefore necessary to consider the die deflection for accurate springback prediction in draw bending.

8. Discussion
It is necessary to clarify how the die deflection affects the forming state or forming conditions in bending and in general draw bending or deep drawing. Especially the wall tension at the lower dead point (bottom point) might be affected by the die deflection. And the springback has deep relationship to the stress state in wall. It could be possible to elucidate the mechanism of the effects due to the die deflection using FE analysis which considers elastic die model in the next step.

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