FEM analysis of springback control with lump-punch penetration after V-bending

Takayuki Aso¹ᵃ and Takashi Iizuka¹ᵇ
¹Department of Mechanical and System Engineering, Kyoto Institute of Technology,
Matsugasaki Goshokaido-cho, Sakyō-ku, Japan

ᵃkyotokosen94@gmail.com,ᵇtiizuka@kit.ac.jp

Abstract. In actual manufacturing, some empirical methods such as the bottoming technique are generally used in order to adjust the bend angles of products. However, the problem with this is that it relies on the technique of the engineer. In this study, quantitative springback control by lump-punch penetration after V-bending is investigated with FEM analysis and experimentation. The lump at the punch tip is pushed into a bent section at the final stage of V-bending and stretches the inside surface at the bent section. The method of springback control is suggested based on the deformation state. Then, the suitability of springback control using this mechanism is investigated. It is confirmed that the springback amount is reduced by lump-punch penetration. Accordingly, it is recommended to control springback by sheet forging with a lump punch.

1. Introduction
Bend forming has been used as much as shearing in the production of transportation equipment. However, springback occurs when bend forming. Various methods are used to compensate for springback. One current method is manufacturing metal molds in which the springback amount is accounted for based on finite element method (FEM) analysis estimates [1]. Moreover, bottoming and coining are often as methods for controlling springback [2]. However, these methods strongly depend on the experience of the engineers. Therefore, a method that does not rely on experience is desired. In the preceding study, a method in which springback is quantitatively controlled was investigated. From the experimental results, the possibility that the bend angle can be controlled by the length ratio, depending on the residual strain ratio, was suggested [3]. In this study, the control of the bend angle and the mechanism are investigated by FEM analysis.

2. Control of bend angle with lump-punch penetration after V-bending
2.1. Deformation mechanism with lump-punch penetration after V-bending
In the case of normal bend forming, when the deformation mechanism is focused, the inside surface of the bend section shrinks and the outside stretches during loading [4]. This difference in deformation is considered to be the cause of springback.
The deformation mechanism of bend forming with lump-punch penetration is shown in Figure 1. It is considered that the inside of the bend section is locally stretched, so the springback amount is reduced. In this study, because sheet forging is applied at the bend section by penetration with a lump punch after V-bending, the deformation of the inside is close to that of the outside. The method of obtaining the desired bend angle using this technique is investigated.

![Figure 1. Deformation mechanisms of lump-punch penetration during loading and unloading.](image)

2.2. Mold shape
Figure 2 shows the mold shape used to apply sheet forging. The punch with a lump at the tip is shown...
in Figure 2(a). Sheet forging is applied by pushing this lump into the sheet after V-bending. Figure 2(b) shows the die. The radius of curvature is 10 mm, and the opening angle is 90°. The specimen dimensions are shown in Figure 2(c).

![Figure 2. Mold model.](image)

2.3. Lump-punch penetration procedure
Figure 3 shows the analysis procedure. The punch, die, and specimen are set as shown in Figure 3(a). Then, the lump punch begins to push on the specimen, which conforms to the die. The pushing depth is from 0 mm to 1.8 mm at intervals of 0.2 mm, and the forming speed is 5 mm/min. The analysis procedure imitates the experimental procedure.

![Figure 3. Analysis procedure.](image)

3. Analysis
3.1. Analysis conditions
In this study, Simufact Forming 13.3 was used as the analysis software. Table 1 shows the analysis conditions. In this analysis, isotropic von Mises material behavior was assumed. The material is A5052-H, and the mechanical properties were calculated using a tensile test. Moreover, the coefficient of friction was assumed to be 0.12. A symmetry plane was established at the center in the breadth direction, and the analysis was conducted using a half-symmetric model.

A sheet mesh was adopted because the number of elements in the thickness direction was kept constant during penetration shown in Figure 4. In this analysis, five mesh layers in the sheet thickness direction were used. As for the longitudinal and breadth directions, cube-shaped elements were used.

| Table 1. Analysis conditions |
|-----------------------------|
| **Flow curve** | \( \sigma = F \varepsilon^n \) |
| Young's modulus / GPa | 71 |
| Poason's ratio | 0.33 |
| \( F \)-value / MPa | 381 |
| \( n \)-value | 0.13 |
| Material | A5052-H |
| Friction | 0.12 |

3.2. Shape valuation
The bend angle was measured in the CAD software after completing the analysis, as shown in Figure
5(a). The springback amount ($\Delta \theta$) was calculated from the bend angle after unloading ($\theta_{\text{after}}$) and during loading ($\theta_{\text{before}}$) using equation (1).

$$
\Delta \theta = \theta_{\text{after}} - \theta_{\text{before}}
$$

To measure the bend length, the nodes of the specimen model shown in Figure 5(b) were used. After forming, the nodal coordinates were extracted, and the lengths between the nodes were calculated. The bend length is the sum of these lengths. Moreover, the bend length ratio is defined as the inner length/outer length.

![Figure 5. Shape valuation.](image)

### 4. Analysis results

#### 4.1. Effect of penetration with lump punch on bend angle and springback

The relationship between the pushing depth and the deviation of the bend angle is shown in Figure 6. It is confirmed that the deviation of the bend angle is reduced as the pushing depth increases. From this figure, there is a possibility that the bend angle can be controlled by penetration with a lump punch. There are qualitative deviations of about 2 degrees between the analysis results and the experimental results. However, the analysis tendency is qualitatively the same as the experimental result. The relationship between the pushing depth and the springback amount is shown in Figure 7. The tendency is that the springback amount decreases as the pushing depth increases. When the pushing depth is from 0.6 mm to 1.2 mm, the springback amount is 0 degrees. Then, springgo is transferred after the pushing depth reaches 1.6 mm because the specimen contacts the sidewall of the punch. At this point, although there are quantitative deviations between the analysis and experimental results, the tendencies are qualitatively the same. The inside of the bend section is stretched by sheet forging, and springback can be reduced. From these figures, springback is dominant over the bend angle after loading. Therefore, it is considered that springback needs to be controlled in order to control the bend angle.

#### 4.2. Control of bend angle by bend length ratio

In this study, the possibility that the bend angle can be controlled by the bend length ratio is investigated. The relationship between the pushing depth and the bend length ratio (inner length/outer length) is shown in Figure 8. As for the analysis results, the bend length ratio decreases as the pushing depth increases before the pushing depth reaches 0.4 mm. Then, the tendency is that the bend length ratio increases as the pushing depth increases after the pushing depth reaches 0.6 mm. In other words, the inside of the bend section is stretched more than the outside. When the specimen reaches the die, a space exists between the specimen and the die because the curvature is different between the lump and the die. Before the pushing depth reaches 0.4 mm, the material flows in order to fill these spaces. Therefore, it is considered that the bend length ratio decreases. There are deviations between the analysis and experimental results. As for this deviation, it is considered that the error is in the experimental results. The relationship between the bend length ratio and the bend angle is shown in Figure 9. The analysis results show a different tendency from that originally hypothesized. As the bend length ratio decreases, the deviation of the bend angle also decreases when the initial penetration occurs. After further penetration, as the bend length ratio increases, the bend angle is reduced. Moreover, when the bend length is approximately 0.75 to 0.77, the deviation of the bend angle is 0 degrees. In order to control the bend angle, it is considered that not only the length ratio but also the residual strain needs to be investigated. Because the curvature radius of the tip of the punch is different from that of the die, there...
is space between specimen and die. The bending is caused at this space. Then, the material at this space is flowed into inside of bend section. It is considered that the bend length ratio is reduced in the primary penetration because the material at the space between specimen and die is flowed into the inside of the bend section.

5. Conclusion
In this study, FEM analysis of springback control with lump-punch penetration after V-bending was conducted. From the analysis results, it was determined that the bend angle and springback are reduced with lump-punch penetration, and the tendency of the analysis results is mostly the same as that of the experimental results. Additionally, from the analysis and experimental results, when the bend length ratio is almost 0.76, the deviation of the bend angle is 0°. Thus, it is considered that the bend angle can be controlled by the bend length ratio.

References
[1] Livatyali H and Altan T 2001 J. Mater. Process. Technol 117 262
[2] Forcellese A, Fratini L, Gabrielli F and Micari F 1998 J. Mater. Process. Technol 80-81 108
[3] Aso T, Iizuka T and Ota T 2015 Key. Engineering. Material 651-653 1066
[4] Schroeder W and Calif B 1946 T. A.S.M.E 287