Spring-Back Analysis Method Considering the Die Deformation Due to the Stamping Pressure of the Ultra-High Strength Steel

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Abstract. This paper proposes a spring-back analysis method for investigating the effect of the stamping pressure on the final shape of a B-pillar outer panel manufactured with the ultra-high strength steel. The conventional sheet metal forming simulation of the B-pillar outer panel was conducted with rigid tool surfaces and a deformable blank of CR1180TRIP. Press and die structure was modelled with three dimensional tetrahedral solid elements for the structural analysis. The stamping pressure obtained from the forming simulation was mapped to the tool surfaces in the tool structure model. From the implicit structural analysis, the deformation amount of the press and die structure was investigated quantitatively. The structural analysis method was verified by comparing the total stamping force of rigid surface model and deformable tool structure model. Finally, the conventional sheet metal forming simulation with modified rigid tool surfaces was conducted to investigate the effect of the tool deformation on spring-back. The simulation result shows that the deformation amount due to the stamping pressure can have significant effect on the final product shape.

1. Introduction
Automotive companies are commonly using UHSS (Ultra-High Strength Steel) in the auto-body structural components for the weight reduction and crashworthiness. Spring-back is one of the most serious defects in the sheet metal forming process of UHSS. To improve the spring-back prediction accuracy, most of researchers are mainly focused on how to use advanced material models.[1-3] However, the simulation method with the advanced constitutive model still has the limitation to predict the accurate spring-back shape in the production stage. Some researchers found that the tool deformation due to the high stamping pressure can be a key problem to deteriorate the spring-back prediction accuracy of the forming simulation.[4-5] Therefore, it is required to investigate the effect of the tool deformation on spring-back of a formed part with ultra-high strength steel sheets considering high tensile strength and stamping pressure.

This paper proposes a spring-back analysis method to consider the tool deformation due to the high stamping pressure of the ultra-high strength steel. The tool structural analysis was conducted by applying the stamping pressure obtained from the conventional forming simulation with rigid surfaces. To solve the problem of the drastic stamping force drop due to the tool deformation, a simple calibration method was used to adjust the magnitude of the stamping pressure. Finally, the effect of the stamping pressure on the final product shape were analyzed quantitatively for each forming operations.
2. Material Characterization
The uni-axial tension and tension/compression tests were performed to obtain the material data for anisotropy and hardening characteristics. Figure 1 shows the material testing machines for two different loading conditions. The test material was CR1180TRIP 1.4t which is a 1.2GPa grade uncoated ultra-high strength steel for the cold stamping. The strain rate for the specimen deformation was 0.003 /sec. To capture the anisotropy, the mechanical properties were measured from the uni-axial tension test according to the loading angle from the rolling direction. Figure 2(a) and Table 1 show the hardening curves and mechanical properties, respectively, for different loading angles. The test data explains that this material has weak anisotropy tendency after the steel making process. It means that Hill48 yield function is enough to describe anisotropy of CR1180TRIP for the sheet metal simulation. To obtain the coefficients of Yoshida-Uemori model, which is one of the most advanced material models for spring-back simulation, the tension/compression test was performed for two pre-strains as shown in Figure 2(b). It shows that Yoshida-Uemori model can describe the tension/compression hardening curve successfully for the advanced spring-back simulation. Table 2 provides the coefficients of Yoshida-Uemori model calibrated by using MatPara software. Finally, the material model for the sheet metal forming simulation was determined to Hill48 yield function and Yoshida-Uemori hardening model.

![Material testing machines](image)

Figure 1. Material testing machines for the sheet metal forming simulation.

![Material testing results](image)

Figure 2. Material testing results (CR 1180TRIP 1.4t).
Table 1. Mechanical properties according to the loading angle (from uni-axial tension test).

| Loading angle [deg.] | $\sigma_y$ [GPa] | $\sigma_t$ [GPa] | $\varepsilon_u$ [%] | $\varepsilon_t$ [%] | $r$  |
|----------------------|------------------|------------------|--------------------|--------------------|------|
| 0                    | 0.987            | 1.206            | 10.4               | 15.5               | 0.830|
| 45                   | 0.993            | 1.206            | 9.3                | 14.4               | 0.846|
| 90                   | 0.930            | 1.221            | 10.0               | 14.8               | 0.926|

Table 2. Material parameters of Yoshida-Uemori model (from tension/compression test).

| $B$ [GPa] | $Y$ [GPa] | $C1$ | $C2$ | $m$ | $R_{sat}$ [GPa] |
|-----------|-----------|------|------|-----|-----------------|
| 1.048     | 0.948     | 610  | 260  | 22  | 0.248           |

| $b$ [GPa] | $h$     | $E_0$ [GPa] | $E_a$ [GPa] | $\xi$ |
|-----------|---------|-------------|-------------|------|
| 0.169     | 0.17    | 207         | 176         | 29   |

3. Establishment of the Forming Simulation Procedure Considering the Tool Deformation

3.1. Initial forming simulation

Initial sheet metal forming simulation of B-pillar Outer part in an auto-body side structure was conducted with rigid tool surfaces as shown in Figure 3(a). The forming process consists of three operations such as drawing (OP10), trimming (OP20) and re-striking (OP30). The friction coefficient was 0.15 for OP10 and OP30. The simulation program was LS-DYNA3D v971 explicit. Because of the excellent elongation property of TRIP steel, there were no formability issues during the forming operations. From the forming simulations, the contact pressure distribution can be obtained at die, punch and binder as shown in Figure 3(b).

3.2. Die deformation simulation

To simulate the tool deformation, the contact pressure was mapped on the surfaces at the tool structure model. VPG (Virtual Proving Ground) program, which is a pre-processing software for LS-DYNA3D, was utilized for mapping the contact pressure. The fixed boundary condition was applied to the upper and lower bolster plates because it is clamped to a press bed. Using this boundary condition mapped by VPG program, the tool structural analysis was conducted in order to observe the amount of the tool deformation. The simulation program was LS-DYNA3D v971 implicit. Figure 4 shows the tool structure model and the die deformation contour. The maximum deflection was 1.19 mm near the center of the die in the vertical direction.

Figure 3. Sheet metal forming simulation with rigid surface (explicit calculation).
3.3. Verification of the pressure mapping

The total stamping force of forming and die deformation simulations was compared so as to verify the pressure mapping procedure using VPG program. As shown in Figure 5, the stamping force profile is almost same for two simulations. It means that the pressure mapping process between two simulations was successful. Based on the verification result, the forming simulation with consideration of the tool deformation was conducted as a next step in order to check the effect of the stamping pressure on the final product shape.

3.4. Forming simulation with consideration of the tool deformation

To consider the die deformation in the forming simulation, the rigid surface was modified based on the displacement distribution obtained for the tool deformation simulation. As a result of the tool deformation consideration, the maximum stamping force in OP10 drastically drops from 13005 kN to 3818 kN. It means that the tool deformation is over-estimated compared to the real stamping situation. Therefore, some modification process is required to compensate the over-estimation of the tool deformation.

3.5. Stamping pressure calibration

![Figure 4. Die deformation simulation with deformable models (implicit calculation).](image)

![Figure 5. Comparison of the total stamping force in OP10 and OP30.](image)
The stamping pressure calibration was performed to compensate large stamping force discrepancy. Figure 6 shows the overall simulation procedure for the stamping pressure calibration. If the tool deformation is properly reflected to the rigid surfaces, the scaled stamping force should coincide with the stamping force obtained from the forming simulation considering the tool deformation. The tool deformation simulation was conducted by scaling down the mapping pressure. After the tool deformation simulation, the forming simulation was conducted by applying the tool deformation according to the scale factor. Finally, intersection points give optimum scale factors for drawing and re-striking operations as shown in Figure 7. The maximum displacement with optimum scale factors was presented in Table 3. As a result of the calibration process, the maximum die deflection was decreased from 1.19 mm to 0.34 mm. It seems to be an acceptable level considering the total elastic deformation of the tool and the press. However, it is required to check the change of the final product shape since small tool deformation can make severe quality problem for ultra-high strength steels.

![Figure 6. Overall simulation procedure for the stamping pressure calibration.](image_url)

![Figure 7. Calibration result of the scale factor (α) for the stamping pressure adjustment.](image_url)

| Operation     | Die [mm] | Punch [mm] |
|---------------|----------|------------|
| Drawing       | 0.34     | 0.51       |
| Re-striking   | 0.07     | 0.23       |
4. Spring-Back Change Due to the Tool Deformation

The spring-back shape was observed with and without consideration of the tool deformation. Best-fit option in PAM-STAMP 2017 was utilized to compare the spring-back shape. Figure 8 shows the spring-back change for initial and deformed rigid surface models in each operation. In the drawing process, the magnitude of the spring-back change is about 10 mm although the die and punch displacement was only 0.34 mm and 0.51 mm. After the re-striking process, the magnitude of the spring-back change is decreased to about 6 mm. However, it is still very large value considering the product shape quality criterion (±0.5mm or ±1.0mm) in the press shop. The conventional sheet metal forming simulation do not take account of the tool deformation for the spring-back calculation. It can be a main reason to deteriorate the spring-back predictability of the conventional forming simulation method, especially for ultra-high strength steel sheets. The proposed simulation method can help to improve the spring-back prediction accuracy and the die surface design efficiency.

\[ \text{(a) OP10 (drawing)} \]  \[ \text{(b) OP20 (trimming)} \]  \[ \text{(c) OP30 (re-striking)} \]

**Figure 8.** Spring-back discrepancy before and after consideration of the die deformation.
5. Conclusions
This paper suggested an improved forming simulation method to consider the tool deformation effect on the spring-back shape prediction. Small amount of the tool deformation can have significant effect on predictability of the final product shape, especially for ultra-high strength steel. It can be a main reason of the spring-back simulation inaccuracy. The established simulation method can be a useful tool for the die surface and structure design for ultra-high strength steels.

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