

# Development of High Precision Die Technology That Takes into Account Deflection of Press Machine and Die

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## Abstract

*To reduce environmental burdens, the use of ultra-high-strength steel sheets for automotive parts is increasing. However, it is difficult to ensure dimensional accuracy with high-strength steel sheets due to their large springback. Therefore, in order to predict springback of ultra-high-strength steel sheets with high accuracy, we have developed analysis technology focusing on the “deflection of press machines and dies”. By taking deflection into account in the forming analysis, die clearance at the bottom dead center in analysis becomes the same as that of the actual machine, and it was shown that highly accurate forming analysis with a small shape error after springback can be performed. Furthermore, by using a developed method that can easily reproduce press deflection (PS-Opt model) and a die design method that takes into account part shape errors (digital die prospecting), it was confirmed that high dimensional accuracy can be achieved with a minimum number of die revisions.*

## 1. Introduction

To reduce environmental burdens, automobiles are required to lower emissions of greenhouse gases, including CO<sub>2</sub>, as evaluated by Life Cycle Assessment (LCA).<sup>1-3)</sup> Achieving CO<sub>2</sub> reduction in LCA necessitates decreasing emissions not only during vehicle use but also in raw-material production and processing; therefore, body lightweighting and the adoption of materials with low CO<sub>2</sub> intensity are crucial. From this perspective, using Advanced High-Strength Steel (AHSS)<sup>4)</sup> is an effective approach to reduce life-cycle CO<sub>2</sub> emissions in both Battery Electric Vehicles (BEVs) and Internal Combustion Engine (ICE) vehicles.<sup>5)</sup> Nippon Steel Corporation has been promoting the expansion of Ultra-High-Strength Steel (UHSS) applications, including hot stamping, to achieve automotive body parts that are thinner and lighter.<sup>4,6,7)</sup> This contributes to components that deliver value through reduced CO<sub>2</sub> emissions, lower vehicle body weight, and cost savings. However, in cold press forming, higher steel sheet strength generally leads to larger springback, which reduces the accuracy of finite element method (FEM) simulations of springback. Therefore, the man-hours and costs associated with production preparation—such as trials and die modifications

based on FEM simulations to ensure the required dimensional accuracy of UHSS parts—increase. Therefore, improving the accuracy of FEM simulations for UHSS parts is crucial during production preparation.

To improve the accuracy of FEM simulations for springback in UHSS parts, we focused on the deflection of presses and dies as an essential factor.<sup>8-10)</sup> In actual press forming, presses and dies deform elastically. However, in conventional forming simulations, presses and dies are assumed to be rigid bodies. This assumption is considered a cause of reduced simulation accuracy. **Figure 1** shows an example of improving the accuracy of forming FEM simulations by considering the deflection of presses and dies using a curved hat-shaped part made of 590 MPa-grade UHSS sheet.<sup>11)</sup> The flange lengths (at the stretch-flange and shrink-flange sections) in the forming simulation results that considered deflection were closer to the experimental data than those from conventional simulations that did not consider deflection, confirming improved accuracy. Efforts to improve accuracy through forming simulations that account for deflection have been reported for deep-drawn parts made from low-strength steel sheets, but there are few case studies for bend-formed

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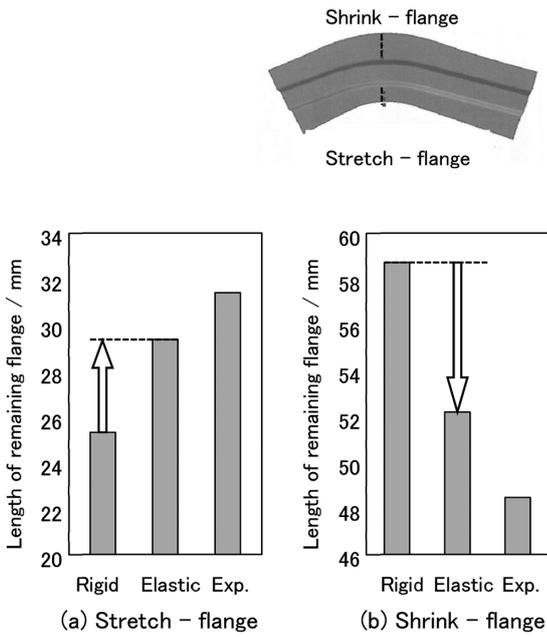


Fig. 1 Example of accuracy improvement by analysis considering deflection<sup>11)</sup>

parts made from UHSS sheets.

This paper presents methods to improve the accuracy of forming simulations. First, we conducted forming simulations for UHSS parts, taking into account the deflection of presses and dies. Next, to reduce the man-hours required for forming simulations, we developed a simplified and optimized press machine stiffness model (Press machine Stiffness Optimization model: PS-Opt model) and verified the improvement in simulation accuracy using this model. Furthermore, we devised a die design method (digital die compensation) that considers dimensional deviations in pressed parts. By applying these methods, we confirmed that UHSS sheet parts with high dimensional accuracy can be achieved with a minimum number of die corrections.

## 2. Measurement of Press-Machine Deflection

To validate forming simulations that account for press and die deflection and to determine the parameters of the PS-Opt model (described later), it is essential to accurately measure press machine deflection.

Therefore, measurements of the press deflection were conducted during press forming of a 1.0 mm-thick, 1470 MPa-grade UHSS sheet into the roof cross model shape shown in Fig. 2.

Figure 3 shows the deflection measurement device for the bolster plate and slide plate of the press machine. The device consists of a measurement die (A), a fixture (B), and laser displacement sensors (C). The overall deflection ( $\Delta z$ ) of the press machine was evaluated based on the deflection of the slide plate and bolster plate measured using the laser displacement sensors. Simultaneously, the clearances ( $CL$ ) between the upper and lower dies were measured. The measurement points were located on the centerline in the width direction (line  $L$ ) of the press-formed part, as shown in Fig. 4. The maximum press load was set to 7000 kN, and measurements were performed on two press types (A and B) with different slide and bolster plate dimensions.

Figure 5 shows the measured deflection along the central longi-

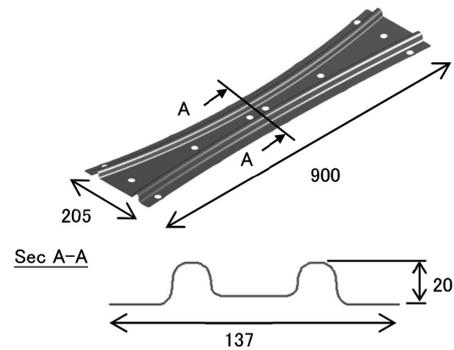


Fig. 2 Schematic drawing of press formed sample that imitates roof cross

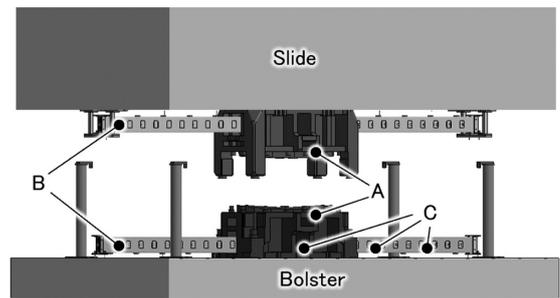


Fig. 3 Press machine deflection measurement

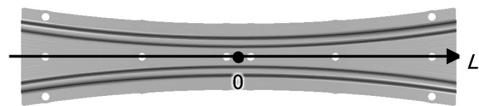


Fig. 4 Measurement position of clearance between punch and die

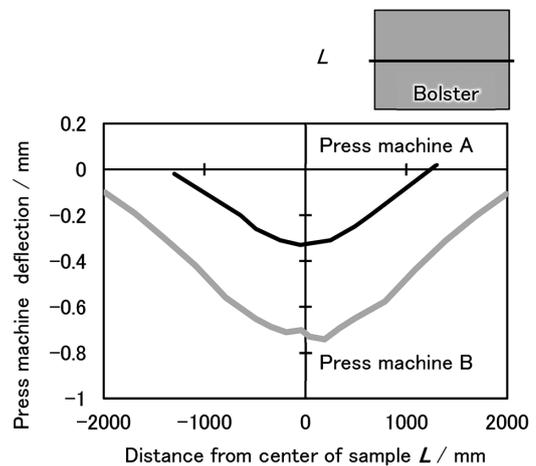


Fig. 5 Distribution of bolster deflection

tudinal direction of the bolster plates for presses A and B when the press load was set to 7000 kN. The amount of bolster plate deflection increases toward the center of each press machine, but the deflection varies significantly between machines. Similarly, the slide plate deflections exhibited the same trend. Figure 6 shows the measured distributions of upper-lower die clearance at bottom dead center for press B at forming loads of 3500 kN and 7000 kN. Die clearance varies in response to deflection of the press's bolster plate

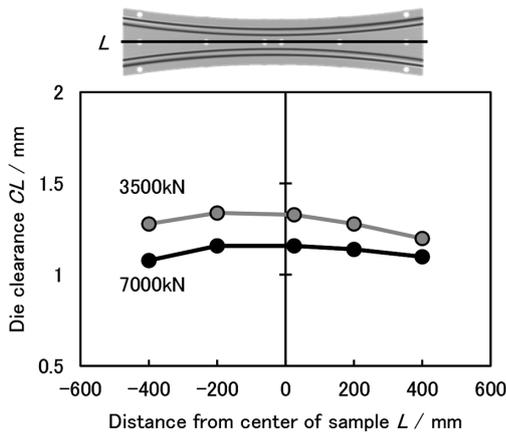


Fig. 6 Distribution of clearance between punch and die

and slide plate, tending to become larger at the center, and it further decreases as the forming load increases.

These results revealed that the press machine deflection was greatest at the center, and that the amount of deflection varied depending on the press machine. Furthermore, press deflection affects the clearance between dies at the press bottom dead center, and is therefore considered to significantly impact the dimensional accuracy of press-formed parts.

### 3. Forming Simulation Accounting for Press and Die Deflection

As mentioned earlier, in actual pressing operations, both the press machine and the die undergo deflection. However, in typical forming simulations, these deflections are generally not considered, and the press machine and die are treated as rigid bodies. Therefore, we conducted press forming simulations that accounted for these deflections and evaluated the improvement in simulation accuracy achieved by incorporating them.

#### 3.1 Methods for considering deflection in forming simulation

Figure 7 shows schematic diagrams of a general forming simulation model (Fig. 7(a)), hereafter referred to as the conventional model, which treats the dies as rigid bodies without considering deflection, and two forming simulation models that account for press and die deflection: ① the full solid model (Fig. 7(b)) and ② the PS-Opt model (Fig. 7(c)). In the full solid model and PS-Opt model, the press machine and die were modeled as elastic solid elements. In the full solid model, the press machine and die shapes were modeled accurately. However, in the PS-Opt model, the press machine was simplified to a rectangular prism shape to reduce modeling effort while maintaining practicality, and given stiffness that reproduces the measured press machine deflection. Figure 8 shows the reduction in modeling hours achieved with the PS-Opt model; the modeling hours are drastically reduced compared with the full solid model.

#### 3.2 Verification of forming simulation accuracy improvement by considering deflection

To verify the simulation accuracy improvement effect of the full solid model and the PS-Opt model, a prototype press of the roof cross model shape shown in Fig. 2 was carried out using Press Machine B, along with its forming simulations. The material model of forming simulations for the steel sheet adopted the Yoshida-Uemori

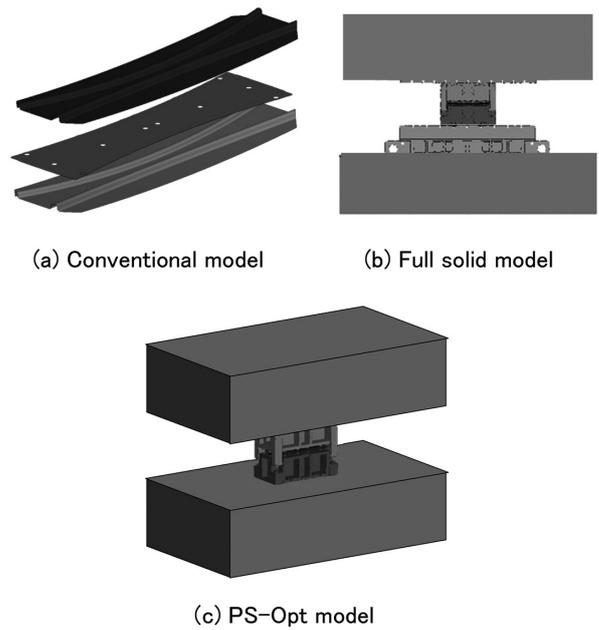


Fig. 7 Schematic drawings of conventional and analysis considering the deflection model

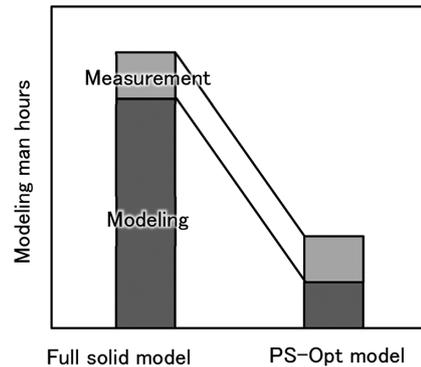


Fig. 8 Effect of reducing man hours by the PS-Opt model

model<sup>12)</sup>. The shape of the prototype press part was measured using an optical 3D scanner (ATOS 5, GOM GmbH).

Figure 9 shows the deflection distributions of the bolster plate obtained from simulations using the full solid model and the PS-Opt model, together with the measured deflection distribution from the prototype press under a press load of 3 500 kN. Simulation results for the deflection of the two models accurately reproduce the deflection measured on the prototype press. Figure 10 shows the clearances between the upper and lower dies obtained from simulations using the full solid model and the PS-Opt model, together with the measured clearance from the prototype press under a press load of 3 500 kN. The clearance values obtained from the simulations of the two models closely match the clearance measured on the prototype press. Therefore, it is expected that both the full solid model and the PS-Opt model will improve the accuracy in terms of how accurately the simulated press part shape replicates the actual prototype press part.

Figure 11 shows color contour diagrams illustrating differences between the shapes obtained from simulations for the conventional model, the full solid model, and the PS-Opt model, each simulated

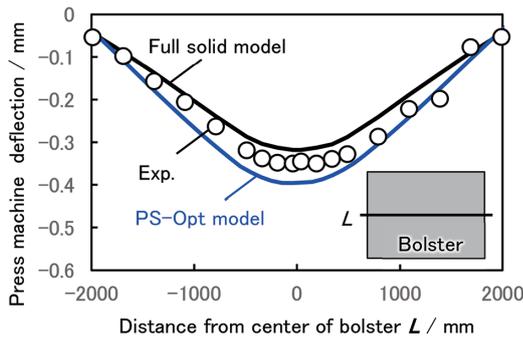


Fig. 9 Comparison of press machine deflection distribution between deflection aware analysis and experiment

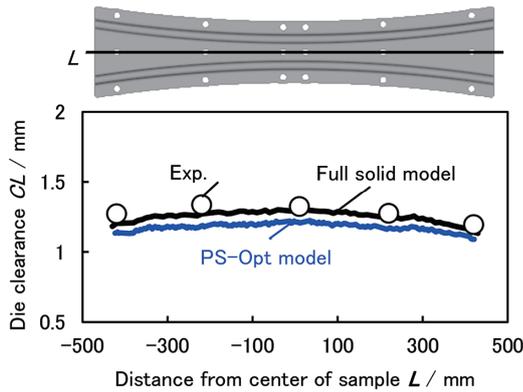


Fig. 10 Die clearance at bottom dead center of press forming

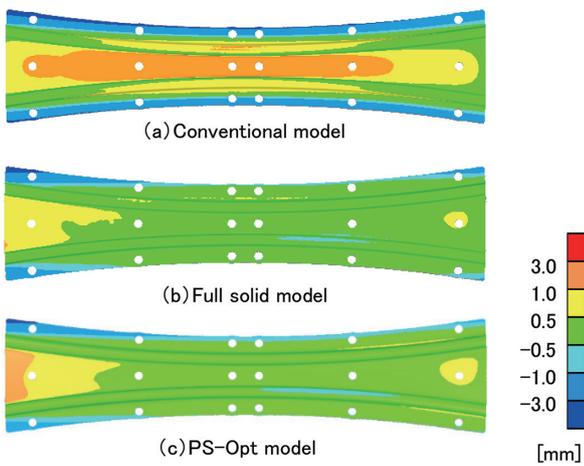


Fig. 11 Improvement of analysis accuracy by the method considering deflection

with a press forming load of 3500 kN, and the measured shape of the prototype press part formed under the same conditions. **Figure 12** shows the area ratio for each range of shape difference between the prototype press parts and the simulation models depicted in Fig. 11. Compared to the conventional model, the full solid model and PS-Opt model, which account for press and die deflection, show smaller differences from prototype press parts and exhibit higher simulation accuracy. The area ratio within a shape difference of 0.5 mm is 36% for the conventional model, whereas the model accounting for deflection achieves over 80%—significantly improving simulation accuracy. The PS-Opt model simplifies the geometry of the

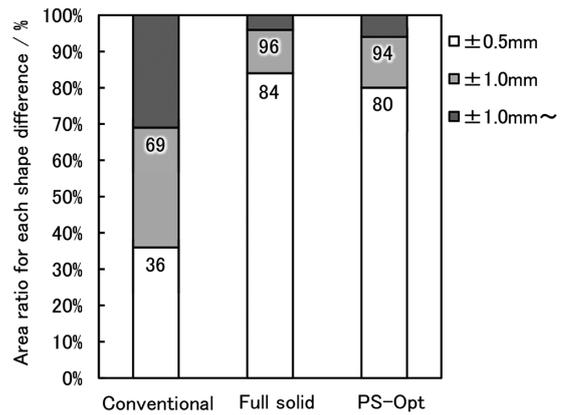


Fig. 12 Comparison of analysis accuracy between each model

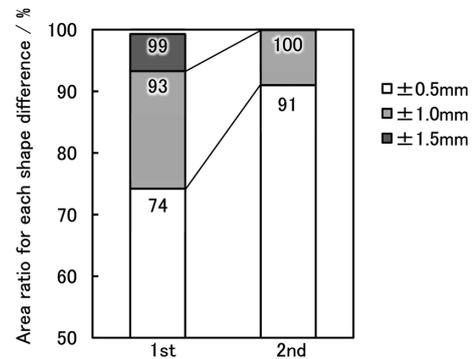


Fig. 13 Improvement of dimensional accuracy by applying the PS-Opt model and digital die prospecting

press machine but achieves simulation accuracy equivalent to the full solid model.

#### 4. Evaluation of PS-Opt Models and Digital Die Compensation Technology for Die Making

To verify the effectiveness of simulation using the PS-Opt model in die design, a die shape was designed using PS-Opt model simulation to compensate for springback deformation after press forming. Press experiments were then conducted using the designed die. We developed a highly convergent digital die compensation technology that semi-automatically determines the compensation amount using PS-Opt model simulations to compensate for springback deformation in die shapes.

The model used for this verification was a long hat-shaped part simulating an automotive structural part. The material was a galvanized steel sheet with a thickness of 1.2 mm and a strength grade of 1180 MPa. To conduct this verification under conditions involving significant springback deformation, where die compensation is particularly challenging, no countermeasures against springback deformation other than die compensation were applied in the die design (maximum springback deformation: approximately 14 mm). The results of the press trials conducted using the designed die (1st) showed that the compensation was not fully achieved. Therefore, based on the dimensional differences observed in the actual pressed parts, the die was modified only once, and press trials were conducted again (2nd).

**Figure 13** shows the area ratio for each range of deviation between the shapes of the 1st and 2nd trial press parts and the target

shape. In the 1st trial, the area ratio within  $\pm 0.5$  mm was 74%. In the 2nd trial, the area ratio within  $\pm 0.5$  mm was 91%, and the area ratio within 1.0 mm was 100%. By utilizing PS-Opt model simulation and digital die compensation, die compensations—which typically require multiple iterations to complete—were achieved in a single pass, demonstrating a significant reduction in die-making labor hours.

## 5. Conclusion

To promote the wider application of UHSS, which is effective in reducing CO<sub>2</sub> emissions as evaluated by LCA, we have been developing finite element simulation technology capable of accurately predicting springback deformation during press forming of UHSS sheets. This paper proposed forming simulation technologies that account for the deflection of presses and dies, and verified the validity of the proposed technologies and the improvement in simulation accuracy. The findings are summarized as follows:

- (1) We measured the deflection of the press machine's bolster plate and slide plate, as well as the clearance between the upper and lower dies. The results confirmed that the press machine deflected with greater deflection near the center, and that the degree of deflection varied significantly between press machines. Furthermore, the clearance between the upper and lower dies is affected by the press machine's deflection, resulting in a distribution where it becomes larger in the central area.
- (2) To improve the accuracy of forming simulations, we developed the full solid model and the PS-Opt model, both of which are FEM simulation models that account for deflection. Compared to the full solid model, the PS-Opt model simplifies the press

machine geometry, thereby significantly reducing modeling effort.

- (3) Simulation results from the full solid model and PS-Opt model accurately reproduce the deflection of the bolster plate and slide plate measured during prototype pressing, as well as the clearance between the upper and lower dies. Furthermore, compared to the conventional model, the simulation accuracies of these models have significantly improved.
- (4) Using the developed PS-Opt model simulation and digital die compensation technology, we performed die design and subsequently conducted trial press forming with the designed die. As a result, we verified that die compensation, which typically requires several iterations to complete, could be achieved in a single pass, significantly reducing die modification effort.

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