Effect of the Draw-bead and Blanking Holding Force on the Sheet Metal Forming Process

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Abstract. This paper is concerned with the quantitative effect of the draw-bead and the blank holding force on the sheet metal formed part. The draw-bead analysis is newly carried out to provide the restraints force of the draw-bead for finite element analysis of sheet metal forming. The draw-bead analysis has been carried out in the two steps: first, the draw forming analysis has been carried out; and secondly, the drawing analysis has been performed. The results provide the restraint force of the draw-bead as well as the displacement in the region of the draw-bead, which is utilized as boundary conditions in finite element analysis of sheet metal forming. And then, the sheet metal forming analysis is carried out to investigate the effect of the draw-bead on the quality of forming. Numerical results demonstrate that the forming history becomes totally different depending on the restraining method such that the forming is not successful with the use of only the blank-holding force while it is successful with the use of the draw-bead. It is also noted from the comparison of the analysis result with the experimental one that the present analysis method is effective in sheet metal forming simulation.

INTRODUCTION

The sheet metal forming process is influenced by many process parameters such as the die geometry, the initial shape of blank, the blank holding force, the draw-bead force, friction and so forth. Recently many studies are forced on the manufacturability and formability of the complicated shapes like auto-body members. The manufacturability of deep drawing products with the complicated shape strongly depends on the material flow into the die cavity during the stamping process. Usually the material flow is controlled by both the blank holding force and the draw-bead as well as the initial shape of blank in order to secure the part quality and avoid wrinkling and tearing. However, blank holding force is not an accurate tool to control the material flow and in some case the required blank holding force may exceed the capacity of the blank. To control the material flow effectively, draw-beads are widely utilized in sheet metal forming processes as a mechanism for providing the proper restraining force to control the flow of the blank into the die cavity during the stamping process.

The draw-bead plays an important role in sheet metal forming and its function becomes indispensable for the forming of complicated shapes like auto-body panels. However, it is difficult to include the draw-bead in real finite element simulations since the dimension of draw-beads is relatively small in comparison with the typical dimension. The mesh system has to be fine enough to describe the draw-beads and the computation time is drastically increased. For this reason, the equivalent draw-bead, which is defined on the tool surface as the restraining force, is utilized in sheet metal forming simulation. This restraining force of the equivalent draw-bead is assigned through a 2-D finite element simulation or an experiment.

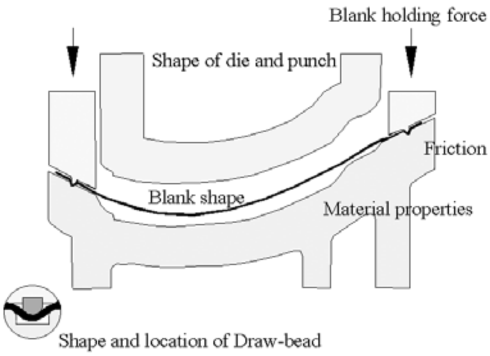

FIGURE 1. Process parameters in the sheet metal forming

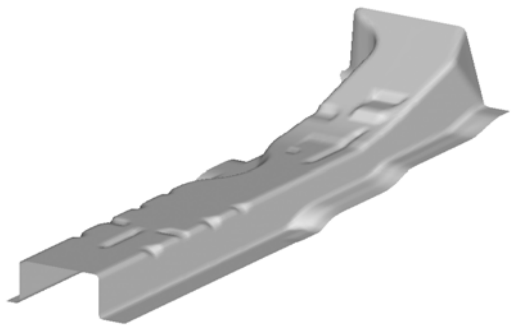

FIGURE 2. Shape of the inner panel in front frame member

Many researchers have studied the material flow controlled by the blank holding force and the restraining force of the draw-bead. Triantafyllidis *et al.* [1] considered the effects of the draw-bead using one-dimensional elasto-plastic shell element and compared numerical results with experimental results. Wang and Shah[2] formulated a mathematical model for the circular draw-bead and evaluated the restraining force. The analysis was carried out with experiments, numerical methods and formulas of the theoretical equations. Cao and Boyce[3] analyzed the restraining force with respect to the depth of draw-bead and Choi and Huh[4] also evaluated the restraining force of the draw-bead with elasto-plastic finite element method considering the variation of the blank size. Recently, design sensitivity analyses are also carried out to optimize the blank holding force and the draw-bead force in the stamping process. Kim *et al.* [5] optimized the variable blank holding force with a direct differential method to prevent the fracture by excessive stretching. The numerical simulations of sheet metal forming with the equivalent draw-bead have been carried out by imposing proper equivalent boundary conditions. Mattiasson *et al*. [6] suggested the restraining force considering the shape of draw-bead, the gap between the tool and the blank and the drawing direction as the equivalent boundary condition. Huetink *et al*. [7] used not only the restraining force but also the lifting force due to the draw-bead and thickness strain as boundary conditions in stamping processes. Park and Huh[8] considered the displacement and restraining force due to the draw-bead as the equivalent boundary condition and applied the result to forming analysis of the front door panel.

This paper represents the effect of the blank holding force and the draw-bead force on sheet metal forming analysis of an inner panel in the front side member of an auto-body. The shape of the inner panel is shown in Fig. 2. The panel is designed to have complicated shapes for the purpose of the efficient crashworthness. Since the material flow plays an important role in achievement of successful forming, complicated parts need to be controlled by the blank holding force and the draw-bead force. Finite element simulations are carried out with respect to the blank holding force, the initial size of the blank and the draw-bead force to investigate the effect of those parameters on the quality of forming. The forming history is quite different depending on the parameters because the material flow into the die cavity is governed by those parameters. In the first approach, forming analysis with the closed channel type is carried out with the variation of the blank holding force. The deformed shape and thickness distribution is examined to confirm the formability of the inner panel. Numerical analysis results produce the non-uniform metal flow that causes failures such as wrinkling and tearing. In the second approach to overcome these problems, forming analysis with the open and semi-open channel type is also carried out by changing the initial size of a blank. Finally the draw-bead is introduced to impose the restraining force by controlling the metal flow into the die cavity. The restraining force of the draw-bead is applied to the forming analysis as the equivalent boundary condition. Draw-bead analysis is carried out to obtain the restraining force as the equivalent boundary condition in the binder wrap process and the stamping process. The equivalent boundary condition is then applied to the forming analysis of an inner panel. The thickness distribution of the inner panel is compared with that in a real product for verification of the analysis result.

NUMERICAL SIMULATION

Numerical forming analysis of the inner panel is carried out to investigate the effect of the blank holding force and the draw-bead force. A commercial explicit finite element code, LS-DYNA3D, is employed in forming simulation for computational efficiency since it requires tremendous calculation time to simulate forming processes with the implicit finite element method. The material of the blank used in the analysis is the SPRC 40 whose flow stress is express as $\bar{\sigma} = 734.7(0.01 + \bar{\varepsilon})^{0.245}$ MPa. The initial sheet thickness is 1.6 mm. The coulomb friction coefficient is 0.15 between the sheet and tools. In the explicit simulation, the step size for the analysis is determined form the elastic modulus, the density and the mesh size of the blank. A mass scaling scheme is used to increase the density of the blank to ten times of the original density, which increases the time step size about 3.3 times. The mass scaling scheme satisfies the static condition and produces no problem of the excessive kinetic energy during the simulation. The punch speed is fixed to 2 m/s. The analysis is carried out until the blank is fully drawn from the binder.

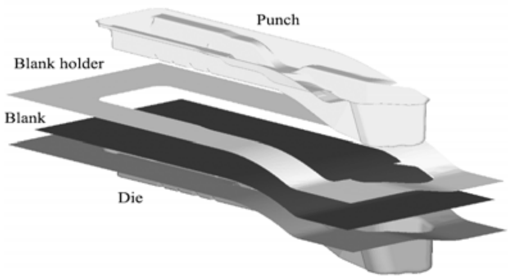

FIGURE 3. Initial setting of tools and the blank for the numerical analysis of the inner panel.

Numerical Forming Analysis with the Variation of the Blank Holding Force

The die, the punch and the blank holder are modeled with finite element patches for forming simulation. Figure 3 shows the tooling system for the analysis of the inner panel. Initially, the blank is assumed to be formed with closed channel type. The binder wrap analysis and the punch forming analysis are carried out with the variation of the blank holding force. Only the blank holding force is applied to the blank holder for the purpose of controlling the material flow into the die cavity with the variation from 100 kN to 300 kN.

Figure 4 shows the deformed shape and distribution of the thickness strain with the variation of the blank holding force. Numerical analysis results explain that tearing is occurred for the blank holding force of 300 kN while wrinkling is not eliminated until the blank holding force of 300 kN. The analysis results also demonstrate that elements of the blank near the punch shoulder are torn by necking when the high blank holding force is applied and elements of the blank at the flange show severe distortion due to wrinkling when the low blank holding force is applied. The results indicate that only the blank holding force is not sufficient to control the uniform metal flow and the additional parameter is required for achievement of successful forming analysis.

Numerical Forming Analysis with the Variation of the Initial Blank Size

Analysis results in the previous section indicate that the closed channel type with the blank holding force only is not appropriate for successful forming because it induces non-uniform metal flow to cause the failure such as wrinkling and tearing. As a remedy, initial blank size is changed so that the inner panel is formed with open or semi-open type. The initial blank used in the forming analysis is shown in Fig. 5. The blank holding force of 100 kN are imposed in the analysis and the r-type adaptive mesh system is adopted for the precise description of the deformed shape. The deformed shape and thickness strain are shown in Fig. 6. The analysis result represents that both wrinkling at the flange and tearing near the die

(a) (b) (c)

FIGURE 4. Distribution of the thickness strain on the inner panel with the variation of the blank holding force: (a) BHF = 100 kN; (b) BHF = 200 kN; (c) BHF = 300 kN.

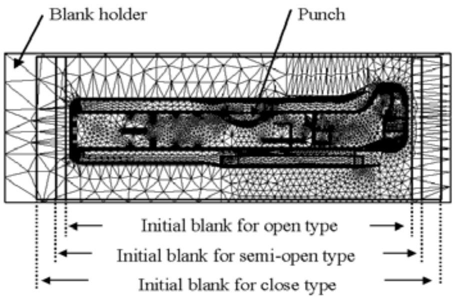

FIGURE 5. Initial blank for the forming analysis of an inner panel with open and semi-open type.

shoulder do not occurred with the blank holding force of 100 kN when the panel is formed with open and semi-open type.

For precise comparison between the open type and the semi-open type, the deformed shape and thickness distribution are examined along the section as shown in Fig. 7 where the geometry is steeply changed and a longitudinal dimple is exists. Figures 7 (a) and (b) show the deformed shape near the section. The analysis result shows that elements of the blank near the side wall along the section tend to be folded when the panel is formed with the open type channel while these tendency is weakened when the panel is formed with the semi-open type channel. Figure 7 (c) shows the quantitative comparison of the thick-ness variation along the designated section between the open type and semi-open type forming analysis. The thickness is increased up to 2.6 mm for the open type forming near the side wall while the thickness is increased up to 1.9 mm for the semi-open type and the perimeter along the section with the open type forming is about 10 mm longer than that with the semi-open type forming. It is because the restraining force imposed along the longitudinal direction with the open type is smaller than that with the semi-open type

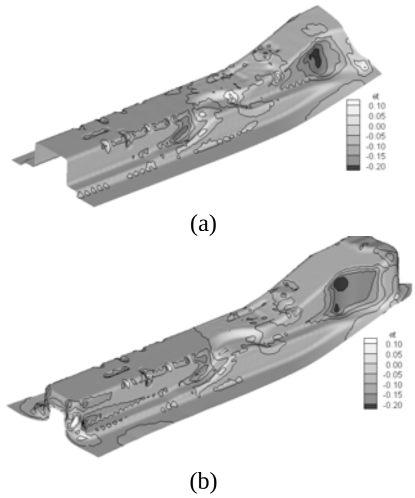

FIGURE 6. Distribution of the thickness strain with respect to the initial blank: (a) open channel type; (b) semi-open channel type;

during the forming process. It is noted from those analysis results that forming analysis with semi-open type is more appropriate than that with the open type. However it is still required to control the non-uniform metal flow in the section with complicated geometry.

Numerical Forming Analysis with the Equivalent Draw-bead Force

Draw-beads are generally utilized in sheet metal forming processes to impose the restraining force for controlling the flow of the blank into the die cavity during the binder wrap and the stamping process. The draw-beads are applied in forming analysis for improvement of the quality of forming. The draw-bead analysis has been carried out in two steps: first, the draw-bead forming analysis has been carried out; and

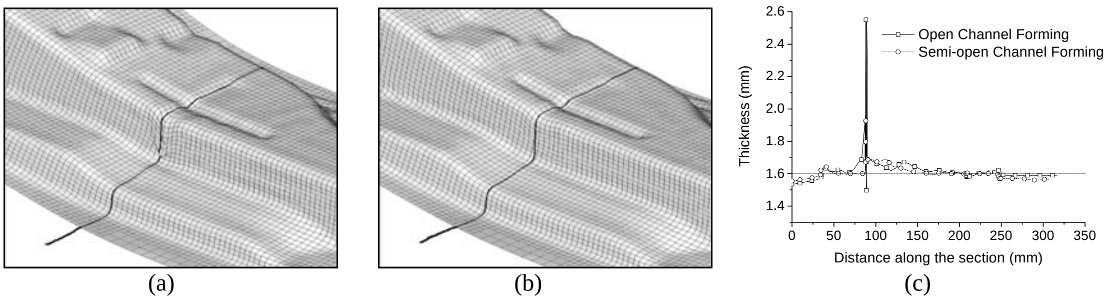

FIGURE 7. Comparison of the deformed shape and thickness distribution with respect to the initial blank: (a) open channel type; (b) semi-open channel type; (c) comparison of the thickness distribution

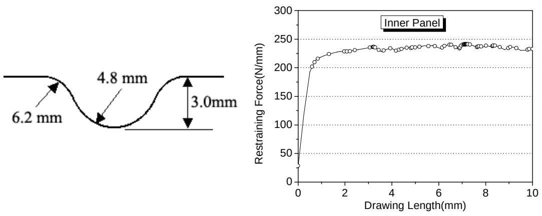

FIGURE 8. The restraining force of the draw-bead in the inner panel

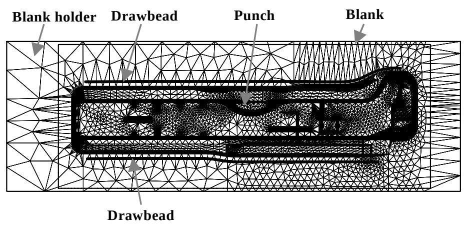

FIGURE 9. Locations of draw-bead in the sheet metal forming die for an inner panel.

secondly, the drawing analysis has been performed. The results provide the restraining force of the draw-bead in the region of the draw-bead, which is utilized as boundary conditions in forming analysis. 2-D plane strain analysis is carried out with ABAQUS/Standard implicitly for the shake of the accuracy. Draw-beads with the circular shape are employed. Figure 8 shows the restraining forces of the draw-bead employed as well as the shape and dimension of draw-bead.

Forming analyses have been carried out with equivalent boundary condition previously calculated for the inner panels. The initial blank size is same as that with the semi-open type and the blank holding force of 100 kN is imposed. The location of the draw-bead is expressed in Fig. 9 with curved lines on the blank holder. Figure 10 shows the thickness strain distribution in the inner panel for the presence of the draw-bead after forming simulation. Figure 11 shows the quantitative comparison of the thickness variation along the designated line. The thickness distribution has been compared with respect to the presence of

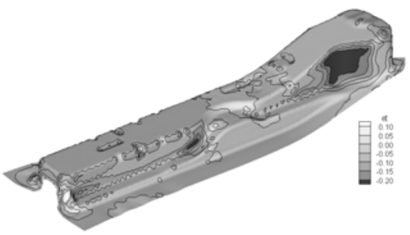

FIGURE 10. Thickness strain distribution of the inner panel when the draw-bead force is applied

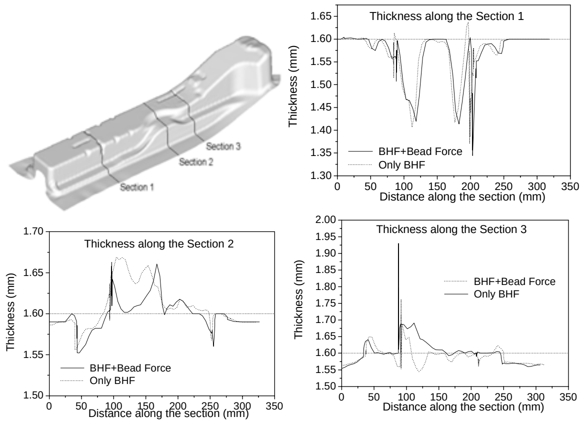

FIGURE 11. Comparison of thickness distribution with respect to the presence of draw-bead.

the draw-bead for the inner panel. The comparison indicates that the draw-bead as well as the blank holding force is so important to control the metal flow along the complicated section. The forming is successful with the use of both the draw-bead force and the blank holding force while it is not successful with the use of the blank-holding force only.

EXPERIMENTAL VERIFICATION

In order to demonstrate the validity of the forming analysis, the deformed shape and thickness obtained form the analysis are compared with those obtained from the real product. The real product is formed with the semi-open type and the draw-bead is also adopted same as the analysis. The deformed shape obtained form the forming analysis is almost same as the one from the real product as shown in Fig. 12. And the figure indicates that the forming analysis in this paper predicts the winkling and thinning of the blank. Figure 13 shows the quantitative comparison of the thickness

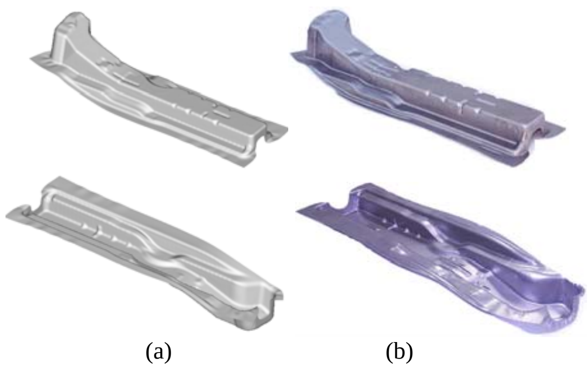

FIGURE 12. Comparison of the deformed shape for the experimental verification: (a) analysis result; (b) real product

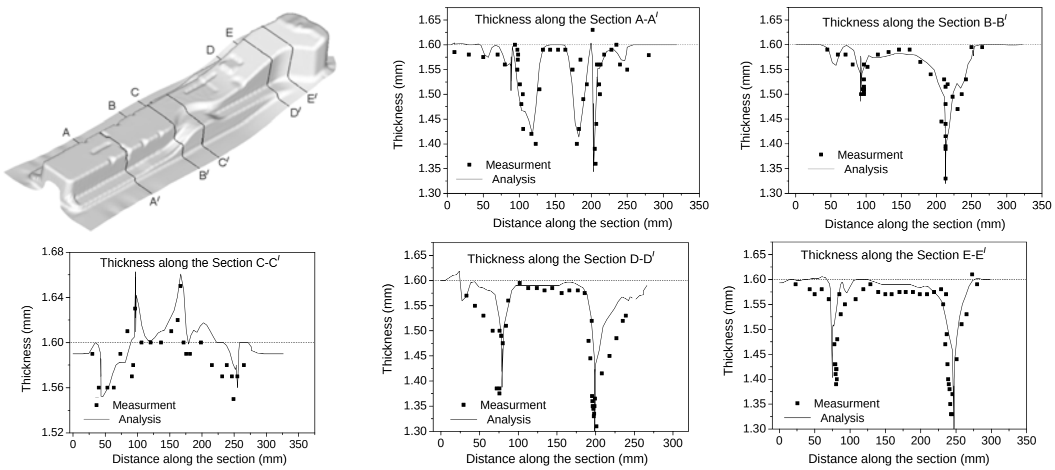

FIGURE 13. Comparison of the thickness distribution along the designated section for the experimental verification.

variation along the designated lines between the real product and the finite element simulation result. The figures explain that the calculated results are in close coincidence with the measured result. The comparison fully demonstrates the reliability of the forming simulation both with the blank holding force and the draw-bead force.

CONCLUSION

This paper represents the effect of the blank holding force and the draw-bead force on sheet metal forming analysis of the inner panel. The closed channel type forming analysis is performed with the variation of the blank holding force. Analysis results indicate the non-uniform metal flow to cause failures such as wrinkling and tearing. To overcome these problems, forming analyses with the open and the semi-open channel type are carried out by changing the initial size of the blank. The result explains that forming analysis with the semi-open type is more appropriate than that with the open type, but it is still required to control the non-uniform metal flow in the complicated geometry. Finally, the draw-bead is employed to the forming of the inner panel and analysis is carried out to investigate the effect of the draw-bead on the quality of forming. The numerical results demonstrate that the forming history becomes totally different depend on the restraining method such that the forming is not successful with the use of the blank-holding force only while it is successful with the use of the draw-bead. The quantitative comparison of the analysis result with the experimental one demonstrates that the present analysis is reliable and accurate in sheet metal forming simulation.

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