ABSTRACT

This paper is concerned with the quantitative effect of design parameters on a stamped part of the auto body. The considered parameters in this paper are the blank holding force, the draw-bead force and the blank size which greatly affect the metal flow during stamping. The indicators of formability selected in this paper are failures such as tearing, wrinkling. The stamping process of the front side inner member is simulated using the finite element analysis changing the design parameters. The numerical results demonstrate that the blank holding force cannot control the metal flow during forming although it controls the overall metal flow. The modification of the initial blank size considering the punch opening line ensures the local wrinkling after forming. The restraining force of draw-bead controls the metal flow in the local area and reduces the amount of excess metal. It is noted that the parametric study of design parameters such as blank holding force, the blank size and the draw-bead are very important in the process design of the complicated member.

INTRODUCTION

The sheet stamping process is widely used to produce outer panels and structural members of the auto body. Recently, as the trend needs weight reduction of the vehicle with enhanced crash-worthiness, steel sheets with high tensile strength are used more extensively as structural members. The stamping process with the high strength steel commonly involves low forming limit by fracture, low shape accuracy with the large amount of spring back and die wear.

Many researchers have studied the metal 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 a one-dimensional elastic-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 et al. [4] also evaluated the restraining force of the draw-bead with elastic-plastic finite...
element method considering the variation of the blank size. Recently, design sensitivity analysis is also carried out to optimize the blank holding force and the draw-bead force in the stamping process.

**NUMERICAL SIMULATION OF STAMPING PROCESS**

In this paper, numerical forming analysis is carried out to investigate the effect of the design parameter such as the blank holding force, initial size of the blank and the restraining force of the draw-bead on the formability of the inner panel. The initial sheet thickness is 2.5mm, the coulomb friction coefficient is 0.15 between the sheet and tools. In the numerical simulation, adaptive mesh scheme is adopted for the precise description of the deformed shape. In the simulation, the step size for the analysis is determined from 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, which increase the time step size. The mass scaling scheme satisfies the quasi-static condition and produces no problem of the excessive kinetic energy during the simulation. The punch speed is fixed to 1 m/s. The die, the punch and the binder are constructed from the three-dimensional CAD model of the tool with finite element patches for stamping simulation. Fig. 2 shows the finite element model for the analysis of the inner panel.

![Figure 1. Finite element model of tools and the blank.](image1)

**THE EFFECT OF THE BLANK HOLDING FORCE**

The initial 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 binder for the purpose of controlling the metal flow into the die cavity with the variation of 250kN and 500 kN.

Fig. 2 shows the deformed shape and distribution of the thickness strain with the variation of the blank holding force. Numerical analysis results show that there
is a split at the body of the panel when the blank holding force is 500 kN. In the meantime, only a small risk of splits at the same spot if the blank holding force is 250 kN. The analysis results also demonstrate that elements of the blank, near the punch shoulder, are torn by excessive stretching 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. When only the blank holding force is used as the process parameter for improving the formability, it may be possible to control the metal flow globally in the stamping process with the simple shape. Since the inner panel of the front side member has relatively large dimensions along the longitudinal direction compared with the lateral direction and it has the shape similar to the rectangular cup, failure such as tearing or wrinkling occurs near the side wall because the blank holding force is concentrated at the shoulder corner of the punch and the die. The results explain that it is not sufficient to achieve the uniform metal flow with changing the blank holding force only. Additional parameters are required in order to get successful product after the stamping process.

Figure 2. Formability of the inner panel with the variation of the blank holding force with semi–type blank: (a) blank holing force of 250 kN; (c) blank holding force of 500 kN.

Figure 3. Location of the cross section.

THE EFFECT OF THE INITIAL BLANK SIZE

In this section, numerical analysis is carried out to investigate the effect of the initial blank size on the occurrence of wrinkling and spring back. In this paper, three kinds of blank with different dimensions along the longitudinal direction are considered in simulation: 505 mm for CASE1; and 545 mm for CASE2. In CASE1, called open blank type, the inner panel is deformed to be an open channel like U-draw bending and no flange remains along the longitudinal direction; and in CASE2, called semi- open blank type, the inner panel is deformed to a fully drawn shape along the longitudinal direction and the flange remains along the lateral direction on the binder surface.
Fig. 3 designates the locations of the cross-section used in this paper for comparison of the deformed shape and thickness distribution. The geometry is steeply changed and a longitudinal dimple exists for absorbing excess metal near the section C–C. Fig. 4(a, b) shows the quantitative comparison of the thickness variation between CASE 1 and CASE 2.

(a) (b)

Figure 4. Comparison of the thickness along X axis with respect to the shape of initial blank at the section C–C': (a) CASE 1; (b) CASE 2.

THE EFFECT OF THE RESTRAINING FORCE OF THE DRAW-BEAD

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 dimension of the draw-bead is much smaller than other die dimensions. It is very difficult to include the geometric model of the draw-bead in finite element simulation since the computation time is drastically increased due to small elements around the draw-bead. The draw-bead is described as the line elements and the bead forces are assumed as the equivalent force at the nodal point of the bead. The external force at the finite element nodes of the blank, due to the draw-bead, is calculated from the geometric relation between the bead segments and blank material. In this paper, the equivalent restraining force of the draw-bead is calculated numerically and it is imposed as the boundary condition of the equivalent draw-bead for the sake of computational efficiency. In this study, circular draw-beads are employed in order to supply an additional restraining force to the blank material. Fig. 8 shows the shape and the dimension of the employed draw-bead.

Figure 5. Shape and geometric dimension of the circular draw-bead used in the analysis.

The initial blank size used in simulation is the same as that with the semi-open type CASE1 in and the blank holding force of 100 kN is imposed. The location of the draw-bead is expressed in Fig. 6 with curved lines on the binder.
Figure 6. Location of draw-bead in the stamping die.

Figure 7. Comparison of the thickness along X axis with respect to the shape of initial blank at the section D–C': (a) Without draw-bead; (b) With draw-bead.
The thickness distribution shown in Fig. 7 has been compared, with respect to the presence of the draw-bead for the inner panel. The severe thickening tendency of the blank is relaxed at the punch head at the section D-C’ when the draw-bead force is applied. The minimum thickness value at the section D-C’ is 2.21 mm with the blank holding force while that is 1.81 mm with the additional draw-bead force. The phenomenon means that the possibility of wrinkling by excess metal at the punch head is lessened with applying the restraining force of the draw-bead. The comparison indicates that the draw-bead as well as the blank holding force is very important to control the metal flow at the complicated region.

CONCLUSION

This paper represents the quantitative effect of important parameters that control metal flow into the die cavity on the formability in the stamping process of the inner panel of the front side member. Summaries of the present study are as follows:

(1) The stamping analysis with the initial blank of the closed type is performed with changing the value of the blank holding force. It is insufficient to achieve the uniform metal flow with changing the blank holding force.

(2) Parameter studies are carried out by changing the initial size of the blank in order to overcome failure. The initial blank of the semi-open type is more appropriate than that of the open type from the view point of the high formability, but it still needs additional process parameters to improve the metal flow in the complicated geometry.

(3) The draw-bead is employed in order to increase the restraining force to the blank and an analysis is carried out to investigate the effect of the draw-bead on the quality of the stamped part. The restraining force of the draw-bead controls the metal flow in the local area and reduces the amount of excess metal.

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REFERENCES