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Analysis of Drawbead Process by Static-Explicit Finite Element Method

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The problem analyzed here is a sheet metal forming process which requires a drawbead. The drawbead provides the sheet metal enough tension to be deformed plastically along the punch face and consequently, ensures a proper shape of final products by fixing the sheet to the die. Therefore, the optimum design of drawbead is indispensable in obtaining the desired formability. A static-explicit finite element analysis is carried out to provide a perspective tool for designing the drawbead. The finite element formulation is constructed from static equilibrium equation and takes into account the boundary condition that involves a proper contact condition. The deformation behavior of sheet material is formulated by the elastic-plastic constitutive equation. The finite element formulation has been solved based on an existing method that is called the static-explicit method. The main features of the static-explicit method are first that there is no convergence problem. Second, the problem of contact and friction is easily solved by application of very small time interval. During the analysis of drawbead processes, the strain distribution and the drawing force on drawbead can be analyzed. And the effects of bead shape and number of beads on sheet forming processes were investigated. The results of the static explicit analysis of drawbead processes show no convergence problem and comparatively accurate results even though severe high geometric and contact-friction nonlinearity. Moreover, the computational results of a static-explicit finite element analysis can supply very valuable information for designing the drawbead process in which the defects of final sheet product can be removed.

Key Words : Static-Explicit, Drawbead, Sheet Metal, Finite Element Formulation, Convergence

1. Introduction

Since 1960's, the numerical analysis method has rapidly progressed with the development of computer. In aid of that, a lot of research to estimate mechanically the forming process of a sheet metal was actively advanced. One of many numerical methods, the finite element method was generally used nowadays because of wide application and relatively accurate analysis compared with other methods. The finite element method can be classified into many categories according to the numerical technique employed in the process modelling of sheet material. When applied to drawbead processes, static-implicit finite element method has brought about the stable convergence problem (Jung and Yang, 1998). In case of dynamic-explicit method, low solution accuracy has been shown with some vibrated and rough results because of dynamic time integration treatment even though no convergency problem (Jung and Yang, 1998 ; Jung et al., 1995). So, a static -explicit method is suggested and applied to drawbead analysis in present work because it has no convergency problem and it gives relatively accurate solutions for quasic-static and severe

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contact problems.

Located on the binder surface surrounding the die cavity, drawbeads provide elongational restraining force so as to control the flow of sheet metal into the die cavity. As the binder is closed, the male side of the drawbead deforms the sheet into the female drawbead groove. Subsequently as the punch advances to form the part, the sheet must bend and unbend as it passes throuth the drawbead (Maker, 2000). And beads provide an enough tension to deform plastically the material over the punch face and then ensure a proper product shape by fixing the sheet to the die. Drawbead restraining force is generated through the combined effects of bending/unbending and increased friction in the drawbead contact areas. In the present study, the static-explicit finite element method with elasto-plastic continuum element is used to analyze the drawbead process.

2. General Description of the Theory : Elasto-Plastic Finite Element Formulation and Static-Explicit Finite Element Method

The integral equation used with the updated Lagrangian method (Cheng and Kikuchi, 1985) on the basis of a shape Ω^t in any time t can be expressed as the following (Chun, 1992).

$$\begin{aligned}&\int_{\Omega^t}\Delta T_{ji}\bar{u}_{i,j}d\Omega^t\\&=\int_{\Omega^t}\rho\Delta b_i\bar{u}_i d\Omega^t+\int_{\Gamma_F}\Delta t_i\bar{u}_i d\Gamma^t,\ \forall\bar{u}_i\end{aligned}\tag{1}$$

After the component equation is formulated, the approximate expression of finite element with considering the contact and friction boundary condition can be obtained.

$$\begin{aligned}&\left\{\sum_e K^{\Omega e}_{ij\alpha\beta}+\sum_e K^{\Gamma ce}_{ij\alpha\beta}\right\}\Delta u_{j\beta}\\&=\sum_e f^{\Omega e}_{i\alpha}+\sum_e f^{\Gamma_f e}_{i\alpha}+\sum_e f^{\Gamma ce}_{i\alpha}\end{aligned}\tag{2}$$

where the left term is the stiffness matrix and the right term represents the external force.

In order to overcome the weak point of static-implicit method, i.e. convergence problem, the static-explicit finite element method was suggested for drawbead process in this study. The static-explicit method can directly apply the solution obtained on previous step to the present step as initial guess and raise a solution accuracy by decreasing the size of step interval. In this study, the r-min method studied by Yamada and Yoshimura (1968) is used to decide a step size. All elastic values are scaled up in order to induce the element of the maximum equivalent stress $\bar{\sigma}^e_{\max}$ to first yield condition ; the scale factor will be $r_e=Y/\bar{\sigma}^e_{\max}$, where Y denotes the yield stress of the element material. And then choose the minimum r-value among the calculated values, that is, the element of maximum stress.

$$\begin{aligned}&r=\frac{\Gamma+\sqrt{[\Gamma^2+4(\Delta\bar{\sigma}^T_{ij})^2(Y^2-\bar{\sigma}^2)]}}{2(\Delta\bar{\sigma}^T_{ij})^2}\\&\Gamma=(\Delta\bar{\sigma}^T_{ij})^2-2\bar{\sigma}\Delta\bar{\sigma}^T-(\Delta\bar{\sigma}^T)^2\end{aligned}\tag{3}$$

where $\bar{\sigma}$ is the present equivalent stress of the elastic element and $\Delta\bar{\sigma}^T$ denotes the increment of $\bar{\sigma}$ induced by the load increment $\{\Delta L^T\}$. From the above equation, find the minimum value of the factor r, and designate it $r_{\min}$. And by using the minimum r-value, determine the value of $\{\Delta L^T\}$ which is the sufficient load increment to cause yield in each element. As the result of this, the value of $r_{\min}\{\Delta L^T\}$ becomes the new load increment of the next step.

3. Results and Discussions

3.1 Comparison between experiment and static-explicit analysis

The experiment for drawbead process is conducted in order to validate the static-explicit finite element analysis. The radii of circular shape bead and side die are both 4.76 mm and the initial sheet thickness is 0.706 mm. The friction coefficient is calculated to be 0.14 by using Nine (1978) method from experimental results. The drawing speed is 1000 mm/min. From the material tensile test, the initial yield stress is determined to be 216 MPa and the hardening exponent 0.212. Figure 1 shows the calculated drawing force from static-explicit finite element analysis coincides well with experimental result. So, the static-explicit method can be applied to drawbead processes with reasonable accuracy.

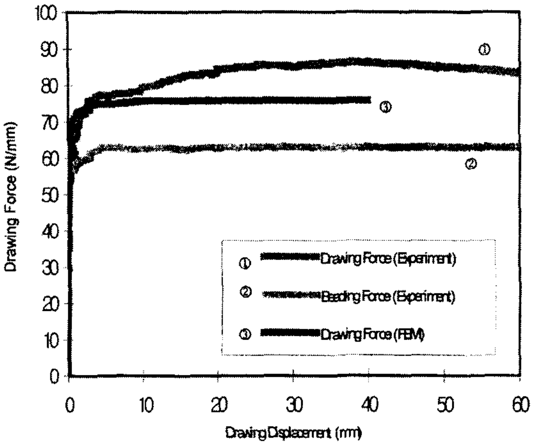
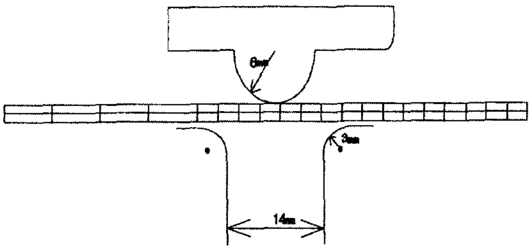
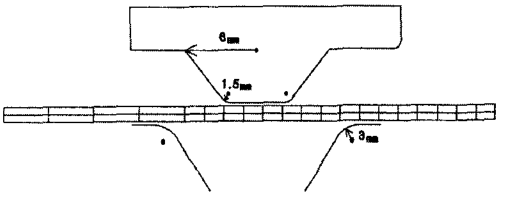


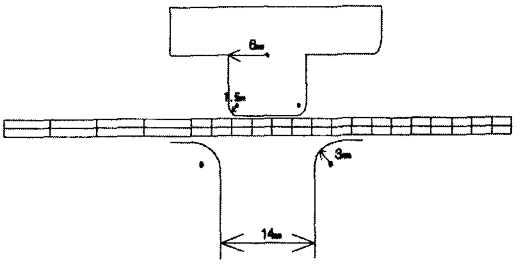
Fig. 1 Comparison between static-explicit method and experiment



(a) Circular shape bead



(b) Trapezoidal shape bead



(c) Rectangular shape bead

Fig. 2 The schematic shapes of beads and dies

3.2 The static-explicit FEM analysis of multi-bead processes

The numerical simulation experiment by using the static-explicit method is conducted for a number of circular shape beads, i.e. single bead, double bead, and triple bead. Figure 2(a) shows the schematic shape of a circular bead and die. The initial yield stress of sheet is 216 MPa and the initial thickness 0.8 mm. For comparison, a static-implicit analysis of single bead (Cheng and Kikuchi, 1985) is also conducted and compared the distributions of elongational strain on the upper layer of sheet after bead forming process with a static-explicit analysis in Fig. 3. Figure 3 shows that the result of the static-explicit analysis is almost the same as that of the static-implicit analysis. But the computation time of static-implicit method is 6 times longer than static-explcit method because of the large number of iterations owing to difficult convergence. In case of static-implicit analysis, the results of double and triple bead can't be obtained because of severe convergence difficulty. In drawing process, the friction coefficient of single bead is assumed to be 0.11. But in case of double and triple beads, friction coefficient is assumed to be zero because of excessive constraint force. Figure 4 shows the drawing force versus the drawing displacement for single, double, and triple bead.

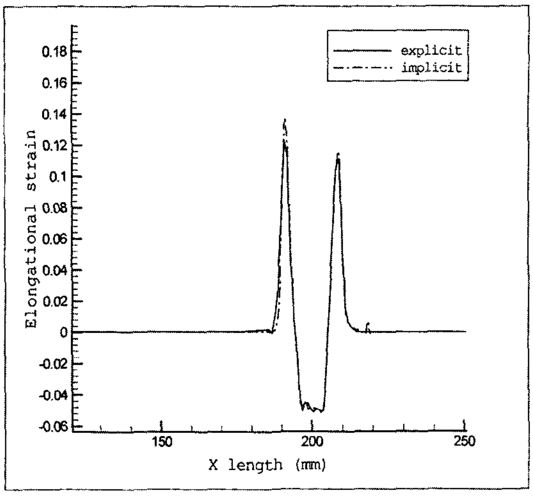
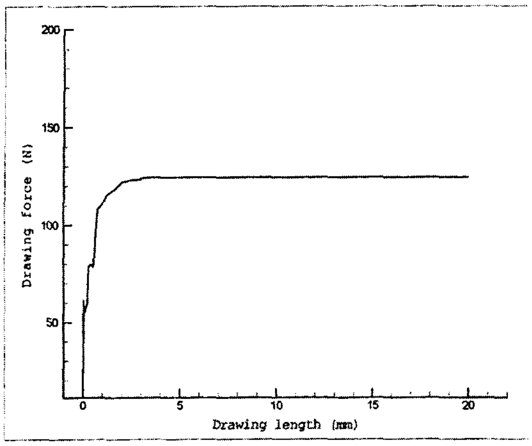


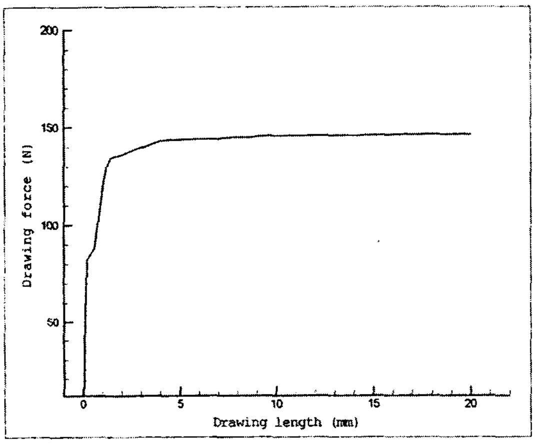
Fig. 3 Comparison between static-explicit and static-implicit methods

3.3 Rectangular and trapezoidal shape beads

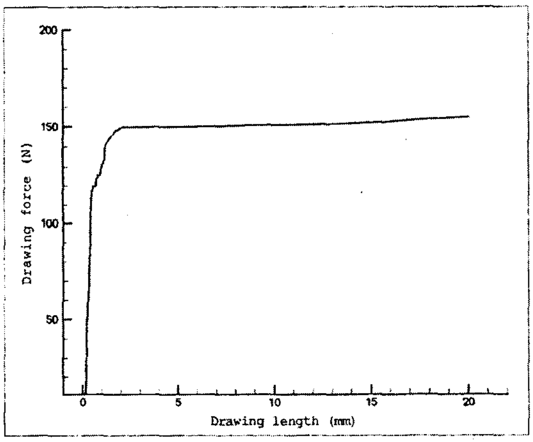
In order to investigate the effect of bead shape,



(a) Single bead

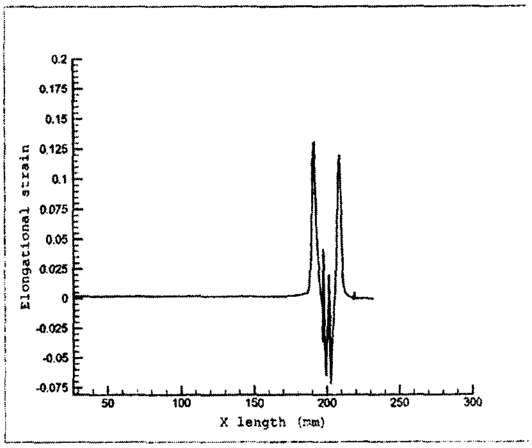


(b) Double bead

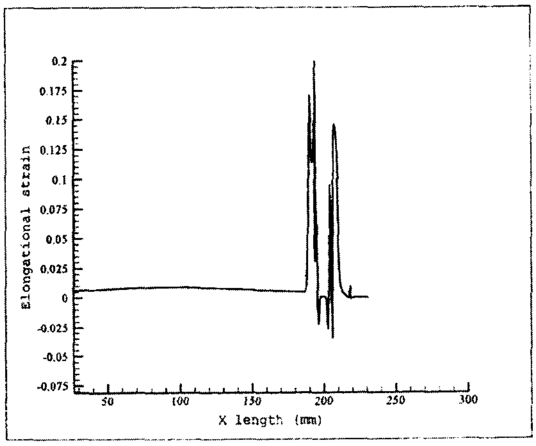


(c) Triple bead

Fig. 4 The drawing force versus the drawing displacement graphs for different numbers of beads



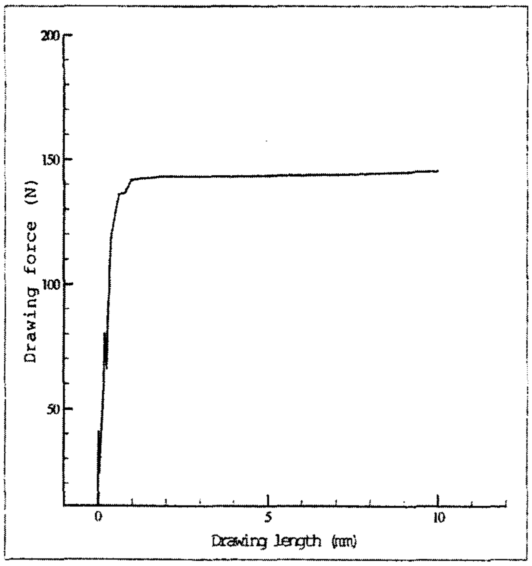
(a) Trapezoidal shape bead



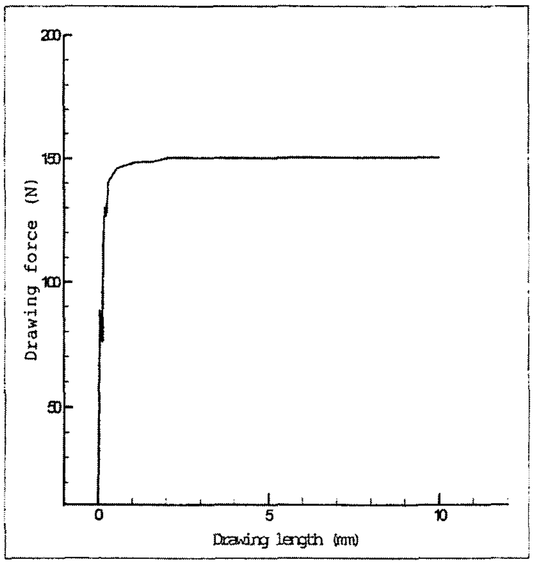
(b) Rectangular shape bead

Fig. 5 Distributions of elongational strain on the upper layer after the forming process

the drawbead processes of rectangular and trapezoidal shape beads are analyzed by using static-explicit method. Figure 2(b) and (c) show the schematic shape of rectangular and trapezoidal beads. Figure 5 shows the distributions of elongational strain on the upper layer after the bead forming process. In case of rectangular bead, the value of elongational strain distribution is much higher. So it can be assumed that the rectangular bead forming process affects strongly the rest part of sheet panel. Figure 6 shows the drawing force versus the drawing displacement for rectangular and trapezoidal beads. The elongational restraining force of rectangular bead is much larger than circular bead, so can control strongly the flow of sheet metal into the die cavity.



(a) Trapezoidal shape bead



(b) Rectangular shape bead

Fig. 6 The drawing force versus the drawing displacement in case of trapezoidal shape and rectangular shape beads

4. Conclusion

The static-explicit elasto-plastic finite element method with continuum element is applied to the drawbead process in order to overcome convergence problem with still reasonable accuracy. The drawbead process is used to provide elongational restraining force which can control easily the flow of sheet metal into the die cavity. The validity of static-explicit method is tested through the comparison with the experiment and the verified static-implicit method. The static-explicit method is also applied to the multi-bead process and the drawbead processes of rectangular and trapezoidal shape beads, i.e. very high non-linear problems of contact and geometric, and reasonable results can be obtained without convergence problem. From the above result, the static-explicit method is proved to be robust, rigorous, and efficient for highly nonlinear drawbead processes, and can be an useful analysis simulation tool for industrial field.

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