Structural analysis of a Micro-Former based on results from the forming analysis of milli-component

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Summary

Manufacturing process for milli-components has recently gained researcher's focus with the increasing tendency toward highly integrated and micro-scaled parts for electronic devices. This process, however, requires high production cost and more accurate final shapes than the conservative forming process technique. In order to fulfill this requirements, the numerical analysis must be preceded in design of the dies and dimensions for components. This paper is concerned with the forming analysis and the structural analysis of milli-components. Forming analysis of milli-components has been studied with a new micro-former with progressive dies. Multi-stage forming sequence has been analyzed with finite element method by LS-DYNA3D. The analysis considers the effect of elastic dies on the dimensional accuracy of the formed parts in order to enhance the forming accuracy and productivity. The analysis result demonstrates that the elastic analysis in the milli-forming process is indispensable for accurate forming analysis. And then, structural analysis for a micro-former has been carried out using the forming analysis results such as punch loads and die pressure. The result provides useful information in design of a new micro-former and milli-components.

Keywords: Milli-structure, Micro-former, Backward extrusion, Elastic die, Structural analysis

1 Introduction

Manufacturing process for milli-components has recently gained researcher's focus with the increasing tendency toward highly integrated and micro-scaled parts for electronic devices. Since milli-components have to be produced in a form of near net-shape precisely, the process for these components is complicated demanding the post-processing for the high quality. The milli-forming process, thus, costs more than conventional forming processes in design of dies and tools. The numerical analysis for milli-forming process using finite element method must be preceded in design of the dies and the dimension on components to reduce the trial-and-error during the manufacturing process in order to save the design cost and time.

In this paper, forming analysis is performed for milli-components that have the dimensions of several milli-meters and a complex shape. The analysis considers the effect of elastic recovery of the die set. The forming analysis results such as punch forces and amount of deflection in forming procedure are applied to structural analysis for determining the dimensions and evaluating the accuracy and capacity of micro-former developed.

2 Forming analysis

2.1 Analysis condition

The Forming analysis is performed for backward extrusion to produce an electronic connector using a commercial code LS-DYNA3D. The material of the connector is brass C2600W that have flow curve as $\bar{\sigma} = 936\bar{\varepsilon}^{0.14863}\ (MPa)$. This component can be formed by backward extrusion process through seven stages. In the 6th stage of the forming procedure, the hole is pierced by pushing out the center part of billet. The forming analysis is carried out using the axi-symmetric element with an adaptive remeshing technique for enhancing the mesh quality. The initial billet is passed into the die set of the next stage continuously for the purpose of considering the state variables such as the effective plastic strain and stress in each stage by modeling the progressive die. In order to identify the effect of elastic deformation of dies on the accuracy of the punch load and the dimensions the analysis is carried out considering the elastic deformation and recovery of the dies.

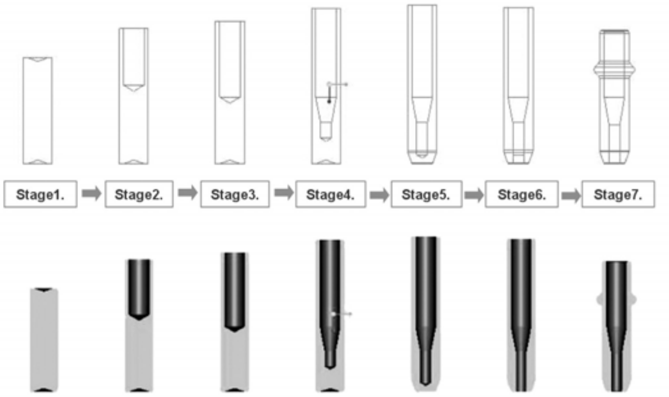


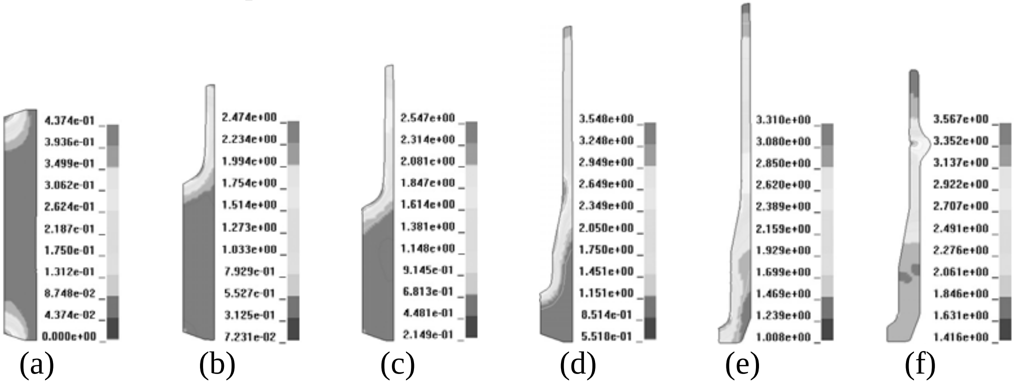
Figure 1: *Sequential formed shape at each stage*

2.2 Results and Discussion

Final shapes and distribution of the effective plastic strain at each forming stage are shown in **Figure 2.** Deformation is concentrated in the center part of contacting region between punch and the billet that is pressed down severely so the stress contour level is extremely high. As the punch moves down, the vertical length of the component is extended by pushing out a billet in backward. The outer wall of a billet is folded to radial direction in the last forming procedure called radial extrusion or crushing. **Figure 3** shows the calculated punch force at the seven forming stages. At the first stage, the punch force is calculated relatively low since the procedure has a short punch stroke to make pre-forming billet. The punch forces in the next stages have similar amount of force level that is expected in the pre-design of the punch and die. The dimension of a shape is changed notably due to the concentrated pressure and stress after punch unloads. That is, the difference between the initial and the final dimension of a shape is about 6% in the region of contacting with the billet and the punch edge. Therefore, elato-plastic analysis has to be performed to consider the effect of elastic recovery where the final dimension has to be precisely estimated.

2.3 Elastic Analysis for the die set

Numerical analysis is performed by regarding the die set as a elastic body so as to observe the effect of elastic recovery. The trace of the outer wall of a billet is plotted during the punch moves down in order to estimate elastic deformation of the die wall due to the increased pressure. This plotting is preceded according to the divided analysis step: punch moves down in first three steps and goes up in last three steps. As seen in the **Figure 4**, the radius of material expands more than initial die radius during the punch moves down because the die and material deform like bulging induced by elastic deformation of die. The die experiences full elastic recovery after the first stage forming process with a punch unloading as shown in **Figure 4(a).** However, in the case of another stages, the radius of billet becomes larger than the initial radius of die despite the punch is unloaded as shown in **Figure 4(b), (c)** and the die wall cannot be fully recovered remaining bulged. This bulging phenomenon is induced by stress concentration on 2, 3-stage having the largest stress level. However, the die wall maintains initial position in another analysis steps except for 2, 3-sage after unloading procedure. In fact, complete elastic recovery takes place after ejector pulls out the billet. Therefore, elastic analysis for die set is required to perform the precise forming analysis in the kind of milli-components.



(a) (b) (c) (d) (e) (f)

Figure 2: *Distribution of the effective plastic strain:* (a)stage 1; (b)stage 2; (c)stage 3; (d)stage 4; (e)stage 5; (f)stage 6;

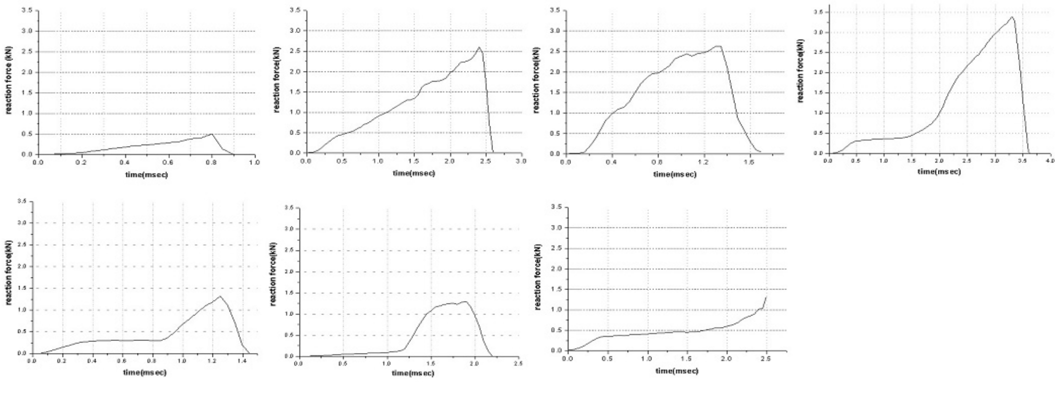
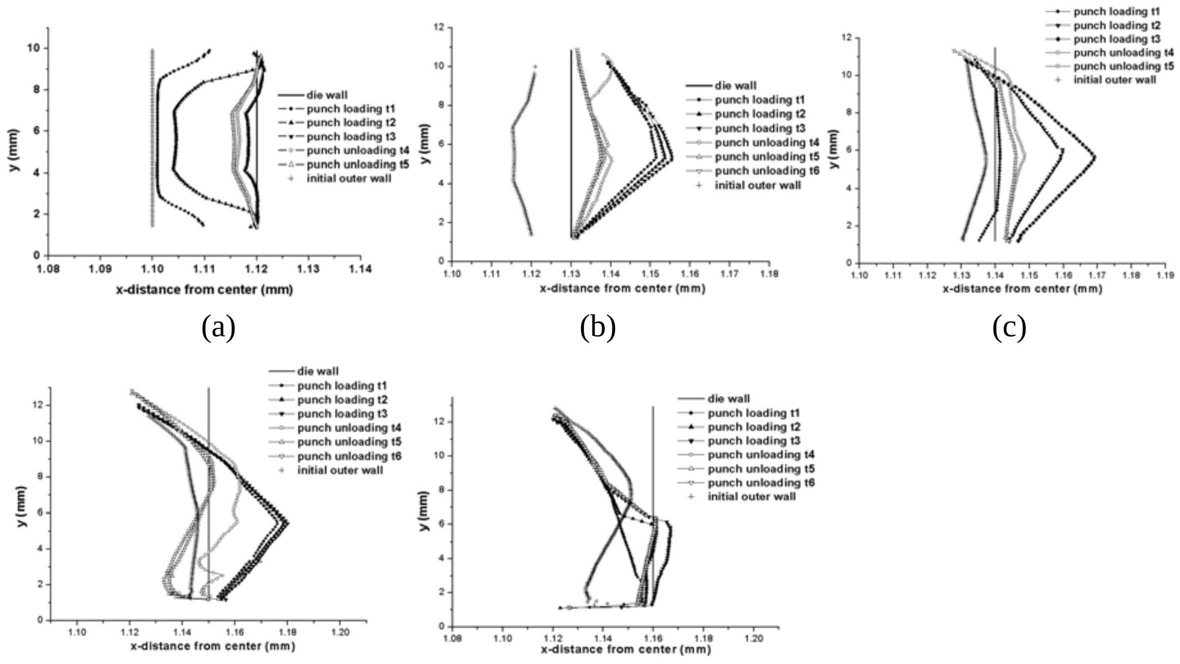


Figure 3: *Punch force vs. time for each process stage (stage 1~7)*



(a) (b) (c)

(d) (e)

Figure 4: *Dimension change of the die and outer wall of the billet during each stage: (a) stage-1; (b) stage-2; (c) stage-3; (d) stage-4; (e) stage-5;*

3 Structural Analysis of a micro-former

3.1 Modeling of a micro-former

Multi-stage forming process is carried out by conveying the billet to the next stage die set after accomplishing the forming process. A sequential operating mechanism is shown schematically in **Figure 5**. The forming mechanism continues with the horizontal movement of the punch P and the vertical movement of the die D. In the first stage, the punch part proceeds toward right direction when initial billet flows into the first die set in the first forming procedure. And then, the punch moves back to the left direction carrying formed initial billet after forming process. At the same time, the die part moves up and the second forming procedure is performed as the punch travels toward the right direction. Finally, the billet is transferred to the next stage die set as the die part moves down carrying the billet. According to this procedure, an initial billet experiences from die set(P1, D1) of the first stage to die set(P7, D7)of the last stage.

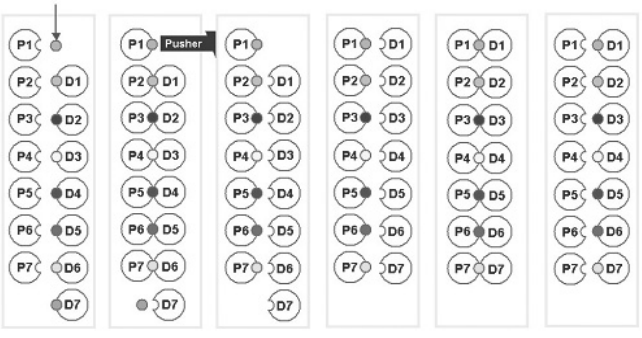


Figure 5: *Schematic diagram of forming sequence in the micro-former*

3.2 Structural analysis of a micro-former

Moving part of a micro-former has been modeled for a finite element mesh system for the purpose of structural analysis. **Figure 6** shows that the punch forces of seven stages obtained in the course of forming analysis are applied to structural analysis for reaction of the micro-former at the time of closing a punch and die. The maximum deflection of the camshaft that retains the concentrated punch load is less than 0.001mm in the structural analysis with the punch loads calculated from the previous forming analysis. This result reveals that each part of the micro-former has been over-designed, which is not efficient in terms of the forming speed and the productivity. In order to optimize the dimension of each part of the micro-former, analysis results are compared with the variation of the radius of the camshaft, which has great effect on the accuracy of forming processes and dimensions of formed parts. The maximum deflection increases abruptly in case that the radius of the camshaft is reduced by 50% from 120mm to 60mm while the maximum deflection increases slightly in case that the radius of the camshaft is reduced by 20% from 120mm to 96mm. The deflection with change of the radius is demonstrated in Fig. 16 for comparison. It is also found that the maximum deflection takes place at the connecting region of the eccentric part and the concentric shaft. From this result, a remedy is made for a better combination of the eccentric part and the concentric shaft as shown in **Figure 7(a)**. The result is depicted in **Figure 7(b)**, which demonstrates that the maximum deflection of a modified model is less than 0.005mm and this combination is good for the precise forming with the final dimensions of each part. While the concentric shaft still has a large value of the radius, the eccentric shaft has a comparably small value of the radius without increase of the maximum deflection. This design can guarantee the increase of the forming speed by reducing the amount of inertia effect compared to the original design.

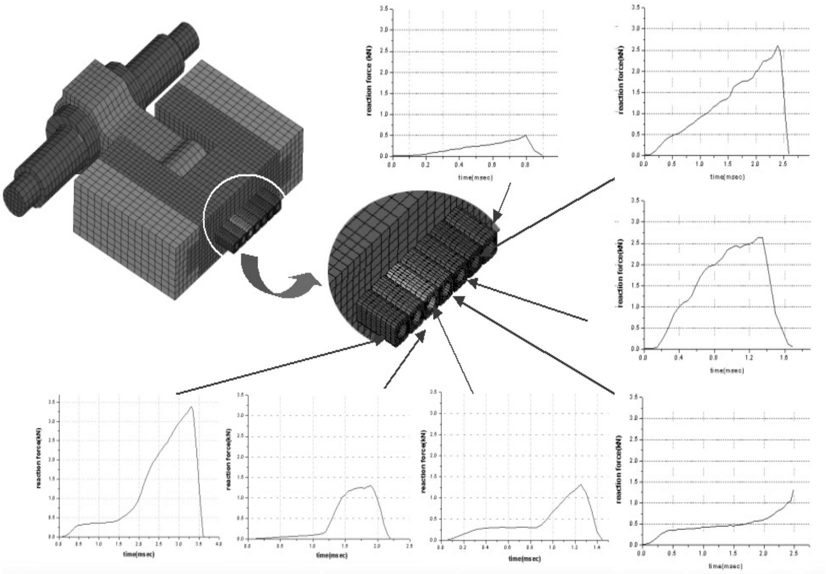
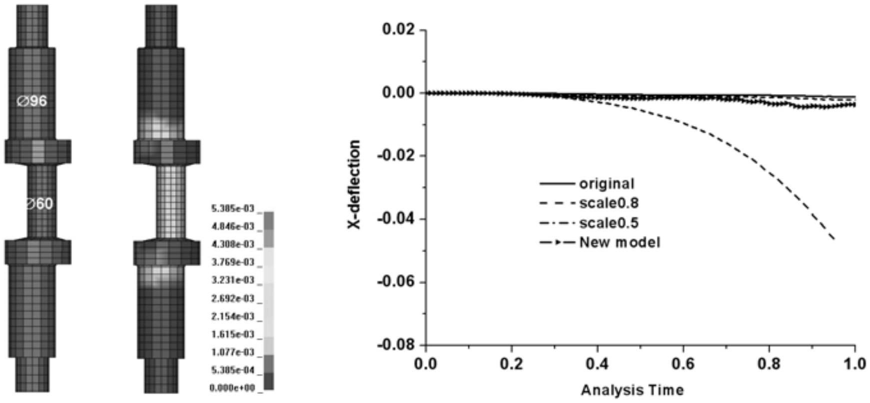


Figure 6: *Input the punch force on the die of micro-former*



(a) (b)

Figure 7: *Distribution of Von-mises stress and deflection for new model during the structural analysis*

4 Conclusion

This paper presents a multi-stage forming analysis to evaluate and determine the forming capacity of a micro-former. Analysis results calculated from forming analysis such as the punch force are imposed to structural analysis of the micro-former as a boundary condition. According to these analysis results, every parts of the micro-former remain under elastic limit so that some parts is evaluated as over-designed. Design modification has been made for optimal design of the structure for improving the efficiency of the micro-former.

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