

Finite Element Analysis of Hot Aluminum Extrusion of Asymmetric Parts

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Abstract

In this study, a design guideline for the die cavity and die bearing length distribution is proposed during an extrusion process of an asymmetrical thin sheet, such as clips of cell-phones. The plastic flow pattern of the billet inside the die cavity is analyzed using a commercial finite element package “DEFORM 3D”. The Module of Die Stress Analysis in the finite element software “DEFORM 3D” is also used to simulate the stress, strain, and the displacement distributions of the die during extrusion of clips of cell-phones. The extrusion load, the stress and strain distributions of the die, the temperature distribution, and thickness distribution of the extruded product are investigated. Furthermore, hot extrusion experiments using A6061 as the specimen are executed. The experimental results of temperature, thickness distribution of the product, extrusion force, etc, are compared with the analytical values to verify the validity of the proposed die design guideline.

Keywords: Finite element analysis, Asymmetrical extrusion, Aluminum, Die design

Introduction

Compared to other forming processes, such as forging, or die-casting, extrusion process is the most cost-effective method for mass-producing computer, communications and consumer electronics (3C) products with uniform cross-sections, such as clips and casings of cell-phones. Clips are asymmetrical parts and casings are hollow parts. The characterization of these parts is small and thin. The dimensional tolerance, which is influenced greatly by the temperature distribution of the billet, the elastic deformation of the die, is strictly demanded. If the flow-guide and the bearing length of the die are not designed appropriately, the extruded product probably appears with a great curvature and even fractures, and the product may generate a large variation of the thickness distribution. Regarding to the previous studies on asymmetrical extrusion, Imamura et al. (1999) used experimental approaches to obtain a simple formula for the flow guide design during spreading extrusion, by which a uniform metal flow at the bearing exit was ensured. Takatsuji et al. (1984) proposed a formula for determining the shape and dimensions of the flow guide of the die for a thin product. Koba et al. (2001) carried out a series of hot extrusion experiments of C-channel products using plasticine as the material model. They discussed the effect of the flow guide configuration and dimensions on the velocity distribution at the die exit section in the steady state stage of the extrusion process. One of the present authors has published a paper on discussion of asymmetrical extrusion processes for manufacturing products with complex shapes like CPU heat sinks [Hwang and Shen (2008)]. However, there are currently few literatures that are involved in the discussion of asymmetrical extrusion processes of a thin clip. In this paper, a simple design guideline for the flow guide or die cavity and bearing length distributions is proposed. Asymmetrical extrusion of a thin clip with two protrusions is analyzed using the finite element method. The product shapes and the stress and deflection distributions of the die are discussed.

Finite Element Simulations

An implicit and static finite element code “DEFORM 3D” is adopted to analyze the plastic flow pattern of the billet within the die cavity during asymmetrical extrusion of a clip. During the simulations, it is assumed that the billet is rigid-plastic, and the die, the container as well as the flow guide are all rigid. The interfaces between the billet and the die, container, and the ram have a constant friction factor m , which is set to be 0.9 to correspond to the condition of hot forming. The

four-node tetrahedron elements are used. The minimum element size is 0.4 mm at the die orifice. The initial relative positions of the billet, die cavity, container and the ram are shown in Fig. 1.

The temperatures of container and die are set as 480°C. The non-isothermal condition is adopted in the finite element simulations. The iteration methods adopted for solving the nonlinear equations are the Newton-Raphson and the direct iteration methods. The direct iteration method is used to generate a good initial guess for the Newton-Raphson method, whereas the Newton-Raphson method is used for speedy final convergence. The diameter of the billet aluminum alloy A6061 is 110 mm. The ram speed is 2 mm/sec. The database of flow stress for A6061 at 480°C in “DEFORM 3D” is used. The extrusion ratio, i.e., the ratio of the cross-sectional area of the billet to that of the product, is 85.

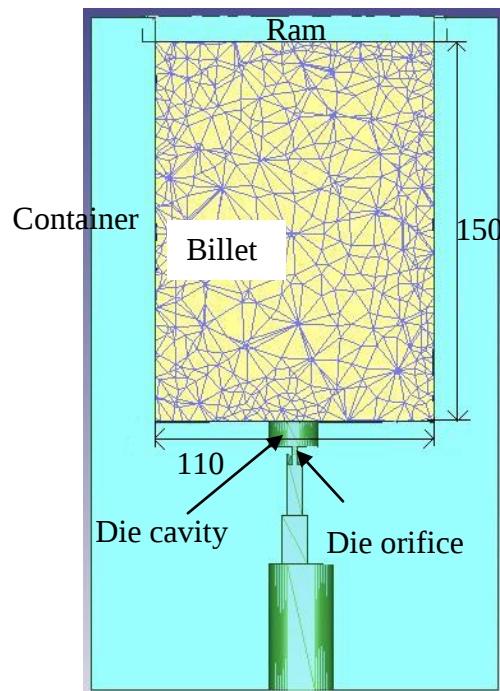
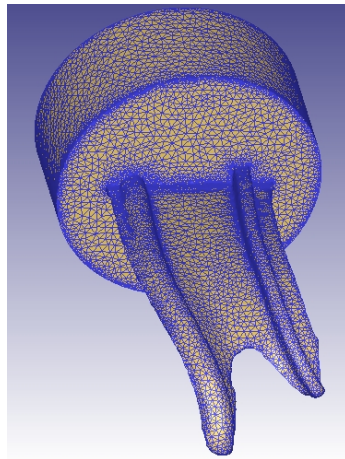


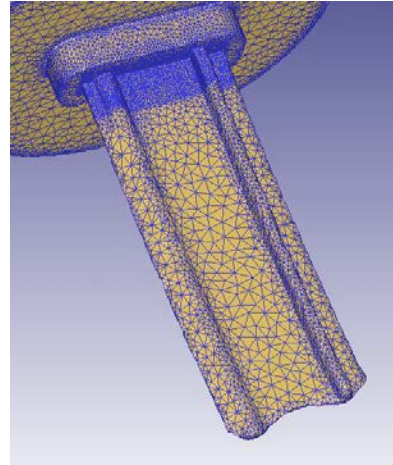
Figure 1. Initial relative positions of billet, die cavity, container and ram.

Figures. 2(a) and 2(b) show the simulated product shapes without and with the die design, respectively. In Fig. 2(a), it is clear that a front end of the product with non-uniform velocity distribution was obtained because of no die cavity and no die bearing length design. In Fig. 2(b), on the contrary, the product flows out with a quite uniform velocity distribution using the proposed design of a die cavity and a die bearing length distribution.

Using the “Die Stress Analysis” mode in DEFORM 3D, stresses, strains, and deflections of the die at a certain step of the simulation can be analyzed. Figs. 3(a) and 3(b) show the simulation results of stress and deflection distributions, respectively, around the die orifice. From Fig. 3(a), it is known that the maximum stress occurring at the middle of the die plate is about 407 MPa, which is smaller than the yielding stress of the die material, 900 MPa. The contour lines shown in Fig. 3(b) denote the deflection distribution in the lateral direction, which will affect the dimension of the extruded product. From Fig. 3(b), it is known that the maximum deflection occurring at the middle of the die plate is about 0.02 mm, which implies that the thickness at the middle part of the extruded product will decrease by 0.02 mm.

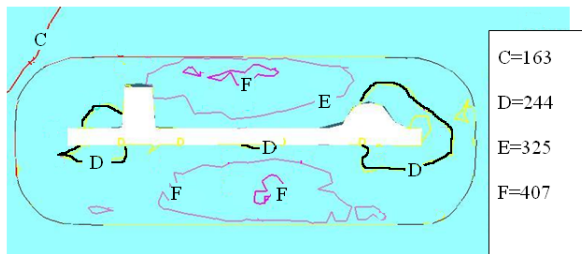


(a) Without die design

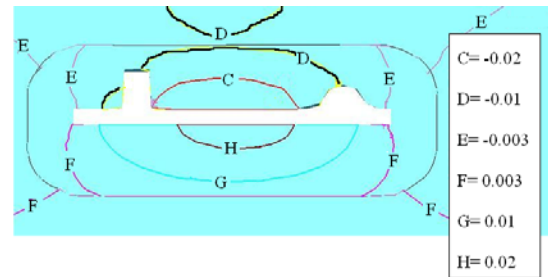


(b) With die design

Figure 2. Finite element simulation results of extruded product shapes.



(a) Effective stress



(b) Deflection in lateral direction

Figure 3. Finite element simulation results of stresses and deflections around the die orifice.

Conclusions

The plastic flow pattern of the billet inside the die cavity and die orifices was analyzed using a commercial finite element package “DEFORM 3D”. The Module of Die Stress Analysis in the finite element software “DEFORM 3D” was also used to simulate the stress, strain, and the displacement distributions of the die during extrusion of a clip for cell-phones. The extrusion load, the stress and strain distributions of the die, the temperature distribution, and thickness distribution of the extruded product were investigated. Hot extrusion experiments of an asymmetric thin sheet using A6061 as the specimen were executed.

Acknowledgments

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References

- Hwang, Y.M., Shen, C.Y. (2008) Analysis of plastic flow and die design during extrusion of CPU heat sinks, *Journal of Materials Processing Technology* **201**, 174-178.
- Imamura, Y., Takatsuji, N., Matsuki, K., Aida, T., Yasuda, H., Sasatani, H. (1999) Metal flow control by flow guide of spreading extrusion—study of spreading extrusion process-III, *Journal of Japan Society for Plasticity of Technology* **40**, 976-980.
- Koba, H., Nakanishi, K., Kamitani, S. (2001) Effects of flow guide configuration on material flow characteristics in extrusion of C-channel product—die design aided by physical simulation system-III, *Journal of Japan Society for Plasticity of Technology* **42**, 954-958.
- Takatsuji, N., Tokizawa, M., Murotani, K., Matsuki, K. (1984) An experimental study on die shapes for balancing metal flow in hot extrusion, *Journal of Japan Society for Plasticity of Technology* **25**, 1000-1005.