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Die land optimization of section extrusion by finite element method①

HAO Nan-hai(郝南海)[1], TIAN Zhu-ping(田柱平)[1], WEI Xing-hua(卫兴华)[2]
(1. Department of Mechanical Engineering, Taiyuan Heavy Machinery Institute, Taiyuan 030024, P. R. China;
2. Taiyuan Aluminum Plant, Taiyuan 030024, P. R. China)

[Abstract] In the extrusion of sections with flat-faced die, the proper design of die land is critically important in avoiding geometry defects. A methodology for the design of die land, which consists of a simulation-adjustment iteration, is proposed. The metal flow in extrusion is simulated by the three dimensional finite element method and the die land is adjusted according to the simulation result. The simulation-adjustment iteration is conducted repeatedly until the uniform metal flow in die land exit is obtained. Both the formulae for adjustment of the die land and the criterion for the judgment of proper die land are suggested. The extrusion of a C-section is chosen as the computational example.

[Key words] extrusion of sections; die design; finite element method (FEM)

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1 INTRODUCTION

In the extrusion of sections with flat-faced dies, as the serious friction on the material/tool interface and the big difference in geometry between the extruded section and the billet, non-uniform metal flow occurs in the deformation zone. This may result, depending on the complexity of the extruded section, in twisting or bending of the product as it emerges from the die. To prevent those defects, the flow rate of the extruded metal is controlled through proper design of the die land. Owing to the complexity of the metal flow in extrusion, the reliable design methodology of die land is still short. The design quality of extrusion die relies mainly on the technical experience and empirical know-hows of the designers[1].

FEM has been extensively used in simulating the forming process[2~9]. By the aid of FEM simulation, it is possible to predict the geometric defects of the product. In the paper, a method based on the finite element analyses is proposed for the design of die land. The proposed method is implemented for the extrusion of a C-section Fig. 1.

2 FINITE ELEMENT FORMULATION

In the extrusion of sections, large progressive plastic deformation occurs. For the sake of simplicity in the analysis, the elastic strains can therefore be neglected and the deformation behavior of the material is simplified to rigid plastic. The variational equation of the rigid plastic material model is given by[10]

$$\int_V \bar{\sigma}\delta\dot{\bar{\varepsilon}}\,\mathrm{d}V + K\int_V \dot{\varepsilon}_V\delta\dot{\varepsilon}_V\,\mathrm{d}V - \int_{S_f} f_i\delta v_i\,\mathrm{d}S \quad (1)$$

where $K = 10^6$; $\dot{\varepsilon}_v$ —Volumetric strain rate.

The frictional force between workpiece and die is

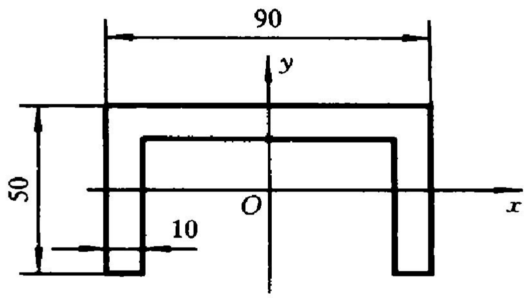

Fig. 1 Dimension of C-section (unit: mm)

given by the following vector form

$$\boldsymbol{f} = -(2/\pi)mk\cdot\tan^{-1}\cdot|\boldsymbol{V}_s|\boldsymbol{t}/u_0 \quad (2)$$

where m —Friction factor; k —Shear flow stress; $\boldsymbol{V}_s$ —Velocity vector of the workpiece vs the die; u_0 —Very small positive number as compared to $|\boldsymbol{V}_s|$; $\boldsymbol{t}$ —Unit vector in the direction of $\boldsymbol{V}_s$.

Eqn. (1) is discretized at the element level which yields a set of nonlinear algebraic equations

$$G(\tilde{u}) = \tilde{0} \quad (3)$$

The Newton-Raphson iteration method is introduced to obtain the solution of Eqn. (3)

$$\left.\frac{\partial G(\tilde{u})}{\partial \tilde{u}}\right|_n \Delta\tilde{u}_{n+1} = -G(\tilde{u})|_n \quad (4)$$

$$\tilde{u}_{n+1} = \tilde{u}_n + \beta\Delta\tilde{u}_{n+1} \quad (5)$$

where β —Relaxation factor, $0 < \beta \leqslant 1$.

3 ANALYSES OF METAL FLOW

In the extrusion of sections, the extrudate becomes rigid as it emerges from the die land, which conceals the tendency of non-uniformity of metal flow in die land exit. For observing the tendency of metal flow, the extrudate is trimmed from the billet along the contour of die land exit, as shown in Fig. 2.

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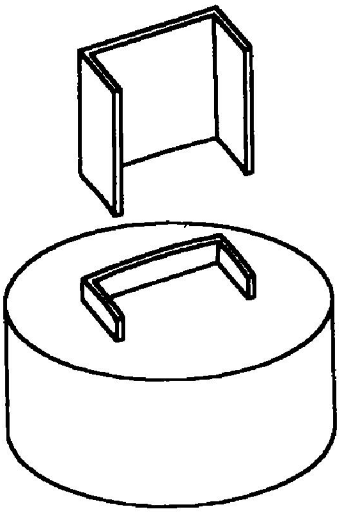

Fig. 2 Trimming rigid extrudate from billet

Having obtained the distribution of velocity at die land exit by rigid plastic finite element method, an appropriate parameter is needed to characterize the non-uniformity of metal flow. For this purpose, the deviation of mean of velocity, v_{DMV}, is chosen. The formulae used for this calculation is

$$v_{DMVi} = \lfloor v_i - v_{AVE} \rfloor / v_{AVE} \quad (6)$$

where v_i —Velocity at node i which locate at the die land exit; v_{AVE} —Average velocity of the die land exit.

The objective of die land design is to remove or if not, to decrease the non-uniformity of metal flow at the die land exit. The reason is, if the metal flow in the die land exit is uniform, there will be no additional stress and geometry defects existing in extruded sections. A criterion for judgment of proper die land is suggested as follows

$$|v_{DMVi}| \leqslant C \quad (7)$$

where C —Constant which is determined by the designer, here we take $C = 0.1$.

4 SCHEME OF DIE LAND DESIGN

The proposed method for the die land design is based on finite element analysis. First, the die land length is the same, equal to the minimum section width of the section. Then the finite element analysis is conducted to obtain the distribution of velocity at the die land exit. If the velocity of any node at the exit of die land does not satisfy the criterion of Eqn. (7), the die land length at the location of that node is adjusted using the following equation

$$l_i^n = (1 + v_{DMVi}) \cdot l_i^{n-1} \quad (8)$$

where l_i —Die land length of node i; n, $n-1$ —Iteration times.

If the velocity of node i is lower than the average velocity, the die land at node i should be shortened. That is, the acceleration of metal flow at node i is achieved by reducing the friction on the surface of die land. If the velocity of node i is higher than the average velocity, the die land at node i should be lengthened. That is, the deceleration of metal flow at node i is achieved by increasing the friction on the surface of die land. For obtaining the optimum die land, the simulation-adjustment iteration is conducted repeatedly until the criterion is satisfied. The design procedure is shown in Fig. 3.

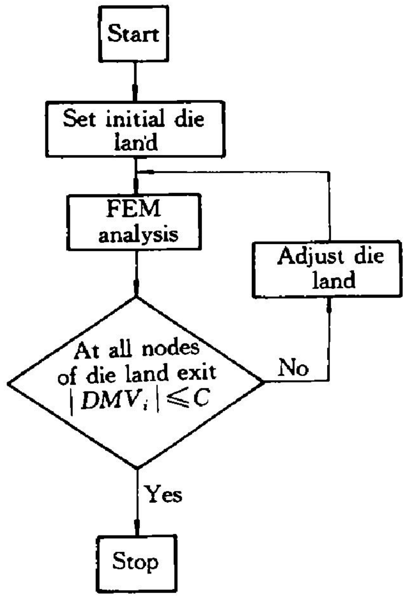

Fig. 3 Design procedure of die land

5 COMPUTATIONAL EXAMPLE

The extrusion of a C-section was chosen as the computational example. The material of the billet is aluminum alloy LD31 and its flow stress is given[11]

$$\bar{\sigma} = 86.3\,\dot{\bar{\varepsilon}}^{0.128} \quad (9)$$

The parameters for calculation are as follows: Billet length = 200 mm; Billet diameter = 197 mm; Ram speed = 1 mm/s; Friction factor = 0.3.

Fig. 4 shows the finite element model used for

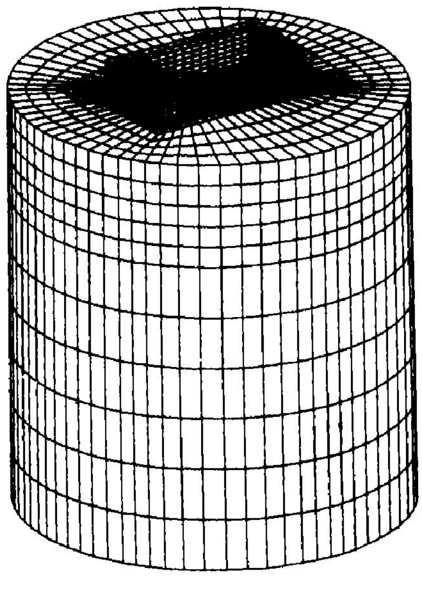

Fig. 4 FEM model of workpiece

simulation. As can be observed, the mesh is more refined toward the entrance of the die land in the die orifice, i. e. the regions of more interest. Fig. 5 shows the comparison of the die land configurations. The calculated configuration is similar to that of industrial design, the latter was obtained by trial-and-error. Fig. 6 shows the velocity distributions for a initial die land length (10 mm) as well as for the calculated variable die land length. It can be seen that the more uniform metal flow is obtained with the calculated die land.

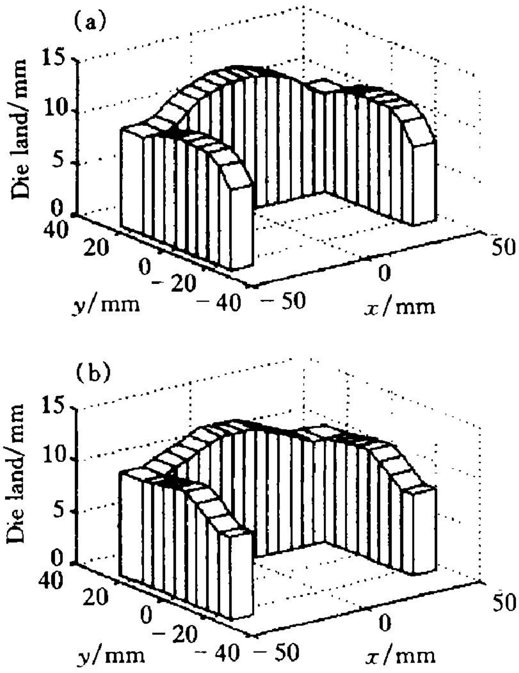

Fig. 5 Configurations of die land
(a) —Calculated result; (b) —Industrial design

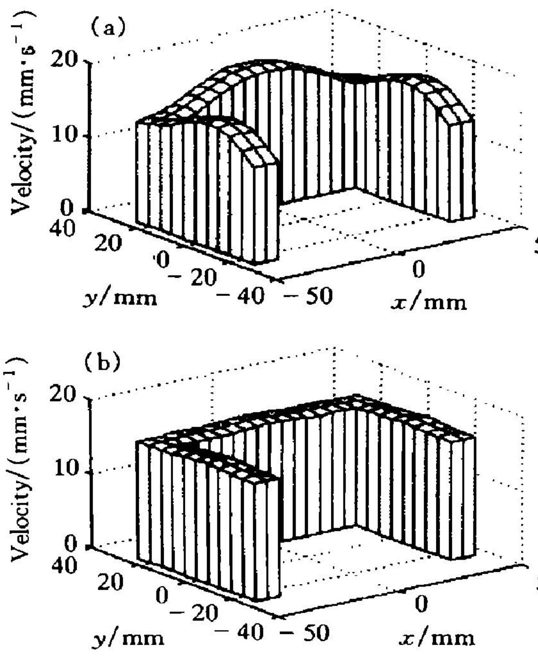

Fig. 6 Distributions of velocity
(a) —Initial die land; (b) —Calculated die land

6 CONCLUSION

In the extrusion of sections with flat-faced die, the proper design of die land is of critical importance in avoiding the generation of geometry defects. A numerical method is proposed for the design of die land. The metal flow in extrusion is simulated by rigid plastic finite element method and the die land length is adjusted according to the simulation result. The uniform metal flow in die land exit is obtained by repeating the simulation-adjust iteration. The extrusion of a C-section shape was chosen as the computational example and the calculated die land is similar to the industrial design. The similarity allows the conclusion that the proposed method is effective for the practical design.

[REFERENCES]

[1] Storen S. The theory of extrusion-advances and challenges [J]. Int J Mech Sci, 1993, 35(2): 1007- 1009.
[2] Park Y B, Yoon J H, Yang D Y. Finite element analysis of steady-state three dimensional helical extrusion of twisted sections using recurrent boundary conditions [J]. Int J Mech Sci, 1994, 36(2): 137- 148.
[3] Yang D Y, Lee C M, Yoon J H. FE analysis of steady state 3-D extrusion of sections through curved dies [J]. Int J Mech Sci, 1989, 31(2): 145- 156.
[4] Mori K, Osakada K, Yamaguchi H. Prediction of curvature of an extended bar with non-circular cross-section by a 3-D rigid plastic finite element method [J]. Int J Mech Sci, 1993, 35(10): 879- 887.
[5] Shivpuri R, Momin S. Computer aided design of dies to control dimensional quality of extruded shapes [J]. Ann CIRP, 1992, 41(1): 275- 279.
[6] Kiuchi M, Yanagimoto J, Victor M. Characterization of three dimensional metal flow in extrusion process [J]. Ann CIRP, 1996, 45(1): 235- 238.
[7] Yang D Y, Kang Y S. Analysis and design of industrial hot extrusion process through square dies for manufacturing complicated Al alloy profiles [J]. Ann CIRP, 1996, 45(1): 239- 243.
[8] Monaghan J. An investigation of plane-strain lateral extrusion to form components having staggered branches [J]. J Mater Proc Tech, 1998, 77(1): 305- 309.
[9] HAO Nan-hai, XUE Ke-min, LU Yan. Numerical simulation on forming process of ear portion of upper case [J]. Trans Nonferrous Met Soc China, 1998, 8(4): 602- 605.
[10] LI Yuan-chun, CUI Jian, YAN Ming-guo. Prediction of surface defects in disk forging process for FGH95 alloy using ring-like billet by computer simulation [J]. Trans Nonferrous Met Soc China, 1998, 8(4): 567- 573.
[11] Kobayashi S, Oh S I, Altan T. Metal Forming and the Finite Element Method [M]. New York: Oxford University Press, 1989. 90- 93.
[12] Altan T, Oh S I, Gegel H L. Metal Forming-Fundamentals and Applications [M]. Cleveland: American Society for Metals, 1983. 55- 58.

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