A SURFACE DEFECT PREDICTION METHOD FOR METAL FORMING PROBLEM①

Peng, Yinghong Ruan, Xueyu
Shanghai Research Institute of Tool & Die Technology, Shanghai Jiao Tong University, Shanghai 200030
Zuo, Tieyong
Department of Science & Technology, State Education Commission, Beijing 100816

ABSTRACT

On the basis of the rigid viscoplastic FEM theories, a surface defect prediction for plastic forming process by FEM numerical simulation has been deeply studied. Some technical treatments and algorithms of defect prediction are proposed. Using this method, the processes of defect initiation and development during CONFORM process are predicted successfully, and some critical technological parameters are obtained. Therefore, it is also an extension for application fields of rigid viscoplastic FEM to predict forming defect.

Key words: continuous extrusion forming surface defect prediction method rigid viscoplastic FEM

1 INTRODUCTION

It is an important subject in industry production to build a quality analysis and protection system. How to predict the initation and development of defects is a keystone of the subject. Meanwhile, it is also an important basis to avoid defect appearance. There are interior and surface defects in plastic forming problems. Many factors could initiate these defects, for example, the interior structures of materials, deforming ways, speed and temperature and structures of dies etc influence on the appearance of defects. In this paper, we study the prediction method of surface defects initiated by unreasonable die structure and getting way of critical structure parameter of dies. The rigid viscoplastic FEM is an effective tool to deal with the large deformation problem, and it has been widely used in simulating many plastic deformation technologies[1-3]. Metal forming process with die is a distinguishing process between the deforming body and the boundary of die, which is also a nature of FEM numerical simulation techniques. Therefore, the autodistinguishing techniques between deforming body and boundary of die and the defect prediction algorithms are proposed in this study. Using defect prediction method, the defect initiation and development during the CONFORM process have been simulated successfully, and the critical technological parameters under which the defects could not appear have been presented. This work provides an important theoretical basis for CAD/CAM of die & mold and technology analysis. It is an extension of application fields for rigid viscoplastic FEM to predict defects, and also a supplement for CONFORM technology criterion.

2 BASIC THEORIES OF RIGID VISCOPLASTIC FEM

The rigid viscoplastic formulation has been extensively used for the analysis material response during metal forming processes. The complete formulation can be found[2]. The basic equations that

① Received Mar. 18, 1994; accepted in revised form May 9, 1994

have to be satisfied during a forming process are:

(1) Equilibrium equation:

$$\sigma_{ij,j} = 0 \tag{1}$$

(2) Strain rate definition:

$$\dot{\varepsilon}_{ij} = 1/2(v_{i,j} + v_{j,i}) \tag{2}$$

(3) Constitutive relation:

$$\sigma'_{ij} = \frac{2\bar{\sigma}}{3\dot{\bar{\varepsilon}}}\dot{\varepsilon}_{ij} \tag{3}$$

(4) Incompressibility condition:

$$\dot{\varepsilon}_{kk} = 0 \tag{4}$$

(5) Boundary conditions:

$$\sigma_{ij} \cdot \boldsymbol{n}_j = \bar{\boldsymbol{F}}_j \quad \text{On the } \boldsymbol{S}_f$$
$$\boldsymbol{v}_i = \bar{\boldsymbol{v}}_i \quad \text{On the } \boldsymbol{S}_v \tag{5}$$

where σ_{ij}, $\dot{\varepsilon}_{ij}$ and $\boldsymbol{v}_i$ are the stress, strain rate and velocity, respectively. V is the volume of the deforming body, and $\boldsymbol{S}_f$, $\boldsymbol{S}_v$ are force surface and velocity surface, respectively. The field equations given above can be solved by a variational principle expressed as:

$$\delta\varphi = \int_v \bar{\sigma} \cdot \delta\dot{\bar{\varepsilon}} \cdot \mathrm{d}v + K\int_v \dot{\varepsilon}_{kk} \cdot \delta\dot{\varepsilon}_{mm} \cdot \mathrm{d}v - \int_S \bar{F}_j \cdot \delta v_j \cdot \mathrm{d}S = 0 \tag{6}$$

where K is a large positive constant to penalize volume change. The variational functional can be converted to non-linear algebraic equations by utilizing the FEM discretization procedure. The solution of non-linear simultaneous equations can be obtained by Newton-Raphson method.

3 SURFACE DEFECT PREDICTION TECHNIQUES

It is the nature of metal forming process that metals flow with the restriction of die so as to satisfy the physic and geometric demands of products. Therefore, the nature of unsteady plastic forming process is distinguishing process between deforming body and boundary of die. The initiation and development of surface defects accompany with this distinguishing process. In a way, it is an important basis for simulating unsteady plastic forming problems to build an accurate distinguishing system. Meanwhile, it is also a keystone for defect prediction. The distinguishing techniques contains: (Ⅰ) mathematics description of die configuration; (Ⅱ) contact judgment of boundary nodes; (Ⅲ) separating judgment of contact node from die; (Ⅳ) correction of contact node.

The computer description of die configuration should satisfy (Ⅰ) the restriction characteristics of die on deforming body can be contained completely; (Ⅱ) the complicated mathematics expression should be avoided; (Ⅲ) the generalization of description method should be considered. For 2-D problem, the configuration of die boundary was described by combination of line, arc and spline. The small arc transition was adopted so as to deal with the velocity singularity problem. The die configuration information is shown in Table 1.

As shown in Fig. 1, the period ($\triangle t$) when the node i could touch on die can be determined by a parametric equation:

$$\begin{aligned} x &= x_i + (v_{ix} - v_{dx}) \cdot \triangle t \\ y &= y_i + (v_{iy} - v_{dy}) \cdot \triangle t \\ y &= F(x) \end{aligned} \tag{7}$$

where (x_i, y_i) is coordinate of node i, its veloci-

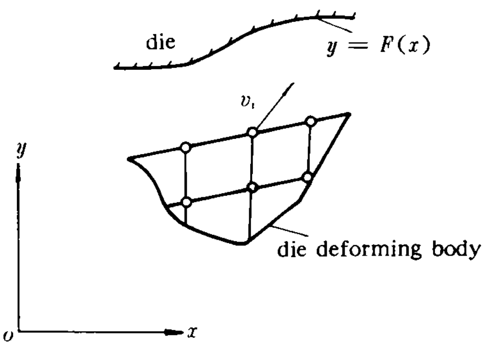

Fig. 1 Algorithm of contacting

Table 1 Information of die configuration

Type	Speed of die	Start point	End point	Control point	Center of arc	Radium of arc	Direction
Line	(v_{dx}, v_{dy})	(x_1, y_1)	(x_2, y_2)	…	…	…	…
Arc	(V_{dx}, v_{dy})	(x_1, y_1)	(x_2, y_2)	…	(x_0, y_0)	R_i	clockwise“-
Spline	(v_{dx}, v_{dy})	(x_1, y_1)	(x_2, y_2)	(x_3, y_3)	…	…	…

ty is (v_{ix}, v_{iy}); $y=F(x)$ is a function of die boundary and its velocity is (v_{dx}, v_{dy}). Assuming the $\triangle t_0$ is the time-increment of FEM analysis, the contact judgment can be expressed as:

$\triangle t \leqslant \triangle t_0$, node i could touch on die

$\triangle t > \triangle t_0$, node i could not touch on die (8)

After node i is determined as contact node, following restriction should be added to node i:

$$v_{in} = v_d \cdot \bar{n} \quad (9)$$

In this way, the node i could not enter the die body.

If the node force component in the normal direction of die surface is positive:

$$F_{in} > 0, \text{ or } \sigma_{in} > 0 \quad (10)$$

the contact node i will separate from die and will become free boundary node. In this case, the normal force acting on the node i is a tension. After determining the separating nodes, the velocity restriction (9) should be removed from these nodes.

After velocity restriction had been added to contact node, it is ensured that the normal direction speed of contact node is the same as that of die. However, the situations could appear as shown in Fig. 2, after updating coordinate of node. The node i could move to i' and separate from die(as shown in Fig. 2(a)). In another case, the node i could move to i' and enter to die (as shown in Fig. 2(b)). At this time, the placement of node i has to be corrected so as to describe the forming process accurately.

The correction method is shown in Fig. 2. Because the time-increment $\triangle t_0$ is very small, we can obtain following relations:

$$\overline{ii'} \approx \widehat{ii''}, \text{ so } \overline{ii''} \approx \widehat{ii''}$$

Therefore, the i'' can be regarded as correct placement of node i after updating coordinate. After correcting the place of node i to i'', the velocity restriction should also be corrected respectively:

$$v_{in} = v_d \cdot n_i$$
$$v_{i\tau} = v_{ix} \cdot T_{i1} + v_{iy} \cdot T_{i2} \quad (11)$$
$$v_{in} = -v_{ix} \cdot T_{i2} + v_{iy} \cdot T_{i1}$$

where T_{ij} is the coordinate transform matrix.

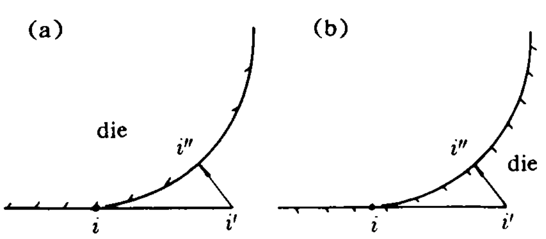

Fig. 2 Correction of contact nodes

4 DEFECT PREDICTION OF CONFORM PROCESS

As can be seen in Fig. 3, the deformation mechanism of CONFORM can be regarded as a side-extrusion with a leak gap through which metal could flow. In general side-extrusion forming process, the surface defect would appear at the bottom of die if $W > H$[4]. For CONFORM, $W > H$ is allowed because there is a leak gap $\triangle h$. Therefore, it is an important task in defect prediction to determine the critical values of W/H.

Based on the defect prediction techniques mentioned above, the initiation and development of surface defect during CONFORM deformation process has been simulated by rigid viscoplastic FEM. In order to determine the critical technological parameters, some special treatments should be considered when analyzing surface defect. When node i is decided as separating node according to state of its node force, the placement of node i is on the boundary of die. In this case, the following three special treatments have to be considered in order to avoid the node i entering in die:

(1) If $v_i=0$, node i is defined as contact node;

(2) If $v_i \neq 0$ and node i moves in entering to die direction, node i is defined as contact node;

(3) If $v_i \neq 0$ and node i moves in separating from die direction, node i is defined as separating node.

The initiation and development of surface defect during CONFORM process are shown in

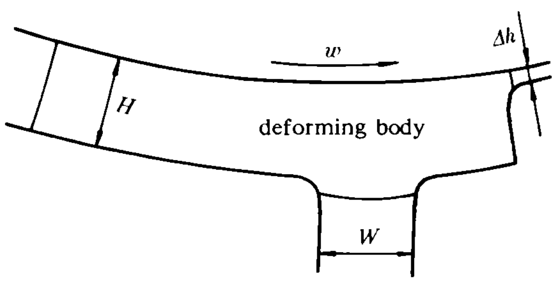

Fig. 3 CONFORM process

Fig. 4. When $W > H$, metals flow easily through the die hole(W), and a cave forms at the bottom of die because some nodes separated from the bottom of die at this time which can be seen in Fig. 4 (a). In further deformation process, the cave becomes larger because more nodes separated from the bottom of die as seen in Fig. 4(b). Finally, a surface defect appears as shown in Fig. 4(c). As we can see in Fig. 4, the density of FEM grids should be increased in order to simulate the initiation of surface defect accurately. Therefore, we can say that the rigid viscoplastic FEM is an effective tool to predict defect during metal forming.

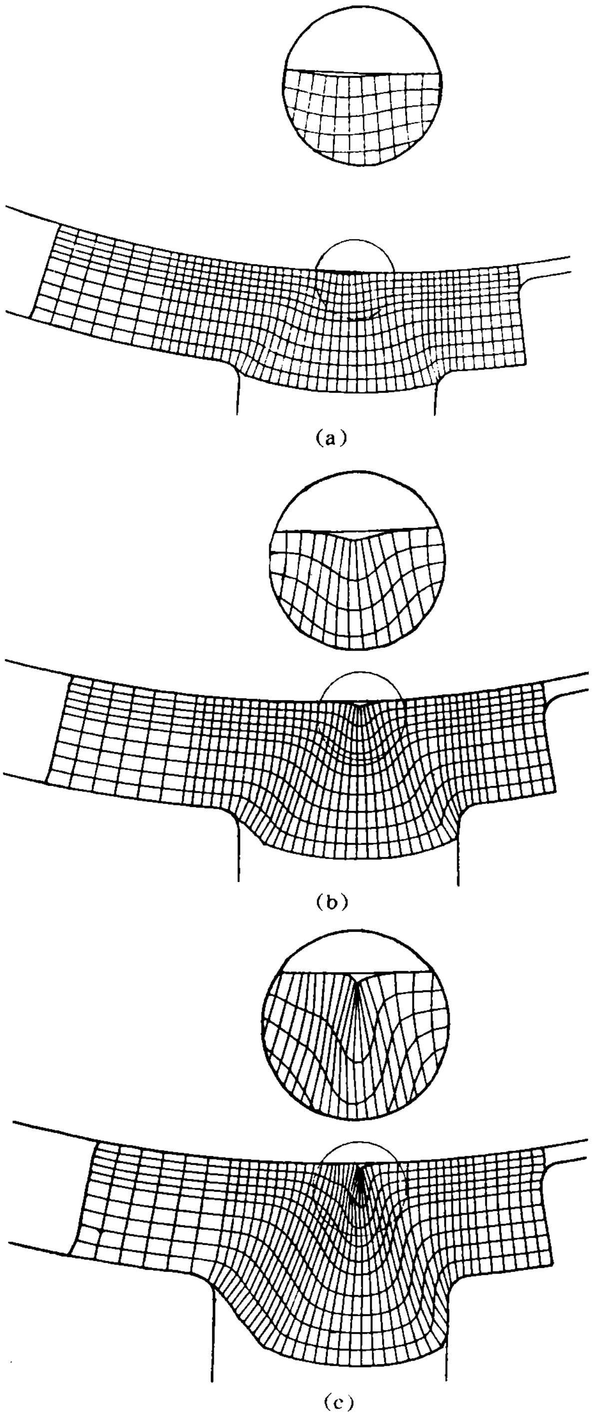

Fig. 4 Surface defect prediction

The critical technological parameters of the CONFORM are obtained by numerical simulation as shown in Table 2.

Table 2 Critical technological parameters of CONFORM

Leak gap: $\triangle h$ /mm	Friction factor: m	Height: H /mm	Critcal value: W/H
1	0.5	10	1.62
1.5	0.5	10	1.84
2	0.5	10	2.14
2.5	0.5	10	2.22

5 CONCLUSION

The auto-distinguishing techniques between deforming body and boundary die built in this paper are important basis not only for accurate numerical simulating of metal forming process but also for surface defect prediction. It should be declared that the density of FEM grids should be increased in order to ensure the accuracy of defect prediction when predicting the initiation of surface dedct.

REFERENCES

1 Zienkiewicz, O C; Godbole, P N. Int J for Num Meth In Eng, 1974, 8: 3.
2 Kobayashi, S; Oh S I; Altan, T. Metal Forming and the Finite Element Method. London: Oxford University Press, 1989.
3 Osakada, K. In: Proc 4th Int Conf Prod Eng, Tokyo, 1980.
4 Johnson, W; Hudo, H. The Mechanics of Metal Extrusion. Manchester: Manchester University Press, 1962. 56—57.