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Simulation of die wall friction's effect on density distribution in metallic powder compaction①

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[Abstract] A computer simulation procedure for metal powder die compaction was described. Friction behavior of metal powder during cold compaction was simulated by the finite element method. The movement of powder relative to the die wall was taken into consideration by utilizing the shear friction model. Friction between the powder and the rigid die wall leads to inhomogeneous density distribution during the compaction process. The floating die technique and double punch pressing can attain more homogenous compacts than the fixed die technique can do. The results obtained from numerical analysis agree well with the experimental results. Simulation model was built in MSC. Mentat, and MSC. Marc software was used to calculate the powder compaction process.

[Key words] powder compaction; friction; computer simulation; finite element method
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1 INTRODUCTION

Die compaction of powder has been used in components manufacturing in different fields[1~4]. In engineering applications, green compacts with uniform density are usually required. Density inhomogeneity can be caused by friction owing to relative slip between powder particles and die wall. Powder forming has evolved into an important manufacturing technique for producing high-performance components economically in the metal-working industry because of its low manufacturing cost compared with conventional metal forming processes. Friction is a complex physical phenomena that involve surface characteristics, normal pressure, and relative velocity etc. The physics of friction continues to be a topic of research in the coming years[5].

Finite element method is a popular tool for simulating metal forming processes such as extrusion, sheet forming and casting. However, applications mostly are concentrated on incompressible, dense materials. In the case of powder compaction process, despite the fact that powder metallurgy is very attractive in energy and material saving, finite element analyses in powder compaction are very limited because of the following difficulties:

1) The choice of suitable yielding criteria;

2) The friction algorithm describing interaction at the powder/wall interface.

In this paper, Shima yield function, a modified von-Mises criteria, is used. The shear friction model is utilized to treat the problem of the relative movement at the die/powder interfaces.

2 FEM SIMULATION

2.1 Yielding criteria

During die compaction the predominant densification is caused by the plastic deformation of metal powder. Various plasticity theories for porous materials have been proposed by several authors[6~14]. In these theories the porous material has been identified as a powder aggregate consisting of voids and a solid matrix. Physical properties of such a material are closely related to internal variable such as relative density ρ, which in turn is defined as the ratio of apparent density to maximum theoretical density. In order to characterize the plastic behavior of powder deformation, the present analysis uses a modified von-Mises plasticity theory for porous materials as proposed by Shima et al[7,15]. The yield function is

$$F = \frac{1}{\gamma}\left[\frac{3}{2}\sigma'_{ij}\sigma'_{ij} + \frac{p^2}{\beta^2}\right]^{1/2} - \sigma_y \qquad (1)$$

Where σ_y is the uniaxial yield stress, σ'_{ij} is the deviatoric stress tensor, p is the hydrostatic pressure, γ and β are material parameters.

2.2 Friction modeling

It is convenient using the Coulomb Function model for the single punch compaction, as shown in Fig. 1(a). However, in the case of the double punch pressing (as shown in Fig. 1(b)), the unknown rela-

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tive moving direction at the die/workpiece interface makes it difficult to handle the boundary condition in straightforward manner.

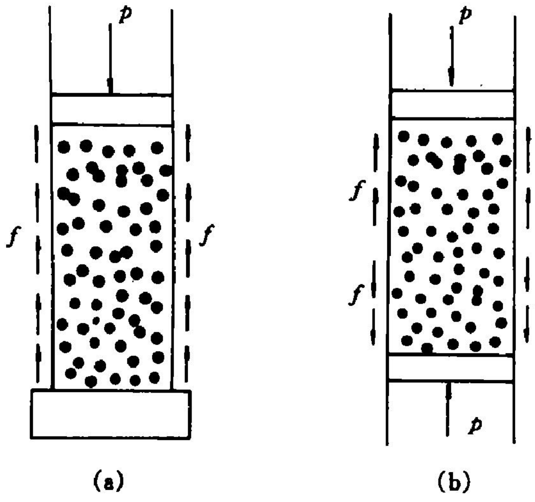

Fig. 1 Schematic diagrams of die wall friction
(a) —Single punch pressing;
(b) —Double punch pressing

The shear based model states that the friction stress is a function of the equivalent stress in the material:

$$\sigma_{fr} \leqslant - m \frac{\bar{\sigma}}{\sqrt{3}} \boldsymbol{t}$$

$$\boldsymbol{t} = \frac{\boldsymbol{v}_r}{|v_r|} \qquad (2)$$

where $\bar{\sigma}$ is equivalent stress, σ_{fr} is tangential stress, $\boldsymbol{t}$ is the tangential vector in the direction of the relative velocity, $\boldsymbol{v}_r$ is the relative sliding velocity, and m is the friction factor.

Again, this model is implemented using an arctangent function to smooth out the step function:

$$\sigma_{fr} \leqslant - m \frac{\bar{\sigma}}{\sqrt{3}} \cdot \frac{2}{\pi} \arctan \frac{v_r}{v_0} \cdot \boldsymbol{t} \qquad (3)$$

Physically, the value of v_0 is the value of the relative velocity when sliding occurs. The value of v_0 is important in determining how closely the mathematic model represents the step function. A very large value of v_0 is a reduced value of the effective friction. A very small value results in poor convergence. It is recommended that value of v_0 be 1 % or 10 % of a typical relative sliding velocity v_r.

2.3 Simulation results

MSC. Marc was applied to simulate the process of powder compaction. Simulation model is built in MSC. Mentat[15]. Fig. 2 shows density distribution after single punch powder pressing when the maximum pressure of the punch is 500 MPa. On the upper surface, which is contact with the punch, the density increases gradually from the center to the edge. The density is the largest on the edge of the upper surface. The density decreases from the top to the bottom on the longitudinal direction. Maximum value of the relative density is 0.918 3. Minimum value of the relative density is 0.791 4. At area near the wall, owing to the friction, axial pressure reduced more than that at the central area, which leads to the lower density on the edge of bottom surface.

The total force of compaction process includes net force and friction. It is this kind of friction that leads to the inhomogeneous density distribution during the single punch compaction process. With compact height increases, density distribution inhomogeneity increases correspondingly. On the contrary decrease of the compact height will obtain more homogenous density distribution.

Fig. 3 shows density distribution when the

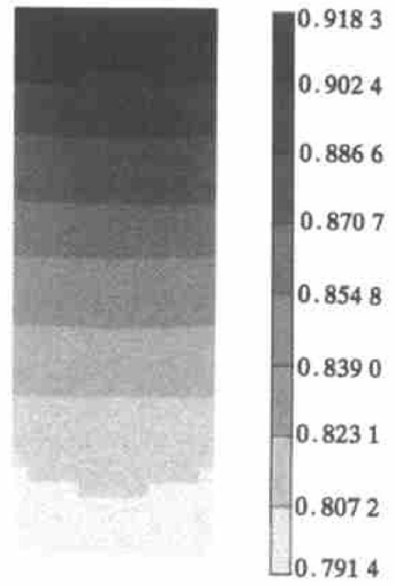

Fig. 2 Simulated relative density distribution for single punch pressing

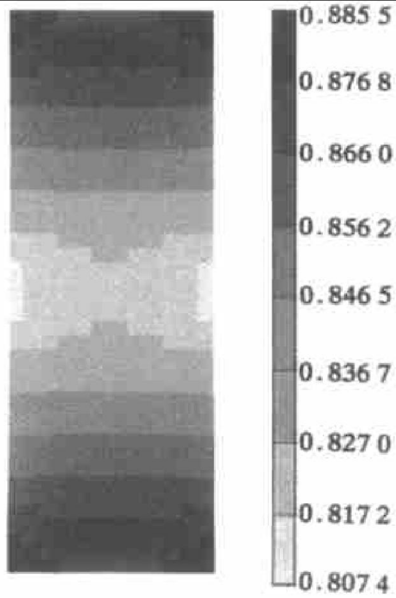

Fig. 3 Simulated relative density distribution for double punch pressing

maximum pressure of the punch is 500 MPa after the double punch pressing. The double punch pressing can reduce inhomogeneous density distribution to a great extent. With this method, the material near the upper punch and lower punch has higher density than that of the material in the middle. Maximum value of the relative density is 0.885 5. Minimum value of the relative density is 0.807 4. From these two figures, It can be seen that in single punch compaction, average density of the section decreases straight from the top to the bottom, but during double punch compaction, the density distribution inhomogeneity is greatly improved although an area with lower density still exists in the middle part.

Using lubricated low-roughness die can reduce the wall friction, thereby can improve the density distribution.

3 EXPERIMENTAL

In practice, floating die compaction is widely adopted instead of the double punch pressing. Fig. 4 shows the diagram of the floating die compaction. During floating die compaction, the force of the upper punch is the sum of the force on the lower punch plus the force on the springs. The force on the springs are the force that supports the die, it is less than 100 N. Meanwhile, the upper punch force reaches to 90 kN. Owing to the fact that the force on the springs is much smaller than the force on the punches, the force on the springs can be ignored. The force of the upper punch is approximately equal to the force of the lower punch. The friction condition between the powder and the die wall during powder densification process in floating die compaction is almost the same as that in double punch pressing. When the force on the springs is ignored, the floating die compaction is

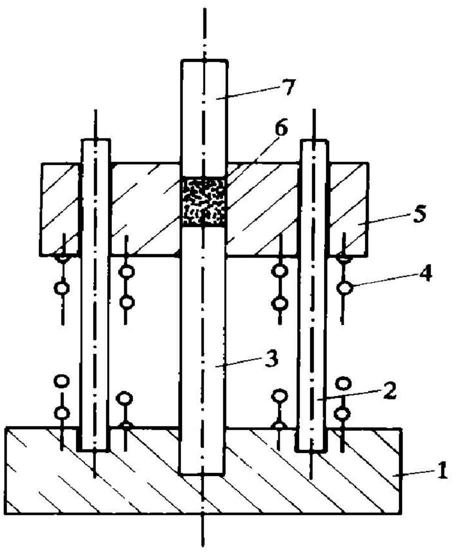

Fig. 4 Diagram of floating die method
1 —Supporter base; 2 —Pin; 3 —Lower punch; 4 —Spring; 5 —Die; 6 —Powder; 7 —Upper punch

the same as the double punch pressing. In order to make the experimental results comparable between the floating die method and the single punch method, the assembly structure of the die for floating die pressing was modified, as shown in Fig. 5. The same die and punch were used when the single punch powder compaction experiments were carried out. The experimental equipment used for powder compaction is a universal tensile testing machine. Fig. 6 shows the plots of the relative density variation versus the height of sample obtained by simulation and experiments respectively when the maximum pressure of the punch is 500 MPa. From the experiment results, the trends of relative density distribution agree well with the analysis results.

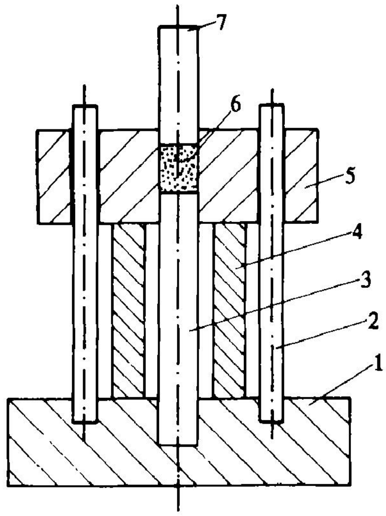

Fig. 5 Diagram of single punch method
1 —Supporter base; 2 —Pin; 3 —Lower punch; 4 —Ring; 5 —Die; 6 —Powder; 7 —Upper punch

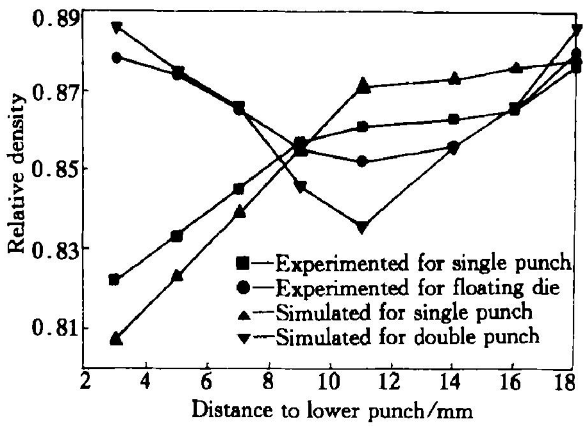

Fig. 6 Curves of density variation vs distance to the lower punch

4 CONCLUSIONS

The effect of die wall friction was studied and simulated, and the following conclusions can be drawn:

1) Die wall friction leads to inhomogeneous den-

sity distribution. FEM simulation and experiment show that floating die method and double punch pressing can reduce the effect of friction on density distribution. Density distribution achieved by floating die and double punch pressing is more homogeneous than that achieved by single punch fixed die pressing.

2) The shear friction model can be used for simulation in the case of double punch pressing where the direction of the relative motion is uncertain.

3) The results for FEM simulation agree well with the experimental results.

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