Densification Behavior of Metal and Ceramic Powder under Cold Compaction

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Abstract

Densification behavior of various metal and ceramic powder was investigated under cold compaction. The Cap model was proposed based on the parameters obtained from axial and radial deformation of sintered metal powder compacts under uniaxial compression and volumetric strain evolution. For ceramic powder, the parameters were obtained from deformation of green powder compacts under triaxial compression. The Cap model was implemented into a finite element program (ABAQUS) to compare with experimental data for densification behavior of various metal and ceramic powder under cold compaction.

Keywords : Cap Model, Cold Isostatic Pressing, Constitutive Model, Densification, Die Compaction

1. Introduction

In this work, the Cap model was developed to predict densification of various ceramic powders as well as metal powders under the general stress state. This model does not need the flow stress of a fully dense metal material and repeated triaxial compression tests, compared to previous models. For metal powder, the Cap model adapted the parameters obtained from the uniaxial compression test and experimental data during cold isostatic pressing, based on the relationship of the stress invariants and the principal and volumetric strain increments under deformation of powder compacts. For ceramic powder, the parameters in the proposed Cap model were obtained from triaxial compression test of silicon carbide powder and were evaluated for the densification behavior of other ceramic powders. Based on the determined parameters and the volumetric strain evolution of each kind of metal and ceramic powder, the proposed Cap model was implemented into a finite element program (ABAQUS) to compare with experimental data under cold compaction.

2. Determination of the parameters in the model and finite element analysis

The yield function for densification behavior of powder can be written as

$$F = \{(p / f(D))^2 + q^2\}^{1/2} - k(D) \qquad (1)$$

where p and q are hydrostatic stress and the effective stress, respectively, and $f(D)$ and $k(D)$ are the functions related to relative density. In uniaxial compression, *f(D)* can be obtained as [1]

$$f(D) = \frac{\sqrt{2}}{3}\left(\frac{d\varepsilon_1 - d\varepsilon_2}{d\varepsilon_v}\right)^{1/2} \qquad (2)$$

Substituting the principal stresses under hydrostatic stress state into Eq. (2), hydrostatic stress, p can be written as

$$p = f(D)k(D) \qquad (5)$$

Lee and Kim [2] carried out triaxial compression test for aluminum alloy powder under a general stress state and investigated on densification behavior of powder under cold compaction. During triaxial compression, confining pressure (σ_c) is applied to a cylindrical specimen in the radial direction. Then, we obtain a function $f(D)$ with terms, p and q, under triaxial compression condition as follows:

$$f(D) = \sqrt{\frac{2}{3}}\left(-\frac{p(d\varepsilon_1 - d\varepsilon_2)}{q d\varepsilon_v}\right)^{1/2} \qquad (4)$$

Shima and Oyane obtained the material parameters, $a = 2.49, m = 0.514$ from the curve-fitting of uniaxial compression data based on the following equation in the case of D_f=1.

$$f(D) = 1 / a(D_f - D)^m \qquad (5)$$

3. Results and Discussion

Fig. 1 shows experimental data obtained from Eq. (4) through triaxial compression of aluminum alloy powder

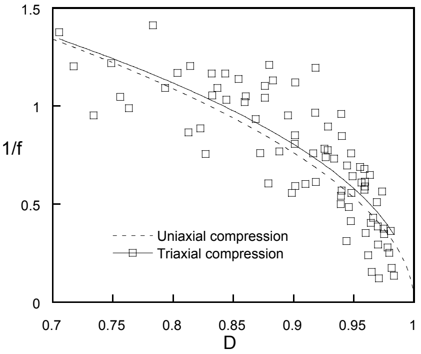

Fig. 1. Comparison between parameters, *1/f* obtained by triaxial compression test and uniaxial compression test for Al6061 powder.

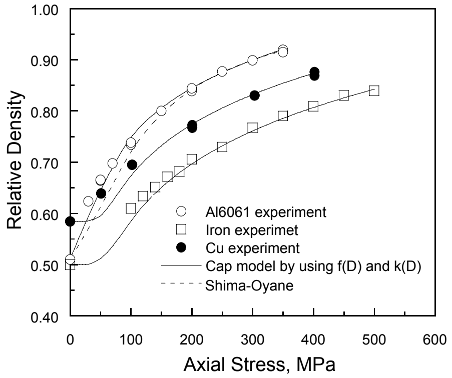

Fig. 2. Comparison between experimental data and finite element calculations from the Cap model for the variation of relative density with axial stress of metal powder during die compaction.

and the fitted curves by using Eq. (5). Then $a = 2.39$ and $m = 0.472$ were obtained in Eq. (5). Shima and Oyane determined material parameters from uniaxial compression test for sintered soft metal powders such as aluminum and copper. Such uniaxial compression tests are difficult to be carried out on green compacts in the overall density range since metal and ceramic green compacts do not have enough strength to induce the sufficient strain level to be measured. The solid curve representing the relationship between $1/f$ and D from triaxial compression test by Lee and Kim is almost the same as the dotted curve from uniaxial compression test by Shima and Oyane. Thus, it represents that $f(D)$ can also be determined for brittle ceramic powder as well as metal powder through triaxial compression by using Eq. (4). As observed in Fig. 2, the finite element results from the proposed Cap model by using Eq. (1), (2), and (3) agree well with experimental data for various metal powder during die compaction. The Shima-Oyane model predicts relatively well densification behavior of aluminum alloy powder, but underestimates at low density region because it was developed based on uniaxial compression test of sintered metal compacts whose strength may be different from a green compact. Since only uniaxial compression test was carried out for sintered metal powder and the solid material (D=1), the model may be difficult in predicting well the densification of metal powder under hydrostatic stress during cold isostatic pressing. Fig. 3 shows comparisons between experimental data of various ceramic powder and finite element calculations for the variation of relative density with axial stress during die compaction. It was also observed that the finite element results for silicon carbide and alumina powder agreed relatively well with experimental data during die compaction, although underestimated in the low density region.

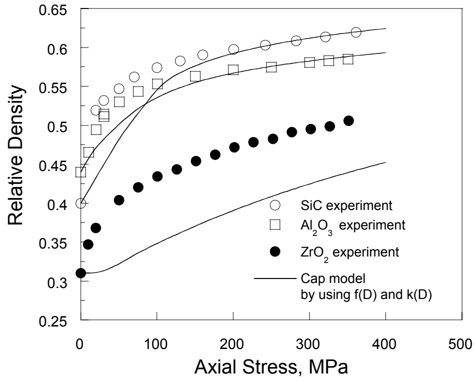

Fig. 3. Comparison between experimental data of ceramic powder and finite element calculations from the Cap model for the variation of relative density with axial stress during die compaction.

4. Summary

In the present paper, the Cap model was proposed by using the parameters involved in the empirical yield function for sintered metal powder and volumetric strain evolution under cold isostatic pressing. The finite element results from the Cap model agree well with experimental data of metal and ceramic powder better than the Shima-Oyane model for metal powder under compaction processes where hydrostatic stress is dominantly subjected to powder compacts. The Cap model agrees well with experimental data for densification of ceramic powders having the similar fracture.

5. References

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