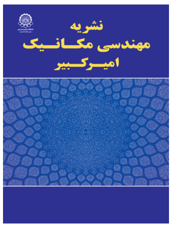

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Experimental Determination of the Modified Drucker-Prager Cap Constitutive Model for 92 Percent Alumina Powder

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ABSTRACT: In this research, the deformation behavior of the commercial ready to press 92 percent alumina powder has been investigated using the modified Drucker-Prager cap model. This model is a multi-surface yield model for the description of the plastic behavior of powders during consolidation. To this end, parameters of the model as functions of density were obtained by means of experiments. The constants of the shear failure yield surface were obtained based on simple diametric and axial compressive loading cylindrical specimens with various relative densities. For determining the remaining parameters of the model, an instrumented die fitted with strain gage and load cell was designed and fabricated. Parameters of the cap surface were achieved based on the uniaxial die compaction experiments. Based on consecutive loading-unloading tests using the instrumented die, the friction coefficient and elastic moduli were derived from loading and unloading phases respectively. For finite element simulation of the uniaxial compaction, density-dependent material parameters were employed in ABAQUS. The variations of density were taken into account using a user-defined filed variable subroutine. Simulation results prove a very good agreement with the experimental counterpart.

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1. Introduction

One of the popular techniques for forming ceramic powders is die compaction. The complex behavior of powders during compaction impacts the properties of the final components. Therefore, it is essential to predict the flow of powder during compaction. This can be achieved by employing proper constitutive models in finite element analyses. Several constitutive models including Cam-Clay [1] and Modified Drucker-Prager CAP (MDPC) [2] for describing porous media could be found in the literature. The calibration of the parameter of these constitutive models for a specific material is a major issue. Particularly for MDPC model, special triaxial test instruments are required. Therefore, combining simple axial test data obtained from an instrumented die with optimization techniques can result in a more cost-effective method for calibration of the model [3-6]. In this paper the density-dependent parameters of MDPC model for alumina powder KMS92 (Martinswerk, GmbH) have been obtained through conducting diametral and axial compression tests and multiple-step uniaxial tests performed using an instrumented die. The elastic moduli of the powder at different densities were determined from the unloading part of the multiple-step uniaxial compaction data. In order to consider the density variations in the finite element simulation with ABAQUS, the USDFLD subroutine was implemented in the analyses. Finally, the experimental and simulation load-displacement curves were compared.

2. Finite Element Model

The MDPC yield surfaces in p-q plane are shown in Fig. 1. Here p is hydrostatic pressure and q is effective stress.

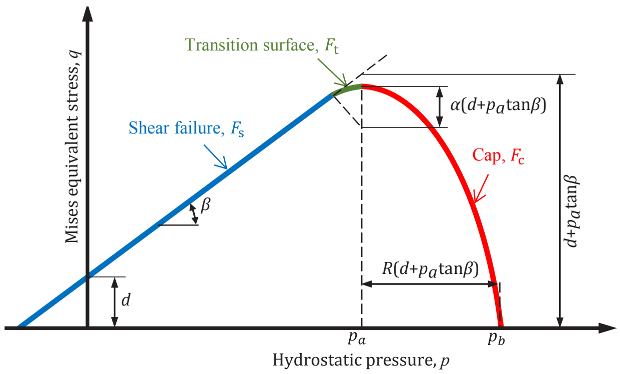

Fig. 1. Yield surface of modified Drucker-Prager CAP (MDPC) model

The equations of these surfaces are given in Eqs. (1) to (3).

$$F_s = q - p\tan\beta - d = 0 \quad (١)$$

$$F_c = \sqrt{(p-p_a)^2 + \left[\frac{Rq}{1+\alpha-\alpha/\cos\beta}\right]^2} - R(d+p_a\tan\beta) = 0 \quad (٢)$$

$$F_t = \sqrt{(p-p_a)^2 + \left[q - \left(1-\frac{\alpha}{\cos\beta}\right)(d+p_a\tan\beta)\right]^2} - \alpha(d+p_a\tan\beta) = 0 \quad (٣)$$

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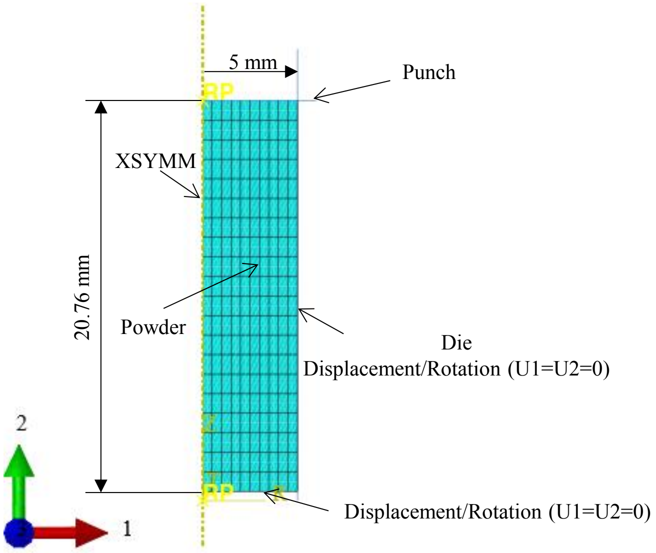

Fig. 2. Finite element model used for simulation of the multiple-step uniaxial compaction process

here β is friction angle, d is cohesion, R is eccentricity, α is a small constant, pa is evolution parameter and pb is hydrostatic yield stress. For calibration of the MDPC model these parameters must be determined. For determination of β and d, diametral and axial compression tests. The parameters related to the cap surface, namely R and pa, are determined using an instrumented die. In addition the elastic moduli of the material are determined based on the unloading part of the multiple-step uniaxial compression test.

The uniaxial compaction model is shown in Fig. 2. The analyses were performed using ABAQUS/Standard solver. In order to consider the density variations, USDFLD subroutine was implemented in the analyses.

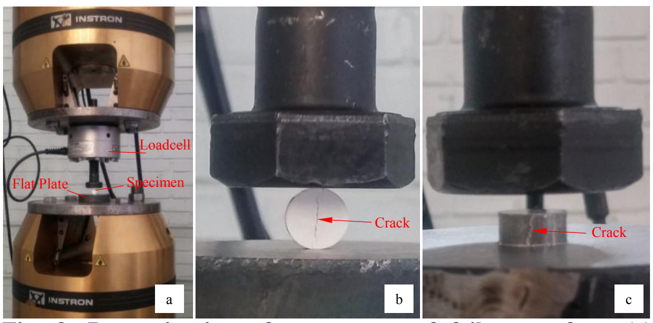

Fig. 3. Determination of parameters of failure surface, (a) experimental setup, (b) diametral compression and (c) axial compression

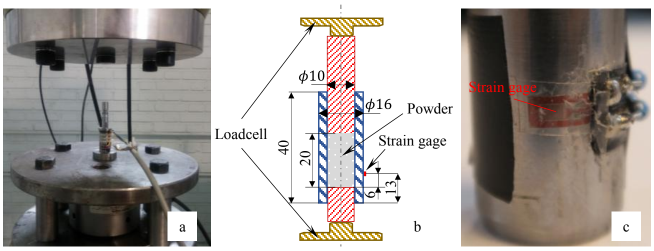

Fig. 4. Structure of instrumented die used for uniaxial compaction tests

3. Experimental Procedure

For determination of β and d, diametral and axial compression tests were performed as shown in Fig. 3. The samples are one gram disks of KMS92 were compacted at different densities. In addition, the setup for instrumented die compaction is given in Fig. 4.

4. Results and Discussions

After the determination of the model parameters, in order to make sure about the accuracy of model calibration, the uniaxial compaction test was simulated in ABAQUS. The load-displacement curves obtained from experiment and simulation are compared in Fig. 5. The figure represents a very good correlation between the two sets of data. Therefore, it can

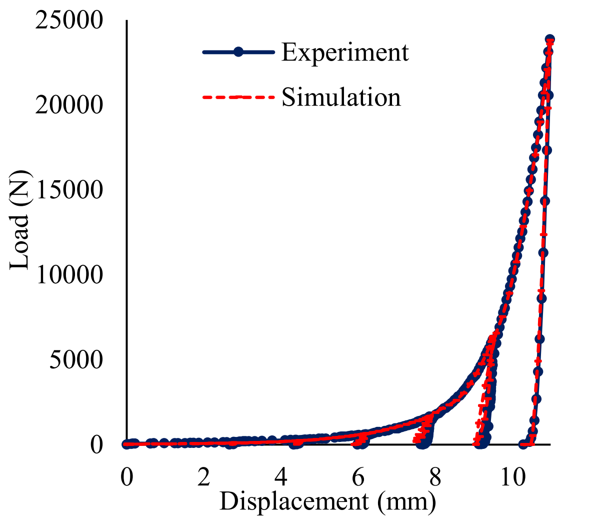

Fig. 5. Comparison of experimental and simulation curves obtained for uniaxial die compaction

be stated that the accuracy of the calibration is desirable. The distribution of density of the green compact can be estimated based on the analysis results. Fig. 6 depicts the distribution of density and stress components after removal of the upper punch. From the figure, it is clear that regions near the upper punch and at the periphery of the sample acquired maximum density. In addition, the compact is still under stress and after removal from die, its diameter will increase.

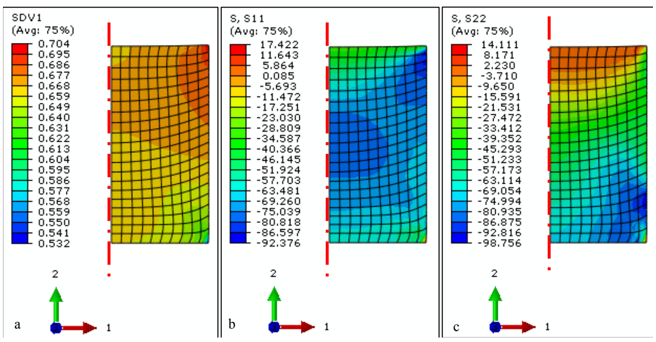

Fig. 6. Distribution of (a) relative density and (b) radial and (c) axial stresses after unloading

5. Conclusions

The parameters of the modified Drucker-Prager cap model for alumina powder KMS92 were determined using simple diametral and axial compression and uniaxial compaction tests in an instrumented die. The results demonstrate that the method can give accurate values for model parameters.

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