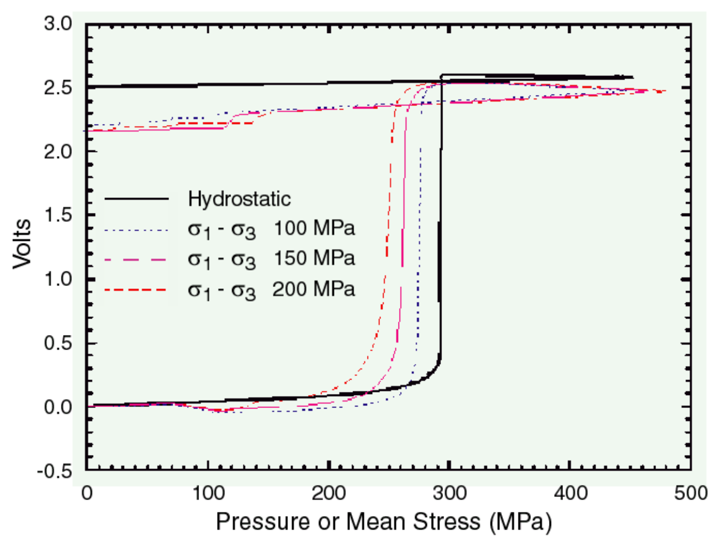
Mechanics of Powder Compaction for Ceramic Manufacturing

Need

Ceramic powders are commonly pressed into dies to produce near-net-shape "green" bodies prior to final sintering. Density gradients in the resulting compacts may cause distortions in the shape of the parts during sintering , necessitating expensive machining or grinding operations to obtain the desired final shape. Nonuniform shrinkage may even generate internal stresses that are sufficiently large to cause fracture of the parts during sintering. Equally importantly, these density gradients can result in green bodies that break during ejection from the die or that are too fragile to be handled.

Increasingly, finite element methods are being used to analyze the causes for density gradients in green compacts. The ultimate objective is to develop comparatively inexpensive numerical models for the pressing process that can optimize the die geometry and pressing method (e.g., single- versus double-acting punches) for a given powder before a single part is even pressed.

Numerical models for the compaction process require, as inputs, constitutive models and mechanical properties for the powder, as well as information on the frictional properties of the powder against the die. Plasticity models developed from the disciplines of soil mechanics and geomechanics turn out to be well-suited for application to the powder compaction problem. Like soils and other granular media, ceramic powders are pressure-sensitive, dilatant materials whose properties vary greatly as functions of confining pressure and density. Substantial differences in mechanical properties exist from powder to powder, depending uppon such variables as powder composition, grain aggolmerate size and shape, binder type and amount, etc. By their interaction with the die during pressing, these properties turn affect the homogeneity with which the powder compacts.



Axial, lateral and volumetric strain response for 99.5% alumina powder deformed at a confining pressure of 34.5 MPa (5000 psi) and a strain rate of 10^{-4} s^{-1}. Unload/reload cycles appear as sharp drops in the stress difference.

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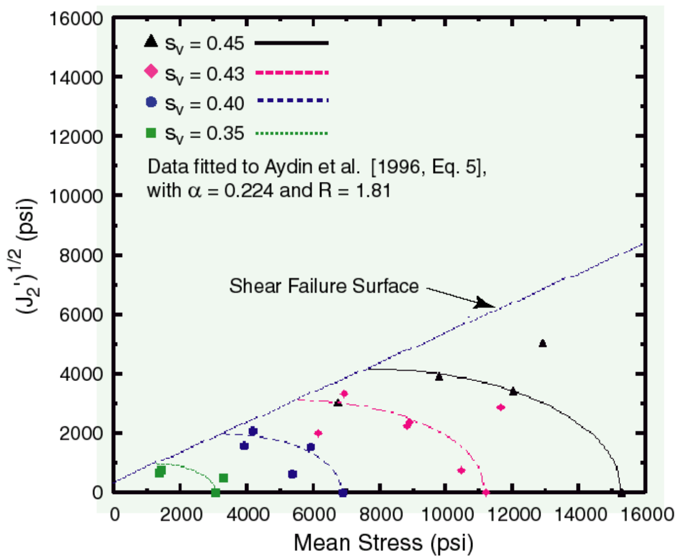
compression for several different ceramic powders. Powders are first pressed hydrostatically in cylindrical rubber jackets to differing final pressures in order to obtain pressure-density relationships. From these pressing experiments, a suite of triaxial test specimens results. The powder compacts are machined into right circular cylinders, and each specimen is tested in deviatoric loading at a confining pressure corresponding to the last pressure "seen" during the hydrostatic testing stage.



Evolution of the "cap" for a 94% alumina powder as inferred from movement of surfaces of constant volume strain.

In addition to the stress-strain response, the bulk modulus, Young's modulus and Poisson's ratio are determined using unload/reload cycles performed many times during the course of each test. Shear modulus is calculated from the other parameters, assuming material isotropy. Shear failure surfaces are determined for each powder, and the shape of the "cap" can be inferred from the data, as well. Over the range of pressures that we have investigated (3.4-69 MPa), the various elastic parameters are functions of pressure and density; they also vary systematically with deviatoric strain during the course of a single test.

Examples

We have shown that differences in mechanical properties, shear failure surfaces and cap shapes are detectable and systematic for different alumina powders in both hydrostatic and triaxial compression [Zeuch et al., 1998; in preparation]. The experimental results are also currently being used in the "Sandia cap model", a modified Drucker-Prager cap-plasticity model. The model is implemented using finite element methods, in order to estimate the effects of the differing mechanical properties on pressing results for simple die geometries [Argüello et al., 1998]. Work is in progress to characterize a zirconia powder.

The next stage of the experimental program will entail careful testing to identify the specific factor(s) responsible for the differences in mechanical properties amongst ceramic powders. We will also attempt to confirm the model predictions by direct investigation of density gradients in the resulting compacts.

References

Argüello, J. G., A. F. Fossum, K. G. Ewsuk and D. H. Zeuch [1998]. Powder Compaction Simulation Using Finite Element and Cap Plasticity Constitutive Laws. Presented at the 100th Annual Meeting of the American Ceramic Society, 3-6 May 1998, Cincinnati, Ohio.

Zeuch, D. H., J. M. Grazier, K. G. Ewsuk and J. G. Argüello [1998]. Comparison of the Mechanical Properties of Micron- and Submicron Size Alumina Powders. Presented at the 100th Annual Meeting of the American Ceramic Society, 3-6 May 1998, Cincinnati, Ohio.

Zeuch, D. H., J. M. Grazier, J. G. Argüello and K. G. Ewsuk [in preparation]. Measurement of the Mechanical Properties and Shear Failure Surfaces of Two Alumina Powders in Triaxial Compression. To be submitted the Journal of the American Ceramic Society.

Contacts

J. Guadalupe (Lupé) Argüello
Engineering and Manufacturing Mechanics Department
Sandia National Laboratories
Albuquerque, NM 87185-0437
Telephone: (505) 844-1482
Fax: (505) 844-9297
e-mail: jgargue@sandia.gov

Kevin G. Ewsuk
Materials Processing Department
Sandia National Laboratories
Albuquerque, NM 87185-1349
Telephone: (505) 272-7620
Fax: (505) 272-7304
e-mail: kgewsuk@sandia.gov