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Common ceramic component manufacturing typically involves the processing of the raw materials in powder form. Granulated powder is formed into a “green” body of the desired size and shape by consolidation, often by simply pressing nominally dry powder. Ceramic powders are commonly pressed in steel dies or rubber bags with the aim of producing a near-net-shape green body for subsequent sintering. Density gradients in these compacts, introduced during the pressing operation, are often severe enough to cause distortions in the shape of the part during sintering due to nonuniform shrinkage. In such cases, green machining or diamond grinding operations may be needed to obtain the desired final shape and size part. In severe cases, nonuniform shrinkage may even cause fracture in the parts during sintering. Likewise, density gradients can result in green bodies that break during ejection from the die or that are too fragile to be handled during subsequent processing. Empirical relationships currently exist to describe powder compaction but provide little understanding of how to control die design or compaction parameters to minimize density gradients thereby forcing the designer to use expensive and time consuming trial and error procedures. For this reason, interest has grown in developing computational tools to address this problem (Aydin et al., 1996 and Coube, 1998).

The goal of the present work was to develop a general continuum-based finite element model for ceramic powder compaction that can be used to aid and guide the design and pressing of ceramic compacts. Such a model can be used to improve both part and die/bag pressing design, resulting in more efficient and cost effective ways to make better parts. The development of this technology followed several distinct steps to arrive at a general purpose three-dimensional finite element tool:

1. We identified a mathematical material description (constitutive model) capable of predicting ceramic powder consolidation response, in the form of a multi-surface plasticity model which is typically referred to as a Cap-Plasticity model (Sandler and Rubin, 1979);
2. We identified, extended, and implemented a testing methodology to characterize specific ceramics powders in a manner consistent with the constitutive description above to allow estimation of parameters for the model;
3. We implemented the constitutive model within a more general purpose, established, and accepted numerical simulation technique (i.e., the finite element method, FEM) as embodied within the nonlinear, inelastic, large deformation finite element program, JAS3D (Blanford, 1998); and
4. We verified and validated the predictive capability afforded by the overall model.

The resulting tool can predict forming stresses, density gradients, and material flow to investigate the effects of compact geometry, compaction ratio, pressing conditions (single, dual, hydrostatic pressing), die-wall friction coefficient, and die design (tapers, corner radii, etc.).

This tool constitutes part of the general underlying software, referred to as the Sandia finite element “toolkit,” that is available to model even the most complicated three-dimensional ceramic
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compacts envisioned. Effective use the software at this level, however, requires significant finite element modeling expertise, insight into the underlying mechanics of the compaction process, and experience in using the constitutive model and the JAS3D code. Furthermore, constructing the finite element mesh that is part of the required input to JAS3D as well as visualizing results from the database output from JAS3D depends on the use of additional pre- and post-processing tools from the toolkit.

These significant requirements and potential impediments for using the underlying software, by the typical engineer on the production floor, called for a more user-friendly tool than the general purpose capability described above. To this end, a higher level specialized software package was developed to wrap around the toolkit to address a particular subclass of "complex" axisymmetric compacts that are quite common in the industry. This subclass of complex parts can be logically broken down into an assembly of simple cylindrical or/and conic pieces that are essentially stacked upon one another, with transitions between the pieces, to make up the complex part, as depicted schematically in Figure 1. The expertise required to build the input deck, run the finite element code, and post-process the results resides in the specialized package. The user simply responds to a series of prompts, evaluates the quality of the finite element mesh generated automatically, and analyzes the graphical results generated from the simulation. This tool allows users with little or no finite element expertise to benefit from the tremendous power and insight that finite element analysis can bring to the design cycle. Furthermore, as the user develops expertise in modeling the powder compaction process with the specialized software package, the
more general underlying software is available to him to allow modeling of more complicated geometries and processes.

A description will be given of the general underlying and specialized software. Its use will be illustrated on several compacts, ranging from the simple axisymmetric compacts to more complex, truly three-dimensional parts.

References


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