PECULIARITIES OF THE USE OF PACKAGE GID FOR THE ANALYSIS OF FORMING PROCESSES IN POWDER METALLURGY

M.Shtern, O.Mikhailov

Institute for Problems of Materials Sciences, Kiev, Ukraine

Some features of mechanical models of behaviour of powders sensitive to consolidation phenomenon are suggested. They are used to formulate the boundary – value problems describing the die - compaction in Finite Element form. The numerical code, including the procedure of the regularization is described. Specialties of the formulation of boundary – value problems in powder metallurgy are discussed. The approach to predict the failure under the die – compaction is suggested.

Introduction

The penetrating of powder materials in different branches of industries stipulates the increase of interest to analysis of powders behaviour under the forming processes. These processes including operations of compaction and sintering are predominantly targeted at the manufacturing of complex shape parts. Meanwhile the failure under the compaction and deflection under sintering inhibit the dissemination of Powder Technologies. Together with technological approaches usually used in Powder Metallurgy preliminary numerical analysis is considered now as the effective method providing the minimizing of the influence of factors above noted. It has been made possible due to essential progress in comprehension of main features of powder behaviour during compaction achieved last decades. Developed in framework of special scientific and industrial programs and based on modern notions of continuum mechanics the theory of compaction allows the definition of the density field and pressure during pressing as well as the shape deviation during the sintering. Further implementation of main results of the given theory into well-known users friendly packages, in particular GID [1] has made the prediction of main features and control of the die –compaction to be available even for production engineers without mechanical or mathematical education.

Meanwhile further dissemination of mentioned packages is restrained by some reasons. The most important among them is the absence of consensus relating the failure criteria. Another one – is the general formulation of the constitutive model, including the description of the sintering. In turn, the general structure of the constitutive relationships defines special features of numerical analysis.

Main Features of Constitutive Models in Powder Compaction and Sintering

Main relationships underlying the computer analysis of powder compaction and sintering are predominantly based on continuum hypothesis. All equations are formulated in the form inherent to continuum mechanics and contain parameters defined at the point of continuum. Among them general parameters describing the state of powder continuum – stress tensor, strain rate, velocity field, density, temperature as well as internal local variables such as accumulated matrix strain, cohesive measures, porosity, damaging. Constitutive equations relating stress tensor components with strain rates are usually [2,3] derived from the expression for constitutive potential Φ_e, which

is supposed to be written in special form $\Phi_e = \Phi_e(w)$, where w -is the smooth , convex and first order homogeneous calibrating function of strain rate components. As result the stress tensor components can be presented in the form

$$\sigma_{ij} = \Phi'_e(w)\frac{\partial w}{\partial e_{ij}} \quad . \qquad (1)$$

Function $\Phi_e = \Phi_e(w)$ is determined both theoretically and from the experimental analysis [2,3]. It is usually connected with the rate sensitivity of matrix or powder mechanical response, whereas $w = w(e_{ij}, \rho)$ is sensitive to structure of material (shape of pores, particles, cohesive properties). In particular, Φ_e can be written so that the stress – strain rate relationship has the form

$$\sigma_{ij} = p_o\delta_{ij} + \varphi\frac{\sigma_{01}}{w}\left(e_{ij} + \frac{((1+\nu)\frac{\sigma}{\sigma_{01}} - (1-2\nu))}{3(1-2\nu)} e\delta_{ij} \right) \quad , \qquad (2)$$

containing two material functions ν and φ of porosity and other material parameters, defined and introduced in [4]. When

$$p_0 = -\sigma_{01}\sqrt{\frac{1}{3}\varphi\frac{1+\nu}{1-2\nu}} \qquad (3)$$

and the equivalent stress σ – is the function of equivalent strain $\omega = \int_0^t w dt$ the given model is reduced to extended Cam – Clay relationships and describes the behaviour of powders ([4]).

Internal variables are satisfying to special evolution equations. In particular the change of relative density ρ is describing by equation following from mass conservation law

$$\frac{d\rho}{dt} = -\rho \ \ div\,\vec{v}\,, \qquad (4)$$

whereas the equivalent strain is satisfying the equation

$$\frac{d\omega}{dt} = \sqrt{\varphi\gamma^2 + \frac{1}{3}\varphi\frac{1+\nu}{1-2\nu}e^2} \qquad (5)$$

For hot pressing and sintering equivalent stress σ –is a function of w. Besides, right hand of equation (2) for sintering contains the additional term P_L , responsible for volume change without external forces.

Specialties of Boundary Value Formulation and Numerical Code

Unlike to conventional problems of metal forming, where the main attention is focussed at the analysis of stress and velocity fields the description of powder metallurgy processes is usually mainly concentrated at the fields of internal parameters, which directly define the service properties of powder parts. Therefore the evolution equations (4), (5) and some other possible relationships induced by additional parameters can give the desired distribution. For this aim, however, the rate field is needed, that in turn requires the consideration of constitutive laws together with

corresponding extremal principals. Mentioned feature defines the specialties of numerical procedures based on step by step integration of evolution equation. The preliminary finite element discretization is supposed to be carrying out. At the first step internal parameters are assumed to be equal to corresponding initial values. Non – linear algebraic equation following from constitutive relationships and extremal principals are solved then relating the nodal rates using iterative calculations. After the first step of the integration new values of material parameters are determined and procedure above noted is carried out f or the next step. It should be noted that procedures described here require the use of some type of regularization. One of them is inherent for the consideration of rigid – plastic flow, where the possible existence of rigid regions does not allow the obtaining of unique rate fields. To avoid this feature authors use the relation between equivalent stress and strain rate in regularized form

$$\sigma = \sqrt{1+n^2}\,\sigma_0 \frac{w}{\sqrt{w^2 + n^2 \gamma_0^{\,2}}} \qquad (6)$$

where n – is supposed to be the small value, and γ_0 has the dimension of strain rate. Another kind of regularization is used to provide the convergence of the iterative procedure.

There are possible two approaches to describe the powders flow. The conventional, based on assumption that the mass of cell is not changed, allows the most detail description of rate field. But on the other hand it hampers the analysis of the situation near singular points (corners). The modified approach – permeable elements method based on assumption that the mass of cell can be changed in accordance with the balance of mass for neighbour cells ([5]). Since the mesh evolution here is prescribed, problems of singular points can be easily avoided. But on the other hand the given approach is not sensitive to detail of the strain rate field.

On the Failure Criteria Under Die - Compaction

The modeling of die – compaction is usually targeted to solve two problems: to control of the density distribution, taking into account both the external friction and pressing diagram effect and to avoid the failure of billets or to predict the appearance and further behaviour of cracks and damages. The solution of the first of problems above can be obtained directly from the integration of boundary – value problem, where the density distribution is directly defined. On the base of obtained distribution all service parameters, depending on porosity are defined as well.

At the same time the prediction of failure usually requires the additional assumptions as a rule in a form of special criteria sensitive to compressive stresses. The most disseminated among them is that following from Drukker – Prager – Cup model. It should be noted that the given approach is closed to conventional mechanical consideration of failure: it only indicates the moment of failure and is not sensitive to the nature of destruction.

Authors use the approach based on stability analysis [6]. Since the model defined by equations (2) – (5) consists only the density as evolution parameter, the material flow is stable when the density grows and unstable under the diminishing of ρ. The loose of stability induces the possible appearance of the shear bands, which may be considered as initial manifestation of overconsolidated cracks. For density controlled model the loose of stability is possible for stress state, for which the potential contour is parallel to hydrostatic axis in space stress tensor components. The given situation is possible for extended Cam – Clay model introduced in [4].

Here the range of the stress states may include the point of pure shear (for extended Cam – Clay model the given state is possible for large compressive stresses) and, moreover, points located left of the peak of contour. It also implies the appearance of the regions in compacted body, when the diminishing of density is possible, that clarifies the nature of destruction as a process following by local softening.

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