ESTIMATION OF INITIAL DAMAGE AND FRACTURE PROPERTIES OF POWDER METALLURGY MATERIALS

V. Pastukhov*

The model of hot pressure presented in previous paper (1) is developed. Process of shaping is considered as instant elastic compression and following creep process under fixed press. Influence of pressure-induced phase transformation is taking into account. Obtained solution for time-dependent cavities volume fraction is used for estimation of time to failure under constant tension loading and high temperature creep conditions. The problems of modelling of subcritical crack growth in initially damaged material are discussed.

INTRODUCTION

The new approach to modelling of powder metallurgy processes is proposed by author in previous paper (1) and based on the elastic-creeping material's model. Instead of grains set the prismatic body with same volume is considered. This approach helps to clearify sometimes aspects of process and to reduce the number if technologic experiments. It also opens the way to evaluation of strength and lifetime estimations under various loading conditions.

This work is aimed to develop model of hot pressure by taking into account some additional aspects and to obtain the results for time to failure of powder metallurgy materials under creep conditions.

It is known that under high temperature and high pressure mechanical properties of materials are

* Department of Solid Mechanics, Samara State University, 443 011, Russia

changing. The nature of this phenomenon is quite complicated. The experimental investigation by Pharr et al. (2) has shown the role of pressure-induced phase transformations of silicon. Evidently, the same is valid for some metals.

The various types of complicated constitutive equations were developed in order to describe the dependence of deformation properties on temperature and stress state. These phenomenological equations give no sufficient advantages in exactness in comparison with more simple ones, but their use in the statement of mechanical problems strongly complicates the solution. It concerns mostly the problems of creep. At the same time the convenient power-law relation permits to reflect main properties of creep. As has been shown by Namestnikov (his work was published in Russian but described in book by Rabotnov (3)), the temperature-dependence of creep exponent may be described with two-sections piece-constant function. The temperature of creep exponent changing may be considered as temperature of phase transformation. The generalization of piece-constant dependence of creep exponent on the case of pressure-induced phase transformations is assumed in present paper.

TECHNOLOGIC PROCESS

Following previous work (1) let's consider the mould with powder. After the instant compression the press is fixed and volume under press is equal to the pure material volume. Cavities between grains are filled due to time-dependent deformation.

The estimation of cavities volume fraction is obtained by considering a deformation of prismatic body with volume equal to the initial pure material volume and the height equal to the height of powder in the mould before pressure. So, the cavities are "moved" to the back walls of the mould.

Constitutive equations

The behaviour of material with elastic response on instant change of loading and viscouplastic response on quasi-constant loading is described by next material law (see for example the reference (3)):

$$\dot{e}_{ij} = (1+\nu)(\dot{\sigma}_{ij} - \nu\dot{\sigma}_{kk}\delta_{ij}/(1+\nu))/E + 3B\sigma_e^{n-1}S_{ij}/2 \quad (1)$$

where ν is Poisson's ratio, S_{ij} is stress deviation tensor ($= \sigma_{ij} - \sigma_{kk}\delta_{ij}/3$), σ_e is Von Mises's effective stress,

$$\sigma_e^2 = 3S_{ij}S_{ij}/2$$

Let's assume that creep exponent n is a piece-constant function of average hydrostatic pressure $p = \sigma_{kk}/3$:

$$n = \begin{cases} n_1, & p \geq p^* \\ n_2, & p < p^* \end{cases} \quad (2)$$

This relation describes the mechanical aspect of pressure-induced phase transformation (p^* is known value of threshold pressure).

Estimation of cavities volume fraction

For the initial elastic compression the result obtained in reference (1) is valid. The differences arise only at the stage of creep deformation if the average hydrostatic pressure exceeds thresold value p^*.

Governing equation. For the considered problem we have the alone non-zero stress component. It's easy to see that equation (1) for strain rate l_c has the form

$$\dot{e}_c = -B|\sigma_z|^n/2 \quad (3)$$

(z is axis of press displacement, index c denotes cross axes x or y). Suppose for simplicity the equivalence of cross axes x and y. During the creep process the current state of body may be considered as a result of instant elastic compression of lower prismatic body with the same initial volume (equals to the pure material volume of powder without cavities). So, the current stress value is

$$\sigma_z(t) = E(k(1+2e_c(t))-1)/(1-2\nu) \quad (4)$$

where k is press ratio (volume under the press with respect to the initial powder volume).
Thus, the governing equation for the strain rate l_c:

$$\dot{e}_c(t) = -\frac{BE^n(1-k-2ke_c(t))^n}{2(1-2\nu)^n} \quad (5)$$

Change of creep exponent Let's determine the value of cross strain correspondent to the change of the creep exponent n. In our case $p = |\sigma_z|/3 = E(1-k-2ke_c(t))/(1-2\nu)/3$ and $p=p^*$ when the cross strain reaches the value

$$e_c^* = (k-1)/(2k) - 3(1-2\nu)p^*/(2Ek) \quad (6)$$

This situation may arise only for the press ratio

$$k < 1 - 3(1-2\nu)p^*/E \quad (7)$$

Results If the press ratio is insufficient to the phase transformation (condition (7) isn't fulfilled), integration of equation (5) gives the simple generalization of results reached in reference (1) for the two-dimensional problem

$$e_c(t) = \{1-k-[(1-k-2ke_{co})^{1-n} + (1-n)Ct]^{\frac{1}{1-n}}\}/(2k) \quad (8)$$

where denoted $C=BE^n/(1-2\nu)/2$ and initial elastic cross strain $e_{co}=\nu-\nu k$, $n=n_1$.

If the initial press ratio satisfies the condition (7) then solution (8) where $n=n_2$ is valid only till $t=t^*$. Time of phase transformation is easy to obtain using eq. (8) and condition $e_c(t^*)=e_c^*$.

$$t^* = [(1-k-2ke_{co})^{1-n} - (1-k-2ke_c^*)^{1-n}]/(2kC(n-1)) \quad (9)$$

For $t>t^*$ we have finally

$$e_c(t) = \{1-k-[(1-k-2ke_{co})^{1-n_2}-(1-k-2ke_c^*)^{1-n_2}+ \quad (10)$$

$$+(1-k-2ke_c^*)^{1-n_1}+(1-n_2)Ct^*+(1-n_1)C(t-t^*)]^{\frac{1}{1-n_1}}\}/(2k)$$

Thus, the time dependence of cavities volume fraction:

$$\omega(t) = [(1-k+ke_{co})^{1-n_2} + (n_2-1)Ct]^{\frac{1}{1-n_2}}, \quad t \leq t* \tag{11}$$

$$\omega(t) = [(1-k-2ke_{co})^{1-n_2} - (1-k-2ke_c^*)^{1-n_2} + (1-k-2ke_c^*)^{1-n_1} + (1-n_2)Ct^* + (1-n_1)C(t-t^*)]^{\frac{1}{1-n_1}}, \quad t>t* \tag{12}$$

TIME TO FAILURE UNDER CONSTANT TENSION

Let's apply the obtained results to estimations of lifetime under constant tension and creep conditions.

Smooth members

Failure of smooth members under creep conditions usually occurs without arising of macrocracks. The cause of such failure is development of continuous damage (microcracks, microvoids, dislocations and other discontinuities). The simplest phenomenological equation for damage accumulation is given in ref. (3):

$$\dot{\omega} = A(\sigma_e/(1-\omega))^m \tag{13}$$

where A and m are material constants, ω=0 for undamaged material and ω=1 for fully failed. For uniaxial tension with load σ_o we have $\sigma_e = \sigma_o$.

Suppose that initial value of scalar damage parameter ω is equal to the cavities volume fraction after processing time t_p an given by equations (11)-(12). Integration of damage kinetic equation (13) from loading time to time of failure gives

$$t_f = (1-\omega(t_p))^{m+1}/(A(m+1)\sigma_o^m) \tag{14}$$

where t_f is time to failure after the loading.

Notched and cracked members Fracture of cracked or notched members under creep conditions occurs due to subcritical growth of dominant crack. The most effective models of creep crack growth are based on the continuum damage concept. It's possible to generalize the solution for crack growth rate obtained by Astafjev and Pastukhov (4) on the case of initially damaged media. The estimations of crack growth rate may be obtained by substitution of real initial damage value $\omega(t_p)$ instead of $\omega=0$ at the moment of loading and further application of technique developed in reference (4).

The generalization of brittle fracture criteria for cracked or notched members of damaged material is quite easy in the case of homogeneous damage. Incorporation of subcritical crack growth stage breaks the condition of homogeneity and formulation of brittle fracture criterion becomes a serious problem.

CONCLUSIONS

The method for evaluation of initial damage of powder metallurgy materials is proposed. Pressure-induced phase transformations are taking into account. The results show that in the case of essential increasing of creep exponent due to pressure-induced phase transformations it's useful to use overpressure at the start of shaping process. It gives more quickly decreasing of cavities volume fraction.

Application of obtained estimations to the problems of creep life-time under constant loading permits determine the necessary processing time in terms of exploitation load and required minimal time to failure. The introduction of initial damage to the problems of brittle fracture of cracked/notched structural members demands the generalization of existing criteria.

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