METHODS OF EVALUATING PROCESSING DUCTILITY IN PRESSURE TREATMENT POWDER METALS.

II. FRACTURE CRITERIA TAKING INTO ACCOUNT THE STRESS STATE

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CRITERIA BASED ON CUMULATED STRAIN

The ductility of metals in pressure working was studied extensively by S. I. Gubkin [1]. In fact, these investigations represent the basis of current approaches to evaluating ductility.

The strain cumulated up to the moment of fracture is one of the measures of ductility more suitable for dense metals [2, 3]:

$$
\varepsilon_p = \int_0^t \varepsilon_i \, dt,
$$

where $\varepsilon_i$ is the strain rate intensity; $\varepsilon_f$ is the limiting strain to fracture at the moment of appearance of the first crack detected visually; $t$ is time.

It is generally accepted that the parameter of the stress state is the ratio of the hydrostatic pressure to the stress intensity. In subsequent considerations, we shall use the parameter of the stress state determined by means of the invariants of the stress tensor:

$$
\beta = I_1 / \sqrt{3 I_2},
$$

where $I_1 = \sigma_1 + \sigma_2 + \sigma_3$ is the first invariant of the stress tensor; $I_2 = 1/6(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2$ is the second invariant of the stress deviator; $\sigma_1, \sigma_2, \sigma_3$ are the main stresses.

To evaluate the ductility of metals, G. A. Smirnov-Alyaev [2] used the ductility diagrams in the $\varepsilon_f - \beta$ coordinates. The ductility of the material decreases (Fig. 1) with an increase of the parameter of the stress state (an increase of tensile stresses). The condition of deformation without fracture is written in the form

$$
\int_0^{t_f} \varepsilon_i \, dt = \varepsilon_p (\beta),
$$

where $\varepsilon_f (\beta)$ is the limiting strain determined at the parameter of the stress state corresponding to the moment of fracture.

The approach is insufficiently accurate as a result of the fact that although the cumulated strain was added up throughout the entire deformation time, it was compared with the limiting strain corresponding to the parameter of the stress state at the moment of fracture. The deformation history was not taken into account.

The loading history was taken into account by V. L. Kolmogorov [3, 4] in the heuristic model of damaged cumulation according to which the fraction of the limiting (for the given $\beta$) strain, obtained at different parameters of the stress state, can be added up: fracture starts when the degree of damage reaches unity. The degree of damage is described by the expression

Experimental verification shows [3, 5] that the dependence (4) reflects satisfactorily the relationships governing damage cumulation in the conditions of monotonic deformation with the variation of the parameter of the stress state in a wide range. Calculations carried out using Eq. (4) for nonmonotonic processes give too high results. The author explains this by the effect on the process of deformation of the third invariant of the stress tensor and the fact is taken into account by introducing the "coefficient of nonmonotonic nature" $B(t)$ into the subintegrand expression. However, the method of selecting $B(t)$ in relation to the deformation path is not described.

The approach based on damage cumulation has been used most extensively in the studies by V. A. Ogorodnikov [5, 6]. The author verified a large number of different criteria, carried out many experimental investigations, analyzed in detail the role of the third invariant in damage cumulation, and proposed various formations of the strain capacity criterion with an allowance made for the stress state. The proposed formulations contain quantities which are difficult to determine in practice and are not yet used extensively.

In [7], V. Vuiovich and A. Shabeik proposed a new strain capacity criterion. Analysis shows that this criterion completely repeats the previously examined approaches and has a number of shortcomings in comparison with these approaches: strain localization is not taken into account, and the deformation history is not considered in constructing the diagrams.

The fracture theory proposed by V. L. Kolmogorov was used by the authors of [8] in designing a porous blank for not stamping. The limiting strain to fracture is determined from the expression obtained in [9]:

$$\lambda_{lim}(\beta) = \lambda_f - \frac{\theta (\ln \theta - 1)^2 + 1) K}{3 V^3 C^2 (C + \alpha K)},$$

where $\lambda_{lim}(\beta)$ is the limiting ductility of the porous material of the given parameter of the stress state $\beta$; $\lambda_f$ is the limiting ductility of the dense metal; $K$ is the intensity of the tangential stress; $\theta$ is porosity; $C$ is the pore form factor; $\zeta$ and $A$ are the constants of the material. The values of $C$, $\zeta$, and $A$ in Eq. (5) were selected on the basis of simplifying assumptions. The diagram of the limiting ductility of the dense material was taken from the literature, and the form of the blank using which the component can be produced without fracture was calculated.

The described method of designing the powder blanks is based on theoretical assumptions. The results of the calculations and experiment were not compared so that it is difficult to evaluate the efficiency of the method.