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PHYSICAL MECHANICS OF METAL WORKING UNDER HIGH PRESSURE

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A mathematical model of plastic deformation of structurally inhomogeneous material with defects of inhomogeneity-type has been developed. The principal relationships have been obtained which are based on the results of physical investigations. The proposed model has been used as a basis for the investigation of viscous fracture and deformation localization at pressure treatment of compact and noncompact materials.

The development of the hydrostatic treatment technologies should be based on the mathematical models describing microfracture of solids at deformation and taking into account the pressure effect on this process.

An adequate description of the microfracture is possible in the framework of the continuum concepts. In this case the consideration involves the magnitude of porosity which is the total relative volume of microdefects.

Thus, the present option is embodied in defining physical relations of the continuum theory, comprising material porosity in terms of inner variable.

The problem can be further reduced with the help of assumption of the flow theory in terms of which physical relations are defined by loading function.

The principal relationships of the flow theory have the form [1]

$$\dot{e}_{ij} = \lambda \frac{\partial f}{\partial \sigma_{ij}}; \tag{1}$$

here the following conditions are fulfilled:

$$\text{at} \quad f = 0, \quad \frac{df}{dt} = 0, \quad \frac{\partial f}{\partial \sigma_{ij}} d\sigma_{ij} \neq 0, \quad \lambda > 0 \tag{2}$$

$$\text{at} \quad f = 0, \quad \frac{df}{dt} = 0, \quad \frac{\partial f}{\partial \sigma_{ij}} d\sigma_{ij} = 0, \quad \lambda = 0 \tag{3}$$

$$\text{at} \quad f = 0, \quad \frac{df}{dt} < 0, \quad \lambda = 0 \tag{4}$$

$$\text{at} \quad f < 0, \quad \lambda = 0 \tag{5}$$

where σ_{ij} and $\dot{e}_{ij}$ are the tensor components of stresses and rates of plastic deformation, respectively; f is the loading function; λ is the Lagrange factor.

Relationship (1) is the mathematical expression of the gradient condition.

Conditions (2)–(5) show that the plastic deformation takes place only when the stresses satisfy the condition of yielding $f = 0$ at the time moment under consideration and the closest one to it, and the stress increment vector does not lie on the loading surface.

Condition (2) is assumed by us in an extended form to take into account the possible loss of the material stability (for stable materials in condition (2) $(\partial f/\partial\sigma_{ik})\, d\sigma_{ik} > 0$, [1]).

The expression for loading function can be constructed on the basis of the physical model reflecting the main features of deformation mechanisms and fracture of material.

The following physical model is proposed by us in the article [2]:

– the material consists of interconnected structural elements;

– plastic deformation of material can be realized by means of joint coordinated deformation of its structural elements, moreover its behavior is defined by the ability of elements to accommodate each other;

– the ability to be accommodated is determined by the plastic deformation mechanisms acting at this or that moment. If they provide arbitrary deformation of the structural elements (e.g. five slip systems work), complete accommodation is possible. Otherwise accommodation is only partial. As a result, gaps (or microinhomogeneities) appear between the elements (if at the beginning the elements were closely adjusted to each other), which results in loosening of the material. If, on the other hand, microinhomogeneities were present before the deformation, they may disappear at certain conditions since the structural elements are able to adjust to each other.

On the basis of analysis of the proposed physical model the following results are achieved by us: an expression for loading function and physical equations of plasticity theory of structurally inhomogeneous materials.

Those equations are summarized in table 1 below where for comparison Mises's plasticity theory equations, describing the plastic deformation of unstructural material are also enlisted.

In physical equations of structurally inhomogeneous material the parameter α – coefficient of inner friction is inherent. According to [2] it is a quantitative measure of separate structural elements ability to accommodate each other.

In the case when complete adaptation of the elements to each other is possible $\alpha = 0$. The value of α grows with the increase of a number of restrictions to the joint plastic deformation. That is, the less efficient are the mechanisms of plastic deformation of the structural elements, the higher is α.

In order to simulate the process of fracture and localization of deformation physical equations of structurally inhomogeneous materials are supplemented by the criteria of macrofracture and stability of the material (see table).

Physical equation system of Mises's plasticity theory increased by the equilibrium of continuous body equations permits us to investigate plastic deformation liberal processes to define the strength-stress parameters of material. The equal abilities are provided by the system of physical equation for the structurally inhomogeneous material. Nevertheless, in addition to the above-mentioned facts the stated system permits us to analyze the changes of porosity (defectiveness) of material, to define the areas of macroscopic fracture and localization of deformation, to investigate hydrostatic pressure influence upon the behavior of material under deformation.

Table

Physical equations of structurally inhomogeneous material theory of plasticity

Physical equations for structurally inhomogeneous material	Physical equations for unstructural material (according to Mises)	Comments
$f = \frac{\sigma^2}{\psi(\theta)} + \frac{\tau^2}{\varphi(\theta)} - (1-\theta)(k_0 - \alpha\sigma)^2$	$f = \tau - k_0$	loading function
$\frac{\sigma^2}{\psi(\theta)} + \frac{\tau^2}{\varphi(\theta)} = (1-\theta)(k_0 - \alpha\sigma)^2$	$\tau = k_0$	condition of yielding
$\frac{e\tau}{\varphi(\theta)} = \dot{\gamma}\left(\frac{\sigma}{\psi(\theta)} + \alpha(1-\theta)(k_0 - \alpha\sigma)\right)$ $e_{ij} - \frac{1}{3}e\delta_{ij} = \frac{\dot{\gamma}}{\tau}(\sigma_{ij} - \sigma\delta_{ij})$	$e = 0$ $i \neq j$	gradient condition
$\theta = \theta_c$	–	criteria of macrofracture of the material
$\frac{d\tau}{d\gamma} \leq 0$	–	criteria of instability of the material and localization of plastic deformation

Notations: $\psi(\theta) = \frac{(1-\theta)^{2n-1}}{6a\theta^m}$, $\varphi(\theta) = (1-\theta)^{2n-1}$, θ - porosity,

$\sigma = \frac{1}{3}\sigma_{ik}\delta_{ik}$, $e = e_{ik}\delta_{ik}$, $\tau = \sqrt{\left(\left(\sigma_{ik} - \frac{1}{3}\sigma\delta_{ik}\right)\left(\sigma_{ik} - \frac{1}{3}\sigma\delta_{ik}\right)\right)}$,

$\dot{\gamma} = \sqrt{\left(\left(e_{ik} - \frac{1}{3}e\,\delta_{ik}\right)\left(e_{ik} - \frac{1}{3}e\delta_{ik}\right)\right)}$, k_0, α, a, m, n – material parameters.

Let us illustrate the functioning of the proposed model with the example of proportional loading of material under pressure. This type of loading is realized, for example, during the cylindrical sample extension up to the moment of appearance of the neck or during the settling till the moment of creation of the barrel. The picture shows (Fig. 1) how the microporosity of the sample changes with the growth of deformation under the constant value of the rigidity index of the stressed state $\eta = \sigma/\tau$.

The proposed model of deformation of structurally inhomogeneous material was applied by us while investigating such processes as hydroextrusion [3], hydromechanical pressure, hydromechanical squeezing, uniaxial extension with the appearance of the neck, shift under pressure.

Basing on this concept a continuum model of contact friction during the treatment of metals under pressure is being elaborated.

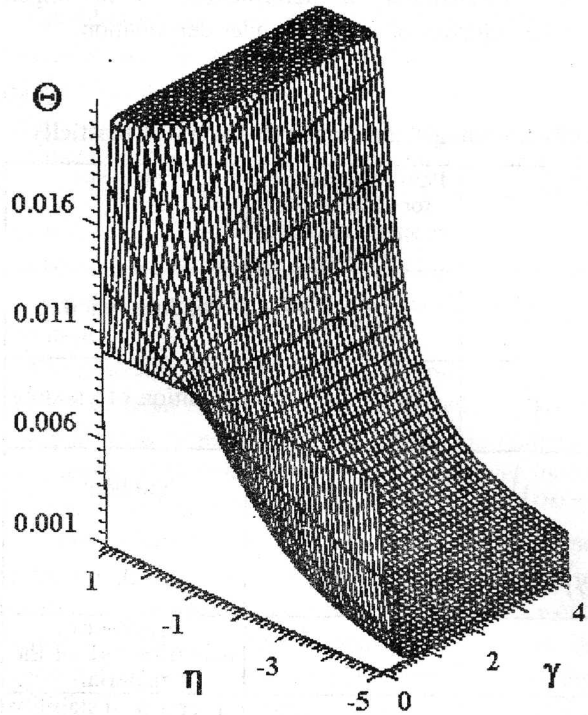

Fig. 1. The calculated dependence of porosity θ on the deformation value γ and stressed state rigidity index η (in calculations: $\theta_0 = 0.01$; $\alpha = 0.01$)

1. *D.D.Ivlev and G.I.Bykovtsev*, Theory of Hardening Plastic Body – Nauka, 1971.
2. *Ya.E.Beigelzimer et al.* , Engng. Fracture Mech. **48**, 629 (1994).
3. *Ya.E.Beigelzimer et al.* , Engng.Mech. **2**, 17 (1995).