SOME INFORMATION ABOUT THE DEFORMATION THEORY OF PLASTICITY

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Abstract. The article outlines the basic laws of the theory of plastic deformation; the doctrine of the magnitude of plastic shear, shows the relationship between stress and deformation. It is shown that when the tension is changed by compression or after changing the direction of the torque, we can re-enter the plastic region.

Keywords: deformation, elasticity, plastic deformation, displacement, elastic potential, isotropic body, deformation diagram, stress, load, temperature.

Plasticity theory is a branch of mechanics in which deformations of solids beyond elasticity are studied. Plasticity theory studies the macroscopic properties of plastic bodies and is not directly related to the physical explanation of the properties of plasticity. Plasticity theory deals with methods for determining the distribution of stresses and deformations in plastically deformable bodies.

To determine the plastic properties of metals, experiments are performed on stretching — compression of a flat or cylindrical sample and deformation of a thin-walled cylindrical tube under the action of tensile force, torque and internal pressure, i.e. experiments that allow independent counting of forces and deformations.

Plasticity is the property of solids to irreversibly change their size and shape (i.e. to deform plastically) under the influence of mechanical loads. The plasticity of crystalline bodies (or materials) is associated with the action of various microscopic mechanisms of plastic deformation, the relative role of each of which is determined by external conditions: temperature, load, deformation rate.

These mechanisms are considered in order of increasing the number of atoms involved in the elementary act of plastic deformation.

The currently existing theories of plasticity can be divided into two groups. In the first group of theories, which are called deformation theories, dependencies between stresses and deformations are established. In the second group, the connections between infinitesimal increments of deformations and stresses are considered. In a particular case, the strain rates dependences on stresses are obtained. In the theories of the second group, plastic deformation is considered as a process of plastic flow of a material.

According to the theory of plastic flow, based on the plasticity of the Cod—Saint-Venant associated flow law, plastic deformation is a simple shift in the plane determined by the axes of the greatest principal stresses. If the deformations are small, then the deformation rate is equal to the time derivative of the deformation. On the other hand, if the hardening material turns out to be in a state of pure shear, then the magnitude of the plastic shear is a completely definite function of the tangential stress

$\gamma_p = \varphi(\tau)$ (1)

It is natural to assume that even in a complex stress state, dependence (1) remains valid. Considering that the total deformation is the sum of elastic and plastic deformation, and noting that

$$\gamma_p = e_{1p} - e_{3p}, \tau = \frac{1}{2}(\sigma_1 - \sigma_3),$$

$e_{2p} = 0$and there is no plastic volumetric deformation, we get the following dependencies between stresses and deformations:

$$e_1 = \frac{1}{E}[\sigma_1 - \nu(\sigma_2 - \sigma_3)] + \frac{1}{2}\varphi\left(\frac{\sigma_1 - \sigma_3}{2}\right),$$

$e_2 = \frac{1}{E}[\sigma_2 - \nu(\sigma_3 - \sigma_1)]$,(2)

$$e_3 = \frac{1}{E}[\sigma_3 - \nu(\sigma_1 - \sigma_2)] - \frac{1}{2}\varphi\left(\frac{\sigma_1 - \sigma_3}{2}\right).$$

At the same time , there should be$\sigma_1 > \sigma_2 > \sigma_3$Equation (2) represents the final relations between stresses and deformations, although it was based on the assumption that plasticity is precisely the flow of the material. The primary experimental fact expressed by equation (1) can also be interpreted in such a way that the plastic flow is a pure shift, but the amount of deformation is not arbitrary, as it was in the theory of ideal plasticity, but depends on the acting stress. Equation (1) is valid when τ does not decrease, a more accurate record of it will be the following.Ifτ changes arbitrarily

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in time ξ from ξ=0 to ξ=t, then
γ_p=supφ[τ(ξ)], ξ ∈[0,t].
This means that plastic deformation persists during unloading. Here we have not provided for the possibility of secondary plastic deformations when large tangential stresses of the opposite sign are applied. Taking into account the corresponding effects requires the introduction of additional hypotheses.
Extremely simple equations (2) are written in the principal voltages. If the directions of the main axes are unknown in advance, the equations must be written in arbitrary axes. At the same time, all simplicity disappears, the resulting equations become extremely complex. Moreover, if the main axes are known, we must know in advance on which axis the greatest voltage σ1 will act, on which the smallest σ3 will act. But it may happen that in the process of loading the corresponding inequality is violated, therefore, the plane in which the shift occurs changes. Thus, the stated theory has only a limited scope of application.
The so-called deformation theory of plasticity is essentially the extension to a plastic body of the law of the relationship between stresses and deformations, which is established by the nonlinear theory of elasticity. The plastic potential, which replaces the elastic potential here, for an isotropic body is a function of invariants of the strain tensor. Thefollowinghypothesesareusuallyusedinthiscase:
1. Volumetric deformation obeys the law of linear elasticity
σ= 3Ke. (3)
2. The elastic-plastic potential U depends only on the second invariant of the strain tensor, for example, on the octahedral shift
U= U(γ_0).
From the second hypothesis it follows that
$\overline{\sigma_{ij}} = 2G_s(\gamma_0)\overline{e_{ij}}$.(4)

Here$\overline{\sigma_{ij}}$и$\overline{e_{ij}}$ –deviators of the corresponding tensors, $G_s(\gamma_0)$-octahedral shift function appearing during potential differentiationU(γ_0). Folding both sides of equality (4) and remembering the definitionsτ_0 иγ_0(*см 7,7*), we find

$$G_s(\gamma_0) = \frac{\tau_0}{\gamma_0}. \quad (5)$$

Relation (5) means the existence of a single curve t_0- y_0 for all types of stressed and deformed states, more precisely for all ways of loading or deformation.Thus, the existence of this curve should be taken as a primary experimental fact, its fulfillment or non-fulfillment during the experiment serves as a criterion for the correctness or incorrectness of the theory as a whole. The value of the plastic shear modulus G_s, defined as a function of the octahedral shear Υ_0, can also be considered as a function of the octahedral shear stress τ_0.Note that the accepted hypothesis expressed by equations (4) and (5) does not imply the separation of deformation into elastic and plastic. Indeed, Hooke's law for deviatory components of stress and strain tensors is written as follows:

$$\overline{\sigma_{ij}} = 2\mu\overline{e_{ij}}.$$

Here μ is the elastic shear modulus.The dependence diagram t_0- y_0, assumed to be the same for all deformation paths, includes elastic shear deformation, whereas elastic volumetric deformation is determined by equation (3).
The type of function $t_0(y_0)$ is easiest to determine from experience for a net shift, for example, when torsion of a thin-walled circular tube.Indeed, with a pure shift

$$\tau_0 = \sqrt{\frac{2}{3}}\tau, \gamma_0 = \sqrt{\frac{2}{3}}\gamma.$$

Here τ and γ are tangential stress and shear.Thus, the diagram τ_0- γ_0 is obtained from the diagram of the net shift of τ- γ by simply changing the scale.Getting the desired dependence from the stretching experience is somewhat more difficult. The fact is that stretching is accompanied by a change in volume, so to find the function $\tau_0(\gamma_0)$, you need to know the volume modulus of elasticity K and recalculate based on the plasticity equations.The main experimental fact observed during uniaxial loading – stretching or compression, as well as during torsion, is as follows. While we are moving along the deformation curve from the origin as shown in Figure (1) by the arrow, i.e. while the stress and deformation, in this case, τ and γ, increase, the relationship between τ and γ is given by the diagram of plastic deformation.
The relationship between stress and strain is unambiguous in the sense that it does not depend on the rate of deformation or the application of the load, but it is violated when moving in the opposite direction, i.e. when the sign of τ or γ changes. Experience shows that when the stress decreases, the material returns to an elastic state, the relationship between stress and deformation during unloading is depicted on the diagram of a straight line passing through the point of the deformation curve from which the unloading was performed. The law of elasticity during unloading is not an exact physical law, in fact, the unloading diagram is not completely straight, and the average modulus obtained when replacing the true unloading diagram with the straight line closest to it may differ slightly from the initial modulus μ, which determines the slope of the first section of the loading diagram. But the theory of plasticity always deals with a hypothetical ideal environment that reproduces the behavior of a real body only with some approximation. Now, for the

general case, it is natural to accept the following assumption. If the octahedral stress or, accordingly, the octahedral shift increases, then plastic deformation occurs, described by equations (4). If for some values $\tau = \tau'_0$ and $\gamma_0 = \gamma'_0$ Unloading occurs,then the deviators change $\overline{\sigma_{ij}} u \overline{e_{ij}}$connected by the law of elasticity, which is convenient to write in differential form:

$\overline{d\sigma_{ij}} = 2\mu \overline{e_{ij}}, \tau < \tau'_0$ (6)

Equations (6) are replaced when unloading equation (4) whereas equation (3), of course, always retains force. In the record of the condition under which (6) is conducted, there is something more than just the unloading law, with repeated loading, the material will deform elastically until the octahedral stress reaches the value τ'_0 from which unloading was performed. With further loading, the dependence $t_0 = y_0$ follows the continuation of the original curve and equations (4) come into force again, continuing to act as if there were no unloading and reloading. We emphasize once again that when the load is reversed, i.e. when the tension is changed by compression or after changing the direction of the torque, we can again enter the plastic region.

The equations of the deformation theory of plasticity are essentially equations of a nonlinear elastic body. Naturally, their use to describe plastic deformations in complex zigzag loading paths can lead to unsatisfactory results. A.A. Ilyushin found that the basic laws of deformation theory are valid when at each point of the body the stress components (or in a weakened formulation, the stress deviator components) increase proportionally to a certain parameter. Such loading is called simple. In a homogeneous stress state, loading will be simple if the external forces increase proportionally to one parameter. For the general case of an inhomogeneous stress state, A.A. Ilyushin formulated and proved the following simple loading theorem: in order for the loading at each point of an incompressible body of arbitrary shape with a proportional increase in external forces to be simple, it is sufficient that the dependence between the stress and strain intensities can be represented as a power function.

Plasticity due to the course of phase transformation. Irreversible shape change can also be the result of the formation of a new phase under load, having a different crystal lattice than the original crystal. In this case, the initial phase must be metastable with respect to the formed one, at least under the action of mechanical stresses. Since the relative stability also depends on temperature, P. in this case significantly depends on the deformation temperature with respect to the equilibrium temperature of the phases. In certain cases, by reducing the stability of the phase formed under load due to temperature changes, it is possible to destroy the deformation obtained during transformation: the crystal returns to its original shape ("memory effect").

The study of plasticity is of great practical interest, because it makes possible a rational choice of technical materials, the plasticity of which is usually subject to a whole set of requirements both during processing and during their operation in various conditions. A number of physical, mathematical and theoretical disciplines are engaged in the study of various aspects of plasticity: solid state physics (in particular, dislocation theory) explores microscopic mechanisms of plasticity, continuum mechanics (theories of plasticity and creep) considers the plasticity of bodies, abstracting from their atomic crystal structure, the resistance of materials, etc.

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