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DEPENDENCE OF PLASTIC ULTIMATE STRAIN FROM A FRICTION AT END FACES AT AXISYMMETRIC COMPRESSION

BY

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Abstract: The axisymmetric compression of cylindrical blank between plane-parallel slabs is considered. The procedure, concrete mathematical model and the program of computing of the mode of deformation and the plastic ultimate strain on a free lateral surface of cylindrical blank are developed.

Keywords: axisymmetric compression, plastic ultimate strain, tensor model damage

1. Introduction

The axisymmetric compression of cylindrical blank is not only widespread technological operation, but also one of ways of laboratory researches for definition of the major technological properties of materials. As is known 0 at compression of cylindrical blanks of a low-plastic materials on a lateral surface flaws are generated. The compression extent at which there are flaws depends on barrel distortion intensity of a lateral surface. In turn the barrel distortion intensity is defined by magnitude of a friction at end faces of blank 0. Procedure of definition of the mode of deformation of a material on a cylindrical blank's free surface at its plastic axisymmetric compression are developed in 0. In this paper the procedure of definition of the plastic ultimate strain depending on barrel distortion intensity is developed.

2. Major part

On a lateral surface of the cylindrical blank in medial over of a altitude area the mesh is marked. The mesh is marked by a typographical expedient 0 or by means of the diamond imprints executed on Vickers hardness tester 0. By measured results of the distorted dividing mesh at the intermediate stages of the straining the dependence between axial strain ε_z and the hoop strain ε_φ is fixed

$$\varepsilon_z = f\left(\varepsilon_\varphi\right) \tag{1}$$

in the form of it tabular a given function. Strains ε_z and ε_φ are defined as natural logarithms of ratios of current sizes to the initial 0.

In 0 approximation of dependence (1) in the form of the differential equation with separable variables is offered

$$\frac{d\varepsilon_z}{d\varepsilon_\varphi} = -\frac{1}{2} - \frac{3}{2} \cdot \frac{m^2}{\varepsilon_\varphi^2 + m^2} \tag{2}$$

where $m > 0$ – experimentally a definable constant.

Taking into account starting conditions

$$\varepsilon_z\big|_{\varepsilon_\varphi = 0} = 0 \tag{3}$$

by the solve of the differential equation (2) we will obtain

$$\varepsilon_z = -\frac{1}{2}\varepsilon_\varphi - \frac{3}{2} \cdot m \cdot arctg\left(\frac{\varepsilon_\varphi}{m}\right) \tag{4}$$

It follows that

$$\lim_{m \to \infty} \frac{d\varepsilon_z}{d\varepsilon_\varphi} = -2, \qquad \lim_{m \to 0} \frac{d\varepsilon_z}{d\varepsilon_\varphi} = -\frac{1}{2}. \tag{5}$$

It means, that at enough great values m, according to (4), with a high accuracy the equality follows

$$\varepsilon_z = -2 \cdot \varepsilon_\varphi \tag{6}$$

what corresponds to the kind of strain - compression, and at enough small values m –

$$\varepsilon_z = -\frac{1}{2}\varepsilon_\varphi \tag{7}$$

what corresponds to the kind of strain – tension. Taking into account an incompressibility condition we will gain $\varepsilon_r = \varepsilon_\varphi, \varepsilon_r = \varepsilon_z$ accordingly at compression and a tension, where ε_r - the radial plastic strain. Thus, changing friction at end faces at axisymmetric compression of the cylindrical blank between plane-parallel slabs, we will gain experimentally different dependences (4). These dependences can be approximated by the relation (4) by selection of value of a constant m. Here it is important, that the constant m is necessary invariable at testing of the particular blank or, that too, friction conditions at end faces are guessed invariable.

On the figure 1 results of experimental and calculation data are presented. Parametre value m for each curve determined by method of least squares. The method of least squares with use of a relation (4) leads to necessity of the solution of a transcendental equation of the complicated structure. Therefore values m determined by means of add-in Microsoft Excel Solver by minimizing of the total of quadrates of residuals.

Transforming relations (4) into the parametric shape, we will obtain 0

$$\begin{cases} \varepsilon_\varphi = m \cdot tg(x) \\ \varepsilon_z = -\frac{m}{2} \cdot (tg(x) + 3 \cdot x) \end{cases} \tag{8}$$
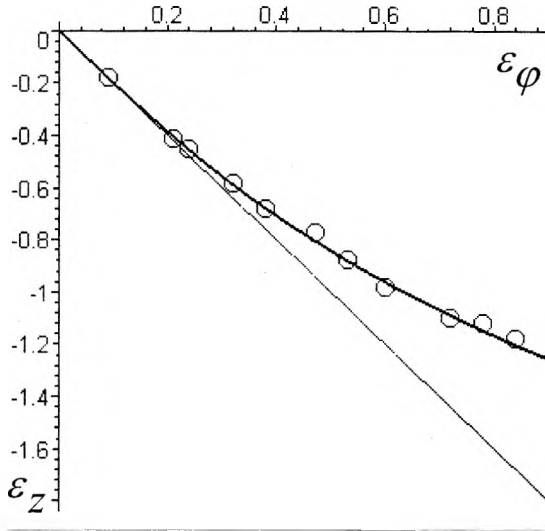
where x – parameter.

Figure 1. Dependence between axial ε_z and hoop ε_φ strains: ;- $\varepsilon_z = -2 \cdot \varepsilon_\varphi$; ——— - calculation based on (4) at m=0,51; o – experimental data.

The accumulated plastic strain it is determined as

$$\varepsilon_u(t) = \int_0^t \dot{\varepsilon}_u(\tau)d\tau, \tag{9}$$

where t, τ – time; $\dot{\varepsilon}_u$ is the intensity of velocities of strains

$$\dot{\varepsilon}_u = \frac{2\sqrt{3}}{3}\sqrt{\dot{\varepsilon}_z^2 + \dot{\varepsilon}_z\dot{\varepsilon}_\varphi + \dot{\varepsilon}_\varphi^2} \tag{10}$$

Using relations of the flow theory we will obtain principal stresses σ_z, σ_φ (on a free surface $\sigma_r = 0$). The index of a stress state, which equal to the division of the first invariant of a stress tensor on stress intensity. This index is equal 0-0

$$\eta = \frac{1-3\cdot\cos^2(x)}{\sqrt{1-3\cdot\cos^4(x)}} \tag{11}$$

The curve of the plastic strain, which accumulated up to fracture at stationary deformation we will approximate by function

$$\varepsilon_{*c}(\eta) = \varepsilon_{*c}(\eta = 0) \cdot \left(\frac{(1-\eta)\cdot\varepsilon_{*c}(\eta=-1)}{2\varepsilon_{*c}(\eta=0)} + \frac{(1+\eta)\cdot\varepsilon_{*c}(\eta=0)}{2\varepsilon_{*c}(\eta=1)}\right)^{-\eta} \tag{12}$$

where $\varepsilon_{*c}(\eta = -1), \varepsilon_{*c}(\eta = 0), \varepsilon_{*c}(\eta = 1)$ - plastic ultimate strain under compression, torsion and a tension accordingly.

Definition of ultimate strains at a non-stationary deforming 0 we will fulfil by on two models.

Kolmogorov's scalar model, 0, 0, 0, is based on a linear principle of accumulation of damage

$$\psi(\varepsilon_u) = \int_0^{\varepsilon_u} \frac{d\varepsilon_u}{\varepsilon_{*c}[\eta(\varepsilon_u)]} \tag{13}$$

where ψ - macroparticles's damage, which varies from 0 in an initial state up to 1 at reaching of the limiting state; $\varepsilon_{*c} = \varepsilon_{*c}(\eta)$ - curve of the plastic strain, which accumulated up to fracture at stationary deformation. Value $\varepsilon_u = \varepsilon_*$ at which equality $\psi = 1$ is attained is the limiting value of the accumulated plastic deformation before macrodamage occurrence.

The tensor-linear model which is based on a linear principle of accumulation of damage 0

$$\psi_{ij}(\varepsilon_u) = \int_0^{\varepsilon_u} \frac{\beta_{ij}(\varepsilon_u)}{\varepsilon_{*c}[\eta(\varepsilon_u)]} \cdot d\varepsilon_u \tag{14}$$

where β_{ij} - the direction tensor of the strains increments, defined by equality

$$\beta_{ij} = \frac{d\varepsilon_{ij}}{\sqrt{d\varepsilon_{ij}d\varepsilon_{ij}}} \tag{15}$$

$d\varepsilon_{ij}$ - increments of plastic deformations. Limiting value of the accumulated plastic deformation before macrodamage occurrence $\varepsilon_u = \varepsilon_*$ it is determined from of a condition of reaching by the second invariant of a deviator of damage of the limiting value:

$$\psi_{ij}(\varepsilon_*)\psi_{ij}(\varepsilon_*) = 1 \tag{16}$$

On the figure 1 results of calculations of dependence of an ultimate strain from parametre m, which characterize distortion intensity are presented.
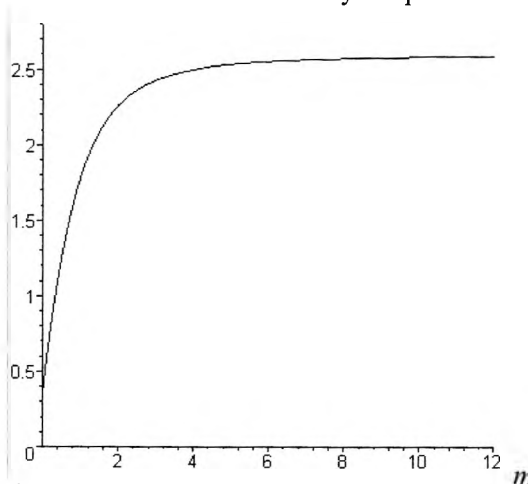

Figure 2. Dependence of an ultimate strain from barrel distortion intensity for steel 10: calculation based on (13) and (14), (16).

From the data presented on figure 2, follows, that calculations based on Kolmogorov's model (13) and on tenzorno-linear model (14), (16), on a drawing are indistinguishable.

3. Conclusions

At barrel distortion intensity magnification the ultimate strain is diminished. The peak discrepancy with value on curves of ultimate strains at the stationary and nonstationary deformation is observed at $m \approx 0.5$. The mathematical apparatus presented in given paper allows to describe and investigate legitimacies of a modification of ultimate strains on a cylindrical blank's free surface at its plastic axisymmetric compression between plane-parallel slabs. The given apparatus is applied both to development of the theory of deformability, and for its practical use at projection of technological process of plastic working.

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DEPENDENTA TENSIUNII DE DEFORMARE PLASTICĂ

Rezumat: Se studiază compresia asimetrică a unei epruvete cilindrice între plăci plan-paralele. Sunt prezentate procedeul, modelul matematic și programul de calcul al modului de deformare.