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ASSESSMENT OF THE ULTIMATE STRAIN IN THE PROCESS OF THE TRANSVERSAL PRESSING OUT WITH FURTHER SETTLING

The paper considers the research of the metal plasticity in the process of the transversal pressing out of the axisymmetric flange with its further settling. The process is characterized by non-monotone loading. That is why, the calculation of the components of the stress deviator is carried out using the model of Backhouse anisotropic strengthening.

As the known tensor models of the damages accumulation process at nonmonotone loading are cumbersome the transition from the tensor model to 3D scalar model is substantiated in the given paper. As the main characteristics of nonmonotone loading index of rigidity of the stress state and Nadai-Lode parameter are used. Instead of the six components of the damage tensor three components of damage deviator in the space of primary stresses are introduced. Function approximation is suggested, which describes the impact of the loading history on the plasticity and takes into account the sensitivity of the deformed metal to the scheme of the stress state. The impact of the stress state on the plasticity is determined by the surface of the ultimate strain, which describes the dependence of ultimate strain on two invariant indices of the stress state.

Developed model of metal plasticity assessment at complex nonmonotone loading is used for the assessment of the impact of the parameters of the transversal pressing out of the flange on ultimate deformation. The suggested method of the combined pressing out enables to use rationally the resource of the plasticity of the deformed metal.

Key words: *plastic deformation, stress, nonmonotone loading, ways of deformation, fracture.*

Introduction

Main task of the metal treatment under pressure is to obtain the blanks of the preset form without disturbing the integrity. In this connection the problem of the plasticity of metals being deformed especially during nonmonotone plastic deformation remains relevant. Mechanism of accumulation and remedy of the damages during nonmonotone plastic deformation has not been studied yet. That is why, there is no common point of view concerning the assessment of the metals deformation in the process of non-monotone loading [1 – 5].

Model of damages accumulation in the process of nonmonotone loading is based on the hypothesis that the damages are of the directed character and described by the second-rank tensor. Components of this tensor are determined by the mechanics of the plastic deformation process in the specific technological process as well as material functions, describing physical-mechanical properties of the material.

Plastic deformation of metals in the conditions of nonmonotone loading

According to [5, 6], we will introduce the damage tensor ψ_{ij}, its components are determined in the following way:

$$\psi_{ij} = \int_0^{e_u^*} F(e_u, \eta, \mu_\sigma)\beta_{ij} de_u, \tag{1}$$

where $F(e_u,\eta,\mu_\sigma)$ – is positive function, characterizing the sensitivity of the material to the stress state scheme.

Components of the director tensor β_{ij} equal [5]:

$$\beta_{ij} = \sqrt{\frac{2}{3}} \frac{d\varepsilon_{ij}}{de_u}. \tag{2}$$

From the correlation flow theory:

$$d\varepsilon_{ij} = \frac{3}{2} \frac{de_u}{\sigma_u} S_{ij} \tag{3}$$

it follows that

$$\frac{d\varepsilon_{ij}}{de_u} = \sqrt{\frac{3}{2}} \beta_{ij} = \frac{3}{2} \frac{S_{ij}}{\sigma_u} \tag{4}$$

or

$$\beta_{ij} = \sqrt{\frac{3}{2}} \frac{S_{ij}}{\sigma_u} \tag{5}$$

where S_{ij} – are components of the stress deviator, σ_u – is stress intensity.

Tensor σ_{ij} is presented in the form:

$$\sigma_{ij}=S_{ij}+\sigma\delta_{ij} \tag{6}$$

where $\sigma = \frac{1}{3} \sigma_{ij} \delta_{ij}$ – is mean stress.

Besides, the known relations are used

$$\mu_\sigma = \frac{2S_2 - S_1 - S_3}{S_1 - S_3} \tag{7}$$

$$S_1+S_2+S_3=0, \; 2\sigma_u^2 = (S_1 - S_2)^2 + (S_2 - S_3)^2 + (S_3 - S_1)^2, \tag{8}$$

where μ_σ – is Nadai-Lode factor.

Having solved the systems (7), (8) we find:

$$\frac{S_1}{\sigma_u} = \mp \frac{1}{3} \frac{\mu_\sigma - 3}{\sqrt{\mu_\sigma^2 + 3}}, \; \frac{S_2}{\sigma_u} = \pm \frac{1}{3} \frac{2\mu_\sigma}{\sqrt{\mu_\sigma^2 + 3}}, \; \frac{S_3}{\sigma_u} = \mp \frac{1}{3} \frac{\mu_\sigma + 3}{\sqrt{\mu_\sigma^2 + 3}}. \tag{9}$$

It follows from (5) and (9) that main components of the tensor β_{ij} equal

$$\beta_1 = \mp \frac{1}{\sqrt{6}} \frac{\mu_\sigma - 3}{\sqrt{\mu_\sigma^2 + 3}}, \; \beta_2 = \pm \frac{1}{\sqrt{6}} \frac{2\mu_\sigma}{\sqrt{\mu_\sigma^2 + 3}}, \; \beta_3 = \mp \frac{1}{\sqrt{6}} \frac{\mu_\sigma + 3}{\sqrt{\mu_\sigma^2 + 3}}. \tag{10}$$

It is provided that during nonmonotone loading the destruction occurs on the condition, when certain function of the invariants of tensor ψ_{ij} reaches certain value. The first invariant of this tensor equals zero, since as a result of the material compression – $\beta_1+\beta_2+\beta_3=0$. Without taking into account the impact of the third invariant the destruction condition can be written in the form:

$$\psi_1^2 + \psi_2^2 + \psi_3^2 = 1. \tag{11}$$

To determine the type of the function $F(e_u,\eta,\mu_\sigma)$, which is the part of (1), simple loading, at which β_{ij}, η, μ_σ remain stable will be considered, then [5]:

$$\psi_{ij} = \beta_{ij} \int_0^{e_u^*} F(e_u, \eta, \mu_\sigma) de_u = \beta_{ij} \varphi(e_u, \eta, \mu_\sigma), \tag{12}$$

where $\varphi(e_u, \eta, \mu_\sigma) = \int_0^{e_u^*} F(e_u, \eta, \mu_\sigma) de_u$. (13)

As $\beta_1^2 + \beta_2^2 + \beta_3^2 = 1$, it follows from (11) that during the destruction, if $e_u = e_p$, $\varphi(e_u, \eta, \mu_\sigma) = 1$. Besides,

$$\varphi(0, \eta, \mu_\sigma) = 0. \tag{14}$$

Meting these requirements, it can be assumed that [5]:

$$\varphi = \sum_{k=1}^{m} b_k \left(\frac{e_u}{e_p(\eta, \mu_\sigma)} \right)^{n_k}, \ \sum b_k = 1,\ n_k > 0. \tag{15}$$

According to (15) and (14) further take:

$$\varphi = (1-a)\frac{e_u}{e_p(\eta, \mu_\sigma)} + a\frac{e_u^2}{e_p^2} \tag{16}$$

where $e_p(\eta,\mu_\sigma)$ – is the surface of the ultimate deformations, a – is constant, depending on the mechanic characteristics of the metal. In the given research a is assumed to be equal a=0,48.

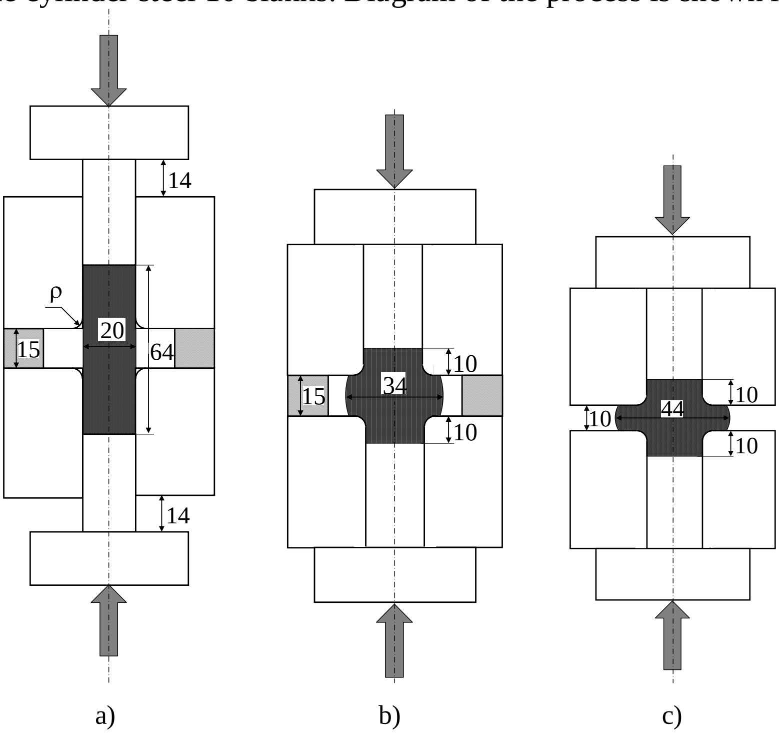
Meeting the requirements of the relations (1), (13), (16) let us assume that in case

$$\psi_1 = \int_0^{e_u} \left(1 - a + 2a\frac{e_u}{e_p(\eta, \mu_\sigma)} \right) \beta_1 \frac{de_u}{e_p(\eta, \mu_\sigma)}. \tag{17}$$

Analogous expressions can be written for ψ_2 and ψ_3, which are the part of the destruction condition (11).

Blanks deformation in the process of radial extrusion with further settling

Failure criterion (11) is used for the investigation of the process of the transversal extrusion with further settling of the cylinder steel 10 blanks. Diagram of the process is shown in Fig. 1.



a) b) c)

Fig. 1. Diagram of the extrusion with further settling of the obtained flange: a – output position; b – transversal extrusion; c – settling

At the first stage the process of the transversal extrusion is realized (Fig. 1, a), at the second stage-settling of the obtained flange (Fig. 1, b). Calculation of the stress-strain state was carried out, applying the method of the coordinate grids, the technique, presented in [7] was used. The process of extrusion and the process of settling were carried out in three stages. Ways of the deformation $\eta(e_u)$, $\mu_\sigma(e_u)$ were constructed, taking into account the impact of the basic technological parameters: relative thickness of the flange $h/2R_0$ and relative value of the rounding of the transient edge $r/2R_0$. As the deformation ways in e_u, η, μ_σ coordinates practically do not depend on the material, for the investigation of the stress-strain state the samples of antimonial lead (d_0=28,2 mm, l_0=60 mm), were used, they were cut in two halves. Rectangular grade grid with a base of 2 mm was applied on the polished surface of one of the halves of the composed sample by the bar blade. Then the samples were soldered and the pressing of the separate samples was made to different degrees of the deformation in three passages. Three samples after the last passage of the transversal pressing were used for the realization of three passages of the contour settling. Thus, each sample characterizes the deformed state at the end of the corresponding stage. After each stage the samples were unsoldered and the coordinates of the deformed grid nodes were measured.

Besides, the grade grid was applied on the lateral surface of the steel 10 samples and the transversal pressing and contour settling were performed according to the same scheme that the lead samples were deformed.

The accumulated deformation was found by the formula:

$$e_u = \int_0^t \dot{\varepsilon}_u d\tau ,$$

where $\dot{\varepsilon}_u$ – is the intensity of the deformation rates, t – is the time of deformation.

Components of the stress deviator were calculated by the relations, enabling to take into account the impact of nonmonotone plastic deformation [8], which takes place in this process:

$$S_{ij} = \frac{2}{3}\sigma_u(e_u)\frac{\dot{\varepsilon}_{ij}}{\dot{\varepsilon}_u} - \frac{1}{3}\int_0^{e_u}\left(1-\beta\left(e_u^*\right)\right)\sigma\left(e_u^*\right)\cdot\varphi\left(e_u^* - e_u^0\right)\frac{d^2\varepsilon_{ij}}{de_u^2}\left(e_u^*\right)de_u^* . \tag{18}$$

Dependences $\beta(e_u)$, $\varphi\left(e_u - e_u^0\right)$ for steel 10 were obtained experimentally, applying the technique [8]. Experimental results were approximated by the functions:

$$\beta=0,34+0,66\exp(-62e_u), \tag{19}$$

$$\varphi=0,19+0,81(-22,3(e_u-e_u^0)^{0,806}). \tag{20}$$

Constants of (19) and (20) were determined by the least square method.

Components of the stress tensor were found by means of integration of the differential equations of equilibrium:

$$\frac{\partial\sigma_r}{\partial r} + \frac{\partial\tau_{rz}}{\partial z} + \frac{\sigma_r - \sigma_\varphi}{r} = 0 ,$$

$$\frac{\partial\tau_{rz}}{\partial r} + \frac{\partial\sigma_z}{\partial z} + \frac{\tau_{rz}}{r} = 0 \tag{21}$$

Using the integral equation

$$\mathrm{P} = 2\pi\int_0^R \sigma_z r dr , \tag{22}$$

where R – is the radius of the deformed blank, P – is the effort, measured in the process of the studied blank deformation.

The obtained results of the stresses and deformations calculation were used for the construction of the loading path $\eta(e_u)$, $\mu_\sigma(e_u)$ and for calculation of β_i values.

Surface of the ultimate deformations for steel 10 were approximated by the dependence, obtained in the research [7]:

$$e_p(\eta,\mu_\sigma)=0{,}68\exp(0{,}43\mu_\sigma-0{,}91\eta). \tag{23}$$

Calculation of the used plasticity resource ψ for three points on the horizontal symmetry axis of the cylindrical sample in case of radial pressing with contour settling can be performed by the formula:

$$\psi=\sqrt{\psi_1^2+\psi_2^2+\psi_3^2} \tag{24}$$

Surfaces of the ultimate deformations of steel 10 and the path of deformation of the materials particles are shown in Fig. 2.

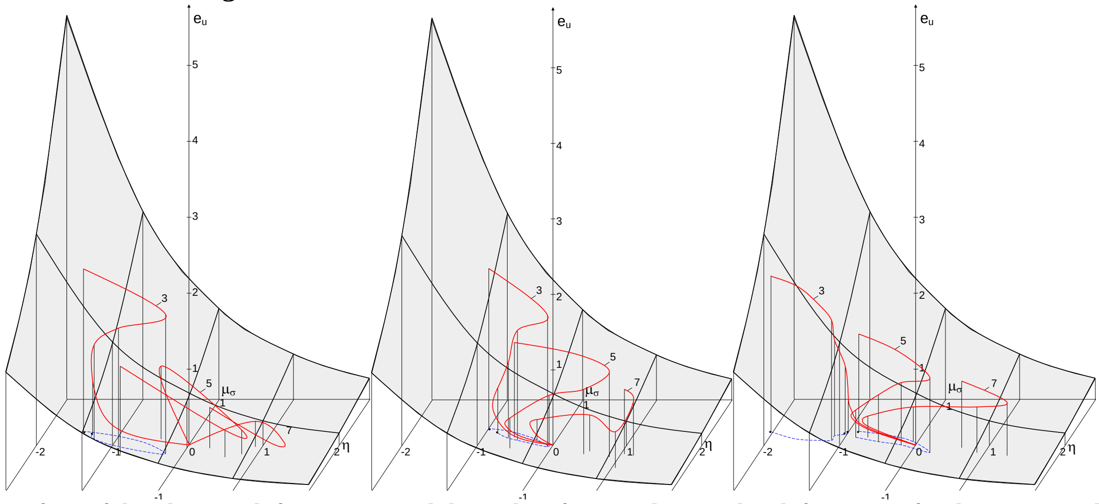


Fig. 2. Surface of the ultimate deformations and the paths of materials particles deformation for the points with initial radii r_{03} = 3.3 mm (point 3), r_{05} = 6.6 mm (point 5) and r_{07} = 10 mm (point 7): a – radius of matrix ρ *rounding* = 1 mm; b – ρ = 3 mm; c – ρ = 5 mm

Conclusions

Calculation of the used resource of the plasticity by the criterion (11) enables to describe experimental results. Discrepancy with the experiment does not exceed 18 %. In this case it should be noted that the account of the nonmonotone plastic deformation characteristic features enables to obtain flanges, the diameter of which exceeds the diameter of the flange at the conventional cross-section pressing by 60 – 80 %.

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