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INFLUENCE OF THE TYPE OF STRESS–STRAIN STATE ON THE TRUE STRESS–STRAIN CURVE FOR THE ELASTOPLASTIC MATERIALS

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Abstract. We present a description of the current status of research on deformation properties of elastoplastic materials under quasi-static loading. Based both on experimental and theoretical approach and on the developed method, true stress-strain curves were produced in the case of stretching of a cylindrical shell and a solid rod until fracture. The difference between produced curves for these types of specimen is shown for the first time for heterogeneous and non-uniaxial stress-strain state after beginning of the localization process of deformation. We show that the difference between the curves is inversely proportional to the volume rate of stress-strain state at the neck of a specimen.

1. Introduction

Plasticity theories based on the hypothesis of single curve are being used for simulation of deformation and fracture of structural elements. In the framework of the hypothesis, material properties are formulated as a scalar dependence of stress intensity on the deformation intensity (the Odqvist parameter). It is assumed that the curve does not depend on the type of stress-strain state. Apparently, the hypothesis of single curve was first proposed by P. Ludwik [1]. The hypothesis has been checked in papers of many famous experimenters, but only for deformations smaller than 10-20 %. There are some research results [2-4] illustrating the influence of the type of stress–strain state on the stress–strain curve, but experiments show that the hypothesis is violated for initially anisotropic material only.

The true stress–strain curves of materials defined up to fracture are required for the study of large deformations and limit states of structural elements. It is stated in [5] that the problem of getting the elastoplastic stress-strain curve up to fracture has not been resolved yet. The main issue lies in the explanation and description of the drop-down part of the curve, which corresponds to so-called phase of unstable (supercritical) deformation [6, 7]. Obtaining these data using available tools and direct measurement is rather difficult because heterogeneous and non-uniaxial stress-strain state arising in laboratory specimens as well as the influence of stress concentrators, boundary effects etc. Traditionally, the deformation and strength properties of the material are identified based on experimental and analytical approaches using experimental data and simplifying hypotheses, which impose restriction on the specimen’s shape and the type of loading. These methods allow obtaining the characteristics of elastoplastic materials using a homogeneous uniaxial stress-strain state only, which is not observed in real experimental conditions for large deformations. So, at the moment there are no effective methods of obtaining the strength and limit properties of materials for large deformations and heterogeneous stress-strain state with acceptable accuracy for engineering calculations. Regarding to this, it is advisable to develop the experimental and computational approach to research strength properties of materials for large deformations free from restrictions of the experimental and analytical methods. This approach involves a joint analysis of the experimental results and full-scale (within the framework of continuum mechanics) computer simulation of deformation process of laboratory specimens and structural elements without accepting of *a priori* force and kinematic hypotheses.

The methods and algorithms of studying the deformation and strength properties of elastoplastic materials under monotonic loading up to destruction are developed in [8-12] based on experimental and computational approach. Considered methods allow reducing the solution of the inverse problem to the sequential solution of a number of direct problems and, finally, obtaining a set of parameters for the mathematical model. The range of applicability of the experimental and computational approach is thus determined by the region of applicability of the mathematical model of elastoplastic media, since unconditional convergence of the iterative procedure guarantees the finding of the unknown parameters of the model with a predetermined accuracy.

2. Experimental and computational method for the construction of the true stress-strain curves under tension

For the proposed method [8-12], it is required to have an experimentally obtained dependence of a tensile force from a specimen’s elongation only. Specimens being tested may have variable cross section. It is known that loading process in the field of plastic strain localization under monotonic tension is active up to destruction. Construction of a stress-strain curve is based on correction of dependence of the stress intensity (σ_i) on the strain intensity (e_i). For this purpose, ratio of the tensile forces obtained in the experiment ($F_Э$) and calculation (F_p) for identical elongation of the specimen: $\beta = F_Э / F_P$ is analyzed during the process of numerical solution. Then, a functional relationship is established between the maximum strain intensity value in the specimen volume (e_i^*) and the corresponding elongation. The iterative procedure for curve correction is performed using the formula $\overline{\sigma}_i(e_i^*) = \beta\sigma_i(e_i^*)$ until the experimental and calculated results are matched with a predetermined accuracy. Studies show that it is sufficient to set any stress-strain curve of hardening material as initial data for the convergence of the iteration procedure. The rate of convergence (the number of iterations) depends little on the initial approximation. The most effective approach is to correct the curve at each step of loading under tension of the specimen. It is possible to adjust the whole stress-strain curve. In this case, it is necessary to solve the problem multiple times, which is more difficult, but allows using available program with direct problem solution without any modifications.

3. Construction of true stress-strain curve for cylindrical shell and solid rod under tension

Investigation of influence of specimen’s type (cylindrical shell and solid rod) on construction of true stress-strain curve under tension is provided based on developed method [8-12]. The research results are presented in Figs. 1, 2. Figure 1 is the true stress-strain curves combined by yield strength (dependency of stress intensity σ_i from plastic strain intensity e_i^p) for 12X18H10T steel defined up to fracture under tension of shell (solid line) and solid rod (dot line). Figure 2 is a relation between spherical component of stress tensor (σ) and plastic strain intensity (e_i^p) in the middle of neck of shell (solid line) and solid rod (dot line) for steel 12X18H10T, obtained by numerical simulation using the same true stress- strain curve (see Fig. 1, solid line).

As a result of these considerations we obtain the following:

- The true stress-strain curves match up to beginning of deformation localization;
- The value of strain intensity on true stress-strain curve for beginning of deformation localization for shell (47 %) is higher than value for solid rod (37 %). Results of the analysis of physical and computational experiments show that this occurs because of the initial hardening and deformation anisotropy resulted from manufacture of the shell is greater that the rod;
- After the beginning of localization the true stress-strain curves differ significantly and the hardening increment for the shell almost corresponds to the value before stability loss; hardening of the solid rod decreases and the stress-strain curve tends to perfect plasticity (see Fig. 1);
- The variation of spherical component of stress tensor after stability loss depends on the type of specimen. Increment of spherical component for a solid rod is significantly greater than that for a shell (see Fig. 2);

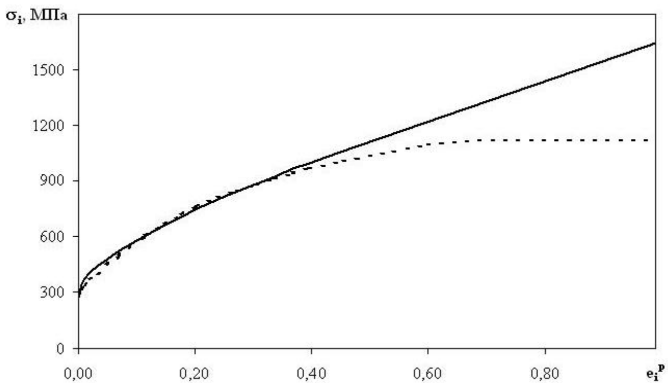

Fig. 1. Dependency of stress intensity σ_i from plastic strain intensity e_i^p for 12X18H10T steel defined up to fracture under tension of shell (solid line) and solid rod (dot line).

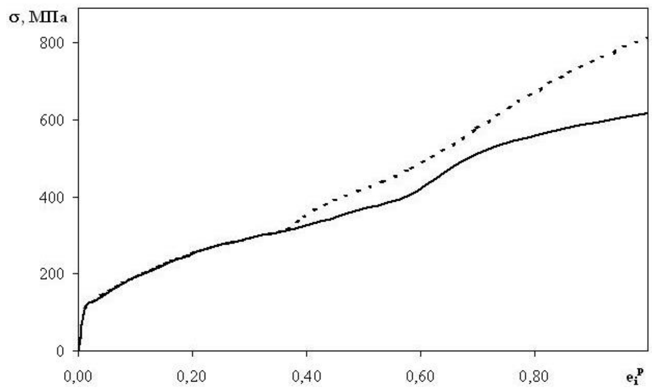

Fig. 2. Relation between spherical component of stress tensor σ and plastic strain intensity e_i^p in the middle of neck of shell (solid line) and solid rod (dot line) for steel 12X18H10T.

We can conclude that the true stress-strain curves constructed for a cylindrical shell and a solid rod with heterogeneous and non-uniaxial stress-strain state after the beginning of localization are different. The deviation between curves is inversely proportional to the volume rate of the stress-strain state in the middle of the neck.

4. Conclusion

It is necessary to use methods based on experimental and computational approach to investigate the deformation and strength properties of elastoplastic materials. This approach allows providing complex analysis of the material properties and studying the behavior of deformation and fracture processes taking into account all required factors. In particular, the method developed previously allows determination of the influence of the type of stress-strain state on the form of true stress-strain curve up to the fracture for a cylindrical shell and a solid rod made from 12X18H10T steel. These results should be considered in the further analysis of experimental and analytical data. Investigations in this area need to be developed and improved as they form the basis for the simulation of deformation and fracture processes of materials.

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