Dependence of the preliminary plastic deformation on the curves of chromium-nickel steel deformation

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Abstract. The test results of pre-deformed tubular samples at various values of preliminary deformation are presented. The article describes the chamber of the apparatus, which makes it possible to test tubular samples under conditions of plane and volumetric stress states. Curves built on test results of samples with different levels of preliminary plastic deformation are presented, as well as the test results of samples deformed by the ray α = 0.5. The experiments make it possible to determine the value of the ultimate uniform deformation after preliminary deformation or on the final segment of the multi-link loading path.

1. Introduction

The research on metal deformation after preliminary plastic deformation with a different loading path is mainly aimed at experimental verification of the fundamental principles of the theory of plasticity. On the other hand, when developing multi-operational technological processes for manufacturing products by stamping methods, it seems extremely important to know the ultimate homogeneous deformations at intermediate or final stages of deformation.

There are quite a lot of research works that describe experiments on plastic deformation of metals along broken (two- or three-link) trajectories. These works are mainly devoted to testing hypotheses and postulates of the deformation theory of plasticity. Researchers in [1, 2, 3] experimentally studied the laws of delay of scalar and vector properties of materials. In [4], according to the results of testing tubular samples along the ray paths after preliminary plastic deformation by other proportional loading paths, a significant change in the loading surface with a strong “cross effect” was noted. In [5], an experimental study of complex paths was used to evaluate various models of elastoplastic deformation. In the works by A. S. Vavakin et al [6], the elastoplastic properties of aluminum alloys were studied under proportional and broken loading trajectories.

It is noteworthy that the experiments mentioned and not mentioned here were carried out at very small values of preliminary plastic deformation (1÷3%).

Below are the test results of pre-deformed tubular samples, presented in the form of the dependence \( \sigma = \sigma(\varepsilon) \) (“stress intensity – strain intensity”) at various values of preliminary deformation.

2. Results and Discussions

Thin-walled samples (outer diameter \( d_H = 26.4 \) mm, wall thickness \( t = 0.3 \) mm) made of H18N10T-VD steel were tested in the apparatus, the test chamber of which is shown in figure 1. A detailed description of the setup is given in [7]; here we mention only some features. The named chamber is a two-layer
vessel containing the inner case 1 and the holder 2. The pressure of the working fluid at the ends of the locking punches 12 and 13 is reversed into compressive forces that displace the holder and the inner case relative to each other, thereby providing radial support to the inner vessel.

Assembled sample 9 with upper 11, lower 10 grippers and plunger 8, transmitting axial force to the sample, is placed in the chamber cavity and loaded with internal $p_w$, external $p_h$ and pressure $p_0$ under the plunger. The purpose of the other parts can be seen from the figure and does not require additional explanation.

The apparatus allows testing tubular samples under conditions of plane and volumetric stress states at maximum working fluid pressures of 1000 MPa. In the test chamber, the well-known loading scheme $p_w - p_h - P$ is implemented, all three pressures taking part in creating the axial force.

From the simulacrum of the deviators of the increments of plastic deformations and stresses, it follows that when loading at $\alpha = \sigma_\theta / \sigma_z = 0.5$ ($\sigma_\theta$, $\sigma_z$ are the annular and axial stresses in the sample wall, respectively), the ring deformation is zero, and the average diameter of the sample does not change. This circumstance, after switching on a multiplier between the cavities of the internal and external pressures with a certain ratio of the diameters of the plungers, allowed testing the samples along the named beam under conditions of strictly proportional (stepless) loading.

Hand pumps with a plunger diameter of 4 mm were used as pressure sources. During the tests, the samples were loaded along the aforementioned ray ($\alpha = 0.5$) to strain intensities $\varepsilon = 0.056; 0.140; 0.198$. Then, the tubes deformed in this way were loaded along the ray at $\alpha = \sigma_\theta / \sigma_z = 2.0$ up to the formation of local deformation and fracture. These tests were carried out on air in a simple...
device placed in the socket of a deadweight gauge. At the same time, in another nest of the latter there is an exemplary pressure gauge for measuring the pressure of the working fluid. During the experiment, the diameter of the sample was periodically measured with a micrometer in order to calculate the strain intensity and stress intensity. Note that under loading along this ray, the axial strain $\varepsilon_z$ is equal to zero, therefore, from the condition of constant volume $\varepsilon_r = -\varepsilon_\theta$, thus, the strain rate is determined as follows:

$$\varepsilon = \frac{2}{\sqrt{3}} \varepsilon_\theta$$

(1)

Stress intensity (when $\sigma_r = 0$) will be:

$$\sigma = \sqrt{\sigma_z^2 - \sigma_z \sigma_\theta + \sigma_\theta^2}$$

(2)

The following are indicated in (1), (2): $\varepsilon_z, \varepsilon_\theta, \varepsilon_r$ are axial, annular and radial logarithmic deformations; $\sigma_z, \sigma_\theta, \sigma_r$ are axial, annular and radial stresses.

Using the calculated values of $\varepsilon$ and $\sigma$, the curves $\sigma = \sigma(\varepsilon)$, were constructed which are shown in figure 2.

![Figure 2](image-url)

Figure 2. Curves $\sigma = \sigma(\varepsilon)$, constructed on the basis of test results of samples with different levels of preliminary plastic deformation: 1 – original sample; 2 – $\varepsilon = 0.056$; $\varepsilon = 0.140$; $\varepsilon = 0.198$.

There is also a diagram based on the results of tests along this ray of the original, that is, previously non-deformed sample. By the type and location of the graphs, we can conclude that the higher the level of preliminary deformation, the lower is the value of the ultimate homogeneous deformation. Noteworthy is also a steeper rise in the initial portion of the diagram for pre-deformed samples. As for the stress intensity corresponding to the moment of failure (or the formation of local deformation), here the discrepancy is about one percent. This value is comparable with the experimental error.

It should be noted that preliminary and subsequent deformation of the samples was carried out under plane deformation (for $\alpha = \sigma_\theta/\sigma_z = 0.5$, $\varepsilon_\theta = 0$, for $\alpha = \sigma_\theta/\sigma_z = 2.0$, $\varepsilon_z = 0$). According to the definition by Davidenkov and Friedman, plane deformation is a "rigid" loading path, usually ending in failure without the formation of local deformation. Indeed, in the sample shown in figure 3, brought to fracture by the ray $\alpha = 0.5$, the diameter remained practically unchanged, and the fracture occurred without localization of deformations.

In the original sample deformed at $\alpha = 2.0$, one-sided swelling occurs, in other, previously deformed samples, local deformation is not observed (figure 4).
Figure 3. A sample brought to fracture during deformation along the ray $\alpha = \sigma_0 / \sigma_z = 0.5$. On the left is a non-deformed sample.

Figure 4. Samples tested under loading along the ray $\alpha = \sigma_0 / \sigma_z = 2.0$ after preliminary deformation at $\alpha = 0.5$.

Figure 5 shows the test results of samples deformed along the ray $\alpha = 0.5$ to the level $\bar{\varepsilon} = 0.140$ and then tested at $\alpha = 2.0$ with a time delay of 10 min, 2 days, 5 months. The first two samples showed no difference. A sample that has been aged for five months has found an increase in ultimate uniform strain by 30% compared to the first. All experimental points are ideally located on one curve.

Figure 5. Samples testing results.

The samples were tested at the same values of preliminary deformation ($\bar{\varepsilon} = 0.140$) and different time delays.

3. Conclusion
The effect of preliminary plastic deformation on the nature of the exhaustion of the bearing capacity of chromium-nickel steel images when deforming them along a different loading path has been studied. The significant influence of preliminary residual strain on the value of ultimate uniform strain and the shape of the curves $\bar{\sigma} = \bar{\sigma}(\bar{\varepsilon})$ ("stress intensity – strain intensity") at the final stage of deformation has
been experimentally established. The steeper rise in the initial part of the diagram for samples with large preliminary deformation also attracts attention.

For samples that have passed a time delay of five months after preliminary deformation $\varepsilon = 0.140$, an increase in the ultimate homogeneous deformation by 30% is found in comparison with samples tested without a time delay.

The loading of the samples along the rays representing the state of plane deformation, the destruction is completed without any local deformation (in the form of a neck or swelling).

A new technique was used to create preliminary deformation by loading the sample along a ray at which its average diameter does not change ($\alpha = \sigma_\theta / \sigma_z = 0.5$).

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