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Yu. I. Yagn and O. A. Shishmarev

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Abstract

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Yu. I. Yagn and O. A. Shishmarev

SOME RESULTS OF AN INVESTIGATION OF THE BOUNDARIES OF THE ELASTIC STATE OF PLASTICALLY STRETCHED NICKEL SPECIMENS

(Presented by Academician L. I. Sedov on 17 X 1957)

For constructing relationships between plastic deformations and stresses, an essential role is played by the loading function, which describes in stress space the boundary of the elastic state of the material at a given stage of deformation. A number of works have recently been devoted to the study of this function ([1–4]); however, in the question under consideration there is still far from the necessary clarity, and in some conclusions different investigators are in complete disagreement with one another. In the work presented here, an experimental study was undertaken of the boundary of the elastic state of a material under a plane stress state produced by tension and torsion of thin-walled tubular nickel specimens that had received plastic deformation under tension. The aim of the experiments was to study the boundary with measurements carried out as accurately as possible and with its points determined according to strict tolerances for plastic deformations, upon the occurrence of which the material was considered to have passed out of the elastic state. At the same time, the experiments included examination of the question of the direction of the vectors of increments of plastic deformations when the material passed beyond the boundary of the elastic state. The investigations were carried out with different holding times of the specimens after the plastic deformation imparted to them.

The tubes used for the tests had an outside diameter of 5 mm and a wall thickness of 0.2 mm. The specimens were first annealed at a temperature of 860°, after which the relation between the elastic limits in tension and torsion satisfied the Mises criterion. The tests were carried out on a special apparatus in which the forces were produced by direct loading with small weights. Mirror instruments were used to measure longitudinal deformations and angles of twist. Longitudinal deformations were measured along four generators lying in two mutually perpendicular meridional sections of the tube. To eliminate the influ-

Fig. 1

Figure 1: Fig. 1

Fig. 2

Figure 2: Fig. 2

ence of overall rotations of the instruments, control mirrors were mounted on their bars. The absence of bending, which could arise from a not quite central application of the tensile force or from inaccuracies in producing the twisting couples, was checked by the equality of the elongations along the four indicated generators of the tube.

In carrying out the experiments, two methods were used. According to the first method, all points of the boundary of the elastic state were determined on one and the same specimen; according to the second method, a series of specimens was used that had received the same plastic deformation, and each specimen was used to determine only one point of the boundary. The first method gave poorer results, since an influence was found on the position of the boundary points from those plastic deformations which, even with a minimal tolerance, had to be produced in the specimen when determining the preceding boundary points.

In the very first tests it became clear that it was impossible to determine the region of the elastic state of the material immediately after the plastic deformation imparted to it, owing to the creep observed in the material. In this case the deformation continued to increase with time not only at the stress that had been reached, but also when its magnitude was reduced. These phenomena practically ceased after 10–15 min. The boundary of the elastic state determined after this, however, was not quite the same under different experimental conditions. It was affected by further holding of the specimens in time, the loading path chosen for its investigation, and, especially, the magnitude of the tolerance adopted in the investigation for plastic deformations. In view of this, a definite answer could be obtained only for a specified holding time of the specimens, a chosen path for investigating the boundary, and a specified tolerance for plastic deformations on passing through it.

Fig. 1

Holding times of three kinds were used: 1) 15 min under full load; 2) 12 hours under the same load;

Fig. 2

Fig. 3

Figure 3: Fig. 3

Fig. 3

3) 6 hours under full load and 12 hours without load. The path of investigating the boundary (with the exception of special tests to establish whether the character of the paths had an effect) consisted in reducing the tensile stress and adding a shear stress, which was successively increased and removed until residual deformations appeared that reached the adopted tolerance; the latter varied within the limits from 0.0005 to 0.036%.

In Figs. 1, 2, and 3, in the coordinates σ–$\tau\sqrt{3}$, the principal results of tests carried out by the second method are presented.

Figure 1 shows the boundaries of the elastic state found with a tolerance of 0.0005% on specimens that had received plastic deformation of 1.1% (curve *a*), 1.9% (), 2.7% (), and 3.5% (). Here curves *a* and correspond to holding time of the 1st kind, curve to holding time of the 2nd kind, and curve to holding time of the 3rd kind.

Figure 2 shows the difference in the boundaries of the elastic state obtained for the same plastic deformation of the specimens (1.1%) and the same holding time (of the 1st kind), when the tolerance for plastic deformations is varied.

···in studying the boundary. Curve *a* in Fig. 2 is the same as in Fig. 1. It corresponds to a tolerance of 0.0005%. The subsequent curves correspond to tolerances: *b*–0.006%, *c*–0.012%, *d*–0.018%, and *e*–0.036%.

Fig. 3 illustrates the changes undergone by the boundary of the elastic state as a function of the magnitude of the plastic deformation of the specimens when it is determined with a sufficiently large tolerance of 0.018%. The curves correspond to the magnitudes of plastic deformation of the specimens: *a*–1.1%, *b*–1.9%, *c*–2.7%, *d*–3.5%, and *e*–4.3%. Curves *a*, *c*, and *e* were obtained on specimens after identical aging of the first type. Curve *b* was constructed from specimens subjected to aging of the second type, and curve *d* from specimens tested after aging of the third type. The portions of the curves located below the σ_x axis were constructed by symmetry with the upper portions. In Fig. 3, in addition, the directions of the vectors of increments of plastic strains ε_x and $\gamma_{xy}/\sqrt{3}$, which were produced upon crossing the boundary in accordance with the adopted tolerance, are shown.

As can be seen from the figures, the boundaries of the elastic state determined according to the minimum tolerance, 0.0005%, are located entirely in the region of positive values of σ_x. Points lying to the left of the maximum of the curves correspond to the interesting phenomenon of the occurrence of compressive plastic strains (which did not disappear with time) while sufficiently large tensile stresses were still present in the material. The character of the curves was affected by the type of aging used. Curve *d* in Fig. 1, which corresponds to aging of the third type, stands out especially strongly. All these curves have a shape different from a circle. With an increase in the tolerance (Fig. 2), the region of the elastic state expands considerably, encompassing the origin of coordinates and approaching a circle in shape. The latter is especially clearly seen from Fig. 3, in which it proved possible to approximate the boundaries of the regions of the elastic state by circles (A–D are the centers of the circles) with insignificant deviations of the experimentally found points. As can be seen from Fig. 3, at a sufficiently large tolerance the influence of the aging regime of the specimens is almost completely smoothed out. With increasing plastic deformation, in all cases the boundaries shift in the direction of the stress axis σ_x.

The directions of the vectors of increments of plastic strains ε_x and $\gamma_{xy}/\sqrt{3}$ in all cases were found to be close to the normals at the corresponding points of the boundaries of the elastic state of the material. At small values of the tolerance the observations could contain rather substantial errors, but with increasing tolerance the directions of the vectors were determined quite reliably, and the picture presented in Fig. 3 clearly testifies to the correctness of the indicated conclusion.

On none of the obtained boundaries were any corners found, the existence of which is insisted upon by a number of investigators ([3,5,6]).

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Note: Figure translations are in progress. See original paper for figures.