CREEP OF IKh18N9T STEEL IN BIAXIAL TENSION

L. A. Prishchepionok

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The Institute of Hydrodynamics of the Siberian Division AS USSR has designed and built a testing machine for studying creep under conditions of biaxial tension. This paper reports on studies aimed at discovering the potentialities of the new machine and at obtaining data on the laws of creep in the complex stress state with a view to clarifying the effect of the third invariant on the creep rate distribution. The experiments were designed with the intention of analyzing the data by the method of [1].

As the object of investigation we chose a familiar material—IKh18N9T steel. Data on the creep of this steel in combined tension and torsion are given in [2] and analyzed in [1].

1. In the tests the specimens were loaded with an axial force and internal pressure.

The specimens were made from rods of commercial grade steel 35 mm in diameter. The chemical composition was: C 0.9%, Mn 1.05%, Si 0.57%, P 0.032%, S 0.0006%, Cr 17.92%, Ni 9.44%, Ti 0.4%. The material was heat-treated by the manufacturer under the following conditions: heating to 1100° C and quenching in water. Metallographic analysis of specimens measuring 10 × 10 × 15 mm with faces parallel and perpendicular to the axis of the rod revealed a quite fine grain. The grain size was of the order of 9–13 μ.

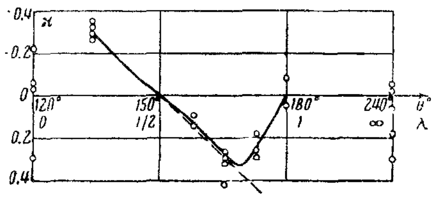

Fig. 1

Preferred directions of grain orientation were not observed. The material was not subjected to additional heat treatment.

The tests were run on specimens with an outside diameter of 16 mm, wall thickness 0.75 mm, and gauge length 100 mm. The loads on each specimen were calculated on the basis of its actual dimensions.

The tests were carried out at 600° C. The temperature was measured with three chromel-alumel thermocouples welded to the specimen. The temperature was maintained at the preset value with an accuracy of ±1.5°, and the temperature drop over the gauge length did not exceed 2° C.

Heating the specimens to the test temperature took 2.5–3 hr. The load was applied 5–6 hr after switching on the furnace.

The tests were conducted at ratios $\lambda = \sigma_3/\sigma_2 = \infty$, 1, 7/8, 3/4, 5/8, 1/2, 1/4, 0. Here we took the axial stress as σ_3, and the tangential stress as σ_2.

The stress levels were as follows: 12, 14, 16, and 19 kg/mm². For a number of test conditions the experiments were duplicated.

2. The stress states for $\lambda = 0$ and $\lambda = \infty$ determine the tension in the tangential and axial directions. In these types of tests the creep curves coincided within the limits of error of the experiment. The coincidence of the curves showed that the material had a sufficient degree of isotropy.

The results of the experiments, plotted in log p vs. log t coordinates, gave a series of straight lines parallel within the limits of the experimental scatter. From this we may conclude that the creep curves are similar for various types of stress state. Therefore the equation of any creep curve may be represented in the form $p = \varepsilon\tau(t)$.

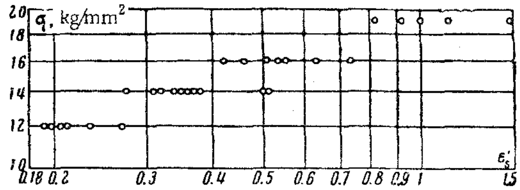

Fig. 2

Here ε is the creep rate with respect to the transformed time $\tau = \tau(t)$.

As standard creep curve we took the curve for $\lambda = \infty$ and $\sigma = 19$ kg/mm². This curve was a graph of the function $\tau(t)$. All the individual curves were reconstructed by varying the scale along the ordinate axis so that the best agreement with the standard curve was obtained. The scale of the construction determined the rate with respect to the transformed time $\tau(t)$.

The test results were reduced using the equations

$$\varepsilon_s = {}^2/_3\,[\varepsilon_1 \cos\theta + \varepsilon_2 \cos(\theta - {}^2/_3\pi) + \varepsilon_3 \cos(\theta - {}^4/_3\pi)] = gv\,(\sigma_i g), \qquad (1)$$
$$\varepsilon_t = -{}^2/_3\,[\varepsilon_1 \sin\theta + \varepsilon_2 \sin(\theta - {}^2/_3\pi) + \varepsilon_3 \sin(\theta - {}^4/_3\pi)] = v\,(\sigma_i g)\, dg\,/\,d\theta.$$

Figure 1 shows the quantity $\varkappa = \varepsilon_t/\varepsilon_s$ as a function of the type of stress state.

In [1] it was shown that at high stress levels the creep law associated with the condition of maximum tangential stress corresponds better to the data than a creep law of the Mises type. However, it is difficult to admit the existence of corner points on the creep surface; it is necessary to assume that the corners of the Tresca-Saint Venant hexagon are rounded. In fact, at $\lambda = 0$, $\lambda = \infty$, and $\lambda = 1$, which corresponds to compression with superposed omnidirectional tension, the experimental points display a considerable scatter. At small deviations from the calculated stresses in one direction or the other the creep strain rate vector sharply changes direction.

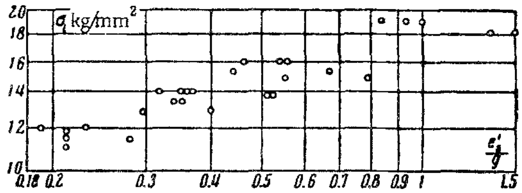

Fig. 3

When the specimen is loaded only with internal pressure ($\lambda = 1/2$) there is no creep in the axial direction; this was previously confirmed in [3]. At $\lambda = 1/4$ the sign becomes negative, the scatter of the experimental points is quite small. For $\lambda = 5/8$, 3/4, and 7/8 the sign of $\varkappa$ changes to positive, the points for $\sigma = 12$, 14, and 16 kg/mm² lie fairly close together.

The broken line in Fig. 1 corresponds to the law of creep associated with the Tresca-Saint Venant condition. Clearly, on the segment ($134° < \theta < 166°$) the experimental points are grouped around the broken line, which is in accord with the conclusions of [1]. To clarify the behavior of the function $\varkappa(\theta)$ in the region close to $\theta = \pi$, we carried out tests at $\lambda = 1/8$ ($\theta = 173°$). The corresponding points depart from the broken curve. The continuous line represents the assumed true dependence $\varkappa(\theta)$ on the natural assumption that $\varkappa(\pi) = 0$. One point at $\lambda = 3/4$ is out of line for reasons so far unexplained.

The invariant relations were checked using the formula

$$\varepsilon_s / g = v(\sigma_i g).$$

The function $g(\theta)$ was found by numerical integration

$$g(\theta) = \exp \int_0^\theta \varkappa(\theta)\, d\theta .$$

The invariant relations have quite a considerable scatter; comparison of the relations $\varepsilon_s' - \sigma_i$ (Fig 2) and $\varepsilon_s'/g - \sigma_i g$ (Fig. 3) does not permit any definite conclusions. Analysis of the data of other authors [1] resulted in a similar situation.

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