CREEP OF A HEAT-RESISTANT ALUMINUM ALLOY IN A COMPLEX STATE OF STRESS

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The article gives the results of experimental investigations of the creep of heat-resistant aluminum alloy AK4-1 with constant and variable loads, at a temperature of 175°C and a duration of the tests equal to 100 h. Based on the experimental data, a verification of the theory of creep is adduced, based on the following hypotheses: 1) the change in the volume is elastic; 2) the deviator of the creep rates is proportional to the deviator of the stresses; 3) the intensities of the stresses, of the creep deformations, and their rates are connected by a relationship which does not depend on the type of the state of stress. It should be pointed out that the results of investigation of creep, under a complex state of stress, in carbon, low-alloy, austenitic steels, copper, and certain light alloys, are given in [1-6].

1. The investigations were carried out on tubular samples made of exactly the same AK4-1 material at the same temperature of 175°C; the samples had a calculated length of 100 mm, a mean diameter of 16 mm, and a wall thickness of 1 mm. The construction of the testing machine permitted various combinations of normal and tangential stresses, from monoaxial elongation to pure torsion. The accuracy in the constancy of load, with the combined action of elongation and torsion, for elongation forces was ± 1%, and for the torque, ± 2%. The temperature was maintained with an accuracy of ± 2°C.

Before the main tests, a verification of the starting isotropy of the material was made. The material was delivered in the form of a slab with a thickness of 40 mm. Samples cut from the slab in longitudinal and transverse directions were tested for simple elongation, as well as for torsion, with the stress intensities and at the temperature of the main tests. The data obtained permitted the assumption that the material being investigated was sufficiently isotropic.

The tests under constant loads were carried out in series, in each of which the intensity of the stresses was constant but, from test to test, the type of stressed state was varied, i.e., the parameter $\lambda = \tau / \sigma$.

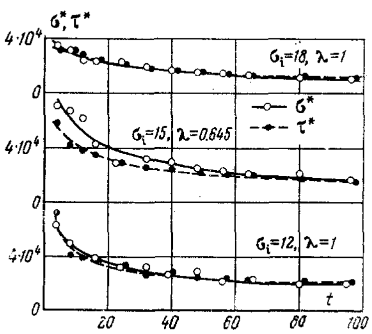

Fig. 1

To obtain more reliable results, each experiment was repeated 2-4 times. In all, four series of tests were carried out, with intensities of the stresses $\sigma_i = 12, 15, 18$, and 21 kg/mm². (In this article, all the values of the stress are given in kg/mm², and the time in h). The total number of samples tested was 40. On the basis of the experimental data, obtained under constant loads, the above-mentioned hypotheses with respect to creep were verified.

2. The hypothesis of the similarity of the deviators, taking account of the incompressibility of the material, can be written in the form

$$p_{kj}^{\cdot} = Q\sigma_{kj}^{*} \tag{2.1}$$

Here, p_{kj}^{*} are the components of the tensor of the deformation rates of the creep; σ_{kj}^{*} are the components of the deviator of the stresses; Q is a function of the invariants.

Novosibirsk. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 2, pp. 83-86, March-April, 1971. Original article submitted September 19, 1970.

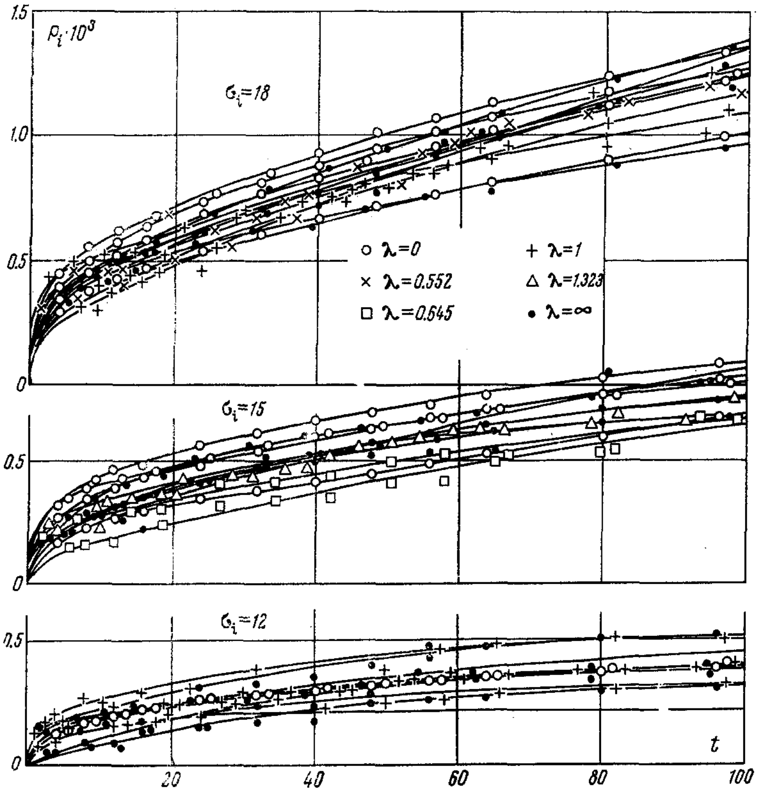

Fig. 2

With constant loads, in the case of elongation with torsion, it follows from (2.1) that:

$$\frac{2\sigma}{3\varepsilon_p} = \frac{2\tau}{\gamma_p} \tag{2.2}$$

Here ε_p is the axial deformation of the creep; γ_p is the shear deformation of the creep; σ and τ are the normal and tangential stresses.

The left- and right-hand parts of Eq. (2.2) are functions depending on the time

$$2\sigma / 3\varepsilon_p = \sigma^* (t), \quad 2\tau / \gamma_p = \tau^* (t)$$

Figure 1 illustrates these functions graphically for different intensities of the stresses, determined from averaged curves of the creep. As can be seen from the curves, relationship (2.2) holds satisfactorily. Thus, the deviators may be assumed to be approximately proportional.

In accordance with the third hypothesis, the curves of the creep, plotted in the coordinates intensity of deformations–time, should coincide with the same intensity of the stresses, for different types of stressed states. Figure 2 gives curves of the creep individually for each sample tested, in order to be able to judge the scatter of the experimental data. The values of the deformation rates of the creep, p_i, and of the intensities of the stresses, σ_i, were determined using the formulas

$$p_i = \sqrt{\varepsilon_p^2 + \gamma_p^2 / 3}, \quad \sigma_i = \sqrt{\sigma^2 + 3\tau^2} \tag{2.3}$$

It is evident from the curves that the scatter of the characteristics of the creep of the individual samples is greater than any kind of systematic differentiation of the experimental points as a function of the parameter λ.

As an analytical expression of the third hypothesis, there was taken part of the usual relationship following from the theory of hardening

$$p_i \cdot p_i^{\alpha} = k\sigma_i^{n} \tag{2.4}$$

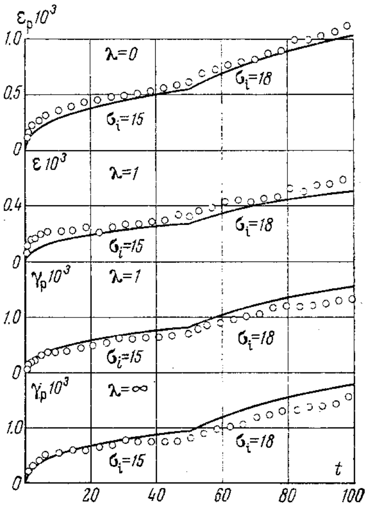

Fig. 3

Here, the dot denotes differentiation with respect to time. For the creep constants, the following values were obtained

$$\alpha = 1.5, \quad n = 7.5, \quad k = 8.375 \cdot 10^{-20}$$

3. The validity of relationships (2.1) and (2.4) was verified as for the case of variable loads. In this case, the following program of experiments was set up: the sample was loaded up to $\sigma_i = 15$ kg/mm^2 and, with this intensity of the stresses, was held for a period of 50 h; then, the load was gradually increased up to $\sigma_i = 18$ kg/mm^2, and the test was continued for another 50 h. Experiments were carried out with simple elongation, with torsion, and with the combined action of elongation and torsion ($\lambda = 1$); in the latter case, the condition of proportional loading was fulfilled. Analogous tests were carried out with a gradual reduction of the load from $\sigma_i = 18$ kg/mm^2 to $\sigma_i = 15$ kg/mm^2. Figure 3 gives the results of experiments with a rising load. Here, the circles denote the axial and shear deformations of the creep averaged over 2-3 samples. The solid lines show calculated values of these deformations, determined from the relationship

$$p_{kj} = \frac{3}{2}\frac{p_i}{\sigma_i}\sigma_{kj}^* \qquad (3.1)$$

This equality is obtained from (2.1), if account is taken of the condition of proportionality of the load. The intensity of the deformation of the creep, p_i, entering into expression (3.1), was found by integration of Eq. (2.4).

Comparing the calculated results with experiment, the conclusion may be drawn that, at an arbitrary ratio τ/σ, the agreement is the same as in the case of simple elongation.

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