EQUATION OF CREEP OF MATERIALS LIABLE TO STRAIN-HARDEN DURING CREEP

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An expression in the form

$$p^{\alpha}dp = K_0 e^{\beta_0\sigma}dt \tag{1}$$

is widely used to describe transient creep phenomena in the framework of the theory of strain hardening.

Here p is creep strain, σ is stress, t is time, and α, K_0, and β_0 are material constants at a given temperature and in a given stress range. However, it was observed in [1] that α and β_0 do not remain constant when the applied stress varies within wide limits. In this article this problem is analyzed in more detail on the basis of experimental data cited in [2-5].

The material characteristics are usually determined in the following way [2]: integrating (1) for σ = const and taking $1/(1 + \alpha) = m$, we obtain the equation

$$p = \frac{K_0}{m} e^{m\beta_0\sigma} t^m \tag{2}$$

which in a system of coordinates log p − log t is represented by a set of straight lines with parameter σ. In [2, 4, 5] but not in [3] these straight lines were almost parallel, which makes it possible to conclude that α = const in the entire stress range under consideration.

Considering the values of creep strain corresponding to different stress levels at a certain time t, from (2) we obtain

$$\beta_0 = \frac{\lg p_j - \lg p_i}{0.4343m(\sigma_j - \sigma_i)} \tag{3}$$

from which the average value of β_0 is found.

Analysis of experimental data in [2-5] showed that β_0 monotonically increases with σ. Values of β_0 calculated from (3) for stresses $\sigma = 1/2\,(\sigma_j + \sigma_i)$ 12 are plotted in Fig. 1, curves 1 and 2, relating, respectively, to data from [4] and [5]. We see that the statement β_0 = const is a very rough approximation of reality. It therefore seems advisable to regard β_0 as a function (e.g., a power function) of stress and replace (1) by an equation in the form

$$p^{\alpha}dp = Ke^{\beta\sigma^n}dt \quad (n > 1) \tag{4}$$

and Eq. (2) by

$$p = \frac{K}{m} e^{m\beta\sigma^n} t^m \tag{5}$$

Taking the logarithm of (5), we obtain

$$\lg p = 0.4343m\beta\sigma^n + \lg\left(\frac{K}{m} t^m\right) \tag{6}$$

Novosibirsk. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, Vol. 10, No. 3, pp. 183-184, May-June, 1969. Original article submitted September 24, 1966.

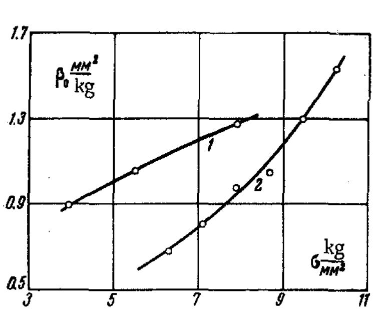

Fig. 1

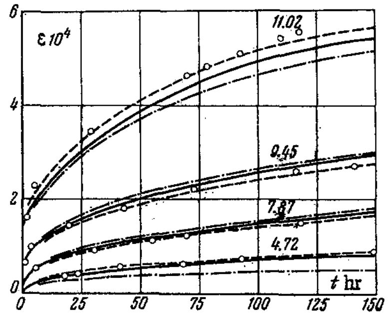

Fig. 2

If the process of creep is described by (4), then experimental points plotted in coordinates log p $-\sigma^n$ should lie on one of a set of straight lines with a parameter t. The index n is determined from the condition stipulating that three experimental points representing the state σ_1, p_1; σ_2, p_2; σ_3, p_3; at a certain time t (where $\sigma_1 < \sigma_2 < \sigma_3$) should lie on one straight line

$$(\sigma_2^n-\sigma_1^n)\lg p_3+(\sigma_3^n-\sigma_2^n)\lg p_1-(\sigma_3^n-\sigma_1^n)\lg p_2=0 \tag{7}$$

When data from [2-5] were processed, it was found that experimental points plotted in coordinates log p $-\sigma^n$ at t = const do, in fact, lie on a set of almost parallel straight lines. For instance, analysis of data from [5] showed that the variation in β determined in different intervals (σ_i, σ_j) from (6) with the aid of a formula

$$\beta=\frac{\lg p_j-\lg p_i}{0.4343m\,(\sigma_j^n-\sigma_i^n)} \tag{8}$$

does not exceed ±5%.

Solving Eq. (7) gave the following values of n:

for duralumin D16T at 150°C [2]	n = 2.817,
for high-quality structural 30CrMo at 500°C [3]	n = 2.188
for Nimonic-75 at 650°C [4]	n = 1.495
and for an aluminum alloy at 200°C [5]	n = 2.620.

The constant K is determined by the previous method [2].

Creep curves calculated from (4) are in very good agreement with experimental data. Figures cited above show that n oscillates about values whose mean is approximately 2.0. Since the introduction of an additional material constant in (4) is, generally speaking, undesirable, it is advisable (in view of the result obtained) to take n = 2 in (4), thereby leaving unchanged the method of determining material characteristics [2].

The results of processing data from [2] are reproduced in Fig. 2, where the dashed lines represent curves calculated from (4) with n = 2.620, the solid lines represent curves calculated from (4) with n = 2, the dot-dash lines are curves calculated from (1), and the numbers indicate stress levels (in kg/mm²) at which creep tests were carried out.

Thus, without complicating the method of determining material constants, curves calculated from (4) with n = 2 give a substantially better approximation than those calculated from (1).

Thanks are due to M. V. Mitrofanov and G. Ya. Sofienko for their assistance in the processing of experimental data and to O. V. Sosnin who sponsored this work.

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