SHORT-TERM CREEP OF ALLOY AMg6
WITH MONOAXIAL EXTENSION

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UDC 539.376+620.172.251.2

The article discusses a method for describing creep for the case when it is necessary to take account of all three stages of deformation: not fully established, fully established, and the start of the accelerated stage. The results of the calculation are compared with the data of an experimental investigation of the short-term creep of alloy Amg6-M, with varying loads.

In [1, 2], on the basis of experimental data, the conclusion is drawn that, for many industrial alloys, short-term creep may be regarded as creep without hardening. Such an approach simplifies the analysis considerably and reduces the volume of computations in the solution of partial problems. However, as noted by the authors of [1, 2], under the conditions of short-term creep, certain materials exhibit a more complex behavior.

1. Following Graham [3], in our analysis of the curves for the creep, we make the following assumptions:

1) the total deformation of the creep, p, is the simple sum of the contributions of the independent mechanisms;

2) the deformation p_i, due to each i-th mechanism, for fixed stresses and temperatures, can be represented by the formula

$$p_i = f_i(\sigma, T)\, t^{m_i} \tag{1.1}$$

Here σ is the stress; T,°K, is the experimental temperature; t is the time; and m_i is a constant.

Approximating functions, suitable for describing creep over a sufficiently broad range of stresses and temperatures, may be taken in the form

$$f_i(\sigma, T) = (a_i\sigma^{n_i} + b_i e^{\beta_i\sigma})\, e^{-\alpha_i/T} \tag{1.2}$$

Here a_i, b_i, α_i, β_i, and n_i are constants, subject to experimental determination.

In the case of varying stresses and temperatures, for calculation of the i-th component of the deformation, we can use a relationship, which is usually applied to describe the initial sectors of the creep curves

$$\dot{p}_i p_i^{(1-m_i)/m_i} = m_i f_i^{1/m_i}(\sigma, T) \tag{1.3}$$

Equation (1.3) is obtained from (1.1) by differentiation, followed by elimination of the time.

TABLE 1

i	n_i	m_i	$\alpha_i 10^{-3}$, °K	β_i, mm²/kg	a_i	b_i
1	1	1/3	4.6	0.72	$5.9\cdot10^{-2}$ mm²/(sec$^{-1/2}$· kg)	$4.5\cdot10^{-4}$ sec$^{-1/3}$
2	3	1	16.8	0.98	$1.05\cdot10^{6}$ mm⁶/(sec · kg)	$5.0\cdot10^{4}$ sec^{-1}
3	8	2	34.8	—	$4.9\cdot10^{13}$ mm^{16}/(sec^2 · kg^8)	0

Novosibirsk. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 1, pp. 141-143, January-February, 1972. Original article submitted February 5, 1971.

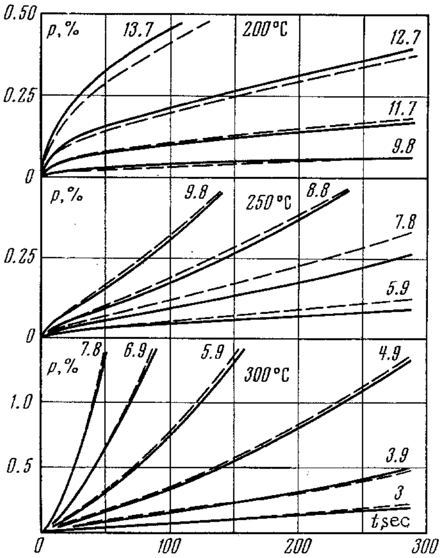

Fig. 1

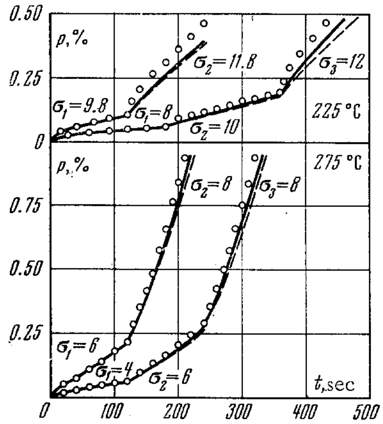

Fig. 2

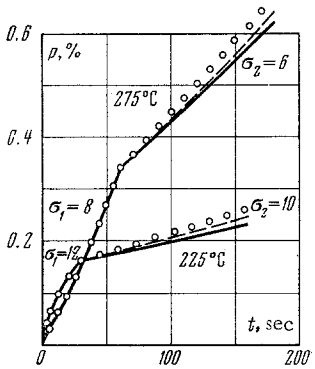

Fig. 3

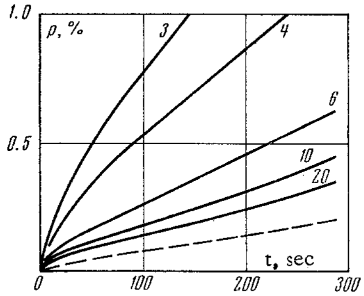

Fig. 4

2. The dependences given above were applied to the analysis of the results of extension tests under conditions of short-term creep, on samples of alloy AMg6-M ($\sigma_b = 35$ kg/mm^2, $\sigma_{0.2} = 16$ kg/mm^2). The experiments were carried out using flat samples with a width of 10 mm and a calculated length of 100 mm, cut along the direction of rolling, from sheets with a thickness of 2.5 mm. The temperature levels in the experiments were 175, 200, 225, 275, 300, and 325°C, while the stresses lay within the limits from 1 to 15 kg/mm^2. The duration of the experiments did not exceed 8 min.

An experimental unit of the lever type, with an infrared heating furnace, permitted rapid heating of the sample in 30-60 sec, and ensured maintaining the given temperature within the limits ±0.5%, using a system of thermoregulation based on an ÉPR-09-M3 instrument. The temperature along the length of the sample was equalized using supplementary heaters mounted on a bar. Rapid and smooth heating (in a period of 0.3-0.7 sec) was effected using an eccentric mechanism with a damper, while the given level of the stress was ensured, with a degree of accuracy not less than ±1% using a set of weights. The deformations were measured using an extensometer with a clock-type dial, with a graduation of 0.002 mm and an upper measurement limit of 2 mm. The readings of the indicator and the second meter were recorded automatically using an RFK-1M photographic camera.

The solid lines in Fig. 1 show, in the form of creep curves, the averaged results of sheet material with a thickness of 2.5 mm. (Here, and in the remaining figures, except for Fig. 4, the numbers on the curves denote the values of the stresses in kg/mm^2.) From 2 to 4 samples were tested for each set of conditions. Under these circumstances, the scatter with respect to the deformations did not exceed ±10%. The point of reference for the deformations of the creep was taken as the deformation corresponding to the moment when the loading was completed. This moment was determined from an oscillogram of the signal of strain gauges, mounted on a bar outside the heating zone.

As follows from Fig. 1, at temperatures of ~ 200°C, the creep is accompanied by a considerable degree of hardening of the material. With an increase in the temperature up to ~ 300°C, the first sector on the creep curves practically disappears; however, already with a deformation of ~ 0.3%, a third stage of creep starts to appear. The elongation of the sample at the moment of failure may reach tens of percents.

3. In view of what has been said above, in the analysis, each creep curve was approximated by a trinomial of the form

$$p = f_1 t^{1/3} + f_2 t + f_3 t^2$$

Here the power exponents are selected from the condition of the best agreement with the experimental curves, as well as for convenience in the calculations. The method of least squares may be used to determine the coefficients f_1, f_2, and f_3. The constants in relationships of the type (1.2) were calculated in the usual manner. In this case, use was made of the simplifying fact that, at temperatures of 275, 300, and 325°C, the effect of the term $b_i e^{\beta_i \sigma}$ for stresses not exceeding the elastic limit, may be neglected. The results of the analysis are given in Table 1, while the quality of the approximation can be evaluated from Fig. 1, on which the calculated curves are shown by the dotted lines. Here it must be noted that the constants given in Table 1 are not of a universal character, and that their use outside of the region of stresses, temperatures, and deformations shown in Fig. 1 may lead to error.

4. To verify the possibility of using equations of type (1.3) in the case of nonsteady-state conditions, experiments were made with stresses, varying with time by degrees. Data from experiments at temperatures of 225 and 275°C are shown by the small circles in Fig. 2 (loaded) and in Fig. 3 (unloaded). Here, as starting points of reference for the deformations of the creep, there were taken the deformations corresponding to the moments when the loading was complete. The loading time was determined from oscillograms and did not exceed 1 sec. The solid lines on Fig. 2 and Fig. 3 give the results of calculation using relationships (1.2) and (1.3), with the coefficients from Table 1, while the dotted lines give the results of a graphical plot. In accordance with the kinetic equation for the creep

$$\dot{p} = u(\sigma, T, p)$$

It is evident from Figs. 2 and 3 that the experimental data are described satisfactorily.

5. To investigate the effect of hardening on creep, experiments were carried out on samples made of sheet material AMg6-N ($\sigma_b = 45$ kg/mm^2, $\sigma_{0.2} = 38$ kg/mm^2) with a thickness of 2 mm. The following conclusions can be drawn from the experimental results. In the first place, the creep rate of hardened material may exceed by several, or even tens of times, the creep rate of soft material. In the second place, at a temperature above ~ 250°C, material AMg6-N becomes structurally unstable. This latter fact is illustrated by Fig. 4. Here the solid lines give the creep curves for material AMg6-N at a temperature of 300°C and under a stress of 3 kg/mm^2. The numbers on the curves denote the holding time (in minutes) of the samples at a temperature of 300°C under the load. The dotted line corresponds to soft material. Thus, the holding of a hardened material at high temperature leads to its further hardening with respect to creep.

LITERATURE CITED

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