THE RELATION BETWEEN CREEP AND LONG-TERM FRACTURE OF MOLYBDENUM AND ITS ALLOYS

E. E. Zasimchuk and V. V. Krivenyuk

One of the methods of improving the heat-resistant properties of refractory metals with a b.c.c lattice is to microalloy them with soluble additions [1]. Since at the present time many elements important in designs for new techniques operate at high temperatures and relatively low loads, an extremely important indication of the heat-resistant properties of the material is its behavior in conditions of high-temperature creep. In practice there is interest not only in the general level of strength, in relation to temperature and the time that the material is under load, but also the characteristics of deformation which determine to a considerable degree the structural changes during creep.

In the present work we carried out an experimental study of the laws of creep and long-term fracture of weakly alloyed alloys based on molybdenum in comparison with molybdenum of commercial purity [2]. The composition of the investigated materials is given in Table 1. Molybdenum and the TsM-2A alloy (see Table 1) were preliminarily treated by hot rolling and annealing for 1 h at 1400°C. The TsM alloy was heated after rolling for 30 min at 1100°C. Flat samples of thickness 1 mm and gauge length 20 mm were tested for creep. The test method was described earlier [2-4].

The connection between long-term strength of the investigated materials and the life $\tau$ and the temperature of testing $T$ is given in Fig. 1. From the figure it can be seen that with $T = \text{const}$ in TsM-2A alloys, the relationship $\sigma = f(\tau)$ may be presented by the function

$$\tau = A\sigma^{-b},$$

where $A$ and $b$ are constants.

Fig. 1. Long-term strength of molybdenum (dotted lines) and TsM (continuous) and TsM-2A (dot-dash) alloy in relation to durability and temperature.

Fig. 2. Temperature dependence of the long-term strength for molybdenum (dotted lines) and the TsM-2A alloy (continuous lines).
where $\beta$ is a parameter (in the alloys $\beta \approx 5$). In contrast to the alloys, for commercially pure molybdenum the relationship (1) is also characteristic but it may not be characterized by the single coefficient $\beta$. For example, with $T = 1800^\circ C$ and $\tau < 2 \ h$ for molybdenum $\beta = 6.8$ (Table 2) while for the large values of $\tau$ (up to $100 \ h$) $\beta = 2.4$. As a result of this it appears that at a temperature of 1800$^\circ C$ the high strength of molybdenum alloyed with zirconium occurs only with prolonged testing and the difference in long-term strength of molybdenum and the TsM-2A alloy (see Fig. 1) increases with increase in $\tau$. For example, at 1800$^\circ C$ and $\tau = 10 \ h$ the strength of molybdenum is 1 kg/mm$^2$ and the strength of the TsM-2A alloy is 1.3 kg/mm$^2$; with $\tau 100 \ h$ the figures are respectively 0.4 and 0.9 kg/mm$^2$.

Figure 2 shows the temperature dependence of the long-term strength $\sigma$ for molybdenum and the TsM-2A alloy with the coordinates $\log \sigma - 1/T$. From the figure it can be seen that this relationship approximates to the exponential

$$
\sigma \sim \exp (Q/RT),
$$

where $Q$ is the so-called temperature coefficient which is not a constant value but increases with increase in test temperature.

In an analysis of the relationship $\sigma = f(T)$ in the coordinates $\log \sigma - 1/T$, we determined the role of diffusion processes in the fracture during creep, for which an exponential relationship is characteristic in the form

$$
D = D_0 \exp (-E/RT),
$$

where $E$ is the activation energy for diffusion.

A graphical estimation of the parameter $Q$ with the obtained relationships $\log \sigma = f(1/T)$ showed that even the maximum value of $Q$ is somewhat less than the activation energy for bulk and boundary self-diffusion of molybdenum [5, 6]. This is obviously connected with the fact that the processes occurring towards fracture (the merging of individual micropores and the formation of cracks) are accomplished not only by diffusion of individual vacancies but it is probable that the role of diffusion in the merging of pores increases with increase in temperature. The cooperative migration of accumulations of vacancies (pores) is possible but the mechanism of such a process is not clear energetically. The sharper temperature dependence of $\sigma$ in molybdenum in comparison with the alloy is obviously caused not only by the influence of the impurities dissolved in the alloy on the kinetics of the merging of pores but also by the more rapid softening of the unalloyed molybdenum as a result of creeping of dislocations [1].

The strengthening created by microalloying sharply decreases with increase in temperature. At 1000$^\circ C$ the difference in the value of $\sigma_1$ for molybdenum and the TsM-2A alloy is 6 kg/mm$^2$, and at 1800$^\circ C$ the difference appears only in conditions of long life and does not exceed 0.5 kg/mm$^2$. The decrease in the role of the impurities with increase in temperature is observed in many processes connected with thermally activated migration of atoms [7-9 et. al] and is obviously caused by the dispersion of the impurity accumulations in local portions of crystallites (grain boundaries, dislocations, etc.), with increase in temperature.