Creep Mechanism in Fe-1.8 At. Pct Mo Alloy at High Temperatures

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High temperature creep of Fe-1.8Mo alloy, the stress exponent, \( n \), of which is about 4, has been studied to check whether the \( n \) value can be a good indication of the creep mechanism or not. Creep tests were carried out at 1124 K under 5.9 to 39.2 MPa. After sudden stress increments during the steady-state creep, inverse-type transient creep curves were obtained with no instantaneous permanent strain. Mean internal stresses were determined by stress-transient dip-tests using a back extrapolation technique. The mean internal stress was obviously smaller than the applied stress. These results indicate that creep deformation of Fe-1.8Mo alloy under the present conditions is controlled by the viscous glide motion of dislocations, though \( n \) is not close to 3. Steady-state creep rates as well as the value of \( n \) calculated from the Orowan-type equation using experimentally obtained values for every parameter, are in reasonable agreement with the observed ones. These findings suggest that classification of creep behavior according to the \( n \) value is not appropriate in some cases for discussing mechanisms of high temperature creep.

Creep behavior of solid solutions is usually classified into two groups according to the value of the stress-exponent, \( n \), for steady-state creep rates at high temperatures. Creep behavior in which \( n \approx 3 \) is classified as Class I, while creep behavior of some solid solutions, in which \( n \approx 5 \) or more as in the case of pure metals, is classified as Class II. Creep of Class I behavior is believed to be controlled by a microcreep mechanism, that is, the viscous glide of dislocations, and that showing Class II behavior is believed to be controlled by a recovery process. At present, however, no theoretical justification of this classification can be found.

In Fe-Mo alloys, \( n \) has been reported to depend greatly on the concentration of molybdenum, as well as on the experimental condition. In alpha-iron, \( n \approx 5 \), the high temperature creep is believed to be controlled by a recovery process as in many other pure metals. The value of \( n \) decreases to about 3 as the molybdenum content increases (see Fig. 1). Creep deformation of Fe-3.5 at. pct Mo alloy, in which \( n \approx 3.4 \), is reported to be controlled by a microcreep mechanism.

In this investigation, creep characteristics of an iron-1.8 at. pct molybdenum alloy have been studied to reveal the rate-controlling step under the condition where \( n \) is about 4 and to check experimentally the correspondence between \( n \) values and rate-controlling steps.

EXPERIMENTAL PROCEDURE

The material used was 1.80 at. pct molybdenum alloy, which was made by vacuum-melting of electrolytic iron (99.99 pct pure) and molybdenum powder (99.99 pct pure). Main impurities (in wt pct) were C: 0.004, N: 0.002, S: 0.003 and P: 0.003.

Sheet specimens 1 mm thick, the gage length and the width of which were respectively 20 and 5 mm, were annealed at about 1470 K for 18 ks. The resulting grain diam was about 0.1 mm.

Experimental procedure was similar to that employed in the study of creep in Al-Mg alloys done in this laboratory. Most creep tests were carried out using a simple lever-type testing machine in an argon atmosphere under a constant-stress condition at 1124 K. The strain was measured from the movement of the pull-rods using a linear variable differential transducer, and was recorded by a conventional recorder of zero-balanced type. Strain could be detected to \( 1 \times 10^{-5} \).

The temperature was controlled to within ±0.5 K of the reported value.

In some creep tests, a small amount of stress was suddenly increased or decreased to examine the instantaneous elongation or contraction associated with the stress changes. In tests of this kind, extra weights of small steel blocks were hung on both sides of the lever arm using strings of a low-melting metal. The extra weights of both sides were balanced initially with each other. The creep stress can be increased by

![Graph showing the applied stress exponent for steady-state creep rates, \( n \), as a function of the atomic fraction of molybdenum, \( N_{Mo} \), in alloys of the Fe-Mo system at 1124 K.](image)

Fig. 1.—The applied stress exponent for steady-state creep rates, \( n \), as a function of the atomic fraction of molybdenum, \( N_{Mo} \), in alloys of the Fe-Mo system at 1124 K.
Fig. 2—Steady-state creep rates, $\dot{\varepsilon}_s$, of Fe-1.8 Mo alloy at 1124 K as a function of the applied stress, $\sigma_a$. The types of primary creep curves are also shown.

removing the steel block from the lever of the specimen side. When the steel block is removed from the lever of the other side (loading side), the stress is returned to the base (initial) stress. These stress changes were done within 0.02 s by burning the metal string off. The strain was recorded on "LINEAR-CORDER", a modified pen-galvanometer, which can record sinusoidal waves up to 50 Hz.

Internal stress during the steady-state creep was determined by the stress-transient dip tests applying a back-extrapolation technique. In these cases creep tests were carried out using an Instron-type tensile machine equipped with a load controller. The temperature fluctuation during the dip tests was within ±0.1 K.

Fig. 3—Examples of the time-displacement recordings during stress change tests in Fe-1.8 Mo alloy. The stress is increased by the amount of 1.4 MPa (a), and after a while it is decreased to the base stress level (13.7 MPa) (b).

RESULTS AND DISCUSSION

A. General Characteristics of Creep

Creep tests were done at 1124 K under applied stresses ranging from 5.9 to 39.2 MPa. The type of primary creep curve depended on the level of the applied stress, $\sigma_a$. The inverse-, the sigmoidal- and the normal-type curves appeared with increasing $\sigma_a$ in this order as reported elsewhere.

The steady-state creep rates, $\dot{\varepsilon}_s$, are shown in Fig. 2 as a function of $\sigma_a$, in which the types of primary creep curves are also shown. The applied-stress exponent for steady-state creep rates, $n$, was $4.0 \pm 0.2$ under the present experimental conditions.

B. Transient Creep Behavior

Mechanical behavior associated with sudden stress increment depends on the type of the glide motion of dislocations during creep. When the glide motion is a free-flight-like one, a permanent strain arises instantaneously upon the stress increment. The creep rate right after the stress increment is very high, which is gradually slowed down to the value for the new steady-state under the increased stress level. On the other hand, when the glide motion is a viscous one, no instantaneous permanent strain is expected upon the stress increment. The creep rate, which increases slightly upon the stress increment, increases gradually up to the value for the new steady-state under the increased stress.

Hence, the instantaneous permanent, or macroscopically plastic, strain and the normal-type transient creep curve should be obtained when dislocations move in a free-flight-like manner, while no instantaneous permanent strain and the inverse-type transient creep curve should be observed when dislocations move in a viscous manner. These behaviors have actually been observed upon stress increments in aluminum and Al-5.5 at. pct Mg alloy, respectively.

a) Instantaneous Permanent Strain. Instantaneous strain associated with the sudden stress changes was measured during the steady-state creep stage under 13.7 MPa. Typical examples of the time-displacement curves are shown in Fig. 3. The instantaneous elonga-