THE CYCLIC STRENGTH OF TUNGSTEN AT HIGH TEMPERATURES

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A great deal of attention has been devoted in recent years to the high-temperature fatigue failure of metals. However, this problem has a whole series of unresolved aspects, one of which is the elucidation of the mechanism of failure.

It is known that at temperatures above approximately 0.5Tmp fatigue failure, like that in ordinary creep, is intergranular [1-9]. It may be assumed that the failure mechanism in static stressing is similar to that in cyclic stressing [1]. There is, however, another view [4, 5], according to which fundamental differences exist in the nature of the two processes. There is also complexity arising from the fact that different forms of loading (symmetrical, pulsating, tensile, bending, etc.) may affect the failure mechanism in different ways.

According to the results reported in [6, 7], the cavity formation which takes place during cyclic stressing is due to movement at the grain boundaries. It has been shown in [2, 3] that the formation, diffusion, and coalescence of vacancies plays a decisive part in the fatigue failure of lead. Various opinions also exist regarding the growth of the sources of failure that are formed. Some authors [6, 7, 9, 10] consider that the microcavities grow as a result of the absorption of vacancies, the formation of which occurs more intensively during cyclic deformation than during static loading [11]. According to others [8], cavities grow by a process of intergranular movement, and the absorption of vacancies may be material to their growth only in the later stages of fatigue failure.

There has been only an inadequate study of the cyclic strength of metals at temperatures in excess of 2000°C. In particular, only one investigation [12] has been devoted to tests on tungsten up to 2700°C; in this an empirical relationship was obtained between fatigue life and temperature and level of stressing.

In the present communication we report the results of an investigation of the structural changes that take place in tungsten subjected to pulsating tension in the range 2000-3000°C and we also discuss the mechanism of failure. The material tested consisted of annealed grade-VA tungsten wire 100-250 μ in diameter. In the recrystallized state grade-VA tungsten is characterized by a coarsely crystalline structure with long grains elongated in the direction of the axis of the wire and by tortuous boundaries. The fatigue tests were carried out in direct-heating apparatus by the method described in [13].

Figure 1 shows the results of measuring the temperature dependence of the cyclic strength of tungsten wire 160 μ in diameter. It will be seen that, within the limits of experimental error, the relationship is exponential and it may be expressed analytically by the equation

\[ N = \exp(-\alpha T), \]

where \( N \) is the number of cycles to failure; \( \alpha \) is a constant; and \( T \) is the absolute temperature.

A similar expression for the cyclic strength of tungsten has previously been obtained in [12].


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In order to study the mechanism of fatigue failure, metallographic examinations were carried out, and the internal friction was investigated after tests had been made at various temperatures and stress amplitudes. Metallographic analysis revealed that in all cases failure occurred as a result of the formation and growth of cavities. However, the nature of their formation varied at different temperatures. After tests on specimens 250 μ in diameter at relatively low temperatures (below 2300°C) the cavities were uniformly distributed throughout the whole length of the wire, being situated at the grain boundaries (Fig. 2a). In contrast to static stressing (under creep conditions), in cyclic deformation microcavities arose not only at transverse sections of the grain boundaries but also at longitudinal ones. In addition subgrains appeared, and an increased density of etch pits was noted (Fig. 2b).

Differences in the nature of cavity formation at high and relatively low temperatures were determined by the internal-friction method. Figure 3 shows the variation in the internal friction of tungsten during cyclic stressing at 2000°C.

It can be seen from Fig. 3 that the high-temperature part of the internal friction was somewhat higher after testing and then remained constant within the limits of error in measurement. The low-temperature part fell at first, and only after the lapse of a certain time did it begin to increase. In this case the change in internal friction $Q^{-1}$ was more marked than in the high-temperature region. A similar behavior of the curves was observed over the whole range of stresses investigated from 0.2 to 1.25 kgf/mm².

The nature of the variation in the low-temperature branch of the internal friction is substantially different after testing at higher temperatures (2500-3000°C) (Fig. 4). In particular, the level of $Q^{-1}$ does not fall in the initial stages of cyclic stressing.

Analysis of the results obtained suggests the following failure mechanism. In fatigue stressing, as in static stressing, microcavities originate in the way described by Gifkins [14]. At test temperatures of 2000-3000°C, when the grain boundaries have a fairly high plasticity, cyclic deformation takes place mainly by intragranular mechanisms. The sources of failure occur at places where slip lines emerge at the grain boundaries, and they are uniformly distributed along the whole length of the specimen. The microcavities grow principally as a result of the diffusion of vacancies, which proliferate during intragranular deformation. The likelihood of such a mechanism operating is confirmed by the appearance of a substructure and an increased density of etch pits. The results of the internal-friction studies can also be interpreted in terms of the proposed mechanism. As the level of internal friction under low-temperature conditions is determined by the density of the free sections of the dislocations [15], the initial fall in its low-temperature branch after testing at 2000°C (see Fig. 3) is attributed to pinning of the dislocation lines by excess vacancies.