THE ROLE OF ATTRACTIVE JUNCTIONS IN STRAIN HARDENING OF ALUMINIUM AS SHOWN BY CHANGE-IN-STRESS-CREEP EXPERIMENTS

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ABSTRACT

The activation volume in aluminium evaluated from data on stress increments during differential-stress creep experiments is found to be different from that of stress decrements. This is interpreted in terms of the change, on stress decrement, in the number of dislocations that are likely to get activated as a result of the full formation of attractive junctions. The effect of stress on this phenomenon is discussed.

INTRODUCTION

A STRUCTURAL theory was suggested[1] in terms of a dislocation model involving the intersection of glide and forest dislocations to explain logarithmic creep in f.c.c. metals and was supported by later investigations.[2-4] Many investigations[2-6] showed that logarithmic creep can be considered as a process of strain hardening and in fact it was used as an indirect method to study the nature of interactions between dislocations during strain hardening in f.c.c. metals. The relation between strain hardening and logarithmic creep has been discussed extensively.[7] The aim of the present investigation is to shed more light on the interactions occurring during strain hardening from a study of the logarithmic creep behaviour involving change-in-stress-creep experiments. The data from such experiments are often used to estimate the activation volume, v, for the thermally activated deformation process since,

$$v = \frac{\delta \ln \mathring{\epsilon}}{\delta \tau} kT \simeq \frac{\Delta \ln \mathring{\epsilon}}{\Delta \tau} kT$$

where $\mathring{\epsilon}$ is the creep rate, τ the applied shear stress, k the Boltzmann's constant and T the absolute temperature. Shear stress is calculated from the applied tensile stress, σ, by assuming that $\tau = \sigma/2$.

EXPERIMENTAL

Aluminium of 99·997% purity was used in the present work. The specimens in the sheet form were tested on a tensile creep-testing unit described elsewhere.[8] The testing temperature was 87° K. which was obtained by surrounding the sample with liquid oxygen. The creep-testing procedure consisted of recording the creep strain at various stress levels following increments and decrements of stress at each stress level. The accuracy of the strain measurement was 10^{-5}. Creep tests were also conducted on cadmium, a c.p.h. metal, for the sake of comparison.

RESULTS AND DISCUSSION

Figure 1 shows the typical variation of creep rate with changes in stress for aluminium.

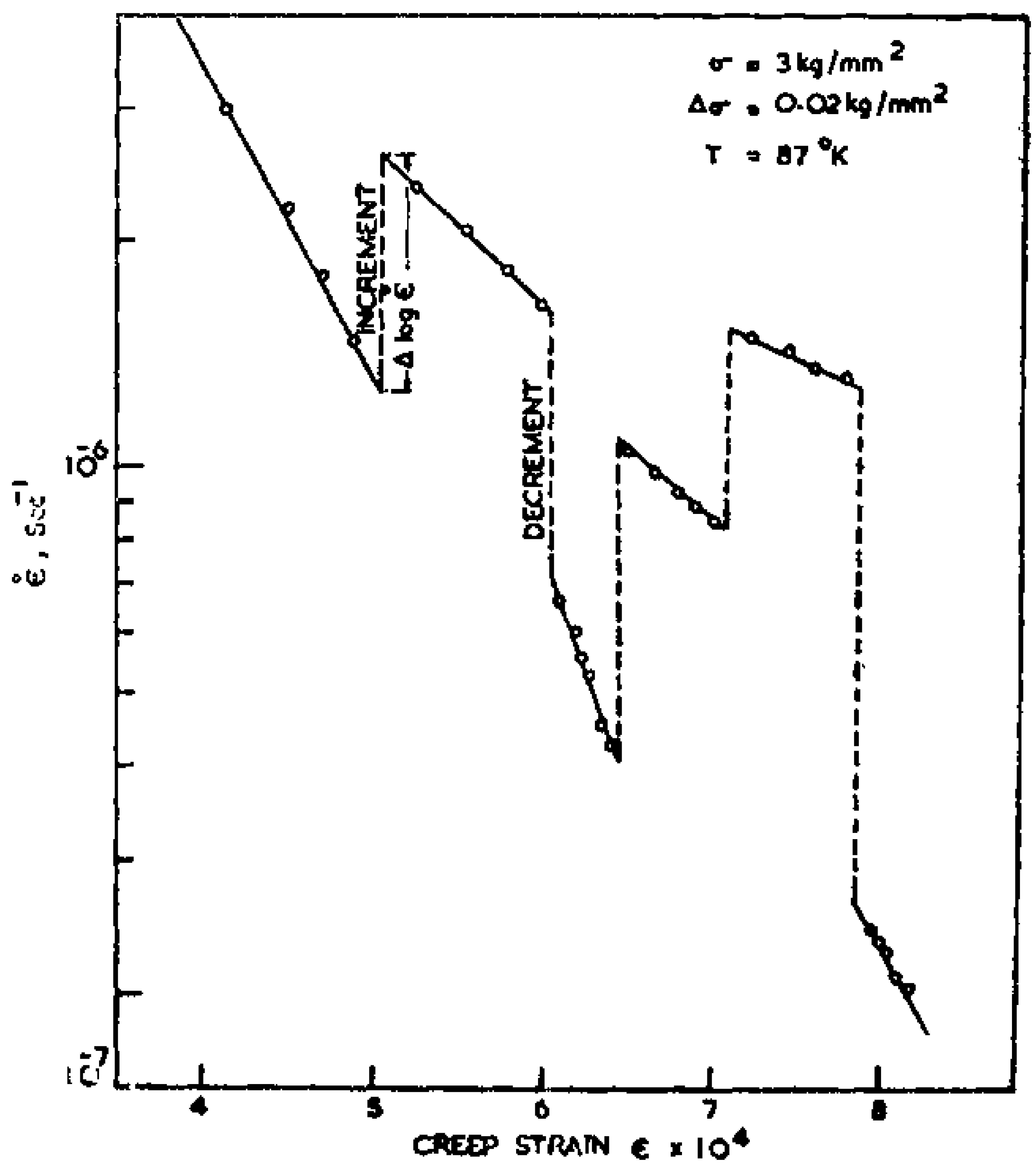

FIG. 1. Change of creep rate, $\mathring{\epsilon}$, with creep strain after stress increment and decrement in aluminium.

The major observation is that the magnitude of the change in creep rate after increment following an increment is less than that observed after a decrement following an increment. Even the creep curve corresponding to the initial load can be considered as similar to that after increment since the incremental creep curve can be made to coincide with the initial creep curve by shifting it along the time axis.[6]

In fact the values of $\Delta\ ln\ \dot{\epsilon}$ corresponding to decrements should probably be more accurate for the calculation of activation volume than those for increments of stress since the creep rate will be infinitely high just after an increment (as the activation stress which is equal to the difference between the "yield stress" and the applied stress will be very low) and will fall down considerably by the time we make a measurement. However, after decrement, complications may be introduced due to strong elastic interactions between glide and forest dislocations. As a result, after the stress decrements, attractive junctions can form fully[7-9] and for certain orientations, the junctions, which would have been broken by thermal activation forming jogs, may no more be thermally activated after decrement. Thus the number of dislocations that are likely to get activated may change.

Let n represent the number of elements requiring an activation energy U for their movement and suppose the n-U distribution curve at the start of the creep is as shown in Fig. 2, the hatched area giving the number of dislocations that are likely to get thermally activated at any instant. As creep proceeds, strain hardening occurs and the whole curve will move to right. It does not seem probable that the shape of the curve changes much. After a stress increment, the activation stress, which is approximately proportional to thermal activation energy, is decreased and the curve is moved to left and we may get a very similar distribution as was existing earlier.[6] After a decrement, however, the number of elements that are likely to get activated decreases since, as a result of the full formation of attractive junctions, the number of junctions at which jogs are formed will be less. This changes the shape of n-U curve as shown in Fig. 2. Thus the change in creep rate following a stress decrement, $\Delta\tau$, is given by:

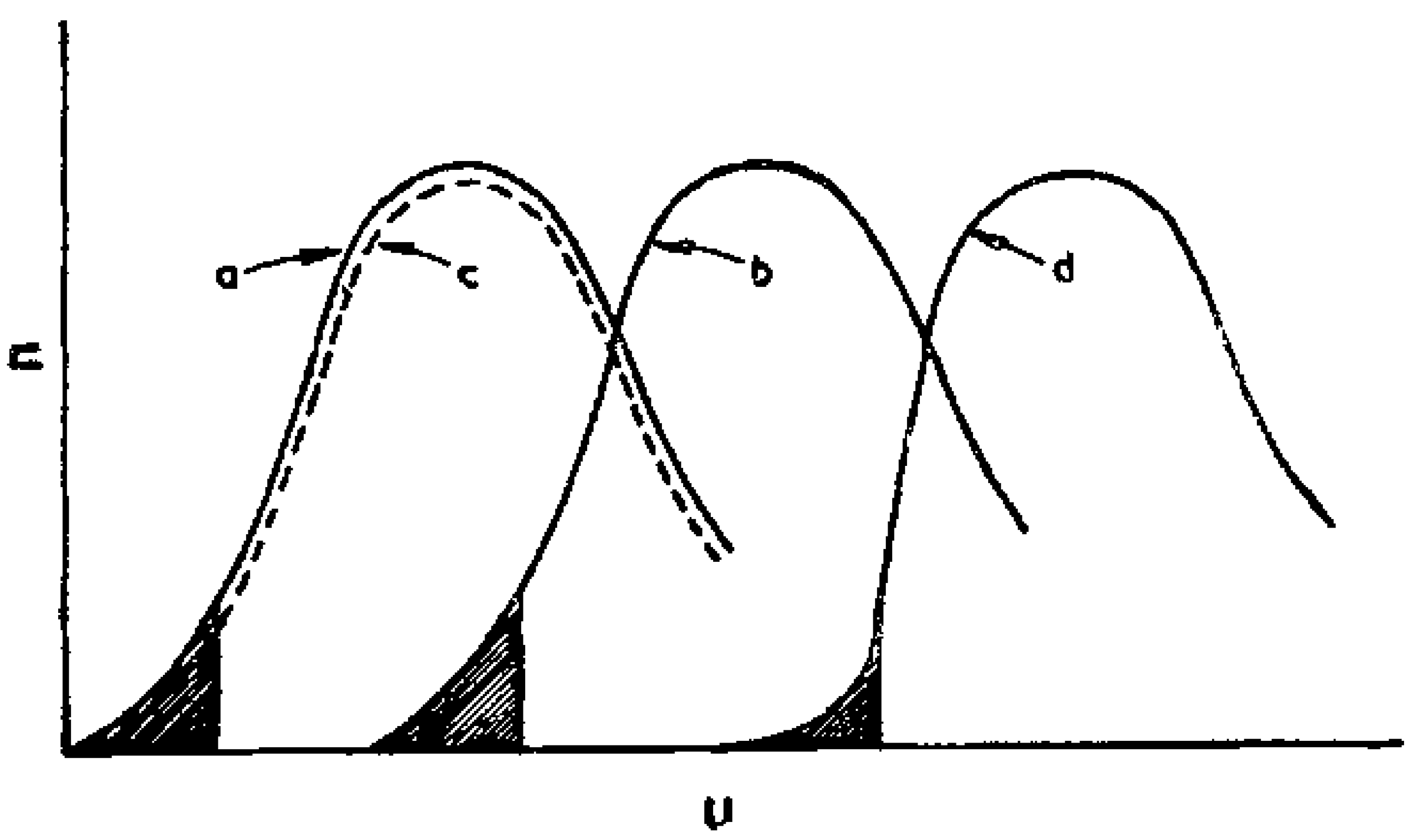

FIG. 2. Schematic representation of the probable n-U relation during creep: (a) at the start of the creep; (b) after some creep strain; (c) immediately after a stress increment is made; (d) after a stress decrement is made.

$$\frac{\delta\, ln\, \dot{\epsilon}}{\delta\tau} = \frac{v}{kT} + \frac{\delta\, ln\, P}{\delta\tau} - \frac{\delta U_0}{\delta\tau} \qquad (1)$$

where P = frequency factor (involving the number of elements per unit volume getting activated, the area slipped during an activation event, the Burgers vector and the frequency of vibration of the dislocation line) and U_0 is the total energy of activation. The difference in the values of $\Delta\ ln\ \dot{\epsilon}$ after increment and decrement is due to the term $\delta\ ln\ P/\delta\tau$ since the other terms on the right-hand side of Eqn. (1) are likely to change to the same extent both after increment and decrement. This difference in the activation volume was found to decrease with stress to the extent of about 5% deformation and is negligible upto about 7% strain beyond which the nature of creep is no more logarithmic. The effect of stress may be due to the fact that the length of the attractive junctions formed will decrease with stress[9] and hence some of the junctions can be thermally activated. Also the change in the creep rate must not be very much different from that observed in the case of increments if we make a decrement after a decrement. This was not possible with our existing recording system and hence was not done.

As seen in Fig. 3, the above effect is conspicuously absent in the tests conducted on

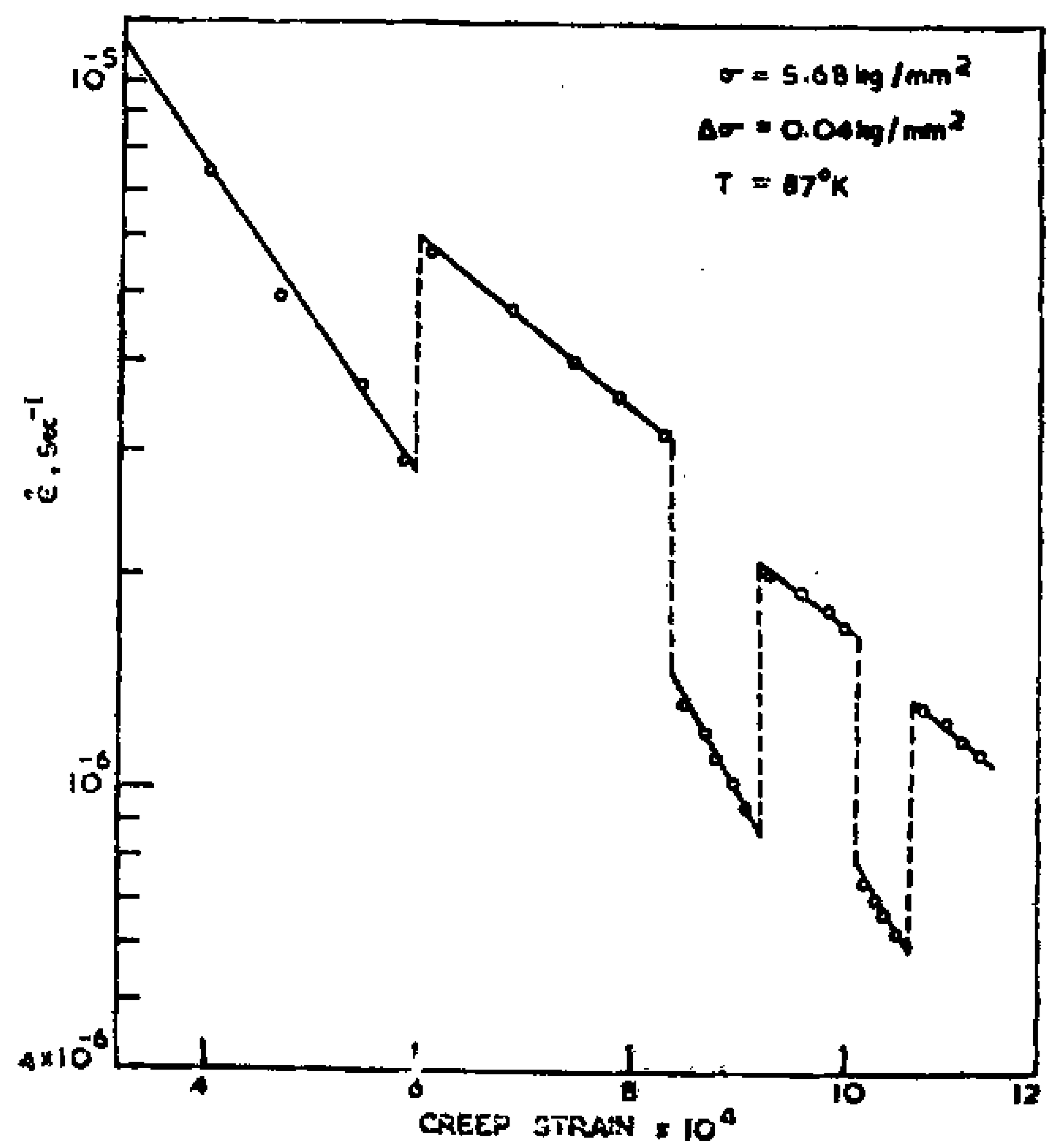

FIG. 3. Change in creep rate, $\dot{\epsilon}$, with creep strain after stress increment and decrement in cadmium.

cadmium, a c.p.h. metal, in which the local interactions between glide and forest dislocations are supposedly absent.[9] This is true even for magnesium as shown by the data of Conrad *et al.*[11]

Thus it can be concluded that the local interactions between glide and forest dislocations forming junctions may paly a significant role in the process of strain hardening in aluminium.

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ON THE GROWTH OF ZINC MONOCRYSTALS FROM THE VAPOUR PHASE

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SINGLE crystals of metals and semiconducting materials are of substantial value as they have found significant applications in solid state devices. To-date almost all naturally occurring crystals and a number of metal crystals have been grown in laboratories for investigation and a great deal of experimental data has been obtained on the growth of these crystals. During recent years, several reports dealing with developments in crystal growth from vapour phase have been published. CdS single crystals have been grown from the vapour phase by Frerichs method.[1] Optimum conditions for the growth of zinc and cadmium single crystals have been investigated in detail by Keepin[2] and Price.[3] Zelenskii and Petel'guzov[4] have grown magnesium single crystals by vacuum evaporation and condensation method. A feature of this particular method is that no seed is required for the growth. At times crystals with a base of 25 mm. were grown. In the present report, an apparatus is described for growing zinc monocrystals from the vapour phase. Conditions for satisfactory growth have been established.

EXPERIMENTAL PROCEDURE

A temperature gradient furnace was constructed for the experiments. The heating element (22 SWG, nichrome wire) was tightly wound on a 35 cm. long silica tube, spacing the turns to suitably achieve a temperature gradient and a short constant temperature zone close to it. The furnace was mounted in a vertical position for the experimentation. High-purity zinc block was sealed under vacuum in a pyrex capsule of about 4 to 5 cm. length and having one end tapered. This capsule was inserted in another slightly larger diameter pyrex tube. This unit was further inserted into the furnace such that the tapered end of the capsule was in the useful or growth zone of the furnace. The line diagram of the experimental set-up and the plot showing the thermal conditions inside the furnace are reproduced in Figs. 1 and 2 respectively.

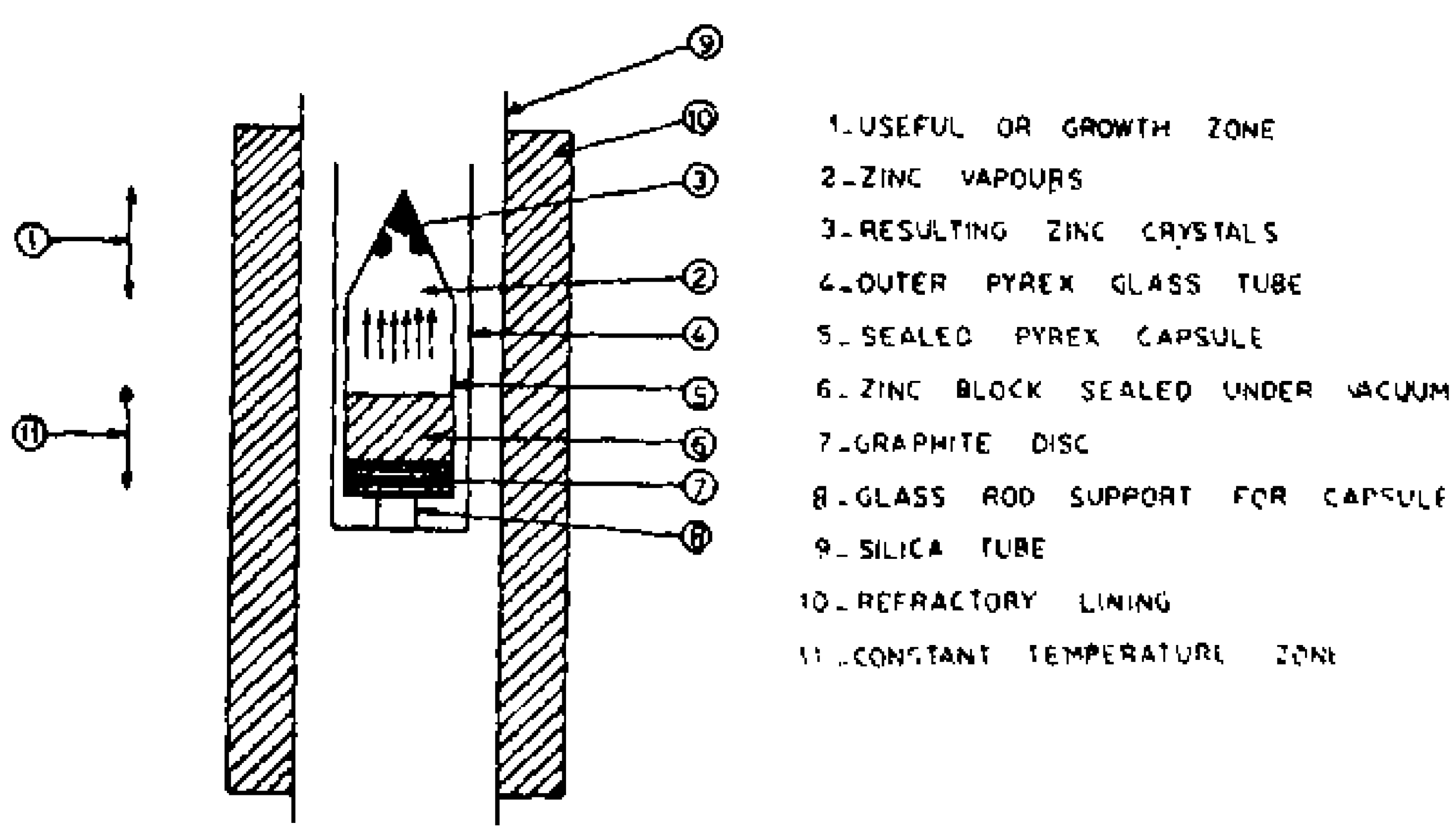

FIG. 1. Experimental set-up

The useful or the growth zone and the constant temperature zone are clearly indicated in Fig. 2. The pyrex tube containing the capsule was pulled at a rate of 0·5 cm. or 1·0 cm./hr. by a motorgear train assembly for a distance of 4 cms. The furnace was gradually