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Activation energy for superplastic flow in Ti-3Al-2.5V alloy

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In a previous letter [1], flow stress strain rate behavior of a two phase titanum alloy Ti-3Al-2.5V was studied in the temperature range 750 to 910 °C. The method of cross-head speed cycling was used and data were expressed graphically as $\ln \sigma$ vs. $\ln \dot{\varepsilon}$ plots. The present work is the continuation of this study and is aimed at the derivatoin of activation energy data for Ti-3Al-2.5V from its flow stress-strain rate behavior in order to find the rate controlling mechanism during superplastic deformation.

The flow behavior of a material during a high temperature deformation test is generally given by the

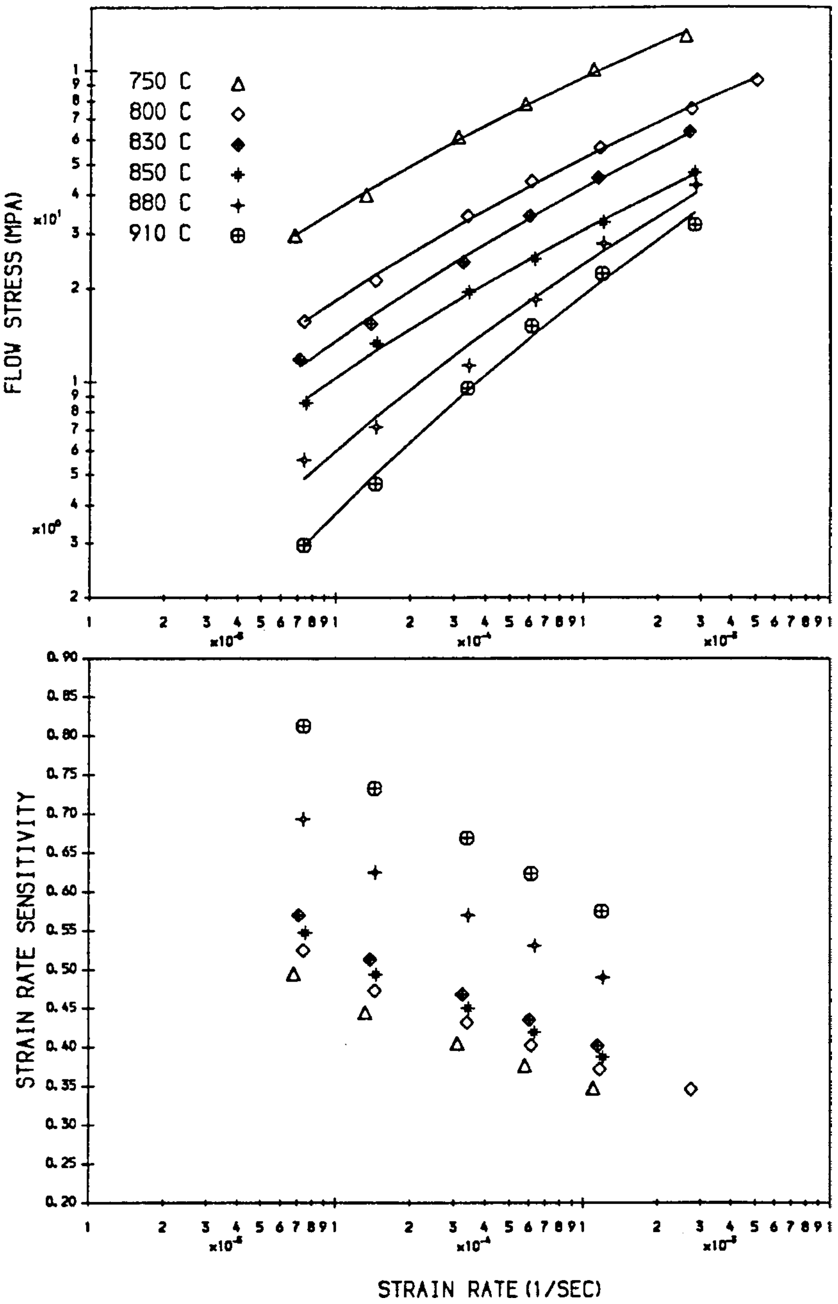

Figure 1 $\ln \sigma$ vs. $\ln \dot{\varepsilon}$ and m vs. $\ln \dot{\varepsilon}$ plots for Ti-3Al-2.5V. For each test, only the increasing strain rate part of first cycle is plotted.

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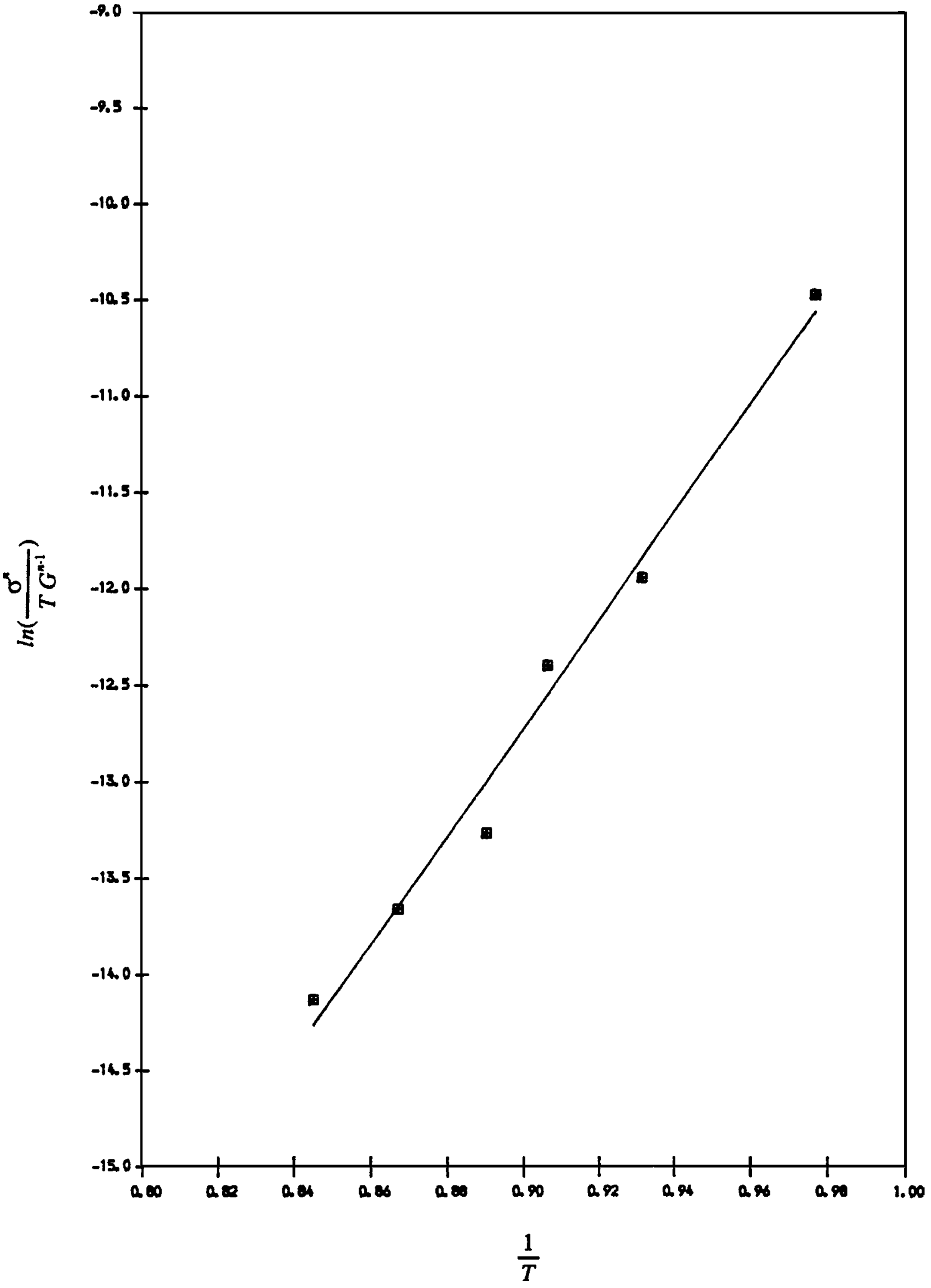

Figure 2 An example of Arrhenius type plot used to calculate the activation energy values for Ti-3Al-2.5V by constant strain rate method.

following relationship.

$$\dot{\varepsilon} KTL^{p}/Gb = A[\sigma/G]^{n} D_{0} \exp(-Q/RT) \qquad (1)$$

in which the strain rate $\dot{\varepsilon}$ is related to flow stress σ by stress sensitivity index n and process activation energy Q, where G, b, L, R and D_0 have their usual meanings.

From Equation 1 the following relationships can be derived.

$$Q_{\dot{\varepsilon}} = R[\{\partial \ln(\sigma^{n}/TG^{n-1})\}/(1/T)\}] \qquad (2)$$

at constant strain rate and

$$Q_{\sigma} = -R[\{\partial \ln(\dot{\varepsilon}TG^{n-1})\}/(1/T)\}] \qquad (3)$$

at constant stress.

Using Equations 2 and 3 activation energy values were calculated from the slopes of the ln (σ^{n}/TG^{n-1}) vs. $1/T$ and ln $(\dot{\varepsilon}TG^{n-1})$ vs. $1/T$ curves at constant strain rates and at a constant stress level. Data from the first increasing strain rate cycles were strain independent (Fig. 1) and therefore were considered appropriate to determine the effect of temperature on the ln σ vs. ln

TABLE I Shear modulus (G) values

Temperature (°C)	750	800	830	850	880	910
Shear modulus (MPa)	2.66×10^4	2.54×10^4	2.47×10^4	2.42×10^4	2.35×10^4	2.28×10^4

TABLE II Stress sensitivity index (n)

Strain rate/stress	Region	n
$\dot{\varepsilon} = 2 \times 10^{-3}$ s^{-1}	II	2.55
$\dot{\varepsilon} = 4 \times 10^{-4}$ s^{-1}	II	2.11
$\dot{\varepsilon} = 7 \times 10^{-5}$ s^{-1}	II	1.75
$\sigma = 30$ MPa	–	2.19

$\dot{\varepsilon}$ plots. Shear modulus (G) values used in the calculations were taken from previous work [2] and are given in Table I. Stress sensitivity index (n) values were determined for the alloy from its flow stress-strain rate behavior and are given in Table II at three different strain rates corresponding to regions III and II and I stress level.

At constant strain rates, activation energy values were calculated to be 247, 232 and 233 KJ/mole for region II (Fig. 2). At a constant stress level, activation energy was found to be 212 KJ/mole, which is somewhat lower than that at constant strain rates. As from ln σ vs. ln $\dot{\varepsilon}$ data, there appears to be no clear distinction between regions II and III, the values calculated here are considered representative of region II only. However, most importantly, all these activation energies are higher than the proposed values for lattice self diffusion i.e., 129 KJ/mole and significantly higher than that for grain boundary diffusion. On comparison with previous work on the same alloy, the data appear to be in approximate agreement with the results of Cope [3] who reported a Q value of 202 KJ/mole for region II in the temperature range 750 to 940 °C, and Arieli *et al.* [2] who reported values of 247 and 228 KJ/mole for region III and 223 and 260 KJ/mole for region II in the temperature range 850 to 925 °C. Mare recently Salam and Hammond [4] reported activation energy values of 232 and 225 KJ/mole for region II and 221 KJ/mole for region III for a two phase titanium alloy Ti-3 Al-4V. Both the activation energy values obtained in this work for region II (i.e., 247 and 232 KJ/mole) are suggestive of a rate controlling mechanism such as that for lattice diffusion in the β in contrast to most superplastic alloys, other than two phase titanium alloys, in which the rate controlling mechanism has been found to be that of grain boundary diffusion [5].

It is concluded that the activation energy value for superplastic deformation of Ti-3 Al-2.5V in region II may be taken to be approximately 232 KJ/mole. This suggests that the rate controlling mechanism during superplastic deformation of the alloy is lattice self-diffusion in β phase rather than grain boundary diffusion.

References

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