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High Temperature Mechanical Properties of High Purity Al and Dilute Al-Si Alloys

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The high temperature mechanical properties of 5N purity Al and Al-Si alloys with 0.02, 0.1, 0.2 and 0.3 wt.% Si content were investigated by impression creep test. According to the experimental results the stress exponent for pure Al depends on the temperature and it was found to be between 5.5 and 3.8. For the Al-Si alloys stress exponents between 3, 5 and 4 were obtained.

The activation enthalpy of pure Al was obtained to be 132 kJ/mol while that of the Al-Si alloys 145 kJ/mol which agree well with the self diffusion energy in Al.

Finally it is shown that there is an empirical relationship between the strain rate and the excess stress which is necessary to reach the same strain rate in an alloy as in the pure Al.

1. Introduction

The high temperature creep rate, $\dot{\varepsilon}$, of pure metals and alloys can be described by the formula:

$$\dot{\varepsilon} = A\sigma^n \exp - \frac{Q}{RT} \tag{1}$$

where σ is the applied stress, A is a material parameter, n is the apparent stress exponent which is the inverse of the strain rate sensitivity and Q is the activation enthalpy [1, 2]. According to empirical evidences the factor, A, depends on the grain size and in some cases on the temperature. If the activation energy obtained experimentally agrees well with the energy of a characteristic microstructural process (for example bulk or grain boundary diffusion), then one can draw conclusions for the micromechanism of the deformation. The parameters of the equation (1) are determined in general by tensile measurements. However, it was shown that they can also be obtained by impression creep tests which leads to equivalent results with the conventional tensile tests [3, 4]. The impression velocity, v, and the applied load, F, can be converted to equivalent strain rate and stress by the formulae:

$$\dot{\varepsilon} = v/d$$

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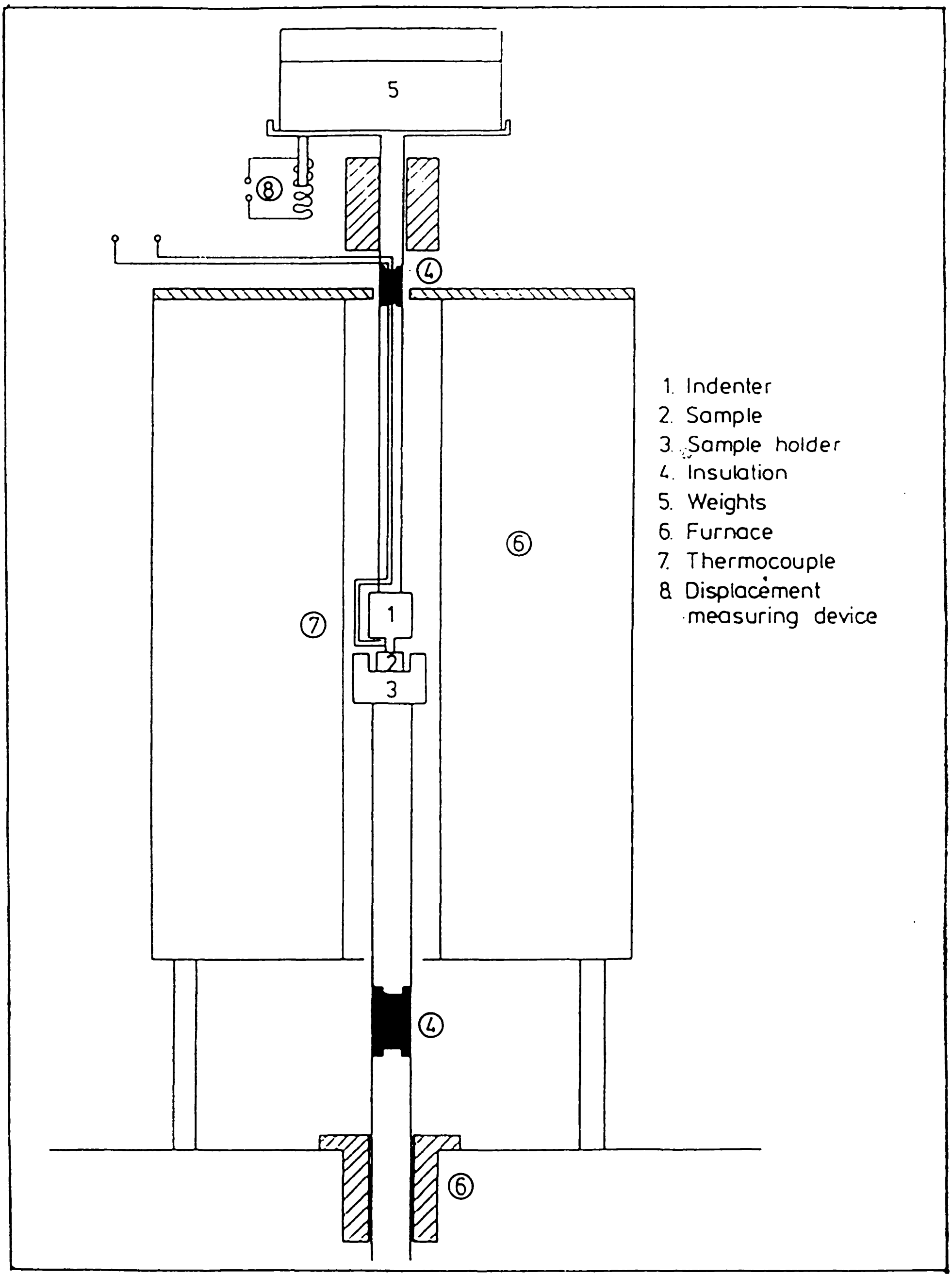

Fig. 1. Schematic picture of the impression creep apparatus.

where d is the diameter of the punch and

$$\sigma = p/3$$

where p is the pressure just below the punch [5, 6].

In this paper the results of impression creep tests conducted on pure Al and dilute Al-Si alloys are presented.

2. Experimentals

High purity Al and Al-Si alloys with 0.1, 0.2 and 0.3 wt.% Si were investigated. The ingots were rolled and annealed. The average grain size of the samples investigated was 60–70 μm. In the course of the creep tests the alloys were in solid solution state.

The indentation creep measurements were performed with a self made apparatus the schematic picture of which is shown in Fig. 1. In the course of the test a small punch of 1 mm diameter is pressed into the surface of the sample by constant loads. The impression depth is recorded as a function of time. The movement of the punch is monitored by linear variable differential transformer (LVDT) unit, that is connected to a C64 personal computer.

3. Results

The parameters of the constitutive equation were determined from the $\ln \sigma - \ln v$ plots taken at different temperatures. Figs. 2 and 3. show this function for pure Al and for the Al-Si alloy respectively.

For pure Al the stress exponents were obtained experimentally to be between 3.8 and 5.5 and they were found to decrease slightly with increasing temperature. 5.3 and 3.9 was accepted as characteristic value of them at lower and at higher temperatures respectively.

In the case of the Al-Si alloys the stress exponent can be regarded as constant. (The experimental values were found to be between 3.5 and 4.)

The activation enthalpies were calculated by cross-cut method from the $\ln p - \ln v$ plots obtained at different temperatures. Fig. 4. and 5. show the $\ln v - 1/T$ functions the slope of which gives the activation enthalpy. It was found that the activation enthalpy depends on the stress (or the pressure). The enthalpy-pressure function was extrapolated to zero stress (Fig. 6) and we got 150 kJ/mol for the Al-Si alloys. Those activation enthalpy agrees well with the self diffusion energy in Al [7].

4. Discussion and conclusions

It is well known that the creep of solid solution alloys can be classified into two classes according to the stress exponent. Using the terminology of Langdon [2] the

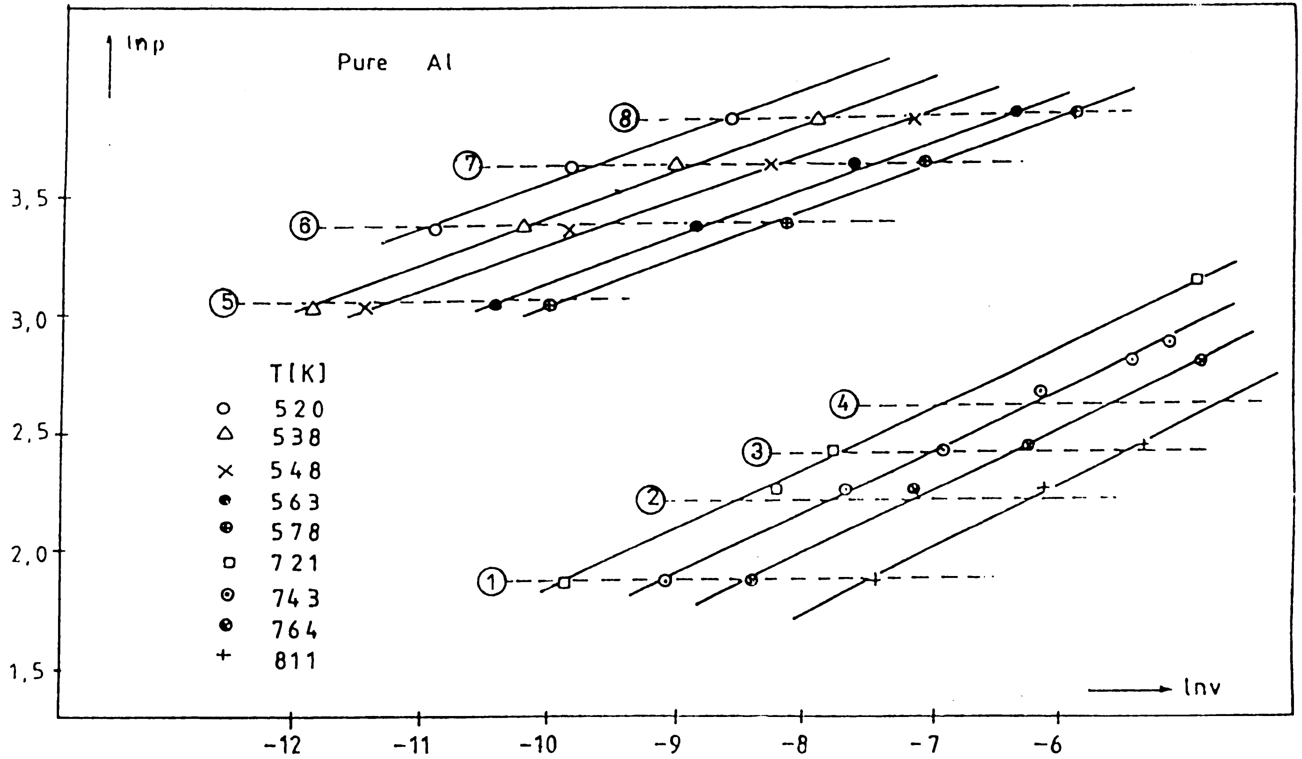

Fig. 2. Double logarithmic plot of the stress-strain rate for pure Al at different temperatures.

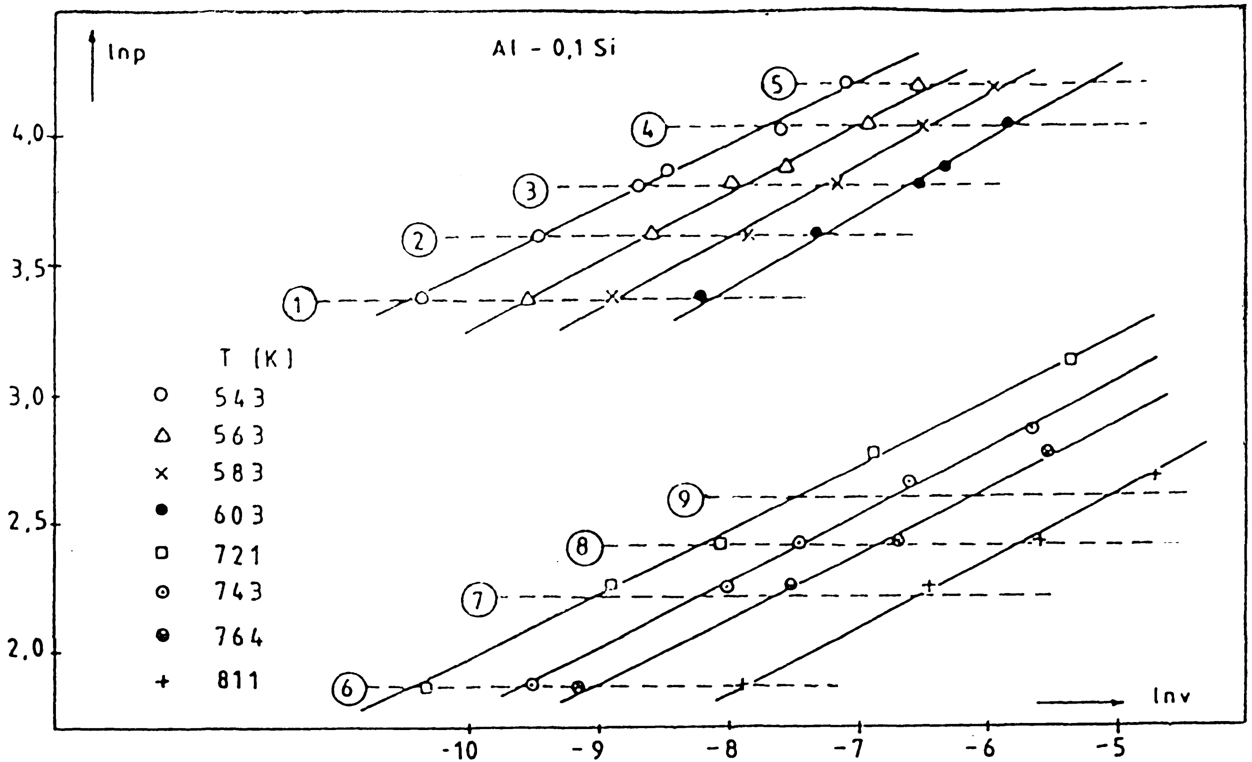

Fig. 3. Double logarithmic plot of the stress-strain rate for Al-Si alloy at different temperatures.

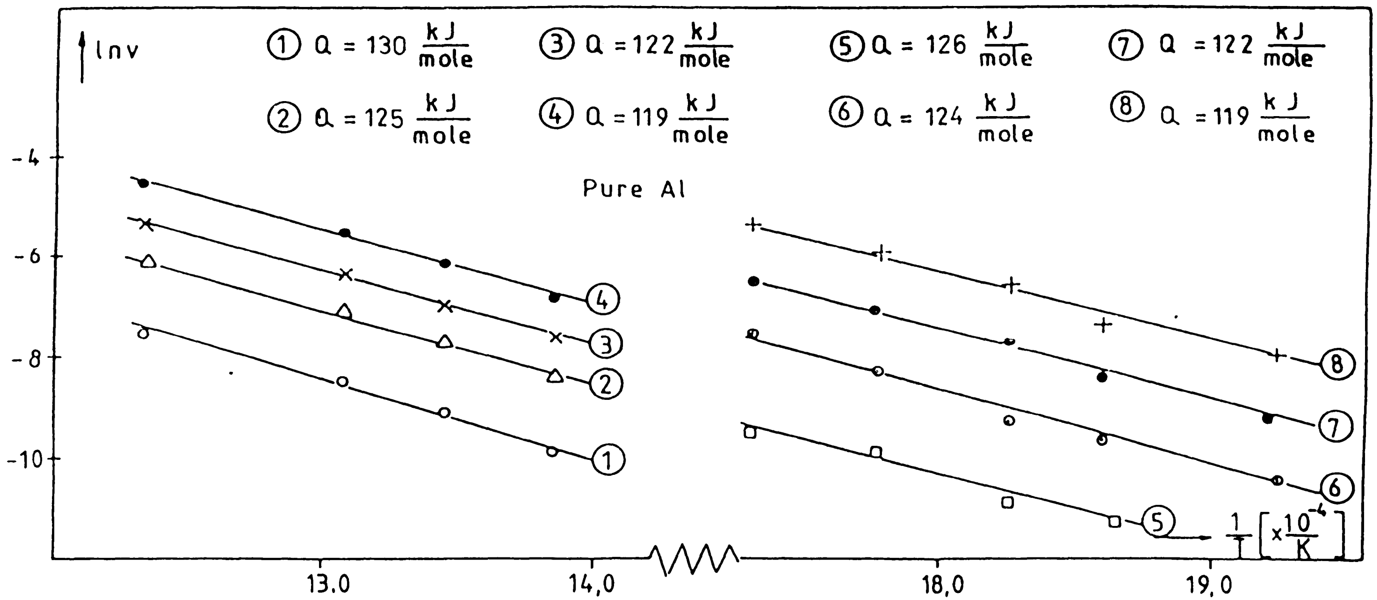

Fig. 4. The ln v — $1/T$ curves for pure Al.

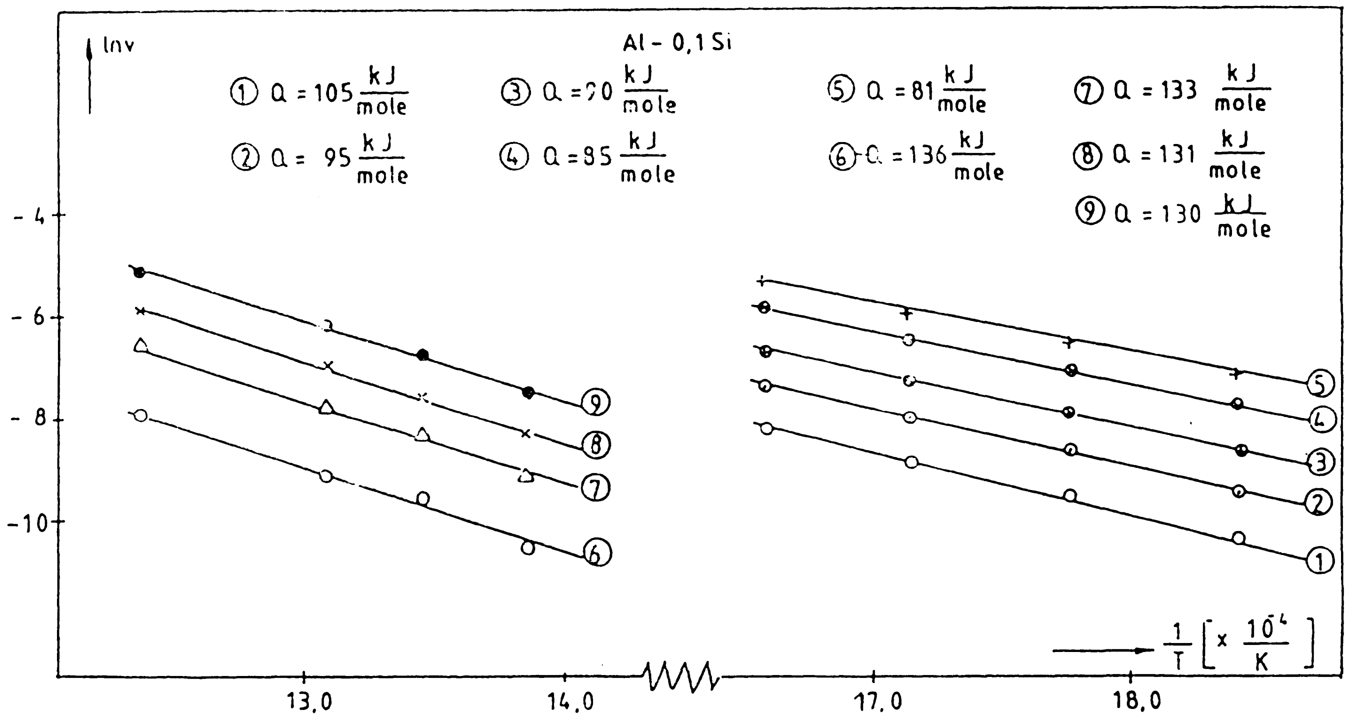

Fig. 5. The ln ν — $1/T$ curves Al-Si alloy.

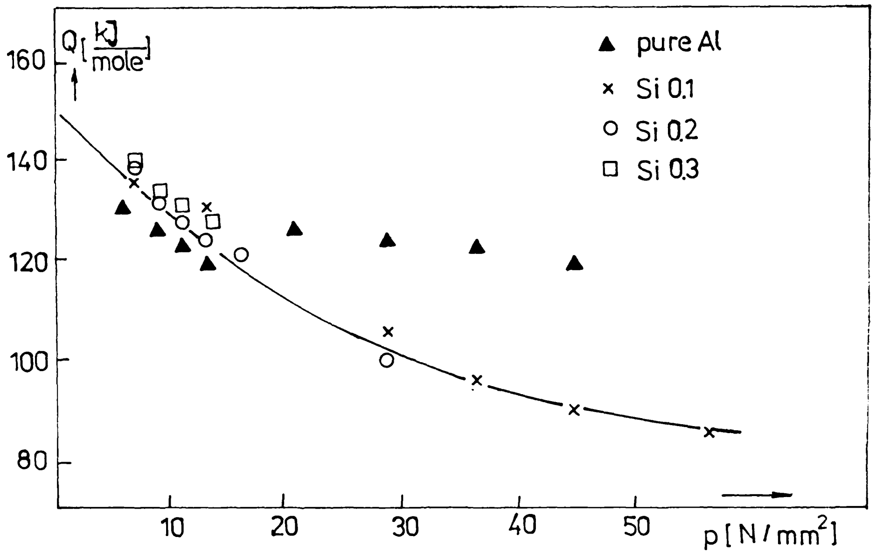

Fig. 6. The enthalpy-pressure functions.

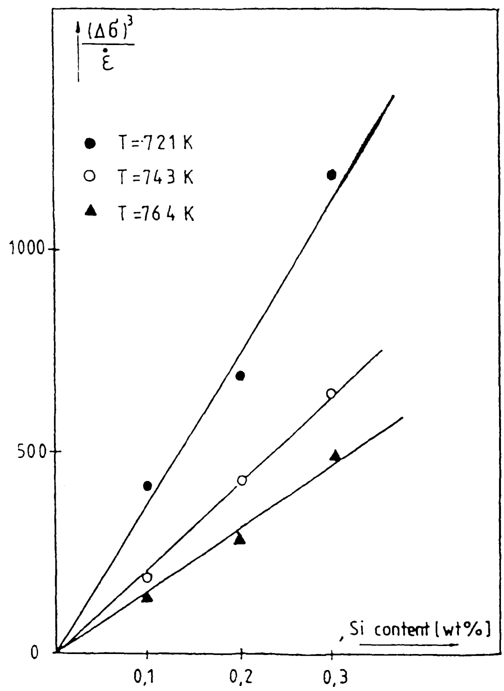

Fig. 7. The $(\Delta\sigma)^3/\dot{\varepsilon}$ as a function of the Si concentration.

alloys with stress exponent $n \sim 3$ belong to class A and alloys in which the creep processes are similar to the pure metals belong to class M. The characteristic value of the stress exponent for class M and for pure metals is $n \sim 5$. For the Al-Si alloys the stress exponents were found to be between 3.5 and 4, therefore the creep processes investigated are due to the transition region between class A and class M behaviour [8, 9].

According to Fig. 6. the activation energy of the Al-Si alloys is strongly pressure dependent, which indicates that the hindering effect of Si atoms on the dislocation motion at a given temperature depends on the dislocation velocities, that is on the strain rate. The details of the nature of the interaction between Si atoms and the dislocations needs further investigations.

In the case of pure Al the pressure dependence of Q is much less pronounced or within the experimental error it can be considered to be constant which is near to the self diffusion energy.

According to the experimental results in the case of Al-Si alloys the strain rate at a given stress and temperature depends on the Si concentration. It was found that the ratio of the cube of the excess stress necessary to reach the same strain rate is a linear function of the Si concentration (Fig. 7.).

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