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Diffusional creep in Cu–Fe solid solutions

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ABSTRACT

The activation energy of diffusional creep in copper–iron solid solutions was studied. Experiments were performed on foil samples in an atmosphere of dry hydrogen in a temperature range from about 1170–1340 K. The foils had a thickness of 1.8×10^{-5} m and a length of about 0.15 m. The stress range was from 0 to 300 kPa. The method of the measurements was developed in our previous work and it was based on measuring the time dependence of stress on a sample.

The viscosity of the solid solutions was higher than that for pure copper. It was shown that there is a gap on temperature dependences of viscosity. The temperature of the gap was about 1295 K. Our previous experiments on the Cu–Co system showed the same feature in the activation energies.

As previously shown, two processes are required for describing the diffusional creep. They are the volume diffusion and generation/annihilation of the vacancies. The processes occur in sequence. We assume that only second type processes could lead to the appearance of the gap on the temperature dependence of viscosity in solid solutions.

1. Introduction

Creep of metallic materials at high temperatures is an important mechanical property for some technical applications. For instance, the service lives of high-temperature components, such as turbine blades, are generally limited by creep rate [1,2]. Usually, the creep behavior of crystals has been studied in the frame of the power law relation between steady state creep rate ($\dot{\varepsilon}$) and applied stress (σ):

$$\dot{\varepsilon} = C \cdot \sigma^n \tag{1}$$

where n is the stress exponent and C is a microstructure and temperature dependent constant. At pre-melting temperatures and low stresses creep is determined by the volume diffusion of vacancies in case coarse grained materials (model of Nabarro [3] and Herring [4]). Nabarro-Herring creep law has stress exponent 1 and activation energy of the creep is close to activation energy of volume diffusion. One-component materials creep in accordance with the model in above conditions [5]. Creep of multi-component single-phase materials are often not described by this model despite the applied stress is quite low for dislocation moving in volume. The reason is an imperfection of vacancy sources and sinks located at grain boundaries and free surfaces. Really, the steady state creep requires two processes: vacancy generations at source (flowing from a sink) and vacancy diffusion between source and sink [6]. An impurity segregates on the surfaces and disimproves the surface for vacancy generation and migration. Such type of diffusional creep is named Interface Controlled Diffusional Creep (ICD creep).

In case stable grain structure the constant C is only temperature dependent and $1/C$ is viscosity in Nabarro–Herring theory. Within this model only vacancy moving from one surface to another is required for deformation of a sample. The processes of vacancy generation and annihilation do not limit the deformation and do not taken into account. In ICD creep models above processes limit the deformation rate. Delivery rate of vacancies to or from the surfaces is the main process in this case. Arzt [6], Burton [7] describes the vacancy flow in grain boundaries as nonconservative moving of grain boundary dislocations. Their mobility depends on temperature and the temperature dependence has the same form as viscosity in Nabarro–Herring theory. Therefore when there is no reason for significant change of energy activation of volume diffusion, a deviation of creep activation energy could be explained by processes of vacancy generation and annihilation.

In our work the creep behavior of Cu–Fe solid solutions was observed in diffusional creep regime. Stress level was lower than 300 kPa and temperature range from about 1170 to 1340 K. The observations were by-products of experiments designed to measure surface energies of studied Cu–Fe alloys.

2. Experimental

Produced electrolytically copper foils were used for preparing the samples. Purity of copper was 99.995 wt.% Cu and foil thickness was 1.8×10^{-5} m. The foils were formed into cylinders with about 0.007 m diameter and 0.15 m length using coaxial quartz tubes. Iron was introduced electrolytically and the sample is homogenized for 1.8×10^5–3.6×10^5 s. The foils were placed into massive copper cylinder and

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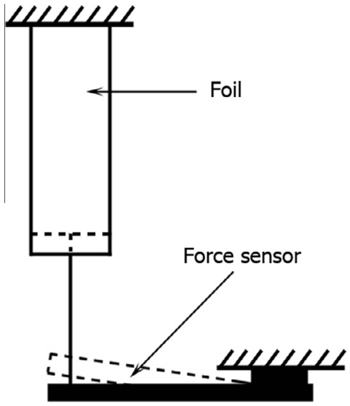

Fig. 1. Experimental scheme. The elastic beam is rigidly connected to the foil. The sample bends the elastic beam due to surface tension.

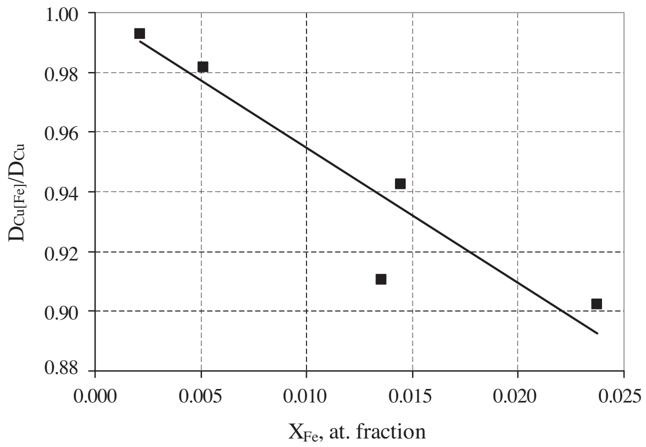

Fig. 3. ^{64}Cu diffusion coefficient relative to the copper selfdiffusion coefficient vs. Fe atomic fraction at 1293 K [9].

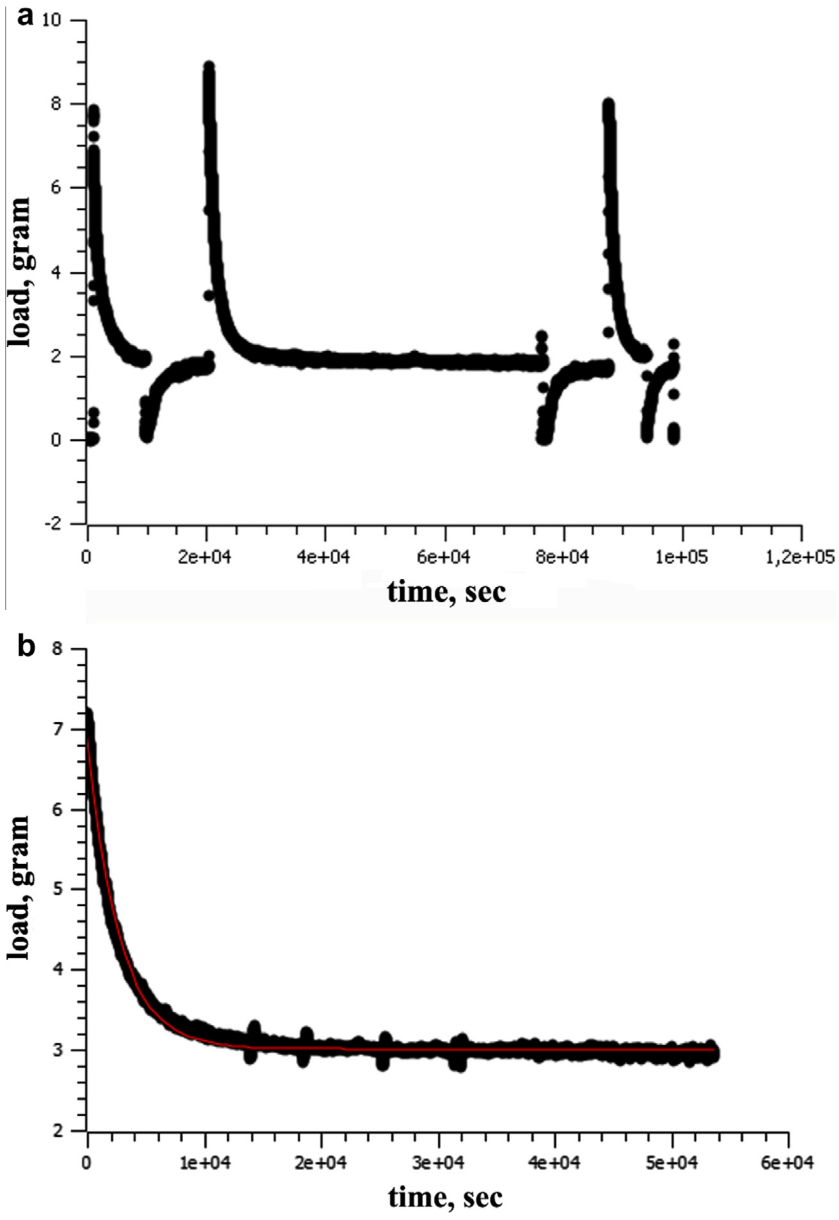

Fig. 2. Time dependence of load on the sample (a) for 6 creep tests at constant experimental condition; (b) the approximation by Eq. (2).