JOURNAL OF MATERIALS SCIENCE 25 (1990) 519–521

On the grain boundary internal friction peak of α-brasses

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A conventional Ke pendulum was used to investigate the temperature dependence of internal friction for thoroughly annealed samples of Cu–30% Zn. The relaxation peak observed at 330° C at a frequency of vibration 0.60 Hz was attributed to grain boundary diffusion. The energy activating the process amounted to 1.84 eV and characterized the activation energy for self diffusion in copper. The relaxation strength showed strain amplitude dependence, however, the activation energy and peak temperature did not show any amplitude dependence. The effect of solute atom concentration, cold work and vacancies was also tested.

1. Introduction

In pure metals the grain boundary peak is not considered now to be due to the motion of lattice dislocations but due to the sliding of grain boundaries by means of grain boundary dislocations [1, 2]. The detailed mechanism is not yet well known. However, in alloys solute atoms usually have a tendency to segregate preferentially on grain boundaries to modify the grain boundary configuration, for example, by pinning of grain boundary dislocations.

Diffusion induced grain boundary migration occurs when diffusion of a solute along the grain boundaries of the specimen causes the migration of the grain boundary. Diffusion-induced grain boundary migration received intensive studies [3–5]. Iwasaki studied the strain amplitude dependence of the grain boundary internal friction peak for pure aluminium [6] and dilute aluminium alloys [7]. He found that the peak strength increases monotonically with strain amplitude, while peak width, activation energy and frequency factor show no amplitude dependence. These results are explained [8] by considering the activation of increasing number of grain boundary dislocations with the help of the applied stress.

To our knowledge no work has been done to study the internal friction grain boundary peak of Cu–Zn alloys. The aim of the present work is to investigate the grain boundary peak and the parameters affecting the formation of this type of relaxation such as strain amplitude, solute atom concentration, lattice dislocation and vacancies in Cu–30% Zn alloy.

2. Experimental and results

The investigation was carried out on wires 0.5 mm in diameter and 4 cm long containing 30 or 10% Zn made from pure copper and zinc by melting in a graphite crucible. All samples before commencing the runs were annealed for 7 h at 300° C to stabilize the internal structure and to make the contribution from lattice dislocations smaller, to give rise to a more distinct grain boundary peak.

The internal friction was measured using a conventional Ke pendulum. Readings were taken during heating between room temperature and 400° C at low frequencies (0.1 to 1.0 Hz).

An internal friction peak was observed for each of the two alloys. The height of the peak was found to depend on the zinc content (as shown in Fig. 1). Increasing the zinc content, increased the height of the peak and shifted it towards lower temperatures. This Q^{-1} peak was attributed to grain boundary relaxation. In order to test the relaxation in action, the same observations were repeated for different frequencies with the samples maintained under constant stress and strain amplitude (see Fig. 2). The activation energy measured from the peak shift method amounted to 1.84 eV for the two alloys. Fig. 3 represents the strain amplitude (1.7×10^{-4} to 5.0×10^{-4}) dependence of

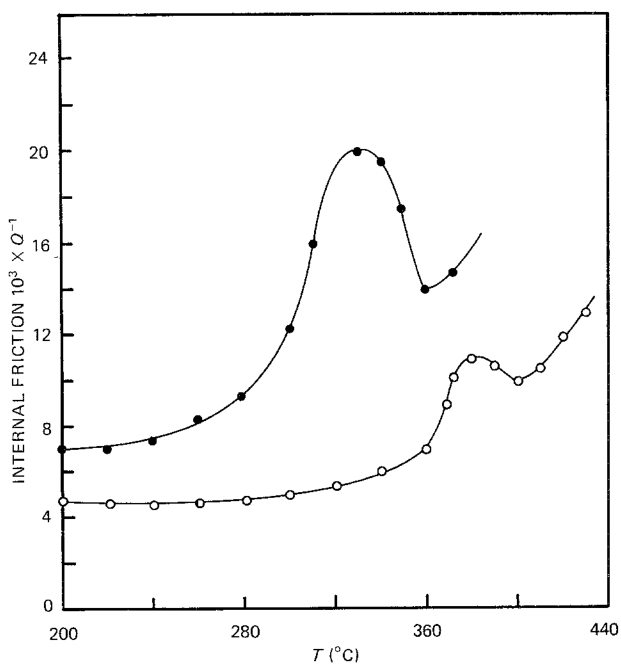

Figure 1 The temperature dependence of internal friction for Cu–30% Zn (●) and Cu–10% Zn (○). ν = 0.60 Hz, σ = 1.00 kg mm^{-2}.

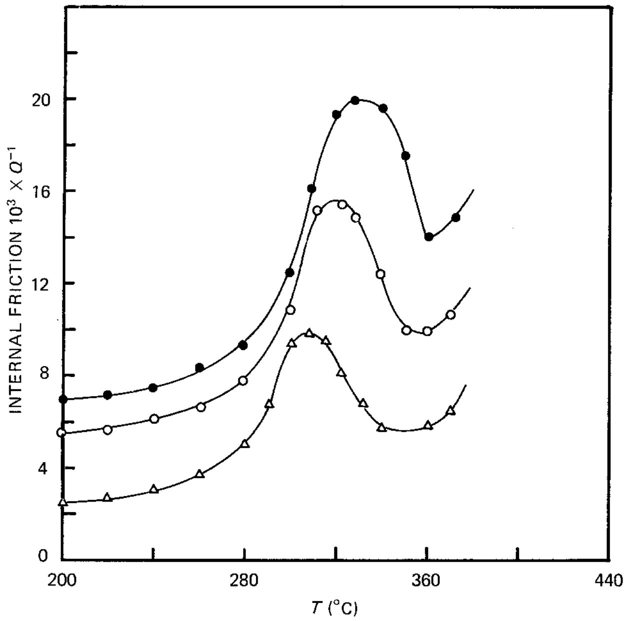

Figure 2 Effect of frequency of vibration on internal friction peak in Cu–30% Zn. (● ν = 0.6 Hz, ○ ν = 0.4 Hz, △ ν = 0.2 Hz) σ = 1.00 kg mm^{-2}.

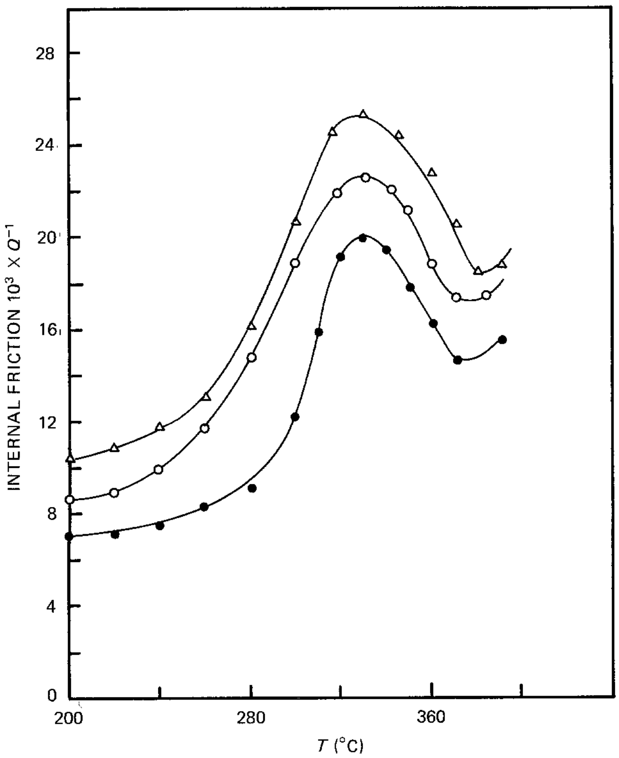

Figure 3 Strain amplitude dependence on the grain boundary peak for Cu–30% Zn. (△ α = 4.5 × 10^{-4}, ○ α = 3.13 × 10^{-4}, ● α = 1.74 × 10^{-4}) σ = 1 kg mm^{-2}, ν = 0.6 Hz.

the relaxation peak observed. An increase in the amplitude caused an increase in the relaxation strength of the Q^{-1} peak, however, the position of the peak and the activation energy remained unchanged. A tensile pre-deformation by 1.25% decreased the peak height. After 2.5% cold work the grain boundary peak nearly disappeared (see Fig. 4) and a peak at rather low temperature appeared, and is thought to be due to lattice dislocations.

The stress dependence of the relaxation peak (Fig. 5) was also tested. Increasing the applied stress increased the peak height, but the peak temperature and activation energy remained the same.

3. Discussion

It is now apparent that grain boundaries contain networks of dislocations having characteristics different from lattice dislocations. These grain boundary dislocations are predominantly responsible for grain boundary sliding. Gates [9] predicted that such behaviour should be controlled by climb and is characterized by an activation enegy close to that for grain boundary diffusion.

In the present work, on annealed Cu–30% Zn samples the observed grain boundary peak is characterized by an activation energy 1.84 eV. Since dislocation climb is controlled by a self-diffusion mechanism, enhanced by the solute content, the activation energy presently obtained could be interpreted as the activation energy by self-diffusion of copper. This value is in reasonable agreement with the values given in the literature [10]. The same value of activation energy was found when the grain boundary peak for annealed Cu–10% Zn

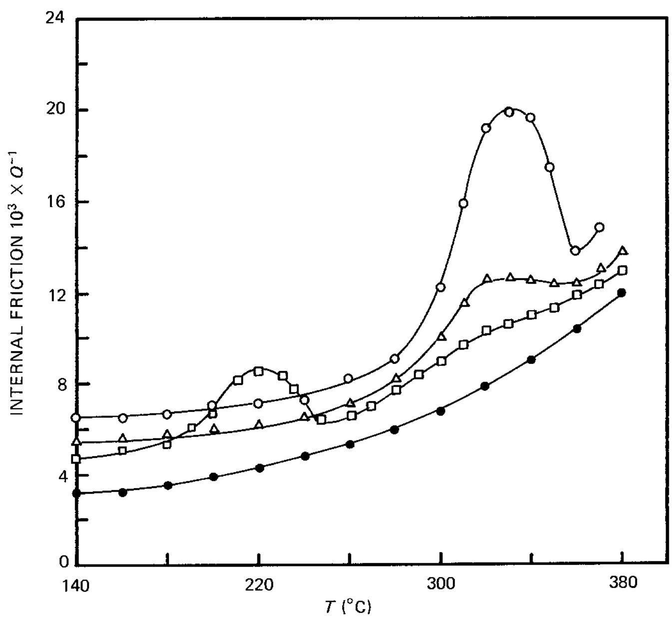

Figure 4 Effect of cold work and quenching on the relaxation strength of the grain boundary peak for Cu–30% Zn (○ annealed at 300° C for 7 h, △ cold work (ND/L) = 1.25%, □ cold work (ND/L) = 2.5%, ● quenched from 300° C to room temperature). ν = 0.6 Hz, σ = 1 kg mm^{-2}.

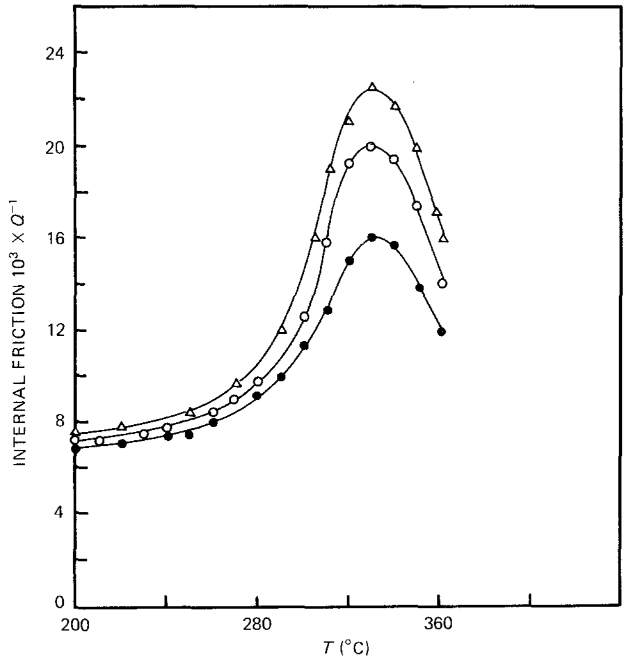

Figure 5 Stress dependence on the grain boundary peak for Cu–30% Zn. (● $\sigma = 0.38\,\mathrm{kg\,mm^{-2}}$, ○ $\sigma = 1.00\,\mathrm{kg\,mm^{-2}}$, △ $\sigma = 2.04\,\mathrm{kg\,mm^{-2}}$) $\alpha = 1.74 \times 10^{-4}$.

was studied, however, the relaxation strength was reduced and the peak temperature shifted to higher values (see Fig. 1). This could be interpreted as due to increased diffusivity (by increasing solute atom concentration) thus enhancing the climb process, and the dissolution of dislocations could take place rapidly.

From Fig. 3 it is clear that the relaxation strength is the property that shows a strain amplitude dependence, however, the peak temperature and activation energy were found to be independent. According to Smith and Leak [8] the amplitude dependence of the grain boundary peak is due to the activation of increasing number of grain boundary dislocations with the increase in strain amplitude. In this model grain boundary dislocations with different activation energy E are distributed on the grain boundary and those with higher activation energy become operative with the help of higher external stress σ. Such a process is realized if we replace E in the equation $\tau = \tau_0 \exp (E/kT)$ by $E - a\sigma$ where a is a positive constant and E the activation energy to be measured. The increase in E is then compensated by the additional term $-a\sigma$, keeping the sum, the apparent activation energy, almost unchanged. A similar mechanism is expected to be applied to the case of Cu–Zn alloys. The grain boundary dislocations in these alloys are pinned down by the zinc solute atoms.

Cold-working the sample decreased the peak height due to the increase of lattice dislocations thus its contribution increased (as shown in Fig. 4) and no distinct grain boundary peak appeared after 2.5% cold work due to the breakdown of the network dislocation [11].

It seems that the number of contributing grain boundary dislocations is stress dependent thus the relaxation strength increased when the tensile applied stress was increased.

Quenching supressed the grain boundary relaxation peak (see Fig. 4) due to the possible trapping of zinc solute atoms by vacancies.

Acknowledgement
The authors would like to thank Professor Dr R. Kamel for valuable discussions.

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Received 26 September 1988
and accepted 13 April 1989