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High temperature background damping

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Abstract

The high temperature background damping of several metals and alloys is analysed in terms of the various constitutive equations proposed in the literature for its description. It is shown how, by means of a new measuring technique, it is possible to obtain information not only on the temperature dependence of this damping but also on its frequency dependence. In fact, not only the temperature dependence of the damping is obtained, but also the derivatives with respect to the temperature and the frequency. The procedure is applied to several hexagonal and cubic metals and alloys and the meaning of the various physical parameters obtained from the experimental data is discussed.

1. Introduction

At relatively high homologous temperatures the damping–temperature curves of most materials rise continuously to very large values of internal friction [1]. This phenomenon, known as "high temperature background (HTB) damping", is highly structure sensitive and, in general is much smaller in single crystals than in polycrystals and is probably due to diffusion-controlled dislocation relaxation. The various expressions proposed in the literature [2–9] for the description of the HTB F can be described by the equation

$$F=C+A(\omega, T)\exp\left(-\frac{B}{kT}\right) \tag{1}$$

where C is a constant which includes a possible damping due to the apparatus, $\omega=2\pi f$ (where f is the frequency of the applied stress), B is some activation enthalpy, T is the absolute temperature and k is Boltzmann's constant. The various models differ mainly in the temperature and frequency dependence of the pre-exponential factor $A(\omega, T)$ and it is very difficult with the usual experimental techniques to separate clearly the influence of ω and T on A owing to the strong temperature dependence of the exponential term in eqn. (1). Since F is a function of two variables, two partial derivatives must be considered, namely $[\partial F/\partial\omega]_T$ and $[\partial F/\partial T]_\omega$. These two partial derivatives can be used to obtain information about the various parameters involved in eqn. (1) within the context of the various models. The procedure will be applied to various metals and alloys of hexagonal and cubic structures.

2. Experimental procedure

A modified traditional torsion pendulum of the inverted type working in free decay was used for the measurement of the HTB as a function of temperature and in high vacuum [10]. This torsion pendulum, with variable moment of inertia, allows measurements of the internal friction *vs.* temperature at both constant (variable frequency) and variable (constant frequency) moment of inertia. In fact, at each temperature the damping is measured in the normal way at the frequency dictated by the fixed moment of inertia and the shear modulus of the specimen and subsequently the moment of inertia is corrected automatically from outside the

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TABLE 1. Type, shape and purity of the various specimens studied

Material	Shape	Purity
Mg	Wire	99.994%
Zry-4	Wire	Nuclear grade
Nb	Sheet	99.999%
Ta	Sheet	99.99%
Cu	Sheet	99.99%
Cu–5at.%Au	Wire	99.99%

pendulum in such a way that the oscillation frequency can always be kept constant, *e.g.* at the value corresponding to room temperature. This procedure gives three curves as a function of temperature: F and ω *vs.* T and a third curve, F_c *vs.* T, where F_c is measured at constant frequency ω_c. Since ω changes only slightly with temperature, the partial derivatives $[\partial F/\partial\omega]_T$ and $[\partial F/\partial T]_\omega$ are given by

$$\left.\frac{\delta F}{\partial\omega}\right|_T = \left.\frac{F_c-F}{\omega_c-\omega}\right|_T \tag{2}$$

$$\left.\frac{\partial F}{\partial T}\right|_\omega = \frac{\mathrm{d}F_c}{\mathrm{d}T} \tag{3}$$

Two different types of specimens were employed: a pure magnesium single crystal wire whose orientation has been given elsewhere [11] and various polycrystalline specimens as indicated in Table 1.

Maximum strain amplitudes of the order of 5×10^{-5} were used and no amplitude dependence of the damping was encountered. The measurements were performed from room temperature up to about 1173 K for Cu, Ta, Nb and Cu–5at.%Au. The Zry-4 and Mg specimens were measured up to 1110 and 910 K respectively. Prior to the measurements all specimens were annealed to the highest temperature for 3 h under high vacuum in order to stabilize the structure. The HTB was reproducible on both heating and cooling. On increasing the heating rate to high values, the curves were shifted rigidly without changing their shapes.

3. Results

Figure 1, for example, illustrates the results obtained in Cu–5at.%Au for F, F_c and ω. The data points are indicated by open and full circles and crosses in this figure, together with the average curves obtained by means of a computer programme described elsewhere [12]. Similar results were obtained for the other specimens.

Once the average F, F_c and ω curves have been properly evaluated, it is possible to obtain $[\partial F/\partial(\ln\omega)]_T$ and $[\partial F/\partial(1/T)]_\omega$ by means of eqns. (2) and (3). Furthermore, differentiating eqn. (1) leads to

$$\left.\frac{\partial F}{\partial\omega}\right|_T = (F-C)\left.\frac{\partial[\ln A(\omega,T)]}{\partial\omega}\right|_T \tag{4}$$

$$\left.\frac{\delta F}{\partial(1/T)}\right|_\omega = \left(\left.\frac{\partial[\ln A(\omega,T)]}{\partial(1/T)}\right|_\omega - \frac{B}{k}\right)(F-C) \tag{5}$$

The derivatives $[\partial F/\partial(\ln\omega)]_T$ and $[\partial F/\partial(1/T)]_\omega$ are shown in Figs. 2–4 for the b.c.c., f.c.c. and h.c.p. structures respectively. Since $[\partial F/\partial(\ln\omega)]_T\neq0$ except in a small temperature range and for some specimens, it can be established that if the HTB is described by eqn. (1), the pre-exponential factor $A(\omega, T)$ must at least be a function of ω. This excludes automatically some of the expressions used in the literature for the description of the HTB. A detailed procedure to be used for the analysis of the rest of the expressions used in the literature for the description of the HTB is given elsewhere [11]. By using this procedure, it can be established that none of the equations of the type of

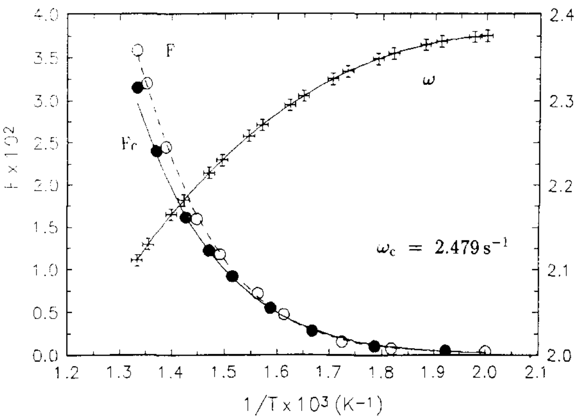

Fig. 1. High temperature internal friction background F and F_c and oscillation frequency ω *vs.* reciprocal temperature for Cu–5at.%Au specimen.

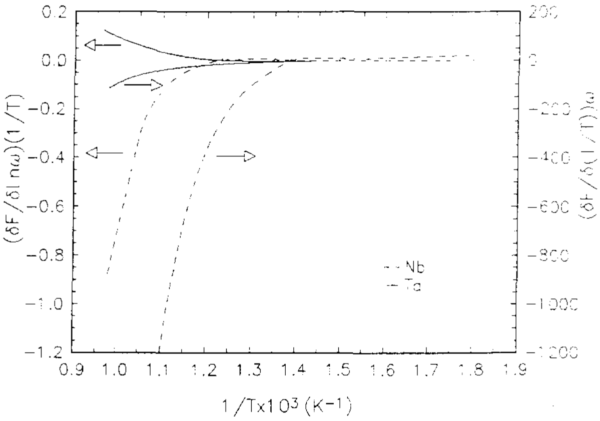

Fig. 2. Partial derivatives of HTB *vs.* reciprocal temperature for b.c.c. metals.

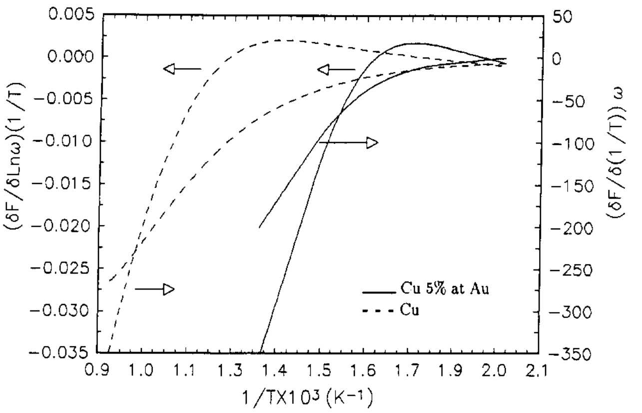

Fig. 3. Partial derivatives of HTB *vs.* reciprocal temperature for f.c.c. metals.

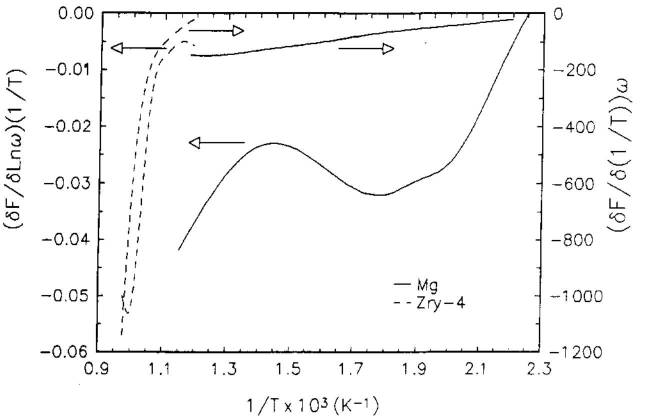

Fig. 4. Partial derivatives of HTB *vs.* reciprocal temperature for h.c.p. metals.

eqn. (1) can be used to describe the HTB of the specimens indicated in Table 1.

The results shown depend not only on the crystalline structure of the materials but also on the microstructure. In fact, as shown in Fig. 4 the derivatives for Mg and Zry-4 are completely different. This might be due to the influence of grain boundaries in the case of polycrystals or to a difference in the dislocation structure.

4. Discussion

Schoeck *et al.* [3] have assumed the definition

$$\hat{U}_0 = -k \left.\frac{\partial(\ln \omega)}{\partial(1/T)}\right|_F = k\alpha \tag{6}$$

with

$$\alpha = \frac{[\partial(\ln F)/\partial(1/T)]_\omega}{[\partial(\ln F)/\partial(\ln \omega)]_T} \tag{7}$$

for the apparent activation enthalpy of an internal friction process. According to eqn. (1), $\hat{U}_0$ is given by

$$\hat{U}_0 = \frac{k \left.\dfrac{\partial[\ln A(\omega, T)]}{\partial(1/T)}\right|_\omega - B}{\left.\dfrac{\partial[\ln A(\omega, T)]}{\partial(\ln \omega)}\right|_T} \tag{8}$$

Then $\hat{U}_0$ is a constant independent of ω and T only if $A(\omega, T) = f(\omega)$ and

$$\left.\frac{\partial[\ln A(\omega, T)]}{\partial(\ln \omega)}\right|_T = \frac{f(\omega)}{f'(\omega)} \tag{9}$$

is a negative constant, *i.e.* $f(\omega) = D\omega^{-n}$, where D and n are constants. This is the case only for equations for the HTB where

$$A(\omega, T) = \frac{K}{\omega^n g(T)} \tag{10}$$

where K is a constant and $g(T)$ is a function of temperature. Values of $\hat{U}_0/k$ for the b.c.c., f.c.c. and h.c.p. specimens are shown in Figs. 5–7 respectively. It can be seen from these figures that $\hat{U}_0$ in general depends on temperature. This temperature dependence might

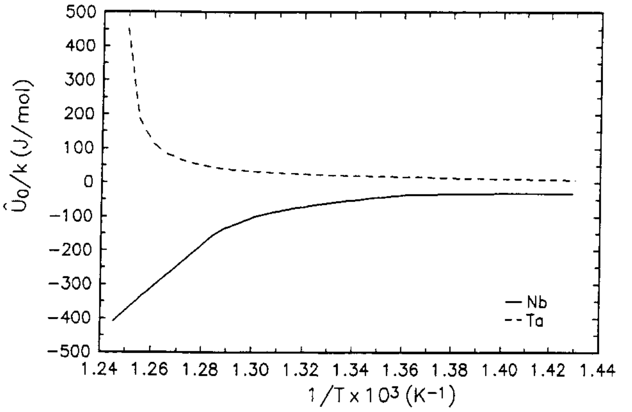

Fig. 5. Apparent activation enthalpy *vs.* reciprocal temperature for b.c.c. metals.

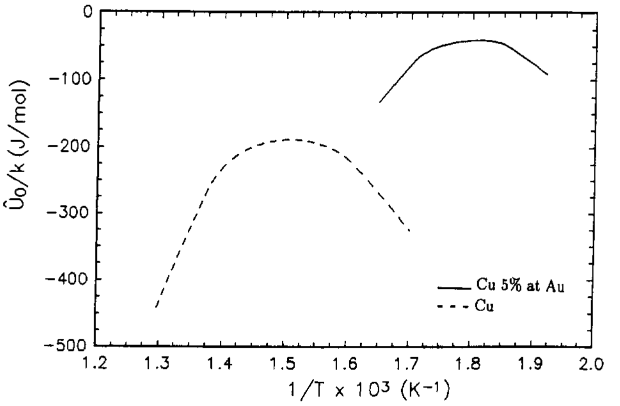

Fig. 6. Apparent activation enthalpy *vs.* reciprocal temperature for f.c.c. metals.

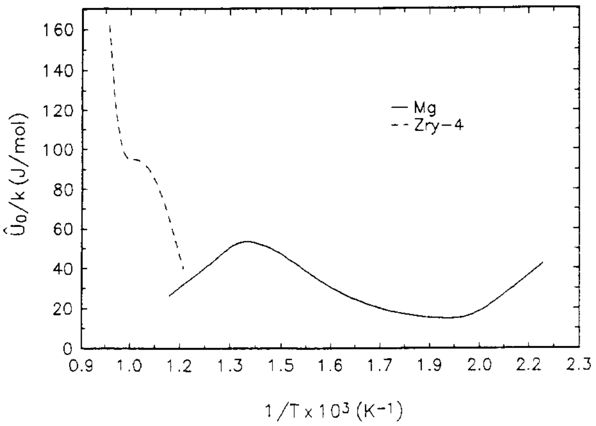

Fig. 7. Apparent activation enthalpy *vs.* reciprocal temperature for h.c.p. metals.

indicate that the distribution of relaxation times is changing with temperature and there is only an activation enthalpy. In fact, Schoeck *et al.* [3] used the approximate expression

$$F = \frac{K}{[\omega \exp(U_0/kT)]^n} \tag{11}$$

where U_0 is the true activation enthalpy of the relaxation process and K and n are constants if the width of the distribution of relaxation times does not change with temperature. When K and n depend on temperature, it is clear that $\hat{U}_0 \neq U_0$. Further theoretical and experimental work is needed in this field.

5. Conclusions

A procedure was given to establish whether the various constitutive equations proposed in the literature adequately describe the high temperature background damping of metals and alloys. The method proposed has shown that none of these expressions represents this damping.

Acknowledgments

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