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On the Frequency Dependence of the High Temperature Background

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Abstract: The high temperature background (HTB) damping in metals and alloys has been measured mostly as a function of temperature. These data were described by several empirical expressions proposed in the literature.

In the present work, HTB in pure Mg and in two alloys (Zry-4 and Cu-5at.%Au), measured with a torsion pendulum with variable moment of inertia, are analyzed on considering a new treatment of the data. This analysis provides an useful tool to determine whether a damping process is linear or not.

1 INTRODUCTION

At relatively high homologous temperatures the damping-temperature curves of most materials rises continuously to very large values [1]. This phenomenon, known as "high temperature background (HTB) damping", is highly structure sensitive, usually much smaller in single crystals than in polycrystals and probably due to diffusion-controlled dislocation relaxation. Furthermore, this damping increases exponentially with temperature, that is, has the form $A(\omega, T) \exp\left(-\frac{H}{kT}\right)$ with ω the angular frequency of the applied stress, A a pre-exponential factor which goes to zero as ω tends to zero and infinity, H the activation enthalpy, T the absolute temperature and k Boltzmann's constant. Moreover, the experimental data are fitted on including a constant C which represents a possible damping due to the apparatus. Therefore the empirical expressions and models proposed in the literature [2-6] to describe the HTB, F , can be summarized as

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

The various fits differ mainly in the frequency and temperature dependence of $A(\omega, T)$; however, this factor cannot be resolved experimentally owing to the exponential temperature dependence of eq. (1). In addition, complementary data such as the HTB measured as a function of ω or changing the stress-amplitude in order to analyze non-linear effects are scarcely found in the literature. Nevertheless, it was shown recently [7, 8] how the derivative $(\partial F / \partial \omega)_T$ provides useful information to determine the dependence of A on ω when $F \gg C$ since

$$\frac{\partial \ln A}{\partial \ln \omega} \bigg|_T \approx \frac{\partial \ln F}{\partial \ln \omega} \bigg|_T \quad (2)$$

It will be shown that the frequency dependence of F can be used also to establish whether linear or non-linear phenomena are involved in the HTB damping. The procedure will be described and its application to some experimental data will be discussed.

2 THEORETICAL BACKGROUND

The internal friction of linear viscoelastic materials, $\tilde{F}$, can be expressed as an integral transformation using the tangent distribution function Φ_t as [9]

$$\tilde{F}(\omega, T) = \frac{1}{2} \int_{-\infty}^{\infty} \frac{\Phi_t(\tau, T)}{\cosh[\ln(\omega\tau)]} d(\ln \tau). \quad (3)$$

where τ is the relaxation time. If eq. (3) is fulfilled, it can be shown that [10]

$$\left| \frac{\partial \ln \tilde{F}}{\partial \ln \omega} \right|_T \leq 1 \quad (4)$$

Conversely, $\left| \partial \ln \tilde{F} / \partial \ln \omega \right|_T > 1$ means that the internal friction is not described by linear viscoelasticity, that is, non-linear phenomena are involved and the damping should be amplitude dependent. It is noticed, however, that even if eq. (4) is satisfied the internal friction may be amplitude dependent; in fact, only when this equation is not obeyed it can be assured that non-linear phenomena are involved.

3 EXPERIMENTAL PROCEDURE

As described in detail elsewhere [11] a modified traditional torsion pendulum was used to measure the HTB as a function of temperature in high vacuum. This torsion pendulum, with variable moment of inertia, allows to measure not only the traditional curves of internal friction and frequency against temperature (at a fixed moment of inertia) but also the internal friction F_c measured at a constant frequency ω_c (on changing the moment of inertia). Since ω changes only slightly with temperature, the partial derivative $\partial \ln F / \partial \ln \omega|_T$ can be approximated as follows

$$\frac{\partial \ln F}{\partial \ln \omega} \bigg|_T \approx \frac{\ln(F_c/F)}{\ln(\omega_c/\omega)} \bigg|_T \quad (5)$$

Three different types of specimens were employed: a Mg single crystal wire 99.994% pure, a nuclear grade Zircaloy-4 polycrystalline wire and a Cu-5at.%Au polycrystalline wire 99.99% pure. Prior to the tests all specimens were annealed to the highest temperature of the measurements for three hours in high vacuum in order to stabilize the structure. The HTB was reproducible on both heating and cooling. A more detailed description of the experimental procedure is given elsewhere. [7, 8].

4 RESULTS

Figures 1(a) to 3(a) illustrate the results obtained in the three specimens. Once F , F_c , ω and ω_c are known, it is possible in principle to get $\partial \ln A / \partial \ln \omega|_T$ using eqs.(2) and (5). The problem to evaluate this derivative is to establish if $F \gg C$, because the determination of C is usually wide inaccurate. However, the curve $\partial \ln F / \partial \ln \omega|_T$ against T aids to establish when F is close to C , since the derivative get apart from $\partial \ln A / \partial \ln \omega|_T$ and tends to zero. In fact, the curves shown in Figs. 1(b) to 3(b) exhibit a tendency towards zero at low temperatures.

5 DISCUSSION

Schoeck et al. [3] have proposed a dislocation model for the HTB in which the internal friction is caused by the motion of dislocations which are in some way interacting with point defects and

Fig. 1(a): HTB in Mg measured with the pendulum with variable moment of inertia [7].

Fig. 1(b): Logarithmic derivative calculated using eq. (5) and the data of Fig. 1(a).

Fig. 2(a): HTB in Zry-4 measured using the pendulum with variable moment of inertia [7].

Fig. 2(b): Logarithmic derivative calculated using eq. (5) and the data of Fig. 2(a).

Fig. 3(a): HTB in Cu-5at.%Au measured using the pendulum with variable moment of inertia [8].

Fig. 3(b): Logarithmic derivative calculated using eq. (5) and the data of Fig. 3(a).

move at high temperatures in a viscous way. They obtained a final expression which is similar to eq. (3) indicating that a linear viscoelastic process is present. This is valid also for the approximate expression of the damping proposed in [3] as

$$F = \frac{K}{[\omega \exp(-H/kT)]^n} \quad (6)$$

with $n \leq 1$, because in this case $\partial \ln F / \partial \ln \omega|_T = n$ satisfies eq.(4).

Nevertheless, as shown in Figs. 1(b) and 3(b), the derivatives for Mg and Cu-5at.%Au indicate clearly that $|\partial \ln F / \partial \ln \omega|_T| > 1$. For Zry-4, the minimum value of this derivative is slightly lower than -1, as depicted in Fig. 2(b). In conclusion, it can be stated that in the cases of Mg and Cu-5at.%Au, the HTB involves non-linear processes, that is, the internal friction must be amplitude dependent.

The only data available in the literature about the frequency dependence of the HTB were reported by Gadaud et al. [6] in silicon single crystals. They described the HTB as

$$F = C + \frac{A_0 \exp(-H/kT)}{\omega^{\alpha-\beta T}} \quad (7)$$

being A_0 , α and β parameters independent of T . It is noticed that this expression corresponds to the low temperature limit of the internal friction of a modified anelastic element with an extremely high peak temperature [12, 13] characterized by a parameter $\gamma = \alpha - \beta T$. In the range of temperatures considered by the authors, $|\partial \ln A / \partial \ln \omega|_T| = \gamma < 1$ so, it cannot be established whether the damping is non-linear.

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