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Experimental Verification of the Behaviour of the Different Expressions for Measuring Amplitude Dependent Damping

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Abstract. The agreement between the intrinsic damping, obtained from the sustained oscillations measurements, and the values measured directly in forced oscillations has been verified. Therefore, it is possible to measure directly the intrinsic damping from forced oscillations, without additional calculations and with minor effort. At the same time the damping behaviour measured by different modes with a torsion pendulum, i. e. forced oscillations, sustained oscillations and free decay, in presence of amplitude dependent damping was also studied and similar results are obtained..

1. INTRODUCTION

The relevance of the study of the amplitude dependent damping is related to the great amount of information which can be obtained for the microstructural characterisation of materials, both in science and in the field of engineering. Moreover, the analysis of the physical models for describing the mechanical behaviour of materials must be done in terms of the intrinsic damping, i. e., the damping that would be measured if the stress distribution in the specimen is uniform [1].

The possibility of measuring directly the intrinsic damping by means of measuring the damping in forced oscillations at γ=0.707 was proposed by Molinas and Povolo [2]. It was also found, that the damping measured by means of free decay method, FD, masks the dependence of damping on the amplitude of deformation while the damping measured with forced oscillations, FO, better describes this dependence. In fact, the measured values with sustained oscillations (SO), FD and FO coincide only when the material behaves linearly, i. e. the damping of the material is amplitude independent. Consequently the measured damping, F, coincides with the intrinsic damping (F_I). When amplitude dependent damping effects appear, the measured dampings in SO, FD and FO are different for each loading condition and do not coincide with the intrinsic damping. Therefore, it is necessary to correct the measured damping in order to obtain the F_I from forced oscillations measurements.

The aim of this work is to corroborate experimentally the agreement between the intrinsic damping and the damping measured in forced oscillations. This agreement shows the possibility of obtaining directly intrinsic damping. Furthermore, the effect of hiding the dependence of the damping measured by free decay and the better description of the dependence for the damping measured in forced oscillations are also experimentally verified.

2. EXPERIMENTAL PROCEDURE

Two types of pendula were used. One is an inverted torsion pendulum at variable moments of inertia which operates at low frequency from 0.2 Hz up to 40 Hz [3,4]. The other one is also, an inverted torsion pendulum at variable moments of inertia, but operated at medium frequency from 30 Hz up to 150 Hz [3,5]. Both work at low and high temperatures under high vacuum and are driven by a PCL-812 Card [3]. The absolute damping, AF_{FD}, was calculated with free decay method, fitting a straight line by least

[(1)] *Present address*: Departamento de Física de la Materia Condensada, Facultad de Ciencias, Universidad del País Vasco, Apdo. 644, 48080 Bilbao, Spain squares to the natural logarithm of all the torsion decaying amplitudes, A_n, as a function of the number of oscillations, n, at constant temperature, T. The AF_{FD} value is in agreement with the value of damping measured in SO (in the amplitude independent zone). The distortion effect in the measured value in FD appears with the beginning of amplitude dependent damping. This distortion is larger for bigger ratios, C, between the initial and final decaying amplitudes [2, 6]. However, obviously, systematic qualitative damping measurements can be performed in FD keeping the same C ratio during the test.

The sustained oscillation method damping, F_{SO}, was measured in order to survey the voltage application of the exciting force, V, and to divide this voltage by a tension related to f_0^2, f_0 being the natural oscillation frequency, that is

$$F_{SO} = \frac{K}{f_0^2} V \text{ , where K is a constant for a given apparatus [7,8]} \qquad (1)$$

These values are correlated to the data measured in AF_{FD} through measurements performed in the range of Snoek relaxation temperatures, which is an amplitude independent phenomenon.

The damping in forced oscillations measurements, F_{FO} , is calculated by means of expression (2)

$$F_{FO} = \Gamma \frac{f_1 - f_2}{f_0} \qquad (2)$$

where f_1 and f_2 are the frequencies where the amplitude of the forced oscillations decays to a value γ times lower than the amplitude at f_0. Typical values are $\Gamma = 1$ for $\gamma = 0.707$ and $\Gamma = (1/3)^{(1/2)}$ for $\gamma = 0.5$ [2, 8,].

The manual operation of the pendulum in forced oscillation was performed with a programmable multifunction synthetizer Keithley 3930 A with a frequency resolution of 0.1 mHz. Furthermore, the measurement of damping in the forced oscillation mode, by means of equation (2), was also done automatically through the PCL-812 card plus control software. The computer and the pendulum are synchronised; the run up in temperature and the equilibrium of the measurement temperatures are also controlled. For a given temperature, the computer (or the operator in the manual case) finds the natural frequency of oscillation for a determined deformation amplitude. Subsequently, the computer (or operator) changes the frequency towards higher values of frequency up to a value where the oscillation amplitude decays γ times, obtaining f_1. This procedure is repeated for frequencies lower than the natural frequency, obtaining f_2. The processes mentioned above are repeated for other maximum deformation amplitudes, at the same temperature.

The intrinsic damping at strain ε_0, $FI_I(\varepsilon_0)$ for the case of torsional vibrations in cylindric bars is obtained from the damping measured in sustained oscillations at strain ε_0, $F_{SO}(\varepsilon_0)$; by means of equation (3) [9].

$$F_I(\varepsilon_0) = F_{SO}(\varepsilon_0) + \frac{\varepsilon_0}{4} \frac{d F_{SO}(\varepsilon_0)}{d \varepsilon_0} \qquad (3)$$

It should be mentioned that the main assumption made in the obtainment of eq.(3) is that the energy density, E, can be expressed as a function of the mean modulus, M, and the scalar parameter ε, in the form $E(\varepsilon)=M \varepsilon^2/2$.

The measurements performed at low frequency were made employing a stress-relieved high purity niobium and zirconium samples in the shape of cylinders of 50 mm long and 1 mm radius. While, the measurements carried out at medium frequency employed the same materials in the form of cylinders, 28 mm in length and 2 mm radius. The niobium samples were deformed 15% by tensile test after annealing.

The damping as a function of the maximum strain was also calculated by means of the first derivative of the fitted polynomial ln (A_n) against n, F_{DER}. In fact, the discrete data pairs (n, $\ln A_n$), were fitted with polynomials and a least squares method. This procedure allows to obtain the derivative of an analytic expression for $\ln A_n$ against n from which the F_{DER} can be calculated using this first derivative [7]. Besides this, considering that A_n = constant x ε_0, the value of F_{DER} at each ε_0 can be easily obtained by evaluating this first derivative at ε_0 [10].

3. RESULTS AND DISCUSSION

Figure 1 shows amplitude dependent damping effects for the zirconium sample measured at medium frequencies at 595 K. This temperature is near the Zr-O peak (at low damping) due to the dislocations break-away from pinning points. The three modes of operation of the pendulum FD, SO, and FO, are compared. The empty circles represent the values measured in SO. The F_{DER} curve also is plotted, with a full line, in order to demonstrate the good functioning of the equipment. Figure 2 shows the non linear effects for the Zr - O system but measured at low frequency at 570 K. The same symbols as in figure 1 is employed.

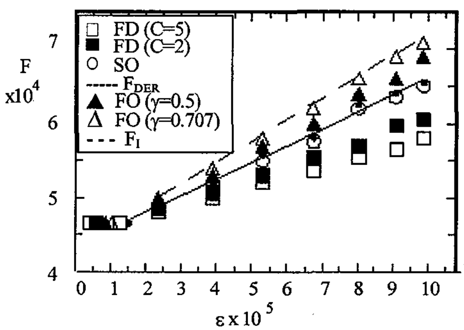

Figure 1: Amplitude dependent damping, measured at medium frequencies at 595 K in Zr - O

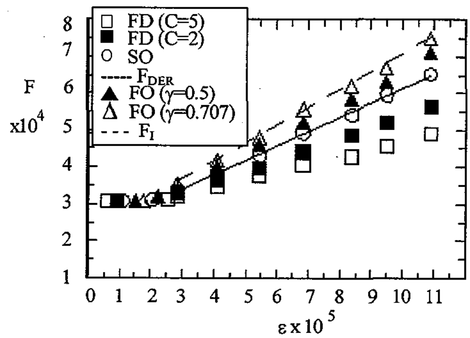

Figure 2: Amplitude dependent damping measured at low frequency at 570 K in Zr - O.

The behaviour of these curves is in agreement with the theoretical calculations reported by Molinas and Povolo [2]. In fact, the damping measured in FD masks the dependence while the damping measured in FO better describes the non-linear effects. Moreover, the most important result is the experimental corroboration of the agreement between the F_I, broken line, calculated by means of equation (3) and the values measured in FO for $\gamma = 0.707$.

The behaviour for the niobium samples at medium and low frequencies, which present other laws of amplitude dependent damping, is presented in figures 3 and 4 respectively after checking carefully the expressions under different conditions. The symbols are the same as for the other figures, but one more value has been added for the FD mode with C = 3, and FO mode with $\gamma = 0.2$.

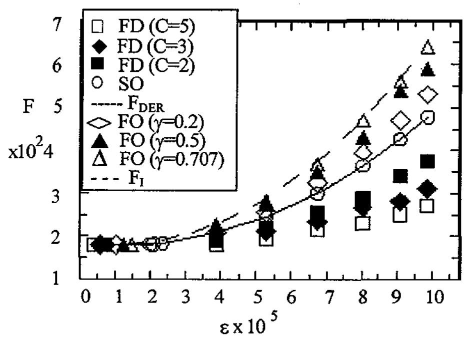

Figure 3: Amplitude dependent damping, measured at medium frequencies at 973 K in Nb - O

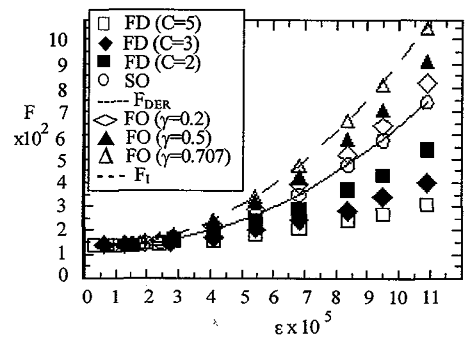

Figure 4: Amplitude dependent damping measured at low frequency at 652 K in Nb - O.

The medium frequency measurements were performed at 973 K, while the low frequency measurements were carried out at 652 K. These temperatures are near to the Snoek - Koester relaxation. In the Nb case both the general behaviour of the expressions has been also corroborated and a satisfactory agreement has been achieved between the FO measured values for $\gamma = 0.707$ and the intrinsic damping calculated by means of equation (3).

4. CONCLUSIONS

1) The agreement between the intrinsic damping, obtained from sustained oscillations, and the values measured in forced oscillations with $\gamma = 0.707$ has been verified. Therefore, it is possible to measure the intrinsic damping directly by the forced oscillation method, with a strong reduction in time and effort. 2) The behaviour of amplitude dependent damping measurements in the different modes of operation of a torsion pendulum as a function of the strain has been experimentally verified. In fact, the free decay method masks the amplitude dependent damping effects, while the forced oscillations method better describes the amplitude dependent damping effects..

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