



**HAL**  
open science

# INFRARED TECHNIQUE FOR MEASURING ULTRASONIC ABSORPTION IN POLYCRYSTALLINE METALS

J. Monchalin, J. Bussière

► **To cite this version:**

J. Monchalin, J. Bussière. INFRARED TECHNIQUE FOR MEASURING ULTRASONIC ABSORPTION IN POLYCRYSTALLINE METALS. *Journal de Physique Colloques*, 1985, 46 (C10), pp.C3-775-C3-778. 10.1051/jphyscol:198510169 . jpa-00225377

**HAL Id: jpa-00225377**

**<https://hal.science/jpa-00225377>**

Submitted on 4 Feb 2008

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

**INFRARED TECHNIQUE FOR MEASURING ULTRASONIC ABSORPTION IN POLYCRYSTALLINE METALS \***

J.P. MONCHALIN\* AND J.F. BUSSIÈRE\*\*

\* *Physical Metallurgy Research Laboratories, CANMET, Energy, Mines and Resources, Canada, 588 Booth Street, Ottawa, Ontario, Canada K1A 0G1*

\*\* *Industrial Materials Research Institute, National Research Council of Canada, 75 de Mortagne Boulevard, Boucherville, Québec, Canada J4B 6Y4*

**Résumé** - Dans la plupart des matériaux polycristallins, l'atténuation due à la diffusion par les grains est dominante et a pour conséquence de ne pas permettre la mesure de l'absorption (ou frottement interne). Nous avons mis au point une technique qui permet de mesurer directement le frottement interne aux fréquences ultrasonores, même en présence de la diffusion. Cette technique est basée sur la détection infrarouge de la chaleur produite par un faisceau ultrasonore modulé à basse fréquence. Nous présentons des résultats expérimentaux pour un acier commercial qui montre clairement les contributions dues à la diffusion, aux mouvements des parois des domaines magnétiques et à d'autres phénomènes.

**Abstract** - In most polycrystalline materials, attenuation at high frequencies is dominated by grain boundary scattering making it impossible to measure absorption (or internal friction) with any accuracy. A technique was devised to measure internal friction directly at ultrasonic frequencies even in the presence of substantial scattering. The method is based on the infrared detection of the heat produced by slowly modulated ultrasound. Results, presented for a commercial steel sample, clearly separate contributions due to scattering, magnetic domain wall motion and other sources.

**I - INTRODUCTION**

Ultrasonic attenuation measurements have long been recognized as a useful nondestructive tool for probing strength related microstructural changes in metals. In particular attenuation due to scattering from grain boundaries has been intensively studied with recent commercial developments of on-line systems for grain size determination. In such measurements contributions due to absorption (or internal friction) are usually neglected or treated in a simplistic indirect manner because of the usually dominant scattering contribution and the impossibility to separate the two in classical pulse-echo measurements. Absorption measurements in addition to clarifying contributions from scattering, can provide an important supplementary tool for probing microstructural parameters occurring on a much finer scale such as dislocations and point defects.

We present below a new technique which allows direct measurements of ultrasonic absorption even in the presence of large scattering contributions in polycrystalline metals. The technique is based on the infrared detection of the heat produced by a slowly amplitude modulated or chopped ultrasonic beam. Results are presented for a commercial constructional steel sample clearly indicating the presence of several mechanisms for absorption.

**II - EXPERIMENTAL METHODS**

The experimental setup is shown schematically in figure 1. An infrared detector measures synchronously the temperature variation of a surface exposed to slowly

\* Work performed and present address of both authors: IMRI, Boucherville, Québec.

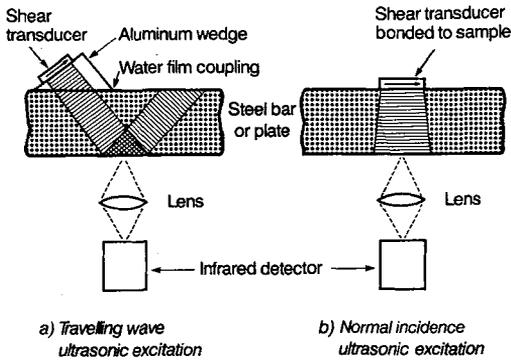


Figure 1:

Schematic of two experimental setups used for the direct measurement of ultrasonic absorption.

modulated or chopped (0.1 Hz - 1 kHz) ultrasonic power provided by a piezoelectric transducer. In such a configuration the IR detector is sensitive to the heat generated by ultrasonic absorption occurring within approximately one thermal skin depth  $\mu$  of the surface/1/ where:

$$\mu = [K/\pi\rho cf]^{1/2} \quad (1)$$

$K$  and  $c$  are respectively thermal conductivity and specific heat,  $\rho$  is density and  $f$  is the frequency of modulation. For mild steel and aluminum at 1 Hz,  $\mu$  is typically 2 and 5.4 mm respectively.

For perpendicular ultrasonic incidence and uniform heat distribution in the observed area, which is the case when  $\mu$  is much larger than half an ultrasonic wavelength, it can be readily shown that the rms value,  $\tau_{\text{rms}}$  and the phase  $\phi$  of the surface temperature modulation  $\tau/2$  are given by:

$$\tau_{\text{rms}} = \pi \alpha Z f_u^2 U^2 / (2 \sqrt{2} f \rho c) \quad (2)$$

$$\phi = -\pi/2 \quad (\text{with respect to applied ultrasonic stress})$$

where  $Z$  is the acoustic impedance,  $U$  is the maximum amplitude of the surface displacement, and  $\alpha$  is the absorption coefficient (for the stress or strain). Ultrasonic powers used are generally less than 100 W/cm<sup>2</sup> and strains less than 10<sup>-5</sup>. Surface modulation temperatures are generally much less than 1°K. Using sensitive pyroelectric detectors placed near the surface or a Golay detector and a viewing area of  $\approx 1$  cm<sup>2</sup>, a detection limit of  $\approx 10^{-5}$  °K Hz<sup>-1/2</sup> can be achieved.

In addition to surface temperature measurements ( $\tau_{\text{rms}}$ ), evaluations of the absorption coefficient  $\alpha$  from equation (2) require simultaneous measurements of the surface displacement  $U$ . This can be achieved using optical interferometers. However, we have also devised a method which enables us to determine the absorption without calibration of the detection apparatus, knowledge of the surface emissivity, and measurement of the ultrasonic power in the probed region. This method consists in monitoring for the same experimental conditions the change of infrared signal and the change of ultrasonic transmission (e.g., by pulse echo) when a material parameter which affects absorption (e.g., magnetic field, applied stress) is varied /3/.

For a magnetic material the absorption coefficient can be considered to be the sum of a magnetic and nonmagnetic contribution

$$\alpha = \alpha_M + \alpha_{\text{NM}} \quad (3)$$

By applying a saturating magnetic field the magnetic contribution  $\alpha_M$  can be decreased to zero. The ratio of infrared signals observed at saturation  $I_s$  to its value in zero field  $I_0$  is then given by

$$I_s/I_0 = P_s \alpha_{NM}/P_0 (\alpha_M + \alpha_{NM}) \quad (4)$$

where  $P_0$  and  $P_s$  are the ultrasonic powers reaching the probed zone in the demagnetized and saturated states respectively. The ratio of powers  $P_s/P_0$  can be measured by covering the surface with a strongly absorbing adhesive tape and again measuring temperature modulations in the saturated and demagnetized states. By combining these two results in equation (4), we readily obtain  $\alpha_{NM}/\alpha_M$ . The magnetic absorption  $\alpha_M$  is then measured by the pulse-echo technique by monitoring the change in attenuation between saturated and demagnetized states.

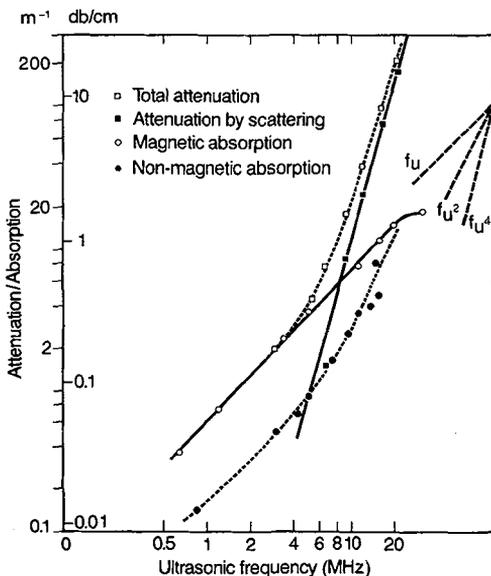
The total attenuation  $\alpha_T$  was also measured using the pulse-echo buffer technique taking into account diffraction corrections /4/. Total attenuation is the sum of three contributions:

$$\alpha_T = \alpha_{SC} + \alpha_M + \alpha_{NM} \quad (5)$$

where  $\alpha_{SC}$  is the scattering attenuation coefficient.  $\alpha_{SC}$  can be readily deduced from eq. (5) and measurements of  $\alpha_M$ , and  $\alpha_{NM}$ . The results presented in this paper are for type A36 constructional steel having a ferrite-pearlite structure. Both configurations shown in figure 1 were used for the infrared measurements.

### III - RESULTS AND DISCUSSION

Total attenuation measurements together with separate contributions from scattering,  $\alpha_{SC}$ , and magnetic and nonmagnetic absorption,  $\alpha_M$  and  $\alpha_{NM}$  are shown in figure 2 as a function of frequency. The scattering contribution obtained by subtracting absorption from  $\alpha_T$  is seen to vary as the fourth power of ultrasonic frequency,  $f_u^4$ . This is expected since the grain size of the sample is  $\approx 20$ -25  $\mu\text{m}$  and the ultrasonic wavelength is much larger than grain size at all studied frequencies (i.e. Rayleigh scattering occurs). Magnetic absorption  $\alpha_M$  (figure 2) increases linearly with frequency except for one point above 20 MHz and is dominant at low frequencies up to  $\approx 5$  MHz. This loss is associated with stress-induced vibration of magnetic domain walls which induce micro-eddy currents. Theory



**Figure 2:**  
Absorption and scattering contributions to total attenuation in a type A36 steel. The nonmagnetic absorption was deduced from infrared measurements. Scattering was obtained by subtracting absorption from total attenuation.

predicts a relaxation type loss leading to an absorption term of the following form /5, 6/.

$$\alpha_M = c f_u^2 / f_0 [1 + (f_u / f_0)] \quad (6)$$

where  $f_0 = 10^9 R / [96 \chi_0 d_m^2]$  and  $R$  is electrical resistivity in ohm-cm,  $d_m$  is magnetic domain size (cm) and  $\chi_0$  is initial magnetic susceptibility. Assuming  $R = 20 \mu$  ohm-cm,  $d_m = 8 \mu$  ( $\approx 1/3$  grain size) and  $\chi_0 = 1000/4\pi$  yields a value of  $f_0 \approx 15$  MHz. This is not inconsistent with the apparent plateau in  $\alpha_M$  beginning near a frequency of  $\approx 25$  MHz. However one would expect an  $f_u^2$  instead of the observed  $f_u$  dependence at lower frequencies. Such discrepancies can probably be accounted for by taking into account the distribution of domain sizes and the possibility of domain rotation /6/.

Absorption of nonmagnetic origin  $\alpha_{NM}$  also shown in figure 2 is seen to vary roughly linearly with  $f_u$  below 4 MHz and to vary approximately as  $f_u^2$  above  $\approx 8$  MHz. The behavior at low frequency appears consistent with intergranular thermal currents which become progressively more important as frequencies of  $\approx 0.1$  MHz are approached /3/. The  $f_u^2$  behavior at higher frequency appears consistent with the conventional Granato-Lücke model of dislocation damping. However the magnitude of the damping should be much smaller since dislocation loops in this sample should be completely pinned by carbon or other impurity atoms. The present observations are, however, in agreement with other experimental results obtained in polycrystalline steel and aluminum samples using a different technique /8, 9/ and we suspect that they are also associated with dislocations, as conjectured by these authors.

#### CONCLUSION

Using a new technique for measuring ultrasonic absorption combined with pulse-echo measurements, several contributions to attenuation in a polycrystalline steel sample were clearly identified between 0.5 and 25 MHz. At low frequency ( $\leq 5$  MHz), the attenuation is dominated by absorption of magnetic origin associated with micro-eddy currents. An absorption contribution of nonmagnetic origin was also observed over the entire frequency range. It increases as the square of ultrasonic frequency (for  $f > 8$  MHz) and is apparently associated with dislocations. After subtraction of these two absorption contributions from the total attenuation, an  $f_u^4$  term associated with grain scattering is clearly identified.

#### ACKNOWLEDGEMENTS

We acknowledge the skillful technical assistance of M. Lord, R. Héon and S. Faucher.

#### REFERENCES

- /1/ H.S. Carslaw and J.C. Jaeger, Conduction of Heat in Solids, 2<sup>nd</sup> edition, Oxford Press, 1959, chap. 2.6.
- /2/ J.-P. Monchalin and J.F. Bussièrre in Nondestructive Methods for Material Property Determination, edited by C.O. Ruud and R.E. Green, Jr., Plenum Press, 1984, p. 289-298.
- /3/ J.-P. Monchalin and J.F. Bussièrre, in Review of Progress in Quantitative Nondestructive Evaluation, Vol. 4B, ed. by D.O. Thompson and D.E. Chimenti, Plenum Press, 1985, p. 965.
- /4/ E.P. Papadakis, K.A. Fowler, and L.C. Lynnworth, J. Acoust. Soc. Am., 53, (1973) 1336.
- /5/ W.P. Mason, Phys. Rev. 83, (1951) 683.
- /6/ W.P. Mason, Rev. Mod. Phys. 25, (1953) 136.
- /7/ A.B. Bhatia, Ultrasonic Absorption, ch. 13, Oxford Univ. Press, 1967.
- /8/ W.N. Reynolds and R.L. Smith, J. Phys. D. Appl. Phys. 17, (1984) 109.
- /9/ S. Perring, R.L. Smith, B. Hudson, and W.N. Reynolds, Harwell Report AERE-R 11384.