Journal of Alloys and Compounds, 211/212 (1994) 613–615
JALCOM 073

Measurement applications of the scanning acoustic microscope

A. Kulik, G. Gremaud, P. Richard and J.-M. Sommer
Ecole Polytechnique Fédérale de Lausanne, Institut de Génie Atomique, CH-1015 Lausanne (Switzerland)

Abstract

Measurement methods using a scanning acoustic microscope are discussed. One of them, interpretation of the interference fringes, was used for measurements of the local elastic properties in an SiC–SiC composite material by studying the velocity of Rayleigh waves. Separate values were obtained for the matrix and for the fibres with good reproducibility.

1. Introduction

Most internal friction and ultrasonic attenuation measurements are performed using bulk samples. Results are spatially averaged and obtained using one mode of vibration or propagation at a time. Scanning acoustic microscopy (SAM) allows similar measurements to be made locally. This can be important when only small samples are available or when the samples are inhomogeneous. A typical application is the separate measurement of the elastic properties of the constituents of composite materials.

Studies of thin layers use the propagation of one or several modes of surface acoustic waves (SAWs). SAW dispersion can be measured as a function of the frequency. Using a numerical inversion procedure, physical properties of the thin films are obtained [1].

2. Existing measurement methods using SAM

2.1. $V(z)$ curves

An acoustic lens is placed near the studied surface. Acoustic waves are coupled to the specimen using a droplet of liquid (usually water). Several acoustic paths exist; two of them are important: (i) direct reflection and (ii) the path of the wave which hits the surface under the SAW critical angle. The latter path excites leaky SAWs, which means that the propagating SAWs leak energy into the coupling fluid. These waves reach the lens' transducer. Now the lens is moved towards the specimen. Since the two acoustic paths do not change in the same way, the waves interfere, resulting in a characteristic curve: transducer voltage V as a function of the distance z between the sample and the lens (the $V(z)$ curve). From the periodicity of the $V(z)$ curve, SAW velocities can be obtained with a typical accuracy of 1%. To push this method to the limits, a cylindrical lens and sophisticated signal processing must be used. Then the reproducibility may reach 10^{-5}; however, absolute values are less precise [2]. The spatial resolution in typical set-ups is of the order of 500 μm and comes from the fact that the lens must be defocussed during the measurements. The attenuation of the leaky SAW is difficult to obtain and unreliable, since the SAW attenuation results mainly from the reradiation into the coupling fluid (leak) and only a small fraction is related to the attenuation of the material.

2.2. Microdefocussing

This method [3] is similar to the classical $V(z)$ approach. The main difference is that, instead of measurements of the whole $V(z)$ curve, gradients of the components' waves are measured. In principle only a small displacement of the lens is needed (of the order of the wavelength in water). This is an advantage, since it allows one to remain close to the focal plane, ensuring a good spatial resolution. The accuracy of the measurements was not reported [3].

2.3. Short-pulse measurements

Using wide-bandwidth transducers it is possible to separate in the time domain acoustic pulses coming from points lying close in space, *i.e.* from both sides of thin films. Such measurements [4] can be performed using an acoustic lens. Usually, the plane-wave approximation is used, which lowers the accuracy of the measurements.

2.4. Acoustic image interpretation as a measurement method

Acoustic images often exhibit interference fringes coming from different sources. In composite materials

0925-8388/94/$07.00
SSDI 0925-8388(93)00073-8

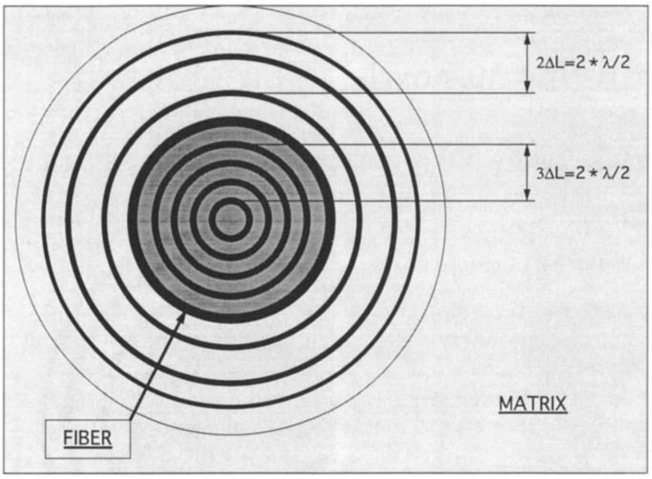

Fig. 1. The principle used for Rayleigh wavelength measurements. The region near the interface was omitted in the measurements owing to the smoothness of changes in periodicity of the fringes.

longitudinal wave fringes are observed if reflectors such as fibres are not perpendicular to the surface of the specimen [5]. Spherical reflectors appear encircled by the interference fringes with unequal spacing. A simple model was proposed in ref. 6. From the fringe spacing the longitudinal wavelength can be calculated with a reasonably good reproducibility – a few per cent.

SAWs are reflected from surface cracks and inhomogeneities forming SAW fringes. If the reflectors are perpendicular to the sample surface the distance between consecutive fringes is constant and equal to one-half of the SAW wavelength. A more general treatment was described in ref. 7. We used SAW fringes in the fibres and in the matrix for characterizing the composites. The method used is explained in Fig. 1.

3. Study of a fibre-reinforced ceramic composite

We observed SiC–SiC composite material samples using a commercial Leica scanning acoustic microscope. The frequency range was between 0.8 and 1.9 GHz and the best results were obtained around 1.3 GHz. Samples were cut perpendicularly to the fibre axis and polished using a standard metallographic procedure, down to 0.5 μm. A typical acoustic micrograph is presented in Fig. 2. Interference fringes with a strong contrast can be distinguished. Two potential problems may be encountered: (i) overlap of the fringe families and (ii) invisible fibre–matrix interfaces. The first problem can be avoided by choosing the region where the distance between fibres is great enough. The second problem may be solved by making the measurements of the fringe spacing sufficiently far from the interface – for this the knowledge of the nominal fibre diameter is helpful. The observed contrast may be simulated, taking into account the reflection and transmission coefficients of the interface [8].

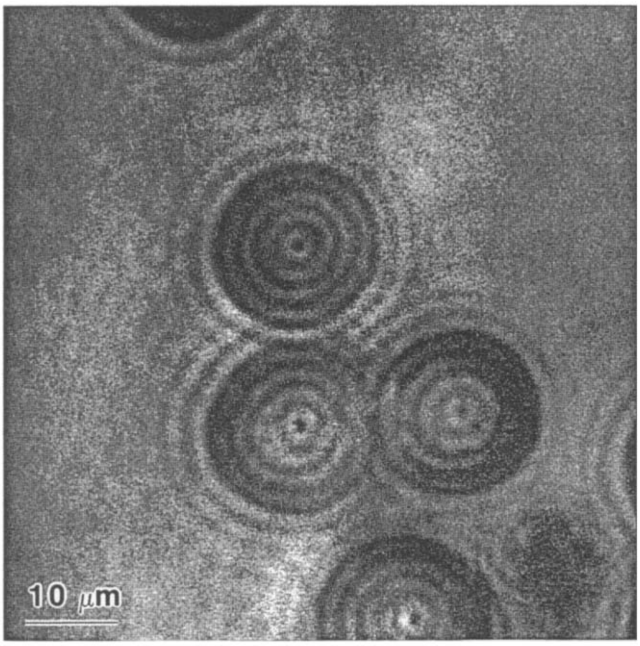

Fig. 2. A typical acoustic micrograph of the SiC–SiC composite sample. Rayleigh SAW fringes are visible around the fibres. From their spacing the Rayleigh wave velocity was calculated separately in the fibres and in the matrix.

The results obtained near 14 different fibres were as follows: Rayleigh wave velocity in the fibres, 4909 ± 148 m s^{-1}; Rayleigh wave velocity in the matrix, 4848 ± 486 m s^{-1}.

Owing to the high attenuation in the matrix, no data are available for longitudinal waves (*i.e.* for a sample cut at 45° with respect to the fibre axis).

4. Discussion

The Rayleigh wave velocity values obtained for this composite are difficult to compare with the literature values owing to the lack of data for materials produced using a similar technology. Nevertheless, measurements in the fibres are very reproducible (±3%), while those in the matrix are slightly worse (±10%), probably owing to the higher attenuation and lower homogeneity of the matrix. Both velocities are reasonable for ceramics.

5. Conclusions

A scanning acoustic microscope allows localized measurements of the Rayleigh wave velocity to be performed in composite materials, separately in the matrix and fibres. Such measurements are feasible even in fibres with a diameter of 10 μm. The knowledge of the local elastic properties of the constituents after processing is crucial for the design of the composites. Simultaneously this method offers structural characterization of the samples using the same acoustic images.

References

1 P. Richard, A. Kulik, G. Gremaud and O. Behrend, this conference.

2 J. Kushibiki and N. Chubachi, Material characterisation by line-focus-beam acoustic microscope, *IEEE Trans. Sonics Ultrason., 32* (1985) 189.

3 N. Chubachi, H. Kanai, T. Sannomiya and T. Wakahara, Acoustic microscope for measuring acoustic properties by micro-defocusing method, in H. Ermert and H.P. Harjes (eds.), *Acoustical Imaging,* Vol. 19, Plenum, New York, 1992, p. 685.

4 G. Gremaud, A. Kulik and S. Sathish, Mechanical properties of surfaces and layers measured with a continuous wave acoustic microscope, in H.E. Exner and V. Schumacher (eds.), *Advanced Materials and Processes,* Deutsche Gesellschaft für Metallkunde Informationsgesellschaft, Oberusel, 1990, p. 1421.

5 A. Kulik, G. Gremaud and S. Sathish, Acoustic microscopy as a polyvalent tool in materials science, in H.Y. Elder (ed.), *Proc. Royal Microscopical Society Conf. Micro 90,* Institute of Physics, Bristol, 1990, p. 85.

6 J.-E. Bidaux, A. Kulik and G. Gremaud, Acoustic microscopy of composite materials, in A. Allipi and A. Petri (eds.), *Acoustic Sensing and Probing,* World Science, Singapore, 1992, p. 419.

7 A. Briggs, *Acoustic Microscopy, Monographs on the Physics and Chemistry of Materials,* Vol. 47, Oxford University Press, Oxford, 1992.

8 C.W. Lawrence, Acoustic microscopy of ceramic fibre composites, *D. Phil. Thesis,* Oxford University, 1990.