Optical Measurement of Acoustic Emission at High and Low Temperatures

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Abstract
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Keywords
Nondestructive Evaluation

Disciplines
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ABSTRACT

Optical probing of acoustic displacement waveforms has a number of advantages over other methods. Among these advantages is the possibility of quantitative, local measurement of acoustic emission waveforms at high and low temperatures. This paper reports the results of some measurements on various materials as a function of temperature.

INTRODUCTION

It is often assumed that acoustic emission signatures are in some way characteristic of the emitting source (growing crack, twinning, slip, void formation, or the like). This hypothesis, reasonable as it is, has never been properly tested because the essential data do not exist.

To test the hypothesis, we need to know the characteristic signature of the various possible sources, including waveform, component wave types, and radiation pattern. We should know how this waveform changes with material, temperature, and specimen size and shape (because of resonances, reflections, and mode conversions). Further, we need to know how the waveform changes with propagation distance (and direction if the material is anisotropic). We can expect the waveform to change for several reasons:

(1) The component wave types -- dilatational, shear, and, perhaps, surface -- travel at different speeds.

(2) The spreading wave is attenuated geometrically, and the geometric factor is different for bulk and surface waves.

(3) Various loss mechanisms depend on frequency, temperature, and material.

(4) Both anisotropy and inhomogeneity will further distort the propagating wavefront.

Accurate measurement of the various waveforms to test the theory evidently requires a transducer whose sensitive area has a diameter much smaller than the shortest wavelength to be measured (for 5 MHz the Rayleigh wavelength is about 0.6 mm). The probe should be non-contact, have a broad frequency response, and be useful at both high and low temperatures. It must be amenable to absolute calibration. Optical methods satisfy these requirements, and they have the further advantage of being able to probe internally in transparent materials.

INSTRUMENTATION

The basic optical sepsor, shown in Fig. 1, has been described elsewhere.\(^1\) It is a modification of the Michelson interferometer in which the illumination is collimated laser light. Lenses are used to focus the light on the specimen, forming a sensitive area perhaps 0.01 mm diameter. The reference beam is focused on a piezoelectrically driven mirror (at the top of the diagram). Low frequency components of the photocurrent (0 - 1 kHz) are mostly caused by mechanical vibrations and atmospheric disturbances; they are amplified and used to drive the piezoelectric correction unit, so as to maintain an optical phase difference of 90° between the two beams for optimum sensitivity. The high frequency signal components are amplified and displayed or recorded. The signal amplifier bandwidth is adjusted to 5 kHz to 5 MHz. Signals are usually video taped unless the frequency response of the video tape (about 3 MHz) is too limited; then they must be recorded directly from the oscilloscope or from a digital transient recorder. Signals played back from the video tape can be filtered to remove any undesirable frequencies.

Figure 2 shows the method of mounting indium ingots used in some of the twinning experiments. The specimen (3 x 3 x 40 mm) was held between two teflon blocks to minimize clamp noises. In turn these teflon blocks were supported in a bakelite mount which permitted suitable adjustment of the position of the specimen. Measurements could be made either at the end of the specimen or at the side very close to the region where twins were generated when the ingot was bent. Probing at the side was necessarily qualitative because the generation of twins distorted the polished surface. Measurements made at the end eliminated this difficulty, but at the expense of attenuating some of the high frequency components as a result of the extra 15 mm of propagation distance through the clamped region.

The specimen temperature could be measured approximately with the thermocouple wires as shown. The No. 30 gauge wire was fine enough to minimize heat transfer to or from the specimen while permitting temperature measurements. The specimen could be heated with a specially constructed tubular oven which slid over the exposed end, or cooled by pouring liquid nitrogen over it.

In another experiment the acoustic emission during the phase change in iron at about 900°C was measured. An iron wire, about 10 cm long, was clamped between two specially designed binding posts which were mechanically insulated from the mount by teflon washers to reduce clamp noise. The wire was kept under slight tension so that it would not sag when heated by an electric current. Then about halfway along its length the wire was compressed between a flat glass plate and a steel cylinder so that it could act as a mirror.
RESULTS

Figure 3 shows the effect of temperature on the acoustic emission from the twinning of indium. The two upper waveforms, recorded at a temperature of about -190°C, show frequencies of the order of 200 kHz. The lower two waveforms, recorded at a temperature of about +100°C, show considerable attenuation of the higher frequencies. Above this temperature, few signals were seen. If the AE signals were sensed at the side of the specimen, close to the AE emission sites, the observed rise time was much faster than when observed at the end, some 15 mm distant from the sites. Figure 4 shows some rise time measurements. At the top is the rapid rise, about 0.2 μsec, observed in the stress corrosion cracking of E4340 steel within a millimeter of the crack (recorded with a transient digitizer). The two lower waveforms show rise times of about 1 μsec in the indium at a temperature of -190°C, also within a millimeter of the twin generation.

Figure 5 shows some characteristic twin signals in indium sensed at the polished end of the specimen (left side of figure) and from a phase change in iron wire at about 900°C (right side). In both sets of waveforms the sweep speed was 20 μsec/div as indicated. The upper two waveforms of each set are almost indistinguishable, and the ones below are recognizably similar in general form. As we have seen above, the high frequency component content of the indium waveforms will be less than when observed at the side, but the signature is still recognizable. As reference 2 shows, the emission from twinning in different metals such as indium, tin, zinc, and cadmium is very similar, though there may be subtle differences.

Experiments have also been done on the duration of the acoustic emission bursts, but the results are not conclusive because it is difficult to sort out the primary characteristic signatures from reflected waves.

CONCLUSION

The experiments reported here are only preliminary, but they clearly demonstrate the power of optical probing methods. (A greatly improved instrument is now under construction.)

Provisionally, we conclude that the hypothesis under consideration, that acoustic emission signatures are characteristic of sources, is at least partially valid. There appears to be a distinctly different signature for twinning and for a phase change in iron. Differences in other kinds of signatures is not so evident, though there may be more subtle distinctions. The frequency spectrum may, perhaps, reveal some differences, but this is not certain. Frequency spectra of events measured far from the source do not seem to be repeatable from event to event.

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REFERENCES

Fig. 3. Effect of temperature on twin signals in indium. Traces A and B: temperature -190°C, gain 500 mVolts/Div. Traces C and D: Temperature +100°C, Gain 200 m Volts/div.

Fig. 4. Rise time measurements. Trace A: Stress corrosion cracking in E4340 steel (note sweep indication). Traces B and C: twinning in indium, temperature -190°C. All measurements within 1 mm of AE source.
Fig. 5. Characteristic acoustic emission signals. Left: Indium twinning measured at the specimen end. Temperature 20°C. Right: Phase change in iron wire, temperature about 900°C.