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Procedia Materials Science 1 (2012) 266 – 272

Procedia Materials Science

www.elsevier.com/locate/procedia

11th International Congress on Metallurgy & Materials SAM/CONAMET 2011.

Characterization of a crack by the acoustic emission signal generated during propagation

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Abstract

Acoustic Emission (AE) generates at different space and time scales ranging from the rupture of atomic bonds to seismic failure. Seismic and AE information are complementary concerning their application and their theoretical grounds. Following previous work we simulate the AE generated at a crack propagating in a bulk material by means of a model coming from Geophysics. The duration, the rise time and the relative amplitude of the AE burst are estimated with the model, and they are related to characteristics of the source. The crack length is estimated by means of the Fourier spectrum of the signal. The objective of the present paper was to apply the model to laboratory fragile samples in order to verify its validity at very different scales. The selected fragile material was methyl methacrylate because the length of fractures could be obtained with high precision. Different tests were performed varying the applied tensile stress. Experimental and modeled AE spectra due to fracture were quite similar. Modeled and measured crack length values were of the same order of magnitude.

Keywords: acoustic emission, crack, modeling, methyl methacrylate.

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2211-8128 © 2012 Published by Elsevier Ltd. Selection and/or peer-review under responsibility of SAM/CONAMET 2011, Rosario, Argentina. Open access under CC BY-NC-ND license. doi:10.1016/j.mspro.2012.06.036

1. Introduction

Acoustic Emission (AE) is constituted by phenomena that release mechanical energy that propagates as elastic waves in materials submitted to external load. AE sources are originated in the sudden change in the stress-strain field in the material and are related to deformation processes, crack growth, dislocation movement, inclusion rupture, etc. (Pollock, 1989). AE generates at different space and time scales ranging from the rupture of atomic bonds to seismic failure. This is the reason why seismic information and AE are both related and complementary since very different scales are involved as was shown by Paparo et al., 2002 and Ruzzante et al., 2008.

In our previous work (Filipussi et al., 2007-2009) AE originated in a propagating crack was simulated after calculating the far field of the crack with a model coming from Geophysics referred by Aki, 1980; Backus et al.,1976; Kasahara, 1981.

The objective of our work is to test if the model used in Geophysics for very long failures in structures formed by fragile rocks is suitable for other fragile materials as acrylic and at very different scales (laboratory samples).

Duration, rise time and relative amplitude of the burst were estimated with the model and related to characteristics of the source. The crack length was determined by the signal Fourier spectrum and is given by Eq. (1),

$$\left|\hat{u}(\omega)\right| = \frac{U_0 A}{\sqrt{1+\omega^2 T^2}} \left|\frac{sen(\tau_0 \omega / 2)}{\tau_0 \omega / 2}\right| \tag{1}$$

where $\hat{u}(\omega)$ is the Fourier transform of the displacement field $u(r)$; U_0 is the maximum value of the displacement discontinuity at the crack; A is the crack area; T is the time needed to achieve a $0.63\,U_0$ displacement discontinuity at the crack and τ_0 is the rise time of the signal.

Within the features of the spectrum obtained with the model we could observe that it was flat at low frequencies and then, at high frequencies, it decreased according to an inverse square law. The frequency value at which both behaviors meet is called *corner frequency* (Savage, 1972), it corresponds to a local maximum, and it is inversely proportional to the crack length as given by Eq. (2). The signal rise time is also related to the crack length as given by Eq. (3).

$$L = v / 2\pi(1-\eta\cos\theta) f_c \tag{2}$$

$$\tau_0 = L(1-\eta\cos\theta)/v \tag{3}$$

where L is the crack length; $\eta = v/c$ is the ratio between the crack advancement velocity (v) and the sound velocity (c) in the material medium (η is nearly 1 in a fragile material); θ is the detection angle with respect to the crack advancement direction and f_c is the corner frequency.

In the present paper AE results of the model were compared with those obtained experimentally in tensile tests that generate and produce the advancement of cracks (Mejías and De Vedia, 1987).

2. Experimental Procedure

Tensile tests were performed on 10 methyl methacrylate specimens obtained by cell casting, with a 72 MPa tensile strength. Specimens were flat plates with a hole that permitted the advance of the conic tool pulled by an industrial test machine Shimadzu AG with a 100 kN maximum load. Specimens were weakened by means of introducing a longitudinal groove in order to enhance the material fracture. A wedge opening enhanced the concentration of stresses at the groove ending.

Two piezoelectric sensors were located on the specimen to detect AE signals; one with a resonant response at 150 kHz and the other one was a 100 kHz - 1 MHz wide band sensor. The test machine and the experimental set up with sensor locations are shown in Figures 1, 2. Specimen and tensile tool are shown in Figure 3.

Fig. 1. Industrial Test Machine Shimadzu AG.

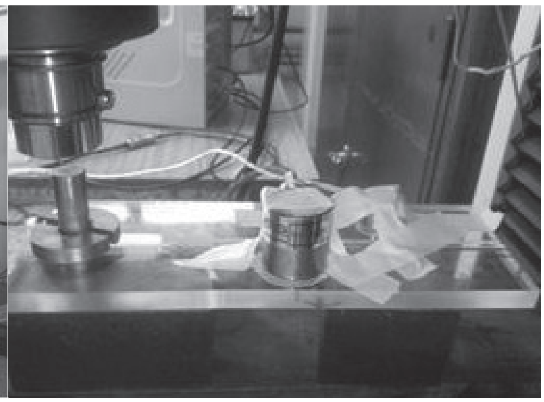

Fig. 2. Experimental set-up: specimen, tensile tool and sensors.

The elastic waves generated at the crack during the tool movement propagate in the material, reach the specimen surface and are detected by the sensors that convert the mechanical vibration to an electrical signal for the ulterior processing and analysis.

The AE equipment was the dedicated PCI-2 Based AE System in PC and the data processing and analysis was performed with the AEWIN software. The data acquisition board had two channels, one for the sensor and the other one for the waveform record, amplitude of the AE signals in volts vs. time. Moreover, an external channel was to acquire the load.

The duration of each test varied between 12 min and 5 min, when the tool velocity varied respectively between a 0.75 mm/min and 3 mm/min. The maximum load values at the fracture varied in these cases between 1022 kN and 1217 kN.

3. Results and Discussion

The crack was always initiated at the previously designed weakened point. Due to geometrical reasons, the crack path departed from a straight line and in some of the tests it reached the border of the specimen. For tool velocity values ranging between 0.25mm/min and 3 mm/min the crack was arrested at some point and in these cases the total crack length could be calculated. In this sense, the most convenient tool velocity was 1.5 mm/min.

The AE signal analysis consisted in evaluating the burst parameters (duration, rise time and relative amplitude) corresponding to the crack advancement. The total number of registered bursts was in general around 60; 80 % of them arrived at channel 1 corresponding to the resonant sensor, which was closer to the crack initiation point.

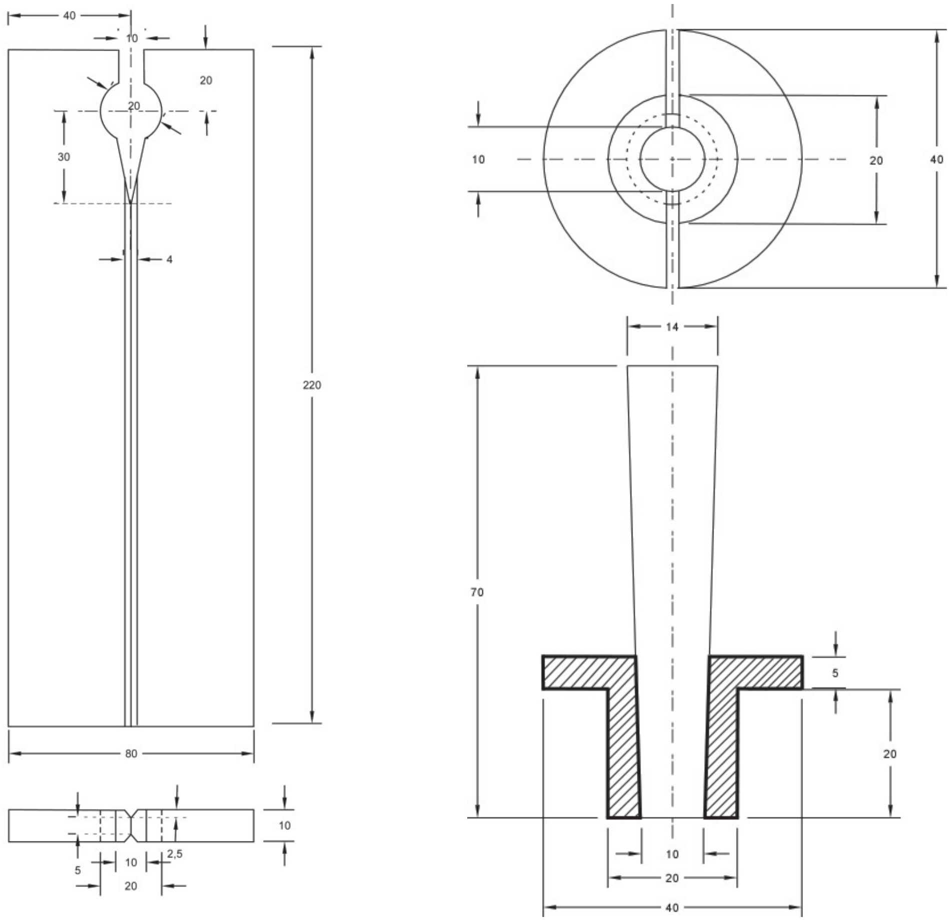

Fig. 3. Specimen and tensile tool.

The parameters took the highest values for these bursts. Load increased as the tool advanced up to a maximum value, after which it abruptly decreased. This was taken as the indicator of the material fracture, and the immediately anteceding bursts were identified as those generated by crack advance. Table 1 shows burst parameters reaching maximum values measured according to the burst (A: amplitude; D: duration; RT: rise time; RMS: root mean square; E: energy and C: load) for three specimens. The underlined values correspond to crack originated bursts. Figure 4 displays graphs that show the evolution of normalized parameters and load for specimen 1. Fourier analysis was applied to the burst clearly assigned to crack propagation as previously described and after filtering out the noise. Figure 5 compares experimentally obtained Fourier spectra with those obtained by modeling referred Filipussi et al., 2007-2009.

The crack length could be properly related to the frequency corner explained in Filipussi et al., 2007. As an example a frequency corner of (160±10) kHz corresponds to a length of (3±0.5) cm and the measured value was coincident within the error interval.

Table 1. AE parameter values for the first three specimens. Chosen values are underlined

Specimen	Burst	AE maximum parameter
1	31	C
1	32	A
1	33	RT
1	34	D, E, RMS
1	35, 36	RMS
2	59	A
2	60	C
2	61	D, E, RMS;RT
2	64, 65	RMS
2	67, 68	RMS
3	35	C
3	43	D, E, RMS, RT, A
3	44	A

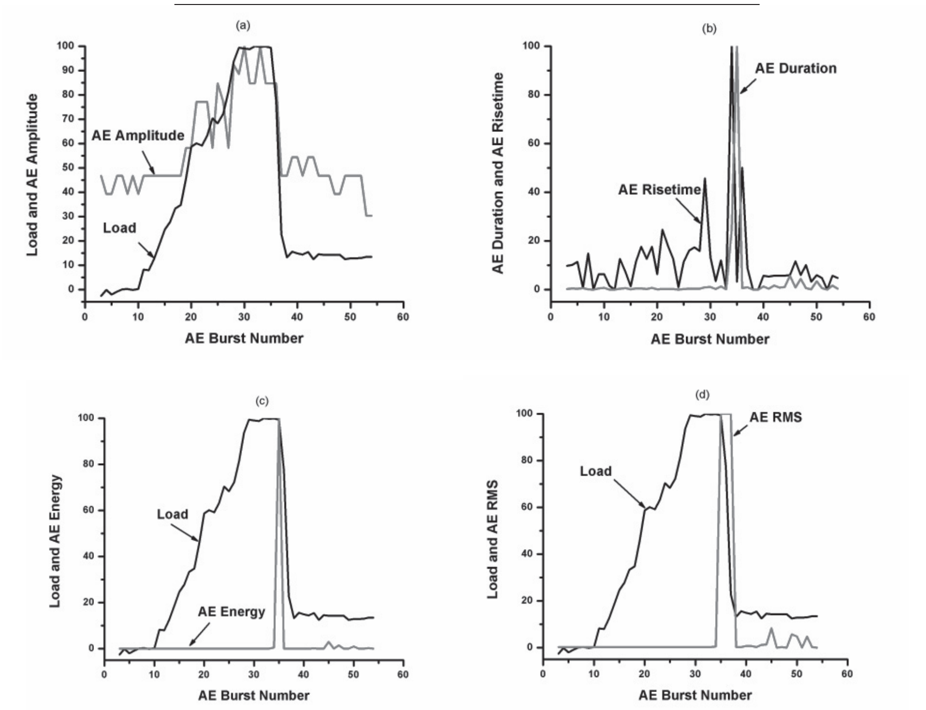

Fig. 4. Load and AE parameters vs. index of AE burst for specimen 1, (a) amplitude, (b) risetime, (c) energy, (d) RMS.

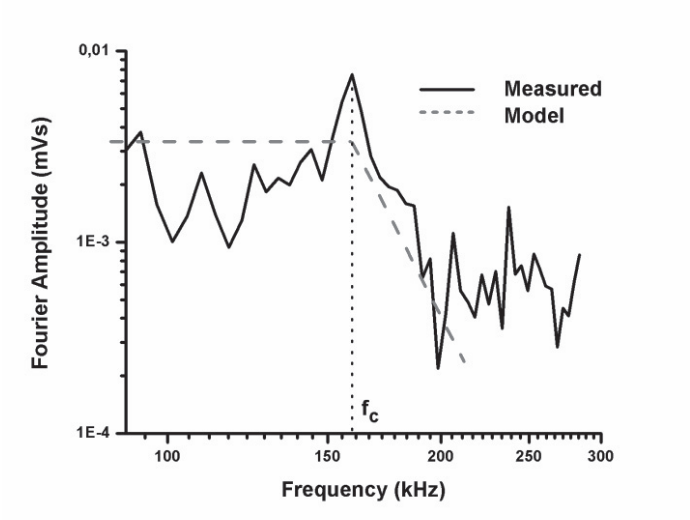

Fig. 5. Theoretical and experimental amplitude Fourier spectra, log-log graphs, specimen 1.

Figure 6 shows the agreement between the model and the experiment, since the modeled and the measured fracture length values are of the same order of magnitude.

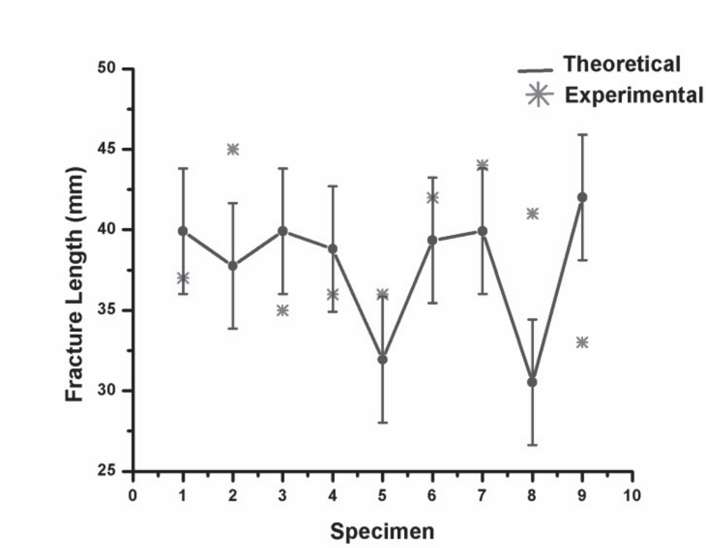

Fig. 6. Theoretical (solid line) and experimental (points) fracture length for each specimen.

4. Conclusions

It could be concluded that: (a) The AE energy and RMS values allow to identify those bursts that correspond to the rupture of the test specimen. (b) The spectrum of the AE burst assigned to cracking compares well with the spectrum predicted by the model. (c) The measured rise time of the AE burst assigned to cracking assumes the expected value as determined by the length-rise time relationship given by the model. (d) In the cases in which the length could be properly measured it compared well with the length obtained with the corner frequency.

The qualitative correspondence between the real spectrum of bursts that characterize a fracture and those proposed by the model in previous work (Filipussi et al., 2007-2009) allows concluding that the fracture model, taken form Geophysics, and proposed by us to be applied in AE, in the cm scale, is still valid.

The load and AE amplitude waveforms are similar. The rise time evolution presents oscillations during the loading process and then it shows a peak when fracture occurs. The duration and rise time evolutions show the same trend, but in the case of duration there are not oscillations. Both the energy and the RMS reached maximum values at fracture. After fracture, energy falls abruptly down, together with the load. RMS remains constant while the load decreases.

Various AE parameters assume maximum values at fracture, which is explained by the high energy release occurring when breaking occurs.

Acknowledgements

Part of this work was possible with the support of the *Agencia de Promoción Científica y Tecnológica*, Argentina, PICT 2007/01769, Cat III, IDAC-ICES: “Emisión Acústica y Precursores Sísmicos”.

Special thanks to Eng. Luis De Vedia for his valuable suggestions concerning Fracture Mechanics.

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