Available online at www.sciencedirect.com
SCIENCE DIRECT®

Cement & Concrete Composites 28 (2006) 330–336

Cement & Concrete Composites

www.elsevier.com/locate/cemconcomp

Quantitative evaluation of fracture processes in concrete using signal-based acoustic emission techniques

Christian U. Grosse [a,b,*], Florian Finck [b,1]

[a] *Department of Civil and Environmental Engineering, University of California, 455 Davis Hall, Berkeley, CA 94720–1710, USA*
[b] *Institute of Construction Materials, University of Stuttgart, Pfaffenwaldring 4, 70550 Stuttgart, Germany*

Available online 30 March 2006

Abstract

Acoustic emission (AE) techniques can be used for the investigation of local damage in materials. Compared to other observation techniques one advantage is the recording of the damage process during the entire load history without any disturbance to the specimen. This is somehow unique and permits for high-resolution studies of the time-dependent failure of materials including precise determinations of the beginning of fractures and their consecutive progression. There are only a few other experimental techniques in fracture mechanics allowing for similar detailed observations of materials' time and spatial behaviour. Moreover, these techniques allow a calibration of experiment and simulation comparing for example the output of finite element modelling with AE data analysis. This paper deals with some experimental results obtained during fracture mechanical experiments at concrete specimens demonstrating the capabilities of quantitative AE techniques.

Keywords: Civil engineering; Non-destructive testing; Acoustic emission; Moment tensor; Localization; Fracture mechanics

1. Introduction

Acoustic emission techniques are usually disposed among the non-destructive testing methods since they allow passively the observation of crack growth or internal defects. However, there are fundamental differences between diverse ways to apply AE techniques due to historical developments in electronics and sensor technologies. *Quantitative* or *signal-based* acoustic emission techniques [1] differ generally from so-called *classical* or *parameter-based* AE techniques, where only parameters are recorded and not the signal itself is stored. Signal-based techniques allow for detailed fracture mechanical evaluations of brittle materials like concrete, if a proper setup and adequate instruments are chosen. Since these differences between the traditional parameter-based and newer signal-based techniques are described earlier [2,3] we will focus to recent results in the following.

There are four different steps of a modern AE analysis consisting of (1) the analysis of mechanical data and the acoustic emission rate, (2) the localization of acoustic emissions, (3) the evaluation of the topography of the fracture plane, and (4) fracture mechanical studies based on moment tensors. Here, advances of the techniques addressed under (2)–(4) are described in more detail along with some examples of measurements to study different failure modes in concrete.

2. AE techniques and localization of fractures

AE is defined as the spontaneous release of localized strain energy in a stressed material resulting, for example, from micro-cracking and can be recorded by transducers (sensors) on the surface in analogue to earthquake recording. One of the advantages compared to other NDE techniques is the possibility to observe the time-dependent

* Corresponding author. Address: Department of Civil and Environmental Engineering, University of California, 455 Davis Hall, Berkeley, CA 94720-1710, USA. Fax: +1 510 643 5264, +49 1805 233633 66866.
E-mail address: grosse@berkeley.edu (C.U. Grosse).
[1] Now at company Behr GmbH & Co. KG, Stuttgart, Germany.

0958-9465/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cemconcomp.2006.02.006

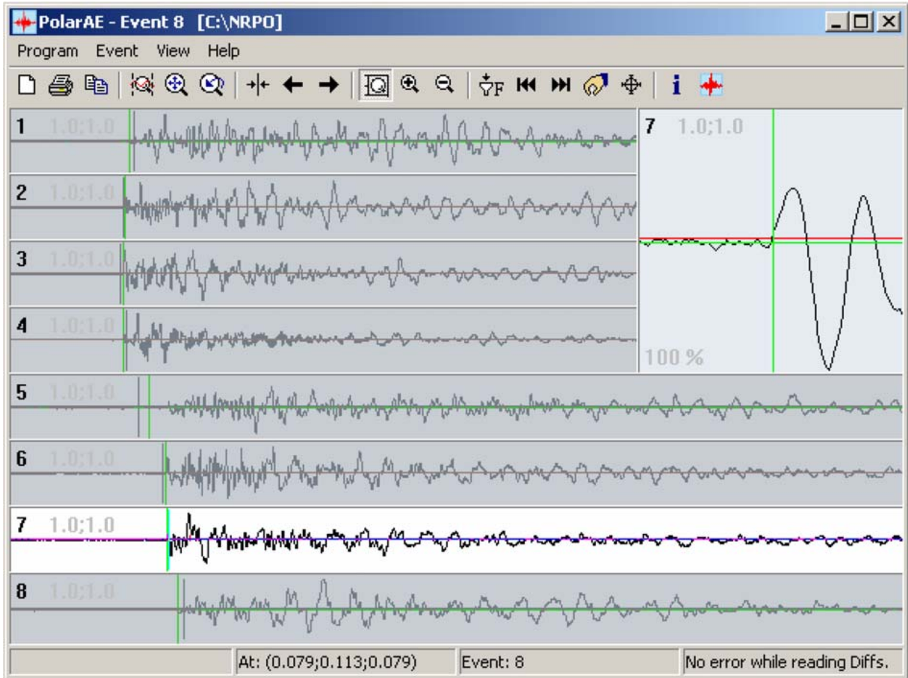

Fig. 1. Example of the arrival time extraction for the 3D localization of acoustic emissions using the *Polar*^{AE} software developed at the University of Stuttgart [21].

damage process during the entire load history. To do so, the application of signal-based methods requires reliable localization, i.e. the determination of the source coordinates of the events. There are several different ways to localize AE events [3–5], whereas the algorithms, using the arrival times of the waves recorded at multiple sensors, are in use since many years. Picking a distinct onset time of a signal at different sensors according to the example shown in Fig. 1, one can calculate the minimum of the sum of squares of the deviations and calculate the source coordinates usually with proper accuracy [6,7]. Besides of these basic techniques two main issues had to be handled prior to the application of signal-based techniques – one concerning the data evaluation and the other concerning hardware requirements.

2.1. Automatic onset time determination

Damage and failure processes often generate several thousand events from one damage zone within a very short time interval, revealing a huge amount of data. With *parameter-based* AE techniques a fast but only rudimentary analysis can be performed even on-line. Concerning the analysis of *signal-based* AE data usually needs the interpretation by an expert manually processing the data including a time consuming picking of the signal onsets by hand. Although for very large data sets this is not applicable. Therefore, the application of automatic analysis methods, including data conversion, denoising, and localization by the use of an automatic onset determination, moment tensor inversion and other features like *b*-value determination or the use of magnitude-squared coherence functions, is indispensable. Regarding the onset time picking the technique presented by Kurz et al. [8] based on the *Akaike information criterion* (AIC) is therefore a significant step forward for the application of the described techniques. It produces reliable results for signal onsets, where the deviation compared to the manual picks varies between 2% and 4%. Usually, the localization of only the 10% of the events results in a mislocation vector greater than 5 mm.

2.2. Fast transient recorder

The acquisition of acoustic emission data requires transient recorder hardware, which is able to make A/D-conversion with a high resolution and simultaneously guarantees fast storage of signals. Conventional transient recorders have a limited performance (rate of signals per second) due to signal storing, which causes gaps in the data recording. Furthermore, a simple threshold trigger, which is standard in commercial recorders, is not able to identify acoustic emissions when the signal to noise ratio is poor. Therefore, the gradient of the signal is a much better indicator using a *slew rate* trigger. This motivated the development of an own transient recorder system. The new system enables continuous recording with up to eight channels, a sampling frequency of 1.25 MHz (up to 5 MHz) and an amplitude resolution of about 12 bit. One improvement is the absolute continuous recording, i.e. all acoustic emissions are recorded without any loss. Recordings are only limited by the hard disk capacity, where the continuous