Acoustic Emission Measurement of Concrete Under High Loading Rates

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OBJECTIVE

It is known since a long time that several material parameters such as strength or modulus of elasticity are increasing under high rates of loading (Abrams, 1917), (Körmeling/Zielinski/Reinhardt, 1980). One of the physical reasons is identified as a changing of the internal stress distribution in front of microcracks and - as a result of it - a time delay of crack initiation and crack growth. This effect has been shown theoretically using the Finite Element Method by the authors (Curbach, 1987), (Eibl/Curbach, 1987).

To verify this theory a number of experiments have been carried out using the method of acoustic emission. By means of this wellknown method several materials have been investigated with great success. Since a few years it has also been extended to concrete to show a connection between internal damage and the applied load level. Summaries about application to concrete have been given by (Maliszkiewicz, 1987), (Diederichs/Schneider/Terrien, 1983) and (Weigler/Klausen, 1979).

METHOD

Acoustic Emission means waves generated by the release of energy internally stored in a structure (Licht, 1979). A crack e.g. results in creation of new surfaces so that strain energy is released which is partly transformed to an "acoustic" signal. Using a transducer mounted on the surface of the test specimen the signal can be registered and stored. One

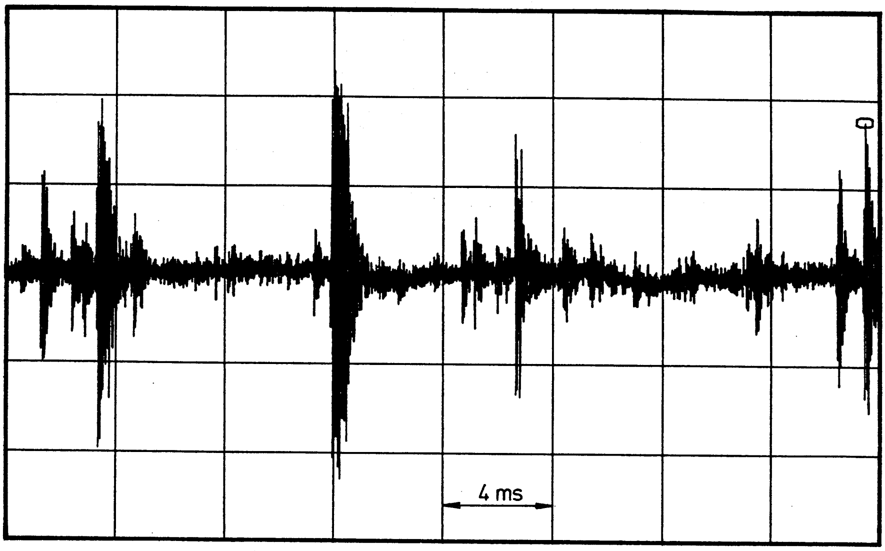

Fig. 1 Acoustic emission versus time; detail with duration of 32 ms

example of such an acoustic signal is shown in Fig. 1. Several bursts are visible which are typical for the development of microcracks and cracks in concrete.

Several possibilities exist to analyse such an acoustic signal. The most important are:

- counting the acoustic emission signals which exceed a fixed threshold level (a),
- counting the number of bursts which consist of several signals with decreasing amplitude (b),
- counting the acoustic emission energy which is assumed to be proportional to the area under the acoustic emission vs. time curve (c).

One typical diagram for results obtained with acoustic emission analysis is given in Fig. 2 in which the relative acoustic emission signals (a), (b) and (c) are related to the stress. It can be seen from the curves — which are nearly identical — that about 70 % of acoustic emission appear during the last 15 % of loading near failure.

To verify the theory of time delay in crack initiation and propagation under dynamic loading (Curbach, 1987), (Eibl/Curbach, 1987) the following test series with 51 concrete cylinders of 0.10 m diameter and 0.30 m height have been carried out. Four different loading rates have been applied using a hydraulic machine:

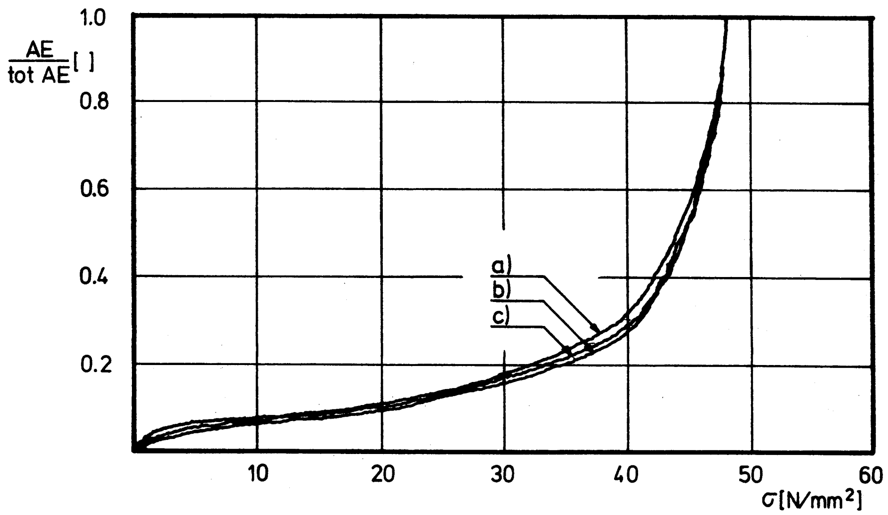

Fig. 2 Acoustic emission versus Stress from one typical experiment

$$\begin{aligned} \dot{\varepsilon}_1 &= 1.7 \cdot 10^{-5}\ 1/s \\ \dot{\varepsilon}_2 &= 1.7 \cdot 10^{-4}\ 1/s \\ \dot{\varepsilon}_3 &= 1.7 \cdot 10^{-3}\ 1/s \\ \dot{\varepsilon}_4 &\sim 1.0 \cdot 10^{-1}\ 1/s \end{aligned}$$

The three test with the lowest strain rates $\dot{\varepsilon}_1$, $\dot{\varepsilon}_2$ and $\dot{\varepsilon}_3$ have been analysed in traditional way using AE analyser.

The original acoustic emission signal for all strain rates was stored in analog way on a magnetic tape and in digital form also for strain rate $\dot{\varepsilon}_4$ using a transient recorder. According signals for strain rate $\dot{\varepsilon}_4$ as load, displacement, longitudinal and lateral strains were stored in the transient recorder.

Due to impact loading the surface of the specimens receives high accelerations in the magnitude up to 2000g which makes it necessary to protect the transducer. Therefore a so-called wave-guide (see Fig. 3) which carries acoustic waves in longitudinal direction to the transducer but which is weak in lateral direction was installed. To avoid losses due to wave reflections this wave guide was made of aluminium with an acoustic impedance of about $\rho c = 17.0 \cdot 10^6\ Ns/m^3$. The acoustic impedance of the used concrete was about $\rho c = 8.65 \cdot 10^6\ Ns/m^3$.

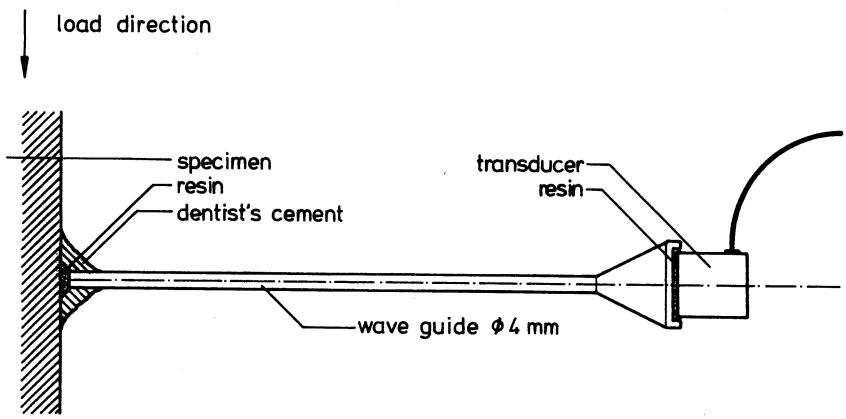

Fig. 3 Wave-guide to avoid damage of transducer due to impact loading

RESULTS

The main object of the tests was a relation between concrete strength due to varying strain rates and the crack propagation resp. inner damage which is measured by acoustic emission.

To give an impression of the strength increase due to strain rates in our tests in the intervall

$$1.7 \cdot 10^{-5} \leq \dot{\varepsilon} \leq 1.0 \cdot 10^{-1}\ 1/s$$

in Fig. 4 relative strength vs. strain rate is shown. The results correspond very well with values taken from literature (Körmeling/Zielinski/Reinhardt, 1980).

In Fig. 5 the original acoustic emission signal the simultaneously measured stress of one test with $\dot{\varepsilon} \sim 1.0 \cdot 10^{-1}\ 1/s$ is given as an example. Results like this have been obtained also from other tests.

Without anticipation of a detailed analysis of the results following can be stated: The failure of concrete takes place in a very short time so that the characteristic bursts (see Fig. 1) cannot be identified as single bursts. Due to superposition of several bursts the AE signal shows an increasing black area with increasing stress.

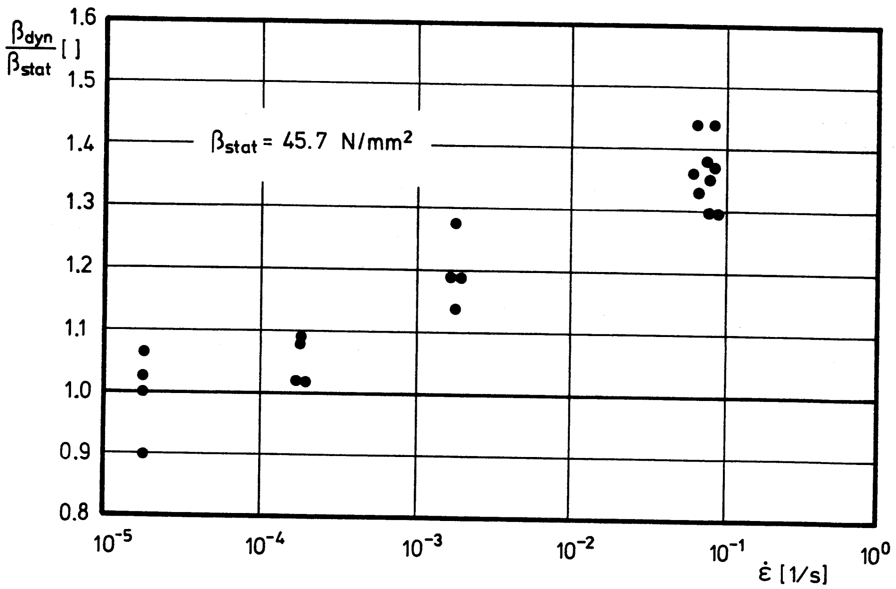

Fig. 4 Relative strength vs. strain rate

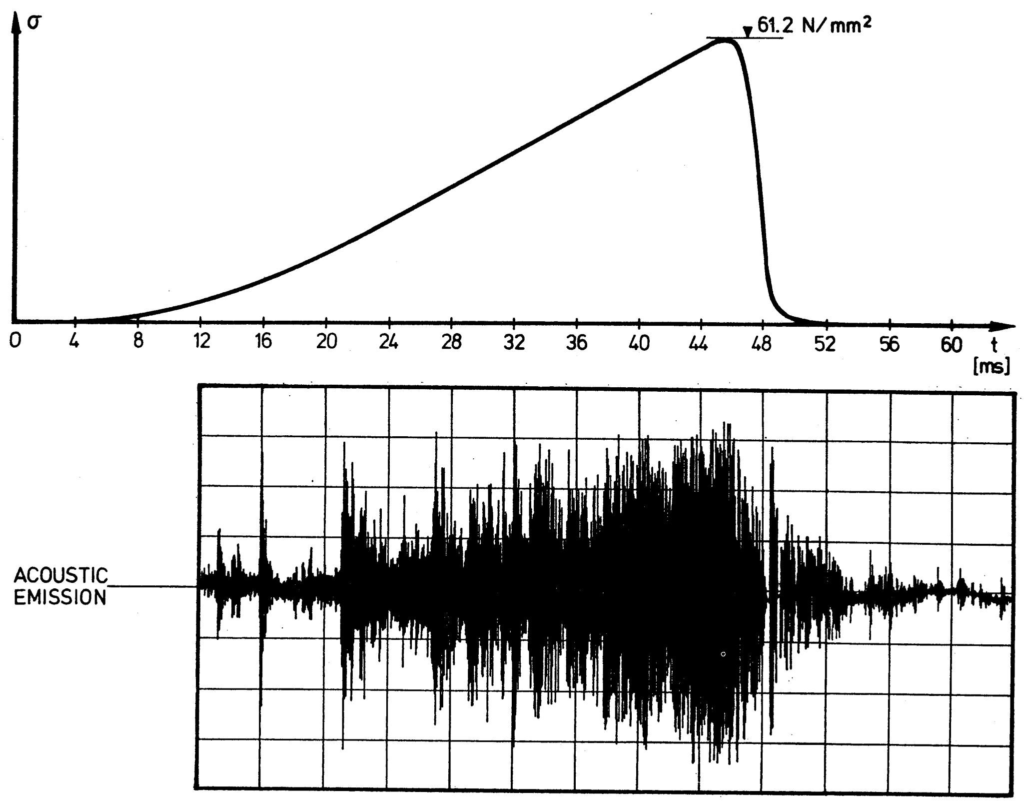

Fig. 5 Stress vs. time and corresponding original acoustic emission signal vs. time

CONCLUSIONS

The application of acoustic emission analysis to high loading rates has been demonstrated. New methods of measuring and recording the acoustic emission signal are necessary to obtain results which can be analysed. Application of a wave-guide avoids damage of the transducer, transient recorder and magnetic tape store the original acoustic emission signal so that AE analysis can be done after the test using a computer. While the herein mentioned experiments have shown general applicability additional tests are necessary to obtain more results especially with higher strain rates due to impact which will be carried out in the future.

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