Methods and Limitations of Source-Localization in Concrete Specimens under Tunnel Fire Exposure

Ronald RICHTER *, Michael JUKNAT **, Manuel RAITH *, Benjamin PORTNER *, Jörg SCHMIDT **, Frank DEHN **, Christian U. GROSSE *
* Technische Universität München Centrum Baustoffe und Materialprüfung (cbm), München, Germany
** MFPA Leipzig GmbH, Leipzig, Germany

Abstract. In most cases acoustic emission techniques are applied to specimen with a homogeneous ultrasonic velocity. In these cases the calculation of 3D source coordinates result usually in accurate values. If the material exhibits anisotropic wave properties, localization becomes more complicated. In the case of concrete under fire exposure, material properties are not time in-variant but rapidly changing during the experiment. Another problem for the localization is the influence of the time-dependent evolution of the damage process. Different algorithms can be used for calculations to solve these difficulties. Furthermore it is important to get information about the localization accuracy. Results of experimental investigations using artificial emission sources for calibration will be presented.

Introduction

Concrete is a noncombustible material. But when it is exposed to high temperature (fire) there is a strong degradation of mechanical properties. In Case of high performance concrete, it shows unfavorable behavior i.e., explosive spalling of the concrete cover. To understand the damage processes, more investigations are considered. But fire tests are difficult and expensive. So it is important to get as much information out of an experiment as possible. In several experiments the behavior of concrete specimen that were exposed to fire was monitored by acoustic emission techniques. Damage processes in concrete can be observed during the entire fire history including the localization and characterization of micro-cracking before failure.

For the practical use of acoustic emission analysis, some boundary conditions must be considered. It is necessary to choose suitable sensor-types, the coupling of the sensors to the surface, the sensor-arrangement and the setup of preamplifiers, hardware filter and transient recorders. Furthermore difficulties because of noise, for example generated by the oil-burners should be considered. So it is important to investigate the possibilities and the limitations for every special application. In this paper, different points for an application of acoustic emission analysis to monitor concrete under fire exposure will be discussed.

1. Experimental setup

The experiments took place in the oil-burner-furnaces at the MFPA Leipzig. The furnaces can be controlled after different temperature curves. The research project included an experimental program with different concrete mixtures, temperature curves and observations of other influences like humidity or compressive stress. In every experiment we used specimen with a size of 70x85x30 cm^3 [Pic. 1].

Pic 1: Specimen on top of the furnace with the connected measurement systems (left) Different types of sensors (middle) and their application on the surface of the specimen (right).

For the application of the acoustic emission analysis at least one side of the specimen surface must be accessible [Pic. 1]. The working temperature of the most AE-sensors is specified at about 60°C. Coaxial cables usually have no temperature protection. These difficulties can be solved by the use of an experimental setup with a fire exposure from one side. On the other side, the sensors can be installed. The time, the temperature needs to go through the concrete can be used for the measurement. At a critical surface temperature the sensors must be removed.

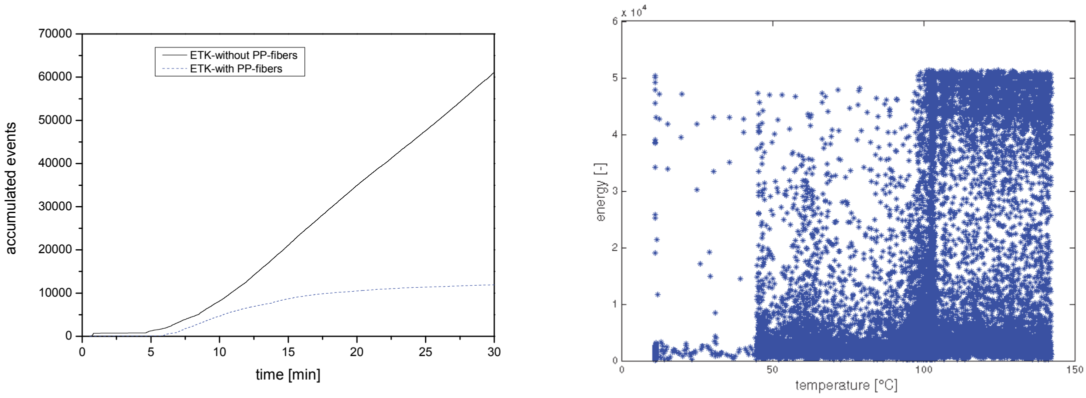
After some investigations of coupling methods, hot glue seems to be the best feasibility to install the sensors. The preparation is very fast, the sensors need no other bracket, the signal transmission is very good and it is easy to remove the sensors if necessary. The sensors should be arranged over the whole surface, to get a senor distribution as evenly as possible. To prevent geometrical effects concerning localization, an unsymmetrical sensor distribution is required. Different types of sensors have been tested [Pic. 1]. For a signal based acoustic emission analysis it is important to use broadband sensors in the right frequency range of AE events in concrete. Furthermore, the sensors have to be easy and fast installed and must be rugged enough.

Pre-amplifiers are in use to increase the signal amplitude. This is very important to detect low signals and to resolve for example micro-cracking-effects. The amplitude of signals due to spalling effect is bigger. So for every application a suitable measurement setup must be determined. To avoid problems with the data-collection because of noise, the analog signals should be filtered. The measurement system records on 16 Channels with a sampling rate of 1 MHz, which is sufficient to sample the important frequency ranges of AE events in concrete.

Pic. 2: View to the specimen inside the furnace with concrete damage because of spalling (left) and a damaged specimen after the experiment (right).

2. Results parameter based methods

The acoustic emission activity is the cumulative frequency over the time. This can give a first overview of the time-development of the damage processes. It is an understandable and clear illustration, including the time information and delivers a two dimensional plot which can be compared with other measurement results. Picture 3 left shows the results of two experiments, one with and one without PP-fibres. A difference in the activity and the so the damage between the two experiments are clearly visible. With a combination of different parameters it is possible to get superior results and information. So the signal energy over the time combined with the results of a temperature sensor inside the specimen show a beginning of high-energy events at 100°C. This could be an indication for pore-pressure as a cause of spalling.



Pic. 3: Acoustic emission activity of specimen with and without PP-fibres tested according to the modified ZTV-Ing standard (left). Occurrence of AE events and their signal-energy plotted over temperature (right) [8].

2. Applied Methods of source-localization

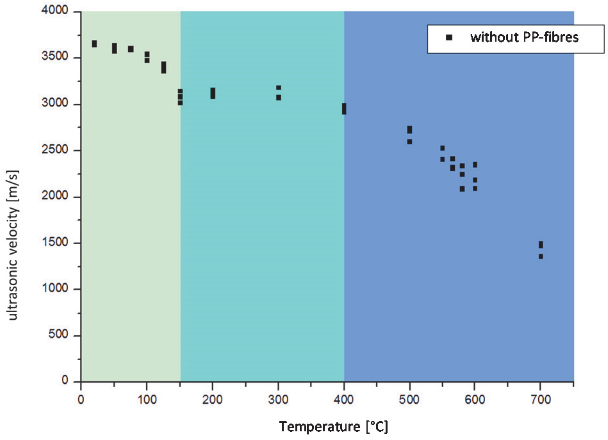
Additional to parameter-based methods, source localization is very important. This is needed to identify real events out of the specimen against noise. And the three-dimensional location information could be used to detect the time-dependent depth of spalling. For source localization, different methods were applied and tested.

At the beginning, the Bancroft algorithm was used to perform the source localization. Due to the limitation to 4 sensors, a permutation approach is necessary. In order to verify the results obtained with the Bancroft algorithm the Geiger's method was implemented as well. When comparing the two methods it became obvious that the Bancroft method is more robust than the Geiger's method. Restricted only to homogenous velocity models, the need for another source localization method became visible.

To get the possibility to include different ultrasonic velocities, a three dimensional grid search with access to a velocity model were implemented. For the velocity model, a temperature simulation was coupled with the information of Picture 4 [3]. The temperature simulation is based on different research projects and is verified with experimental data [1].

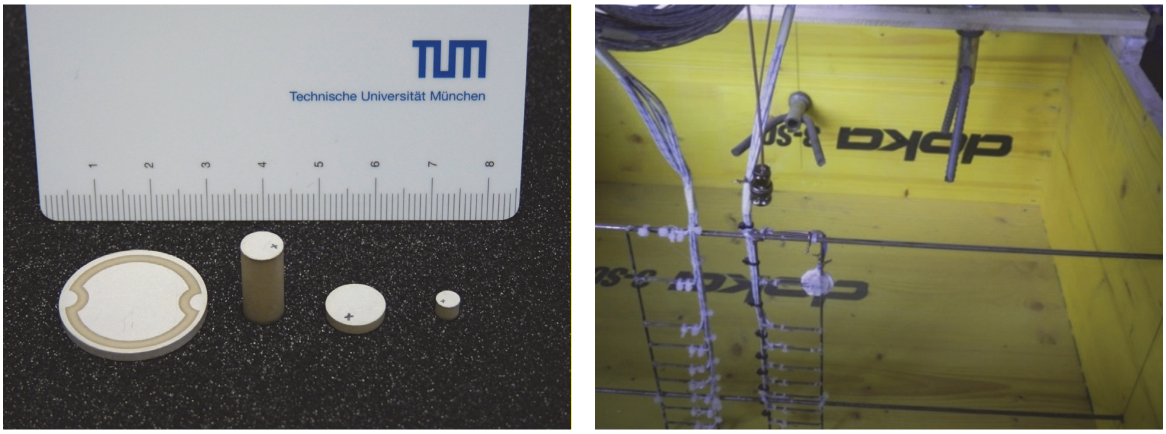
3. Limitations

The reasons for limitations in source localization can be found in the sensor positions, sensor distances, the sizes of the specimens and the inhomogeneous concrete. For concrete under fire exposure there are additional problems because of spalling and cracking effects and a decrease of the ultrasonic velocity inside the specimen with increasing temperature [Pic. 3].

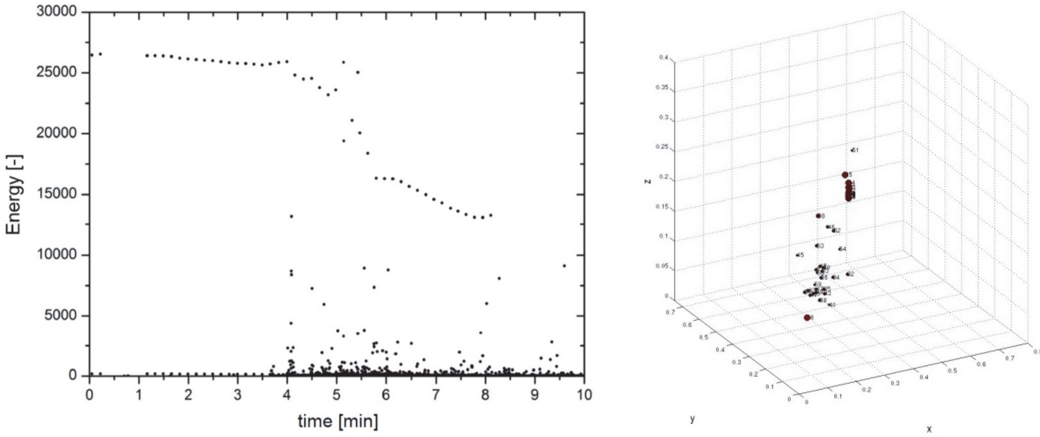


Pic 4: Relation between temperature and the ultrasonic velocity inside the furnace [3].

To work with localization results, statements about the accuracy of the localization are required. To investigate the limitations of the applied localization methods, synthetic sources were used. Ultrasonic transmitter based on piezo-ceramics were placed inside the concrete [Pic. 5]. In consistent time interval during the experiment, these synthetic acoustic emission sources, send a signal which can be detected with the acoustic emission measurement. Because of the consistent signal and the known place of the source it is possible to monitor the changing of signal parameters and the calculated source. In picture 6 left, the signal energy of the synthetic source decrease after 4 minutes, with the beginning of crack processes. Also the localization results become clearly worse at that time. The differences of localization results of the synthetic sensor are shown in picture 6 right.



Pic 5: Different piezo-ceramics to prepare synthetic ultrasonic sources(left) [4] and the application of synthetic sources in the concrete formwork (right) [9].



Pic 6: Signal-energy over time of an experiment with an synthetic AE-source (left) and a 3D-localization of the ultra-sonic signals (right) [9].

4. Conclusions and Outlook

The presented results show that it is possible to use acoustic-emission-analysis to monitor the time-dependant behaviour of concrete under fire exposure. Different display options seem to be able to allow conclusions about the damage processes. It is very important to get information about the localization of acoustic-emission-events. But there are some difficulties for the calculation of localisations, like the changing of the acoustic velocity in concrete, because of temperature exposure [5], the sensor arrangement, the sizes of the specimens and the damage processes because of fire exposure.

To investigate the accuracy and the usability of the presented methods the research project includes an experimental program with synthetic AE sources. With these transmitters, statements about the accuracy of the localizations become possible. The intention is now, to improve the localization with the use of acoustic velocity models. Out of the presented results, it seems to be important to expand the acoustic velocity models from temperature influences to damage effects.

4. Acknowledgements

The authors are grateful for a research project (Feb 2010 – Feb 2012) sponsored by the Deutsche Forschungsgemeinschaft DFG via grant GR1664/7-1 and for the collaboration in this project with the Institute of Construction Materials, University of Stuttgart, Germany. A follow-up research project was sponsored by the German Federal Ministry of Economics and Technology under grant number KF3085901.

References

[1] Dehn F. et al.: Fire and spalling behaviour of fibre reinforced concrete in road tunnels, Report B73, Federal Highway Research Institute (BASt), (2010).
[2] Grosse C., Ohtsu M. (Eds.): Acoustic Emission Testing in Engineering – Basics and Applications. ISBN: 978-3-540-69895-1, 415 S., Springer publ., Heidelberg (2008).
[3] Grosse C., Richter R., Ozbolt J., Dehn F.,Juknat M.: Spalling of HPC evaluated by acoustic emission an numerical analysis. 2nd International RILEM Workshop on Concrete Spalling due to Fire Exposure 5-7 October 2011, Delft, The Netherlands (2011).
[4] Andreisek G.: Einbetonierte Ultraschallgeber zur Kalibrierung von Messsystemen für die Schallemissionsanalyse. Bachelor`s thesis Technical University Munich, (2012).
[5] Krapp M.: Veränderung der Ultraschallgeschwindigkeit bei hochfestem Beton unter Brandbeanspruchung. Master`s thesis, Technical University Munich, (2012).
[6] Raith M.: Schallemissionsanalyse bei Pulloutexperimenten an Verbunddübeln. Master`s thesis Technical University Munich (2013).
[7] Richter R: Einsatz der Schallemissionsanalyse zur Detektion des Riss- und Abplatzungsverhaltens von Beton unter Brandeinwirkung. Diplomarbeit, Materialprüfungsanstalt Universität Stuttgart (2009).
[8] Richter R., Dehn F., Schmidt J., Juknat M., Grosse C.: Measurement systems to detect the time-dependent development of concrete spalling under fire exposure. Concrete Spalling due to Fire Exposure: Proceedings of the 3rd International Workshop, Paris. MATEC Web of Conferences 6, 03006 (2013), 7 p.
[9] Richter R: Anwendung der Schallemissionsanalyse bei Tunelbrandprüfungen. PhD Thesis, Technical University Munich (in preparation).