Acoustic emission analysis used to investigate the spalling effect of concrete under fire load

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Abstract

High performance concrete (HPC) is often used as a material for tunnel walls. However, it shows usually an unfavourable behaviour being exposed to fire due to explosion like spalling effects. In experiments using standard temperature gradients similar to those in case of tunnel fires the cracking behaviour of HPC and standard concrete is monitored by acoustic emission (AE) techniques. By the use of AE techniques damage processes in concrete can be observed during the entire fire history, detecting the initial spalling. This will enable to locate and characterize the micro-cracking behaviour. The paper will describe the concept and first results of the experiments.

Introduction

Concrete properties are changing if the material is exposed to fire. The mechanical attributes for example are altered in a way that strength and elastic modules are reduced. The temperature gradient generates increasing internal stresses leading to micro fractures and lowering the load bearing capacity. Pieces of the hardened concrete surface exposed to fire break away explosively or fall-off during the course of rapid high temperature exposure.

The exposure of concrete to fire is in particular a problem in tunnels, where high performance or high strength concrete, respectively, are often used. The risk of spalling is for high strength concrete higher because of its low permeability that causes higher moisture content at the time of heating and its low porosity that causes faster build up of pore pressures. HPC is often mixed with silica fume which produce concrete with low permeability and low porosity.

The process of deterioration of concrete and steel-reinforced concrete is not sufficiently understood since experimental investigations under fire load are difficult and complex. Usually, no full-scale tests are possible. An alternative are numerical simulations. To achieve realistic results enabling for valid material prognoses a calibration of the used models and model parameters is required. This can be done using acoustic emission and other non-destructive testing techniques. An experimental setup was developed being able to observe the initial micro-cracking process and the spalling. The data will be compared with simulations and used to alter the model. Acoustic emission (AE) techniques can deliver reliably such data and are an appropriate validation tool. Some preliminary results of experiments are shown. The investigations will be continued in a research project that started a few months ago.

Setup and equipment

For the preliminary tests one of the controlled furnace stands of the material testing institute of the University of Stuttgart (MPA) was used (Fig. 1). The furnace is able being equipped with test specimen at two sides as well as on top in the mid of the oven as it is shown in Fig. 2. In this graphic the position of the AE sensors is marked additionally, while the burner is not shown and...
covered by the concrete specimen that had a size of 54 x 22 x 48 cm (side wall) or 80 x 63 x 22 cm (top wall), respectively.

Fig. 1: Furnace stand of the MPA University of Stuttgart

For the preliminary tests a set of 24 different sensors in total (Fig. 3, left) was used including resonant, multi-resonant and broadband transducers [1, 2]. After pre-amplification the signals were recorded by three multi-channel transient recorders. In parallel to the AE data the temperature in the furnace as well as on different positions on the surface was recorded. Additionally the specimen were monitored using an infrared video camera observing the specimen from the outside and with a camcorder inspecting the inner furnace chamber (Fig. 3, right).

Fig. 2: 3D model of the experimental setup including the positions of the AE sensors
Measurements

Concerning acoustic emission recordings the experimental setup is critical due to the noise emitted from the furnace. Accordingly, the number of noise signals was unusual high. However, several hundred events were recorded showing a good signal-to-noise ratio enabling for a localization. An example of such signals showing an event recorded with eight channels is presented in Fig. 4.

Fig. 3, left: Some AE sensors and one of the transient recorders. Right: View into the furnace chamber using the camcorder

Fig. 4: Acoustic emission event recorded by an eight channel transient recorded. The vertical lines mark the signals' onset at each channel
The AE hit rate is an equivalent for the number of recorded AE signals crossing the trigger level previously set. A comparison of the hit rate with the temperature in the furnace is displayed in Fig. 5, what gives a first overview of the deteriorations. The cracking process starts at 500° C and the numbers of acoustic emissions develop with a high slope up to a temperature of approximately 750° C. After reaching this temperature the hit rate gradient is not as high any more. In this temperature range a degradation of hydration products usually occur in concrete.

Fig. 5: Hit rate and temperature evolution inside the furnace chamber

Fig. 6: 3D localization of the AE epicenters and projection to the planes
The recorded AE signals were classified in a way that only events recorded by six or more channels are considered and that a localization accuracy was better like 2 cm. An example of the localized events of one of the experiments is given in Fig. 6. Most source locations are determined in the center of the slab that is the region of the highest temperature gradient. The accuracy of the AE locations given by the deviations in x and z direction is shown in Fig. 7.

A reliable localization is based on a knowledge of the compressional wave velocity that is usually determined prior to the experiment. However, the temperature gradient in the slabs during the experiment caused velocity anomalies prohibiting the use of uniform velocity values. Infrared thermography (Fig. 8) will be used in further experiments to overcome this problem. Moreover, the fracturing of the material at higher temperatures leads to further ambiguities due to micro-cracks that changes the travel path of the waves between source and receiver. A clustered AE event analysis using events clustered in a timely manner will be performed in further experiments to eliminate this effect. Travel time tomography methods will enable for a better determination of the velocity model.

Fig. 7: Projection to the x/z plane and error bars of localization

Fig. 8: Infrared thermography showing the temperature gradient in a slab during the experiment
Conclusions and outlook

The preliminary experiments demonstrated that AE methods can successfully be used to investigate the deterioration of concrete under fire load [3]. Signal-based acoustic emission techniques can produce detailed 3D pictures of the fracture process leading finally to spallation. Problems related to this analysis method are due to the large temperature gradient and the micro-cracking phenomena that both causes ambiguities of the velocity model.

In a research project these problems will be handled and a series of experiments testing different concrete mixes will be conducted. The main goal is the development of a recipe for high performance concrete minimizing the spalling effect. The essential component of this research project will be the combination of real data with numerical simulations [4, 5].

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