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Evaluation of Acoustic Emission Signals Obtained during the Three-Point Bending Loading of Thermally Degraded Concrete Samples

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Abstract. Due to fires of building structures, there has been a growing interest in investigating the properties of concrete at high temperatures. In a fire, a temperature of up to 1400 °C may be measured. Such high temperatures will cause changes in the structures of the entire construction. Ultrasonic methods such as acoustic emission method can be used to monitor changes in the structure caused by a fire.
Heated to selected temperatures of 200 °C, 400 °C, 600 °C, 800 °C, 1000 °C, and 1200 °C, the concrete specimens were maintained for 60 minutes. Then, they were dried for another 48 hours at 110 °C and, after that, cooled down to a laboratory temperature. Beam concrete specimens were loaded under a three-point bending test. The evaluations of the experiments imply the possibility of using the acoustic emission method to describe the changes in a concrete structure after it is fire-degraded at the three-point bending loading.

Introduction

Due to fires of building structures, there has been a growing interest in investigating the properties of concrete at high temperatures. In a fire, a temperature of up to 1400 °C may be measured. Such high temperatures will cause changes in the structures of the entire construction. Ultrasonic methods such as acoustic emission method can be used to monitor changes in the structure caused by a fire [1].

The service-life of concrete structures depends on the behaviour of concrete in its environment and on the concrete mixture. Concrete behaviour depends mainly on the cement type, the aggregate type, the sand and the water-to-cement ratio [2].
Some studies have been made to identify the presumed causes and predict the degradation of concrete under fire conditions.

The thermal mismatch between the aggregate particles and the hydrated cement paste binder leads to a loss of bond among the constituents in addition to the loss of stiffness and strength. The increase in temperature results in water evaporation, C-S-H gel dehydration, calcium hydroxide and calcium aluminates decomposition, etc. Along with the increase in temperature, changes in the aggregate take place [3].

The following three phrases are important for the behaviour of concrete. (1) phase transformations (e.g., loss of free water at about 100 ˚C, decomposition of calcium hydroxide at about 450 ˚C, and crystal transformation of quartz at 573 ˚C from the form), (2) pore structure evolution (e.g., volume and surfaces of pores increase up to a temperature of about 500 ˚C and then decrease with further temperature increase, and (3) coupled thermo-hygro-chemo-mechanical processes (e.g., temperature gradients leading to thermal stresses, multiphase transport of water, and chemical changes that affect pore pressure and structure) [4]. Therefore, when the temperature exceeds 100°C, the capillary pore water changes into water vapour and the cement hydrates begin to desiccate. At higher temperature values, over 200°C, the dehydration of cement hydrates takes place which leads to the cracks in the cement paste being nucleated [5].

A simple three-point bending test can determine the behaviours of the tested specimens. The crack propagation path should be perpendicular to the central force [6].

The acoustic emission method is a tool of a group of the non-destructive testing methods. Due to local plastic deformations, elastic or acoustic waves spread throughout the structure of the material. The acceleration sensors then detect and record these elastic waves [7].

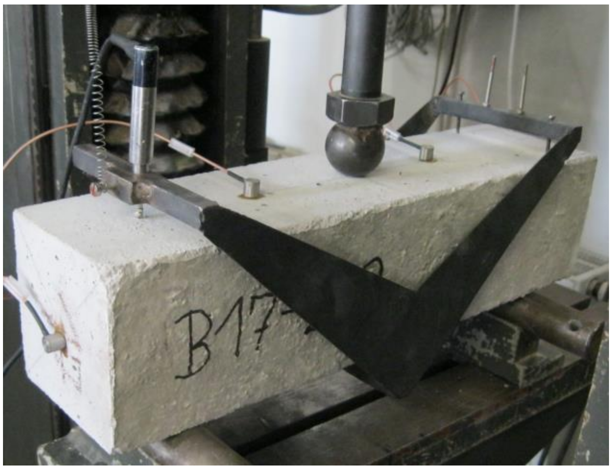
Experiment

Experimental concrete samples with dimensions of 100 mm x 100 mm x 400 mm were prepared from 15 % of Portland cement CEM I, 0.1 % of superplasticizer, 1 % of water and amount sand and gravel aggregates with Table 1 in the laboratory of the Institute of Technology of Building Materials and Components, Faculty of Civil Engineering, Brno University of Technology. Each specimen was immersed in a water bath for 28 days. Then, they were dried for another 48 hours. Heated in a programmable laboratory furnace at a heating rate of 5 °C/min to the selected temperatures of 200 °C, 400 °C, 600 °C, 800 °C, 1000 °C, and 1200 °C, the concrete specimens were maintained for 60 minutes. Then, they were dried for another 48 hours at 110 °C. Then, the specimens were cooled down to a laboratory temperature.

Table 1 Percentage of sand and gravel aggregates in monitored mixtures

Mixture	A	B	C
Sand 0/4 mm	15	38	35
Gravel aggregate 4/8 mm			43
Gravel aggregate 8/16 mm	42	22	
Gravel aggregate 11/22 mm		16	

Beam concrete specimens were loaded under a three-point bending test using the displacement-controlled method [8]. The fracture tests were carried out using a Heckert FPZ 100/1 testing machine within the range of 0 to 10 kN. The notch up to one third of the cross section determined unambiguously the fracture process zone [9]. The depths of notches were 2 mm. The acoustic emission sensors were placed on the surface of the concrete beam specimens. The XEDO acoustic emission system made by Dakel (Czech) recorded acoustic emission hits.



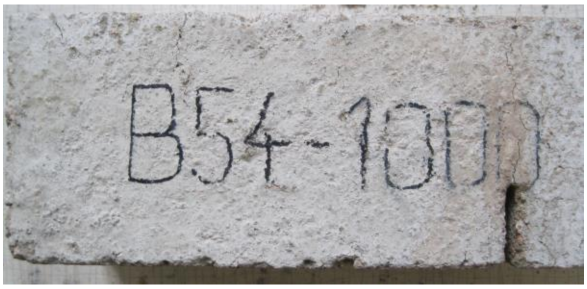


Figure 1 Experimental set-up

Results

The graphs in Figure 2 suggest the following conclusions of the comparison between the formulas (Table 1) in terms of the acoustic emission at a three-point bending test:

For samples at the normal temperature of 20°C - formula B seems to be the best one for which it is evident that, in concrete with three aggregate fractions, a minimum of number of cracks created during the total destruction of a sample. When formula C is loaded, an activity of the acoustic emission appears at the beginning caused probably by the supports being pushed into the sample and the samples settling down.

For samples tested at the temperature of 400 °C, containing no more freely-bound water, the greatest force has been achieved with formula C, which is likely to be caused by the closeness of the aggregate fractions. Although for evaluating the acoustic emission activity during the bending test, the behaviours of the formula A and C samples are similar, a slightly higher activity has been measured for formula A samples. The formula B samples show huge acoustic emission activity immediately before the break, which is caused by the samples being broken in a more abrupt manner as compared to the A and C formula samples.

In the samples tested at the load temperature of 600 °C, the crystalline phase of the aggregate quartz changes from alpha to beta (hexagonal configuration) at a temperature of 573 °C under normal pressure. At this temperature, also the Portlandite begins to disintegrate. The results of the acoustic emission show that the formula A samples showed lowest strength, probably because of a larger space between the aggregate grains filled with cement, which started to disintegrate. For the B and C formula samples, however, the situation is slightly different with the aggregate grains being closer to each other so that there is less cement in between and the samples show an activity typical for acoustic emission before breaking.

By a temperature of 800 °C, the Portlandite has already been totally disintegrated. For this reason, samples of all formulas break by very small forces. The acoustic emission activity is caused mostly by the cement being crushed and crumbled out and, thus, the grains moving in the freed space as proved by the results of the formula B samples containing the largest number of aggregate fractions.

By a temperature of 1000 °C, the samples of all formulas have become almost unmovable with very strong crumpling at the surface caused even by very slight manual handling, which is also corroborated by the results of the maximum force achieved and the acoustic emission activity.

The samples degraded by the temperature of 1200 °C then show completely different properties. The question is then, whether this is still a concrete.

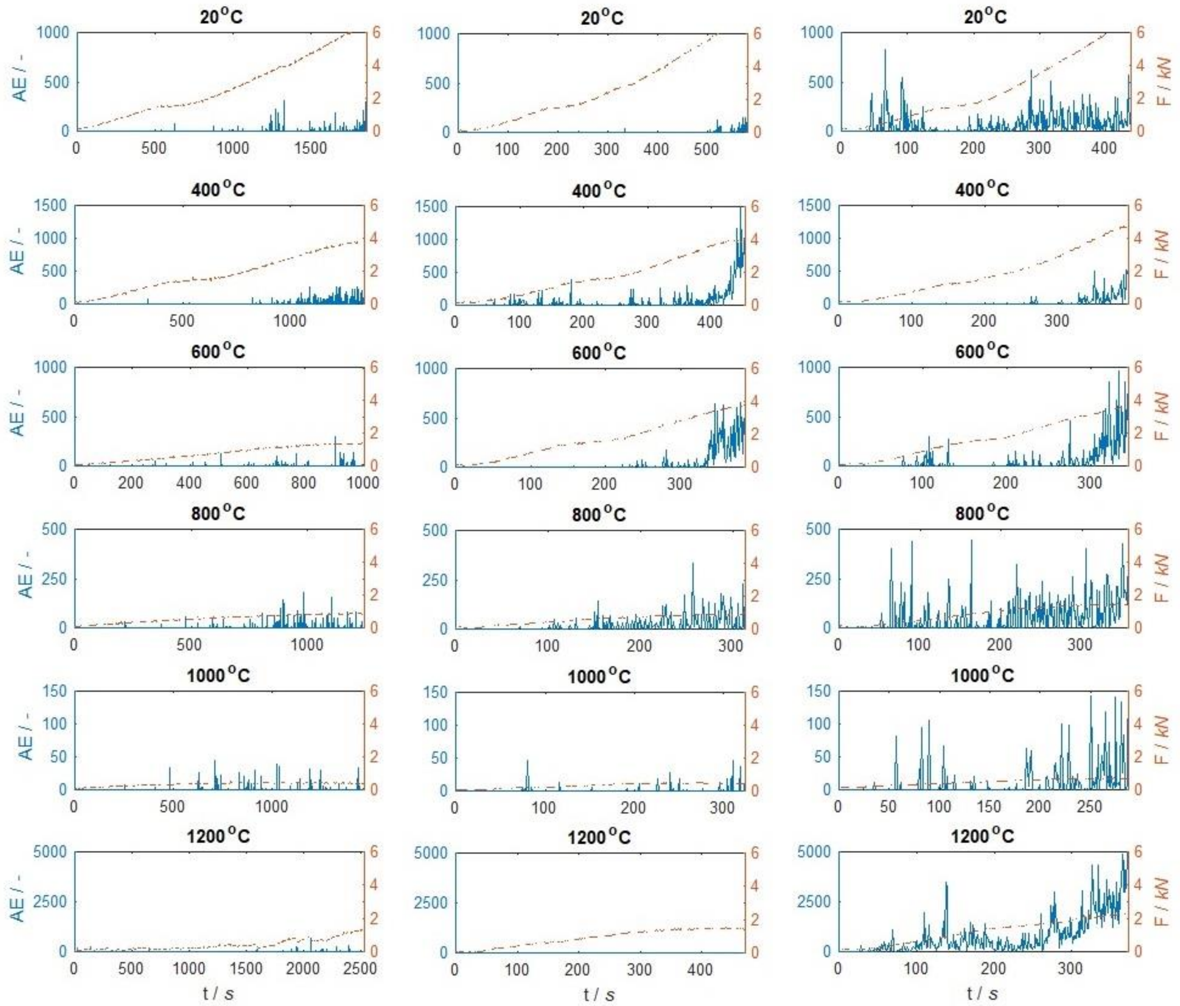


Figure 2 Dependence of acoustic emission activity *AE* (left axis) and load *F* (right axis) on the loading time *t*, of three mixtures A, B and C (diagrams from left to right).

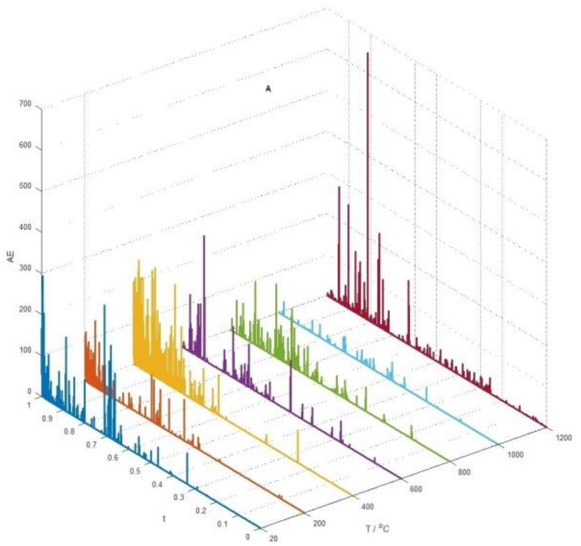


Figure 3 Mixture A

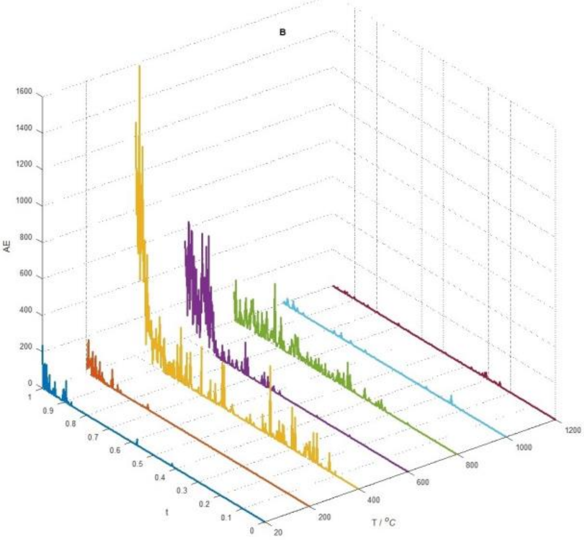


Figure 4 Mixture B

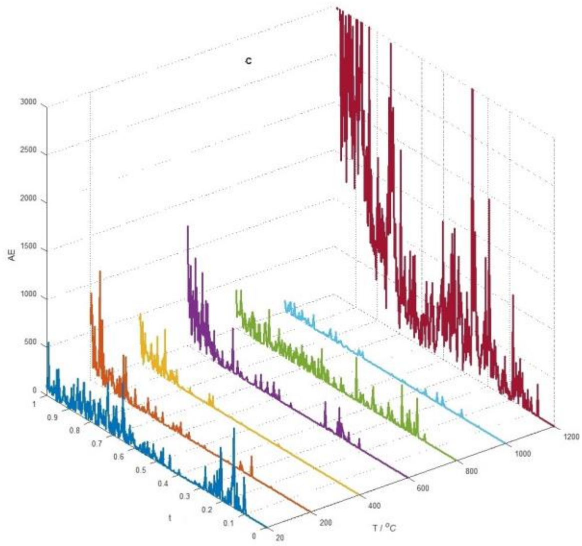


Figure 5 Mixture C

The behaviours of the acoustic emission activity for samples at different temperatures are summarized by diagrams in Figures 3 to 5. The time axis show the time elapsed from the beginning of loading to the sample destruction. Particularly from the diagram in Figure 5, it is clear that the behaviour of the sample after a temperature load over 1000 °C is unexpected due to its disintegration.

Conclusions

The results of an analysis of the acoustic emission signal show that, in terms of heat resistance, it is suitable to use a mixture of more aggregate types, which will be the subject of the next part of the research.

The paper describes an evaluation of the acoustic emission tests carried out on temperature degraded concrete specimens. The evaluations of the experiments imply the possibility of using the acoustic emission method to describe the changes in the concrete structure after its degradation by fire at three-point bending loading. The outcomes of the acoustic emission method can help provide the numerical models with more accurate input parameters.

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