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Acoustic Emission Method Applied on Four Point Loading of Concrete Structures with and without Small Wires

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Abstract: Because concrete is one of the most popular building materials, it is important to know its basic properties and behaviour especially at loading. Concrete strength and its lifetime are significant mechanical properties of building structures. Mechanical properties and their characteristics in co-ordinance of quantity and loading type enable to dimension significant construction parts and to determine their reliability, which determine so-called limiting state. A limiting state is a condition of a structure beyond which it no longer fulfils the relevant design criteria. One of the major strength properties is obtained by four-point bending load. Recording the force, at which the first surface crack is detected, is the conventional procedure. For location of crazing and crack propagation in loaded concrete structure, which four-point bending load qualified for, the Acoustic Emission Method can be applied. Acoustic emission method, which is a part of Non-Destructive Testing techniques, records propagated elastic waves generated from the place of an active crack. This method is more sensitive than visual observation, because it enables to monitor acoustic emission activity during loading continually. In the article monitoring of concrete blocks made from different mixtures is described. Behaviour of four different groups of mixtures is described in the paper. The first group was sleeper concrete, the second was sleeper fibre-concrete, the third was alkali activated fibre-concrete and last was alkali activated concrete with steel reinforcement.

Keywords: Experiment; Analysis, Concrete, Non-Destructive Testing, Acoustic Emission Method, Four-Point Bending Test

1. Introduction

The inspection methods for non-destructive evaluation of concrete structures are in great demand. For this purpose, a variety of inspection methods have been studied to provide early detection and warning for critical defects in concrete. For a quasi-brittle material like concrete, a substantial non-linearity in the shape of micro-cracking exists even before maximum stress is reached. In order to maintain the safety and performance of concrete structures, these cracks should be inspected

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properly for quantifying the condition of structural integrity and assessing the degree of damage and deterioration [6,7].

2. Methods

Three mixtures were chosen for the concreting; the composition and labels of mixtures can be found in the Table 1.

Table 1. Composition of mixture

Component	*CCC [kg]*	*AAC [kg]*
Cement	385	0
Blast furnace slag	250	450
Water glasses (sodium)	0	65
50% dilution KOH	0	37
Water	210	160
Super plasticiser	4,3	0
Sand 0/4	775	840
Rubble 4/8	355	380
Rubble 8/16	360	390

In the first stage, different types of mixtures were placed in two wooden forms. In the second stage of the concreting, only the mixture AAC (meaning in the Table 2) was used and completed with steel reinforcement.

Table 2. Abbreviations

Abbreviation	*Meaning*
SCC	Self Compacting Concrete
AAC	Alkali Activated Concrete
1N	Mixture of self compacting concrete
2N+D	Mixture of self compacting concrete with wires
4A+D	Mixture of alkali activated concrete with wires
5A+D+V	Mixture of alkali activated concrete with wires and steel reinforcement

The Acoustic Emission Method is a powerful technique for non-destructive testing and materials evaluation. It relies on the detection of elastic waves generated by sudden deformation in stressed materials. [13,14] Stress can be tensile, compressive or shear and can have components in all three dimensions. These waves travel from the source to the sensors where they are converted to electrical signals. The acoustic emission instrumentation measures these signals and produces data displays from which the operator evaluates the condition and behaviour of the structure under stress [1,4,12].

The source of the acoustic emission energy is the elastic stress field in the material. Without stress, there is no acoustic emission. Therefore, an acoustic emission inspection is usually carried out during a controlled loading of the structure. This can be a proof load before service a controlled variation of load while the structure is in service a fatigue test, creep test, or a complex loading program. Often, a structure is going to be loaded anyway and acoustic emission inspection is used because it gives valuable additional information about the performance of the structure under load [5,8,12].

Under the action of stress the material expands contracts or shears elastically: this is known as “strain”. Stress for the acoustic emission test can be produced in several ways: by mechanical loading, by pressurizing with a gas or liquid, by thermal means (temperature gradient), or even by an acoustic field from a loud speaker [2,3,12].

Beam flexure represents one of the three most common loading categories for mechanical systems. In four-point bending, the simply supported beam is supported on two outer points, and deformed by driving two concentrated loads. The maximum stresses are located at the loads. When a 'beam' experiences a bending moment it will change its shape and internal stresses (forces) will be developed. The photograph (Fig. 2) shows the shape change of a beam in bending. Note that the material is in compression on the inside of the curve and tension on the outside of the curve, and that transverse planes in the material remain parallel to the radius during bending. The pure bending shown in the (Fig. 1) can be produced by applying four forces to the beam, two of opposite direction at each end. This configuration is known as 'four point bending' and produces a uniform bending moment over the centre section of the beam [10,11].

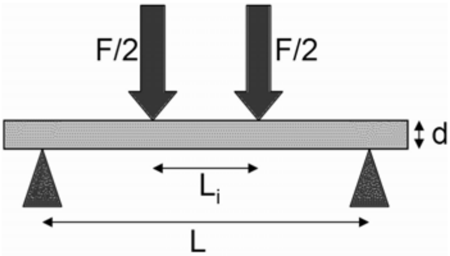

Fig. 1. Four point bending – theory.

Fig. 2. Four point bending – after the experiment (5A+D+V).

3. Results

The measurement was done on device Dakel XEDO with seven channels. Channels 5 to 8 had filter of frequency set to from 27 kHz to 400 kHz with amplification of 20 dB. The channels 3, 4 and 9 had a frequency filter set to from 500 kHz to 2 MHz with amplification 35 dB. Sensors IDK 09 (channels 3, 4 and 9) and sensors MTPA-15 (channels 5 to 8) were used for measuring. Approximate location of sensors is shown in Figure 3.

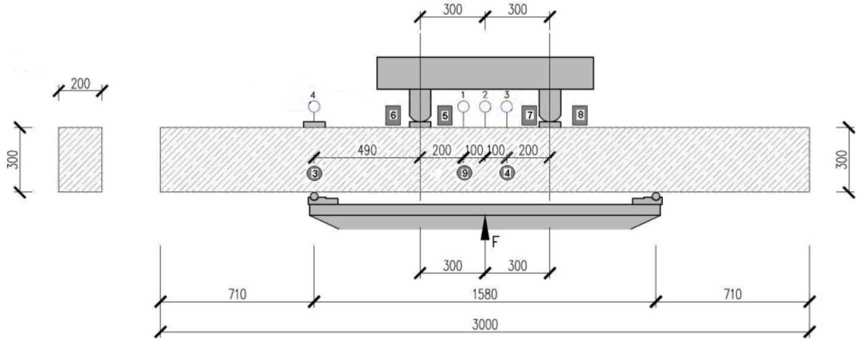

Fig. 3. Approximate location of sensors. (dimensions in mm)

To evaluate the origin of micro cracks during stress, we focused on the activity of acoustic emission, respectively on the most used parameter which is the number overshoot preset threshold.

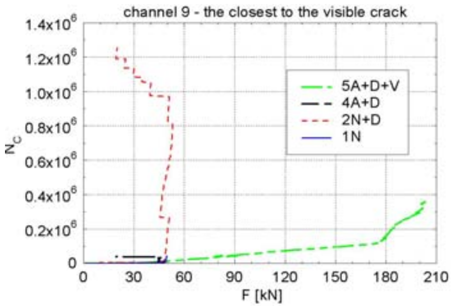

Fig. 4. Dependence of cumulative count of events acoustic emission N_c on the force F.

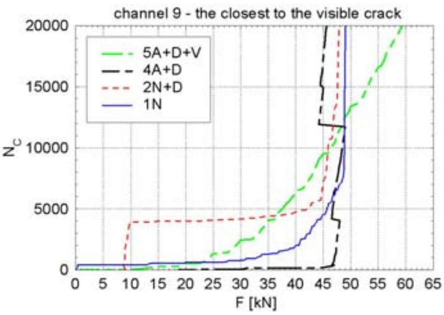

Fig. 5. Dependence of cumulative count of events acoustic emission N_c on the force F (cut out from Fig. 4).

The graphs in Fig. 4 and Fig. 5 are created from data generated by the sensor which are located the closest to the visible crack. Dependence of cumulative count of events acoustic emission on the force (Fig. 4) shows that the mixture 5A+D+V has the greatest increase in counts acoustic emission from 175 kN load. The increase of events of counts of acoustic emission of other mixtures are in the area below 50 kN load.

A mixture of SCC with wires (Fig. 5) has the first increase in emission activities on the value of 10 kN load, which is not be significant and may be caused by outside interference. A mixture of 5A+D+V is compared to other mixtures first increase of acoustic emission events has on the value of forces between 20 kN and 30 kN load, but a mixture 5A+D+V continue to resist stress. Other mixtures show a significant increase number of events of acoustic emission from the of 40 kN load and thus the deformation of the whole structure. An increasing number of events of acoustic emission together with a decrease in stress shows finite deformation structure.

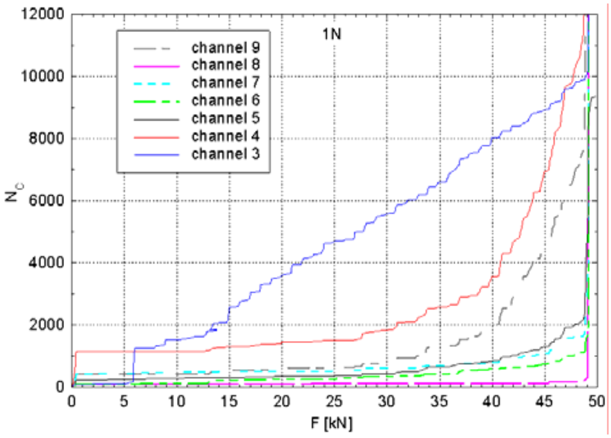

Fig. 6. Dependence of cumulative count of events acoustic emission N_c on the force F (1N – mixture of SCC)

The graph in Figure 6 shows the dependence of cumulative count of events acoustic emission N_c on the force F for all the sensors. The increase in acoustic emission activity in the beginning of channel 4 is caused by sticking the sample during pre-stress seting. Unlike other channels the emission activity on channel 3 linearly increasing from 6 kN load. It may be caused by sensing of microcracks close to, but are these micro cracks do not have significant effect on the structure of the sample. Apparently are these the events caused by ingress an iron support of the sample, above which the sensor was located. Channels 4, 9 and 5 have the beginning with the increase of acoustic emission events in over 30 kN load. The increasing cracks can be assumed at this stage of loading in the vicinity of the sensor are these crack in such an extent that further use of the sample would have been dangerous. In the area of 40 kN load is the obvious that beginning of the destruction of the structures already in the area. Total destruction occurs in about 50 kN load.

If steel wires are inserted into the concrete (Fig. 7), the activity of acoustic emission on channels 9 and 4 is already increased at the value of 8 kN load, which may indicate a crack that does not necessarily have to influence the quality of the structure. Channel 3 shows an emission activity earlier than other sensors, similarly to the mixture of SCC. A significant increase of acoustic emission activity can be detected at the value of 20 kN load, in particular in sensors 9 and 4, which are the closest ones to the predicted crack. The acoustic emission activity rapidly grows at the value of 45 kN load, the sample is in a significant deformation area. This leads to the destruction of the sample at the value of 50 kN load, especially of its concrete parts. The sample is stuck at steel wires, but the load cannot be increased.

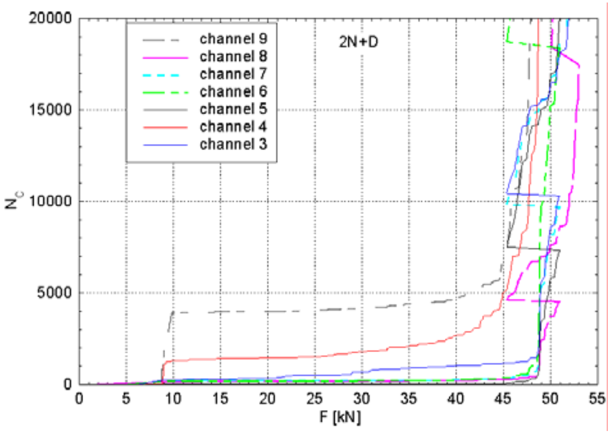

Fig. 7. Dependence of cumulative count of events acoustic emission N_c on the force F (2N+D – mixture of SCC with wires)

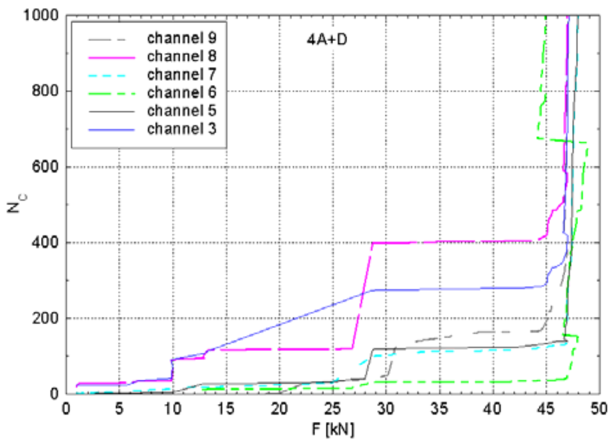

Fig. 8. Dependence of cumulative count of events acoustic emission N_c on the force F (4A+D – mixture of AAC with wires)

A sample of 4A+D (Fig. 8) shows the first activity of acoustic emission at the value of 10 kN load, which may not be significant. However, a significant activity is virtually on all channels in the area of 25 kN load. The increased activity is evident just before the destruction at about 44 kN load, i.e, when there is a remarkable fracture.

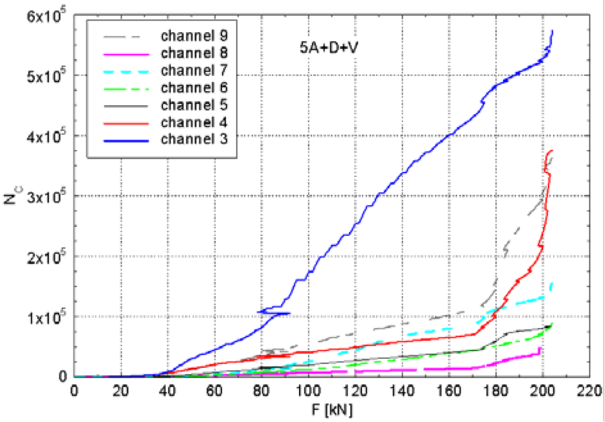

Fig. 9. Dependence of cumulative count of events acoustic emission N_c on the force F (5A+D+V)

The sample made from the same mixture as 4A+D (Fig. 8) shows much higher strength due to the steel reinforcement. The deformation of concrete is evident in the area over 40 kN load. The destruction of steel reinforcement is in the area of 170 kN load, when a significant increase in the number of events of acoustic emission starts. A visible crack is created near the channel 3 and it grows considerably during the loading. Formation of the first cracks is estimated at the value of 10 kN load (Fig. 9) due to the character of acoustic emission activity. The concrete structure is crumbling apart at the value of 25 kN load and the sample is held together only by the reinforcement from the value of 40 kN load.

4. Conclusion

By measurements it was found that alkali-activated concrete is more fragile than concrete based on Portland cement. The activity of acoustic emission mixture marked 4A+D is rapidly increasing, while at the mixture marked 2N+D the activity is gradual. The mixture of alkali activated concrete shows lower compressive and flexural strength and a considerably larger contraction. The results obtained from large beams are quite different from the results obtained on small specimens, which is caused by the so-called "size effect". Acoustic emission is a useful tool in determining the time of the crack creation under load. The method of acoustic emission had warned about crack approaching which appeared after a while on the surface of the sample. Combining the standard methods with a non traditional one, in this case Acoustic Emission Method contributes to a more detailed description of material behaviour during its loading.

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