Crack Detection of Concrete Slab made from Different Concrete Mixtures by Acoustic Emission Method

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Abstract
Most buildings date back to the first half of the last century. Concrete proved to be a durable construction material in the recent years. Concrete is a composite construction material composed primarily of aggregate, cement and water. There are many formulations that have varied properties. New concrete mixture are developed and tested since its discovery. The Acoustic Emission Method is one the most typical methods of the passive acoustic method group. These acoustic methods are only based on the reception of elastic waves, the source of these waves being the object under test itself. The acoustic emission phenomenon consists of emitting elastic waves in the case of material structure changes. In general, acoustic emission is defined as elastic waves originating in consequence of local, dynamic and irreversible changes in the material structure. These changes are due to the solid deformation or structural integrity deterioration. The Acoustic Emission Method has been applied to investigate acoustic phenomena which arise in the material under test as a concurrent phenomenon to the micro-defect generation and are accompanied by the response to the external loading. During the test, the time development of the acoustic emission events was studied. Four sets of concrete slab made of different mixtures, of dimensions of 150 mm x 260 mm x 2600 mm, were measured. Mechanical load at four point bend test was risen up as long as possible until the specimen was destructed. Universal measurement and diagnostic system Dakel-Xedo made by ZD Rpety-Dakel company from the Czech Republic was used for the experiment. This system can record acoustic emission parameters. The system allows sampling of signal from one sensor with speed up to 8 Mega Samples per second, enumerates standard acoustic emission parameters, process emission events parameters for possible emission source localization. Chosen tested mixtures are the following: concrete for sleeper production, fibre-concrete, alkali activated fibre-concrete, alkali activated concrete with steel reinforcement. Non-standard testing procedures and non-standard sleeper mixtures will be discussed in the article.

Keywords: crack propagation, crack, concrete, Acoustic emission (AE), AE sensor, civil engineering

1. Introduction

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-ordination 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 behaviour of a concrete sample under compression is associated with generation of micro-cracks. These micro-cracks are gradually accumulated prior to final
failure. The number of AE events, which correspond to the generation of these cracks, increases due to the accumulation of micro-cracks [1].

This method is more sensitive than visual observation, because it enables to monitor acoustic emission activity during loading continually. In the article is described monitoring of concrete blocks made from different mixtures. The first mixture (1N) was from self compacted concrete, the second (2N+D) was from self compacted concrete with steel wires, the third (4A+D) was from alkali activated concrete with steel wires and last (5A+D+V) was from alkali activated concrete with steel wires and with steel reinforcement.

Many internal flaws and cracks exist in concrete prior to loading. The mechanical behaviour of concrete subjected to different loading conditions is governed by the initiation and propagation of these internal cracks and flaws during loading. For a concrete structure subjected to tension, the cracks propagate in a direction perpendicular to the applied tensile load. On the other hand, for a concrete structure subjected to purely uniaxial compression, the cracks propagate primarily in the same direction as the applied compressive load. Since different mechanical responses of concrete structures can be explained by fracture processes at different loading conditions, one needs to understand when the internal cracks initiate and how they propagate with increasing load [2].

2. Methods

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 [3,4].

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 [5,6]. Beam flexure represents one of the three most common loading categories for mechanical systems. 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.

![Fig. 1. Four point bending – illustrative picture](image1)

![Fig. 2. Photography of real experiment](image2)
The four-stage fracture model was proposed that can likely be applied to many different types of materials, ranging from brittle (cement, glass), to quasi-brittle (mortar, concrete), to ductile (metals, hybrid fibre concrete). The model is schematically shown in Fig. 3 and basically the following four stages in mechanical behaviour can be distinguished [7]:

1. Elastic stage,
2. Microcrack stage (stable),
3. Macrocrack stage (un-stable if no precautions are taken),
4. Bridging stage.

![Four-stage fracture model for cement, plain concrete and fibre concrete [7]](image)

3. Results

The measurement of acoustic emission 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 with integrated preamplifier (channels 5 to 8) were used for measuring. 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. The all graphs are created from data generated by the sensors which are located the closest to the visible crack.

The graph in Figure 4 shows the dependence of force $F$ on deflection $y$ for all mixtures. The increase in deflection together with force is evident for all mixtures to the first maximum. After first maximum is the visible crack appeared. The decrease of force occurs with continued of deflection. At some point comes to rebound until the second maximum of force where there is a total destruction of the specimen. The specimen from mixture marked 1N has got only the first maximum because after this maximum occurs a total destruction of the specimen. The maximum does not occur at the mixture marked 5A+D+V because specimen from this mixture did not break during the measurement.
The graph in Figure 5 shows the dependence of cumulative counts of events $N_C$ and deflection $y$ on force $F$ for mixture marked 2N+D. The increase load on the specimen is increasing internal tension within specimen. The increase in acoustic emission activity occurs from 46 kN load. The greatest activity of acoustic emission is achieved just before the discovery of the first visible crack between the value 48.3 kN - 51 kN load. 51kN - the first visible crack
which shows on the release of internal tensions. Then occurs greater of deflection but load is decreasing and there is no acoustic emission. If again the increasing loading force is increasing number of events of acoustic emissions due the first steel wires are pulling from concrete.

![Graph showing dependence of cumulative counts of events (N_C) and deflection (y) on force (F)](image)

**Fig. 6.** Dependence of cumulative counts of events (N_C) and deflection (y) on force (F) – for mixture marked 4A+D

The graph in Figure 6 shows the dependence of cumulative counts of events \( N_C \) and deflection \( y \) on force \( F \) for mixture marked 4A+D. The specimen marked as 4A + D has a lower increase in the number of events of acoustic emission before the appeared of visible crack than specimen marked as 2N+D. The visible cracks were observed at the value of 48 kN load. Then occurs greater of deflection but load is decreasing and there is no acoustic emission. If again the increasing loading force is increasing number of events of acoustic emissions due the first steel wires are pulling from concrete.

### 4. Conclusion

By measurements it was found that alkali-activated concrete is more fragile than self compacted concrete based on Portland cement. The mixture of alkali activated concrete shows lower compressive and flexural strength and a considerably larger contraction. 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.

### Acknowledgement

This research has been supported by projects of GACR No. P104/10/0535 and MSM 0021630519.
References


