ANALYSIS OF CONSTRUCTIONAL CONCRETE BY THE ACOUSTIC EMISSION METHOD ON MULTIPLE LOADING

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ABSTRACT

The paper uses the Acoustic Emission Method to analyze the appearance and propagation of microcracks in cyclically loaded constructional concrete. Acoustic Emission signals generated under different loading patterns can provide valuable information concerning the structural integrity of a material. This is a detailed analysis of the acoustic emission signals. The change in nature is studied of the acoustic emission parameters in relation to the degree of damage to the loaded structure. Each test specimen was subjected to cyclic loading with the loading force equivalent to one-third of the expected compressive strength value. The Acoustic Emission Method has significant potential to be used for in-situ monitoring and evaluation of the current state of structures.

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Key words: acoustic emission, concrete, civil engineering, cyclic loading, non-destructive testing
1. Introduction

Non-destructive evaluation and diagnostic techniques for concrete structures are recently in great demand for maintenance purposes. All over the world, the increase of aged and damaged structures eventually leads to the need for repair and retrofitting of concrete structures. To this end, NDE techniques to estimate the current state of the concrete structures are extensively investigated and are practically under development [1].

In concrete, the damage of defects and cracks is primarily nucleated due to chemical reaction, mechanical stress, and fatigue. To estimate the damage of a concrete structure in service, a detailed inspection is generally conducted by taking core samples out of the structure. Both chemical and physical properties are usually measured. As for mechanical properties, compressive strength and Young’s modulus are normally determined by conducting a uniaxial compression test. These mechanical properties obtained are then compared, if possible, with those of the specification. Besides, there exist few mature techniques to estimate the mechanical damage of concrete. To this end, measurement of acoustic emission activity in the uniaxial compression test of a core sample has been proposed [1-3].

These obtained mechanical properties are then compared, if possible, with the standard specifications. Measurement of AE acoustic emission activity during the cyclic loading in the uniaxial compression test of the cylindrical specimens have been proposed. A cyclic loading test generally consists of several load cycles on the material or structure of interest. Each cycle includes a loading phase and an unloading phase. The AE activity recorded during the unloading phase of the cycling loading procedure increase when the damage of the specimen is in progress. The increased AE activity observed during the unloading process is generally an indication of structural instability [3-5]. This is consistent with the Kaiser effect for dilatant microcracks and implies that shear cracks do not form until near the macroscopic structural failure. Damage evaluation in concrete by AE activity of a drilled core in a compression test was under investigation [2].

AE parameters obtained by a conventional system are the number of counts, the number of events, amplitude, the energy of AE signals, rise time, duration etc. The RA value and the average frequency can be defined from AE parameters as [6,7]:

RA value = the rise time / the maximum amplitude

Average frequency = the number of counts / the duration time

By means of these two AE indices, cracks could be classified into tensile and shear cracks as referring to Fig. 1.

![Fig. 1: Relationship between average frequency and RA values for crack classification [7]](image-url)
2. Testing method and material

The three acoustic emission sensors (IDK-09) with preamplifiers (AS3K with 35 dB gain) were attached to each specimen using beeswax (see Fig. 2). Acoustic emission signals were taken by measuring equipment DAKEL XEDO. Universal measurement and diagnostic system DAKEL-XEDO was developed by ZD Rpety-Dakel company. XEDO is a modular system. One communication card and up to 15 various input cards can be located in a metal box. Communication between cards within a box is realized by hi-speed bus. An allows sampling of the signal from one sensor (speed up to 8 MSamples/sec), enumerates standard acoustic emission parameters, process emission events parameters for possible emission source localization. Elimination of the noises is achieved by simply setting the threshold level (200 mV) over the noise level, or by filtering during a post-analysis of the data [8].

![Fig. 2: Photo of experiment](image)

Fresh concrete was made so that the quality of the specimens could affect the experiment results to as little a degree as possible. The concrete was mixed in a mixer with the volume of approx. 1 m³ in a concrete plant and stored in polyurethane moulds of a single type. This method was chosen with the purpose of producing concrete as uniform as possible. In order to eliminate the factor of concrete aging during the experiment, the concrete was tested at an age of more than one year.

The fresh concrete composition is in Tab.1 and properties of the concrete in the fresh and hardened state is in Tab. 2. The following specimens were made:

- 6 cylinders with the diameter of 150 mm and height of 300 mm,
- 3 cubes with the size of 150 mm
- 3 beams with the dimensions of 100 x 100 x 400 mm.

The cubes and beams were used for control tests of bulk density and 28-day flexural and compressive strength (Tab. 2).

The loading was performed in accordance with method B described in EN 12390-13 [9]. The testing procedure was configured in a way that allowed performing as many loading cycles as possible within several dozens of hours, while still performing a static loading test. The upper loading stress was set to $\sigma_a = f_c / 3$, where $f_c$ is compressive strength measured on reference specimens of the same shape and dimensions as the test specimens. According to EN 12390-13 [9], the basic loading force should be within $0.1 \cdot f_c \leq \sigma_b \leq 0.15 \cdot f_c$. This experiment used a lower
loading stress of the highest possible value, i.e. \( \sigma_b = 0.15 \cdot f_c \). The reason for this was to save time when transferring between the loading stresses. For the same reason, the highest allowed loading rate was chosen to be 0.80 MPa/s with a holding time of 3 s. The cyclic loading was performed using a mechanical testing press LaborTech with a loading force range of 0–1000 kN; the loading rate was set by a compressive force increment.

### Table 1: Fresh concrete composition

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>AMOUNT PER 1 m³ OF FRESH CONCRETE /kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEM I 42.5 R</td>
<td>338</td>
</tr>
<tr>
<td>Sand 0-4 mm</td>
<td>905</td>
</tr>
<tr>
<td>Aggregates 4-8 mm</td>
<td>183</td>
</tr>
<tr>
<td>Aggregates 8-16 mm</td>
<td>667</td>
</tr>
<tr>
<td>Superplasticizer</td>
<td>1.77</td>
</tr>
<tr>
<td>w/c ratio</td>
<td>0.48</td>
</tr>
</tbody>
</table>

### Table 2: Properties of the concrete in the fresh and hardened state

<table>
<thead>
<tr>
<th>ATTRIBUTE</th>
<th>UNIT</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow table test (fresh concrete)</td>
<td>mm</td>
<td>340</td>
</tr>
<tr>
<td>Slump-test (fresh concrete)</td>
<td>mm</td>
<td>70</td>
</tr>
<tr>
<td>Air content (fresh concrete)</td>
<td>%</td>
<td>4.5</td>
</tr>
<tr>
<td>Bulk density (fresh concrete)</td>
<td>kg/m³</td>
<td>2270</td>
</tr>
<tr>
<td>Compressive strength (hardened concrete)</td>
<td>N/mm²</td>
<td>52.2</td>
</tr>
<tr>
<td>Tensile strength (hardened concrete)</td>
<td>N/mm²</td>
<td>5.6</td>
</tr>
</tbody>
</table>

3. **Results and discussion**

The measurements results presented in Fig. 3 shown, that during the loading the Kaiser effect was detected. The Kaiser effect is a special behavior of the material under uniaxial compression [10]. It results from the fact that cracks which were created due to the previous loading do not propagate until the load exceeds the former stress level in the next loading. This way, a number of critical microcracks in concrete could be evaluated by monitoring AE activity under uniaxial compression stress.

The fundamental approach to the crack classification is the possibility to determine the tensile crack and shear crack in the structure. In the crack classification of composite material, a conventional method based on only one parameter is inadequate [11]. Utilization of several AE parameters such as rise time, count, amplitude, and duration are vital to access the crack location and classification. The classification of cracks namely tensile crack and shear crack based on the relationship between average frequency and RA value has been established by Ohtsu et al. [7, 12] as shown in Fig. 1. Shear crack occurred when AE signal has high RA value and low average
frequency. Meanwhile, the tensile crack occurred when AE signal reflects low RA value and high average frequency. Shear events are characterized by longer rise time and higher amplitude than those of tensile events [13].

The graph (Fig. 4) shows the course of the cumulative number of overshoots on the loading force to destruction of the sample which was previously cyclically loaded. There is a highlighted intersection representing the force that the loading cycles performed previously. As is presented in the graph the number of overshoots rises again after this limit, which is the Kaiser effect.

The relationship between average frequency and RA value (Fig. 5) exhibit a strong sensitivity to the damage modes and the classification enables a warning against final failure. If the real phenomenon is taken into account, most of the structures are subjected to dynamic loading as well as fatigue loading. It is a good opportunity for information if the fatigue loading can be applied to the concrete cylinder for damage modes classification. Both the AE waveform at the low signal and high signal were considered. In the case of fatigue test, the high AE waveform occurred at a few cycles of loading and the AE waveform reduces as the constant load is continuously applied. Therefore, the low AE signal is more dominant. If high and low AE signal is considered, the point in the relationship between average frequency and RA value tends to position itself in the low RA value region [8].

![Figure 4](image-url)  
**Fig. 4**: Response surface for signal amplitude average $m_A$.
4. Conclusions

The acoustic emission method provides a detailed description of the behavior of a sample under load. For quantitative estimation of the damage in structural concrete, AE measurement is applied to a uniaxial compression test of a concrete specimen. AE reflected behavior, which is closely associated with the damage inside concrete. This paper describes the application of a relatively new type of analysis of AE signals (a relationship between average frequency and RA value) which propagate in materials during the loading tests. Inasmuch as it deals with the pilot measurements and the conclusions can be not generalized. This type of analysis appears to be very promising and suitable to practical applications and the results acquired can be employed to advantage in mathematical models to describe the behavior of structures.

5. Acknowledgement

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6. References


