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The Analysis of Acoustic Emission Signals Generated in Cement-based Composites During the Cyclic Loading Test

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Abstract. Acoustic Emission Method (AE) is a non-destructive testing with potential applications for locating and monitoring cracks during structural health management. In this paper, the AE signal properties for identifying the presence of an initial crack are used. AE signals generated under different loading patterns can provide valuable information concerning the structural integrity of a material. The experimental investigation from uniform cyclic loading tests performed on concrete specimens indicated that onset of crack can be identified of AE measurement. Each test specimen was subjected to cyclic loading with the loading force equivalent to one-third of the expected compressive strength value. The total number of loading cycles was one thousand. The AE method has significant potential to be used for in-situ monitoring and evaluation of the current state of structures.

Introduction

Non-destructive testing techniques (NDT) for concrete structures are recently required for maintenance purposes. This results from the fact that concrete constructions are no longer maintenance-free. NDT used to estimation the current state of the concrete structures is 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 construction in service, a detailed inspection is generally conducted by taking the diamant-drilled cores from the structure. Physical properties are generally measured. As for mechanical properties, compressive strength and Young’s modulus are usually determined by conducting an uniaxial compression test [2].

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 [1].

AE parameters obtained by a conventional system are the number of counts, the number of events, an 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 (1)

Average frequency = the number of counts / the duration time (2)

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

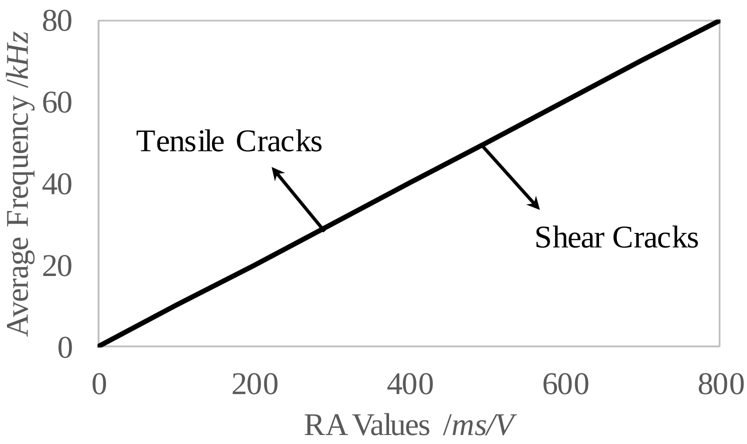

Fig. 1. Relationship between average frequency and RA values for crack classification [7].

Materials and Testing Methods

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 m^3 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.

Fresh concrete composition and properties of the concrete in the fresh and hardened state is in Tab. 1. 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 and 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 (cf. Tab. 1).

The loading was performed in accordance with method B described in EN 12390-13 [8]. 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 goal of the experiment was to observe the behaviour of concrete during loading in the elastic region of the stress-strain curve; for this reason, 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 [8], 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.

Tab. 1. Fresh concrete composition

Material	Amount per 1 m^3 of fresh concrete /*kg*
CEM I 42.5 R	338
Bratčice 0-4 mm	905
Olbramovice 4-8 mm	183
Olbramovice 8-16 mm	667
Sika ViscoCrete 4035	1.77
w/c /–	0.48
Flow table test (fresh concrete) /*mm*	340
Slump-test (fresh concrete) /*mm*	70
Air content (fresh concrete) /*%*	4.5
Density (fresh concrete) /kg/m^3	2 270
Compressive strength (hardened concrete) /N/mm^2	52.2
Tensile strength (hardened concrete) /N/mm^2	5.6

The three acoustic emission sensors (IDK-09) with preamplifiers (AS3K with 35 dB gain) were attached to each specimen using beeswax. 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.

Results and Discussions

The measurements results presented in Fig. 2 shown, that during the loading the Kaiser effect was detected. The Kaiser effect is a special behavior of the material under uniaxial compression [9]. 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. In usual cases, AE activity under uniaxial compression is observed from low-stress level. Some critical microcracks in a loading path usually propagate due to stress applied. When concrete contains a number of critical microcracks, active AE generation is expected from low-stress level due to new crack propagation. In contrast, AE activity in the concrete of few microcracks is considered to be stable and low at low-stress level. Thus, a number of critical microcracks in concrete could be evaluated by monitoring AE activity under uniaxial compression stress.

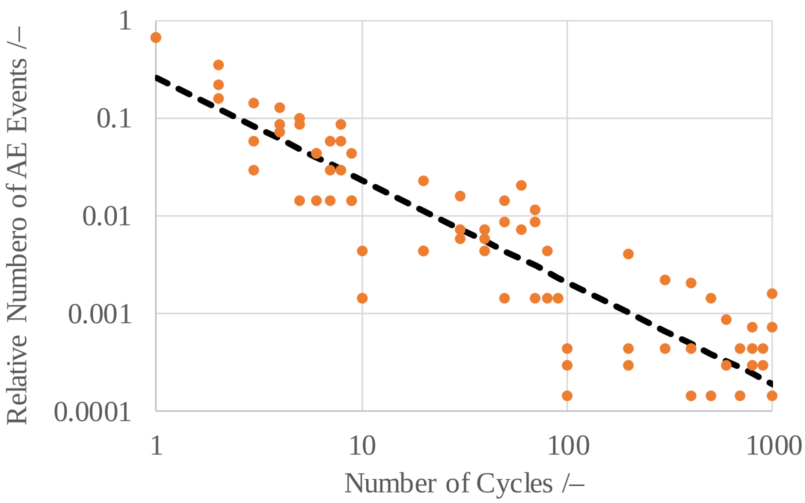

Fig. 2. Kaiser effect in a cyclically loaded concrete specimen

The fundamental approach to the crack classification is the possibility to determine the tensile crack and shear crack in the structure. In crack classification of composite material, a conventional method based on only one parameter is inadequate [10]. 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 relationship between average frequency and RA value has been established by Ohtsu et al. [7,11] as shown in Fig. 1. Shear crack occurred when AE signal has high RA value and low average frequency. Meanwhile, 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 [12].

The relationship between average frequency and RA value (Fig. 3) exhibit strong sensitivity to the damage modes and the classification enables a warning against final failure. In this paper, the application of average frequency versus RA value is limited to the concrete cylinder subjected to static loading. 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 low signal and high signal were considered. In the case of fatigue test, the high AE waveform occurred at a few cycle of loading and the AE waveform reduces as constant load is continuously applied. Therefore, the low AE signal is more dominant. If high and low AE signal are considered, the point in the relationship between average frequency and RA value tends to position itself in the low RA value region (Tab. 2.).

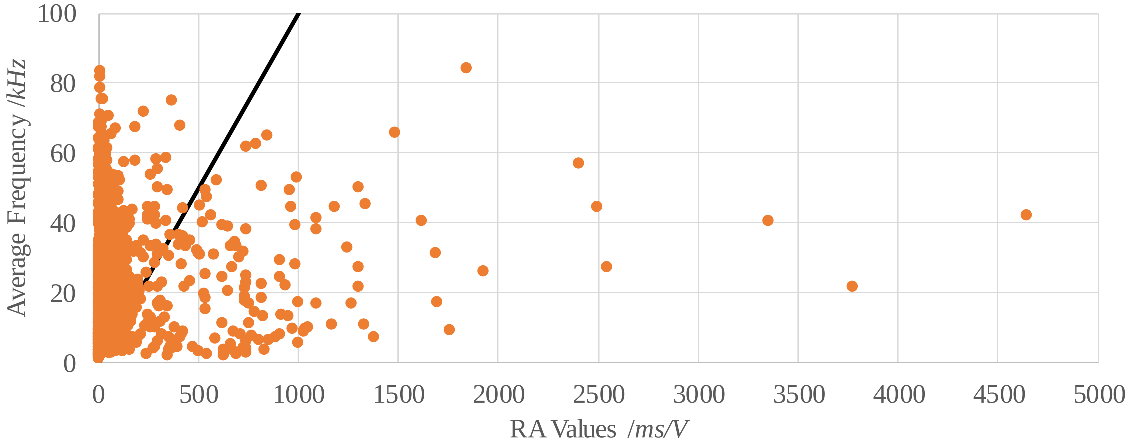

Fig. 3. Types of cracks are shown from the relationship between RA value and the average frequency

Tab. 2. The types of cracks during the first load cycle

Phase of the cycle	Time interval /s	Total Number of AE events /–	Tensile Cracks /%	Shear Cracks /%
Loading	30	732	80.2	19.8
Stress level σ_a	3	191	89.0	11.0
Unloading	30	562	88.1	11.9
Stress level σ_b	3	121	91.7	8.3

Conclusions

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 concrete‘s cylindrical specimens during the cyclic loading compressive uniaxial test. Although, it deals with a pilot measurements and the conclusions can be not generalized. The method of analysis appears to be very promising and suitable to practical applications.

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