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Evaluation of the Acoustic Emission Measurement performed during Freeze-Thaw Cycles Loading

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Abstract. The paper is concerned with the use of the acoustic emission method for testing the frost resistance of air-entrained concrete specimens. The drilling cores obtained in different places of a concrete pillar that was cast along its longer side (on high), that is edgewise, indicate a negligible influence of the casting direction. The acoustic emission method then shows that even if the mechanical properties remain constant, the changes inside the structure can be observed during the freeze-thaw cycles.

Introduction

Concrete blocks have been in use in the civil engineering since the very discovery of cement. During their entire service life, such blocks are exposed to various degradation factors (mechanical and chemical influences, temperature changes, etc.). After several winter and summer seasons, the influence of temperatures is essential. Knowing the impact of temperature fluctuations over time is necessary for the research and, even more, for the civil engineering practice. Apart from the degradation impact of high temperatures, that of low ones is among the most destructive operational factors for many concrete products [1,2]. Freeze-thaw cycles may have a very negative impact on the durability of concrete structures. In terms of research, it is suitable to observe the behaviour of concrete as early as during the actual cyclic freeze-thaw loading [3-5].

Due to its capillarity, concrete is soaked with water. Under freezing then, the temperature fluctuations inside the structure create stress that may damage its structure.

The assessment of the influence of freeze-thaw cycles is usually based on simply monitoring different mechanical characteristics such as moduli of elasticity, etc. [6] Such quantities are obtained after a certain number of cycles. Thus, a concrete is not described continually. In this way, the behaviour is estimated based on different specimens by statistical methods. To observe the status of a specimens, it is suitable to use the non-destructive testing methods [7-10]. Based on acoustic phenomena, the acoustic emission method makes it possible to observe the behaviour of each specimen continually during the entire freeze-thaw cycling process. The acoustic emission signals recorded provided a basis for a more detailed evaluation of materials [11,12].

Acoustic emission events are related to acoustic ultrasound wave that occur in the event of the material being exposed to cracking, that is, plastic deformation. The acoustic waves can be initiated releasing the related energy by micro cracks generated by internal loading. Acoustic emission can cover a wide scale of inaudible and audible frequencies. The acoustic waves captured are usually transformed into electric signals by piezoelectric sensors. The volume of acoustic activity generally depends on the amount of energy released, the distance and orientation of the source in relation to the sensor. The signals are then amplified and recorded in a data collection system. The signals of acoustic waves obtained in this way are then analyzed to determine the level of the resulting damage [13,14].

Experimental set up

To test the frost resistance of air-entrained concrete, drilling cores were used taken from a concrete pillar with parameters shown in Tab. 1. The prescribed water/cement ratio was 0.46. The concrete block was 2.4 m high, 1.8 m wide, and 0.45 m deep. Drilling cores were taken from this air-entrained concrete pillar of different diameters. For the acoustic emission method application, specimens were used with diameters of 150 mm and a length of 400 mm. Such specimens were exposed to a hundred freeze-thaw cycles to be subsequently tested for tensile splitting strength [15].

The acoustic emission sensors were placed on the surface of the concrete specimens. Applied sensors were with diameter 22 mm, height 52 mm, and with internal impedance converter & preamplifier 35 dB. The declared frequency range was up to 600 kHz. The XEDO acoustic emission system made by Dakel (Czech) recorded acoustic emission hits.

Based on a test of fresh concrete, the following data were determined: density 2288 kg/m^3, flow 460/450 mm, slump 180 mm, fresh concrete temperature 28 ^{o}C, and air content 5.0 %. The concreting was done in the vertical direction. The concrete was compacted using an immersion vibrator and treated to prevent moisture leakage.

Note that concrete frost resistance tests are done by alternately freezing and thawing water-saturated beams. One freeze-thaw cycle consists of four-hour freezing and two-hour thawing lasting six hours. The specimens were frozen at -18 ^{o}C and thawed in water warmed at +20 ^{o}C.

To carry out the acoustic emission measurements, a single acoustic emission sensor was attached to the upper base of each specimen as shown in Fig. 1.

Fig. 1: The layout of the test specimens in a freezing device during the frost resistance test.

Table 1: Composition of fresh air-entrained concrete

Material	Content per 1 m^3 of fresh concrete
Cement CEM I 42.5 R	390
Sand 0-4 mm	810
Aggregate 4-8 mm	160
Aggregate 8-16 mm	760
Superplasticising admixture	1.0
Air-entraining admixture	0.6
Workability enhancing admixture	1.6
Water	185

Results

The acoustic emission events were evaluated based on the ring down, i.e., the overshoot counts exceeding a preset threshold (N_{AE}). The overshoot count was evaluated for each loading cycle. Thus, the measurement of 100 freeze-thaw cycles took 600 hours or 25 days. Two specimens were selected to present the evaluation. The first specimen with a wider diameter of 150 mm, that is, a drilling core from the upper part of the concrete pillar, denoted by pt9. The second specimen with a diameter of 100 mm, that is, a drilling core from the lower part of the concrete pillar denoted by pt8.

Depending on the number of cycles N, the frost-resistance coefficient is calculated from the ratio of tensile splitting strengths f_{ct} with N cycles to the reference value (0 cycles) using the equation

$$I_{ft,N} = \frac{f_{ct,N}}{f_{ct,0}} \tag{1}$$

Table 2: Averages mechanical properties

Specimen	Diameter 100 mm			Diameter 150 mm		
Properties / Cycles	0	50	100	0	50	100
Transverse tensile strength f_{ct} [MPa]	3.55	3.45	3.60	3.20	3.25	3.25
Frost-resistance ratio I_{ft}		0.97	1.01		1.02	1.02

In view of the mechanical properties by Tab. 2, measured for reference (without cycles), specimens after 50 and 100 cycles, it can be concluded that the damage of the specimen during the freeze-thaw test were negligible since the tensile splitting strength values measured remain virtually constant with the number of cycles changing, thus, the frost-resistance ratio is close to one.

As compared to the mechanical properties obtained by a destructive method from different specimens with subsequent statistical processing, the acoustic emission method shows the current state of a single specimen. A statistical approach can of course be applied as well, but it is substantially more complicated.

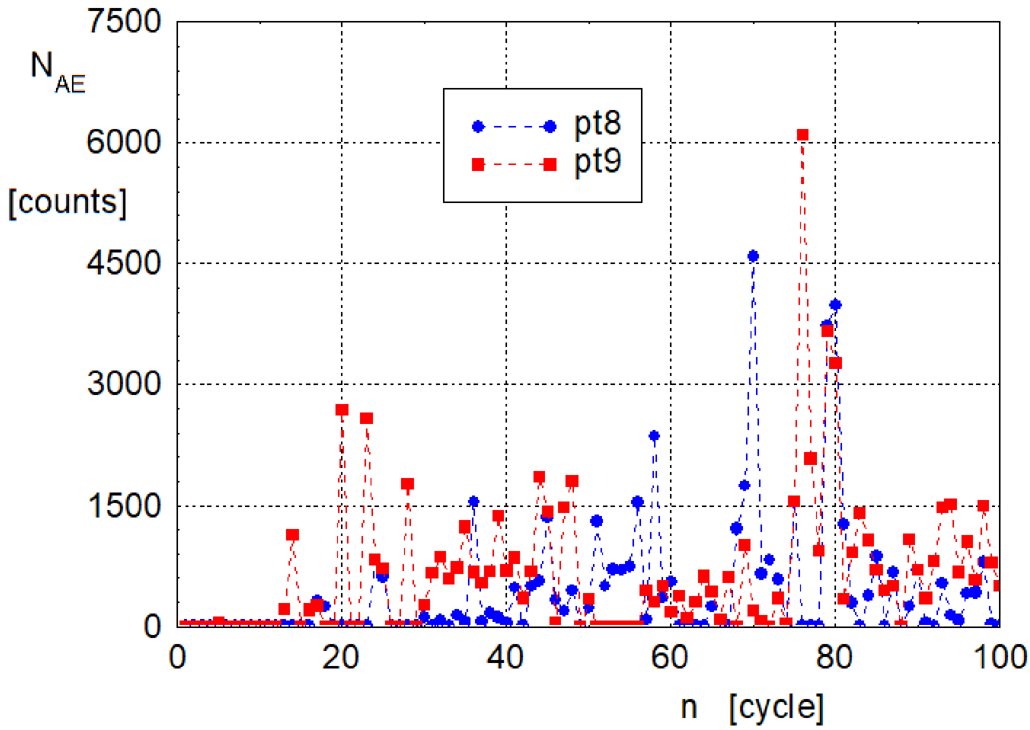

Fig. 2: Acoustic emission overshoot counts N_{AE} versus the number of cycles n for two specimens

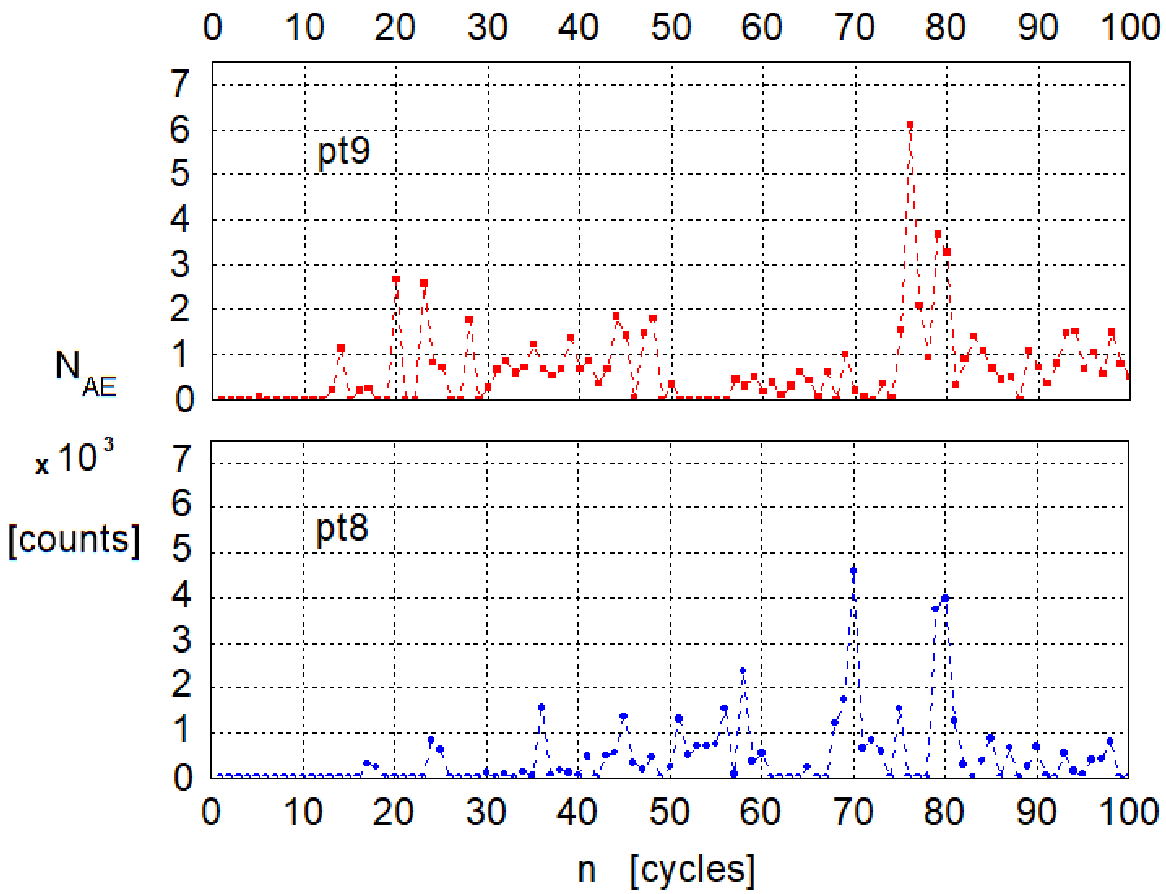

Fig. 3: Acoustic emission overshoot counts N_{AE} versus the number of cycles n for two specimens in separate graphs

Fig. 2 shows the acoustic emission ring-downs for both specimens. Fig. 3 is then used for an easier description of each signal, with one graph corresponding to each specimen. In the event of specimens pt8 and pt9 having the same mechanical properties and as specimen pt8 has a smaller size, its acoustic emission activity can be expected to be less. For the smaller pt8 specimen, the total ring down equals 43160 counts while, for the larger pt9 specimen, it equals 67046 counts. This, however, may not be viewed as a general rule as the acoustic emission activity determined may be influenced by the size of the active cracks as well as by its position within the specimen.

By Fig. 2, the first acoustic emission appears after ten cycles. With the smaller specimen, it occurs somewhat later. The first about twenty cycles show great concrete resistance to cyclic temperature loading. After about fifty cycles, the structure of the material adapts to the external factors with the acoustic emission activity dropping significantly. Next, between 70 and 80 cycles, the acoustic emission activity rises steeply to drop down again.

Conclusions

Measurement and assessment by the acoustic emission method are instrumental in observing the inner structure of air-entrained concrete. It can be concluded that, at present, there is hardly any other method more appropriate than the acoustic emission method for monitoring the state of the inner structure of concrete between the freeze-thaw cycles.

The results obtained make it clear that, despite insignificant changes in the mechanical properties, the acoustic emission activity was recorded in the structure of the specimens. Their size, however, is negligible in terms of the overall structure of the specimens. Determining the total service life would necessitate carrying out experiments until the structure was actually destroyed, which would require a substantial increase in the number of freeze-thaw cycles.

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