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Early-age monitoring of fresh cementitious material by acoustic emission

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ABSTRACT

Concrete properties are mainly affected by the fresh state since it has a significant impact on the long-term concrete performance. In this study, acoustic emission (AE) was applied to monitor the behavior of fresh cement paste. AE is based on the detection of high-frequency elastic waves originating from different material sources. This highly sensitive technique provides data that contribute to a deeper understanding of the different ongoing processes for fresh concrete, as the possible AE sources are many. Characterization of each different source type is difficult and therefore, a combined methodology of AE, capillary pressure in the matrix and specimen deformation was applied to monitor the fresh cement paste.

Keywords: acoustic emission, capillary pressure, cementitious material

1. INTRODUCTION

Cement based materials may develop cracks since the tensile strength is low at an early age. As a result, cracking causes the decrease of the durability of the structure. Therefore, the application of AE technique at very early age, has become the focus of attention. In this case, AE is used in order to clarify the understanding of the several activities in fresh cementitious materials, as well as during hydration of concrete at an early age.

Many researchers studied the effect of cracks in fresh and also hardened state of concrete to determine its significant impact on concrete performance. Van Den Abeele et al. (2009) studied the hardening process in concrete by combining temperature measurement, AE, linear and nonlinear ultrasonic wave spectroscopy [1]. It was shown that most of the activity was recorded after the temperature peak. Specimens reaching higher temperature due to more intense hydration reaction, exhibited also more intensive AE. Chotard et al. (2003) investigated the early hydration of cement paste and the setting of calcium aluminate cement by acoustic emission [2]. The AE in this study was attributed to the drying process, creation of porosity and formation of hydrates. Bella et al. (2016) investigated the effect of the decreasing moisture content on the elastic modulus of cement-based mortar at an early age through single mode resonant ultrasound spectroscopy [3]. Lura et al. (2009) investigated the early-age AE measurements in hydrating cement paste and suggested that the AE activity is caused by creation of gas filled bubbles in the pores [4].

In this study, AE, capillary pressure, settlement, shrinkage and temperature measurement were applied on cement paste to monitor the ongoing processes at an early age. The technique of AE allows monitoring the fresh cement paste immediately after casting and detects the stress waves due to chemical or mechanical activities.

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1.1 AE signal features

The applied AE technique in this research work, based on elastic wave propagation, is presented hereafter. This technique allows a non-destructive evaluation of materials and is able to monitor the changes in materials behavior over a long time [5]. Moreover, this technique is able to detect crack propagation occurring not only on the surface but also deep inside a material [5]. The stress wave is detected by the piezoelectric sensors. The AE signals are recorded on the voltage threshold basis and a typical AE waveform is presented in Figure 1 [5]. The Amplitude describes the highest peak of the signal and is expressed generally in dB. The rise time is the time interval between the first threshold crossing and the highest peak and is expressed generally in µs. The duration is the time interval between the first and last threshold crossing and is also expressed in µs. A “Hit” describes a signal exceeding the threshold and the system channel starts to record the waveform. The average frequency is the obtained number of threshold crossings (counts) divided by the duration and is generally expressed in kHz. The RA value is calculated as the rise time divided by amplitude and is expressed generally in µs /V.

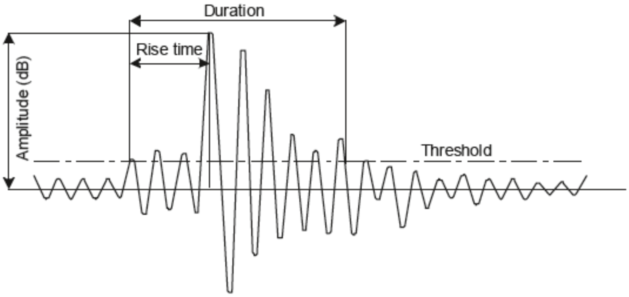

Figure 1. AE signal parameters.

2. EXPERIMENTAL SET-UP

The cement paste monitoring took place in a metallic mold with a dimension of 150 x150 x150 mm^3, see Figure 2. Four AE sensors of type R15 with a resonance frequency of 150 kHz were installed on each side of the form. The threshold for the AE signal is 35 dB and the signals are amplified with a preamplifier by 40 dB. Magnetic clampings were installed on the side of the form to hold the AE sensors during the test. The distance between the AE sensors and the bottom of the form is 100 mm. Two LVDTs sensors were applied to measure the horizontal displacements between the form and the embedded markers in the sample at opposite sides. Furthermore, one LVDT was installed vertically at the specimen surface to measure the settlement. In order to prevent the penetration of the settlement sensors tip into the specimen, the sensor tip was applied on a 20 x20 mm^2 wide metallic wire lattice on the surface of the specimen.

The capillary pressure sensor was set vertically at a distance of 30 mm from the specimen surface. The capillary pressure was measured by a 200 mm long brass tube which was filled with de-ionized water and has an inside diameter of 4 mm. The pressure transducer was coupled to the capillary pressure to monitor the pressure development. In order to monitor the specimen temperature increase, a thermocouple was applied in the specimen. The number of samples performed for this test is 3.

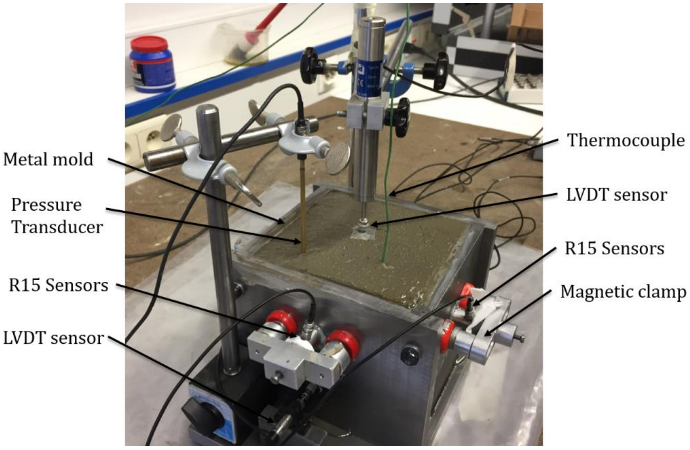

Figure 2. Experimental set-up.

1.2 Materials

Specimens of cement paste were cast using normal Portland cement (Cement CEM I 52.5N) and water. The water to binder ratio was 0.4. Cement and water were added and mixed for 3 min at low speed. Afterwards, the cement paste was poured into the mold of size 150 x150 x150 mm^3 in a single layer. The measured fresh density of the cement paste was 1897 kg/m^3.

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Temperature and shrinkage

The structure formation of cementitious material may last for a long period of time. However, the most significant changes of concrete structure formation occur at very early age. This is noticeably presented by the results of Figure 3. The temperature development and shrinkage of the specimen for 45 hours are shown in Figure 3. The measurement started immediately after pouring the fresh cement paste into the mold. From the beginning of the test to 200 min the temperature of the specimen decreases while the specimen is bleeding. The heat release starts to increase at approximately 290 min and achieves its peak with 44°C after 670 min. This period presents an intensive heat release that is connected to the hydration reaction. Simultaneously, the shrinkage is ongoing until about 460 min but at that point starts to present an inverse trend leading to a maximum expansion at 650 min coinciding with the temperature peak. After that peak the horizontal shrinkage increases (in an absolute value, though technically the numbers decrease due to negative sign) continuously while the temperature decreases.

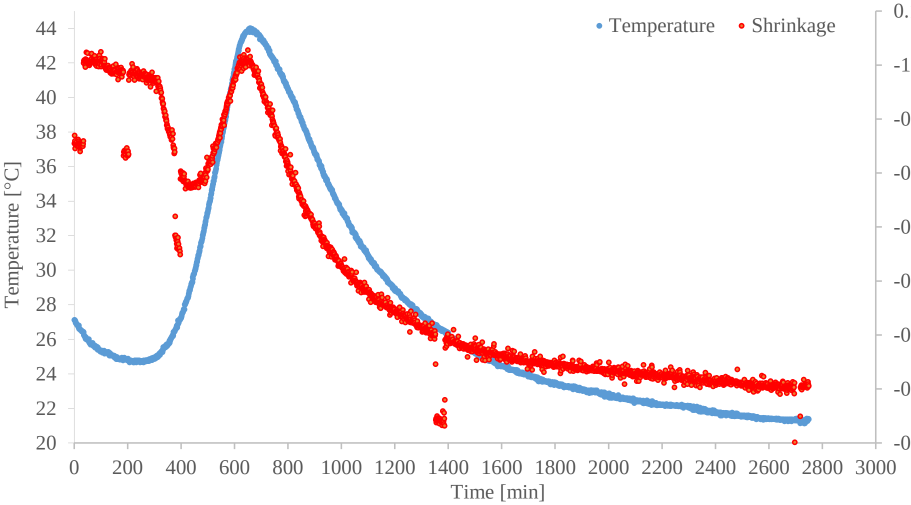

Figure 3. Temperature and Shrinkage versus time.

3.2 Capillary pressure and AE Energy

Figure 4 presents the values of capillary pressure and AE energy as a function of time. The capillary pressure increases rapidly at the beginning of the test. The rapid growth of capillary pressure could be correlated to the self- desiccation due to hydration process and the ongoing water evaporation of the specimen. The capillary pressure increases further and achieves its peak with 11 kPa after 330 min. This progression of capillary pressure is leading to a reduction of the radii of the menisci of the paste [6]. Afterwards, the capillary pressure drops considerably while AE hits with high energy are registered at this time. This period could be related to the air entry into the paste. After that, the capillary pressure remains constant close to zero whereas the energy shows a stepwise increase at 800 min, 1200 min and 2600 min. The increase of energy could be associated with possible cracking (coincides with the air entry point as measured by capillary pressure sudden drop) and friction or detachment of paste from the mould walls.

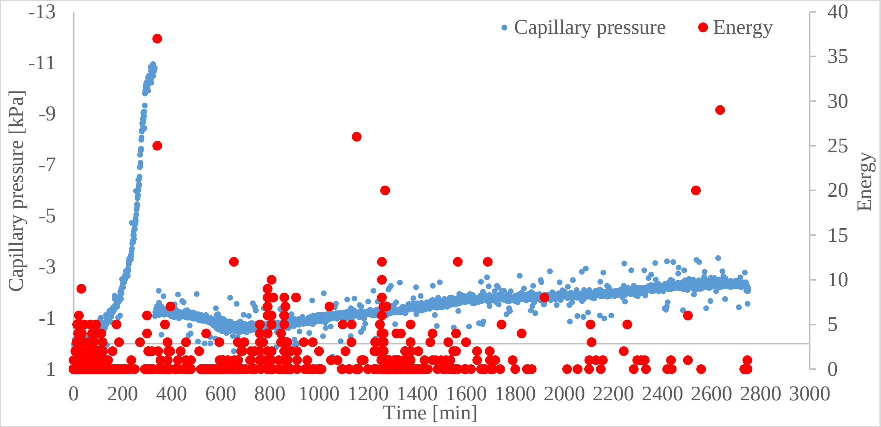

Figure 4. Capillary pressure and AE energy versus time.

3.3 Cumulative hits and settlement

Figure 5 shows the cumulative hits and settlement as a function of time. It can be seen that immediately after casting the AE hits and the settlement increase significantly. The increase of AE hits can be linked to the settlement increase as shown in Figure 5. The solid cement particles settle down and they may cause the increase of AE hits. From 400 min to 600 min the settlement presents a transition from settlement to expansion (opposite movement) while the horizontal shrinkage also presents a volume increase, as shown earlier in Figure 3. This is a strong hint that both these local peaks are due to thermal expansion, since temperature obtains its highest value at that point. At 1254 min a sudden increase of AE hits can be observed while their energy also grows, see Figure 4. Since no other observation is made (i.e. settlement, temperature remain constant) this activity could be related to shrinkage cracking or formation of hydrates. Indeed, this secondary increase of AE after a period of relative silence has been attributed either to shrinkage cracking or the formation of hydrates in [7] and [8].

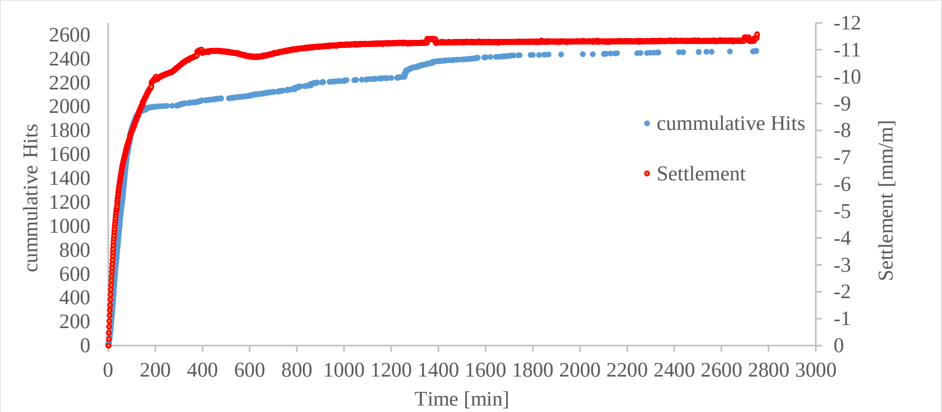

Figure 5. Cumulative hits and settlement versus time.

4. CONCLUSION

The influence of cement paste hardening on AE signals has been investigated using AE method, capillary pressure build-up and specimen deformation measurement via LVDTs. The experimental observations carried out with the combined methods show clearly many AE hits, even from the moment of casting. The experimental results confirmed the efficiency of the highly sensitive non-destructive technique of AE. The main task is to explain the origin of the number of AE recorded. Some basic trends can be mentioned though: the early age AE seems to be well correlated to the settlement of the paste. Also the drop of capillary pressure is escorted by high energy of AE, implying that the air entry point could be correlated with shrinkage cracking. Further tests are needed to validate the observation and to allow assessing the fresh cement paste hydration process.

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