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MONITORING OF FRESH CONCRETE WITH SUPERABSORBENT POLYMERS (SAPS) USING ACOUSTIC EMISSION (AE)

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ABSTRACT

In fresh concrete, early-age shrinkage is affected by many factors, such as thermal deformations moisture loss and the hydration reaction. Novel admixtures for internal curing, like SuperAbsorbent Polymers (SAPs) can be used to mitigate the shrinkage phenomenon. These admixtures strongly modify the microstructure influencing the Acoustic Emission (AE) activity. Acoustic emission has been proven adequate to monitor activities during the curing of fresh cement-based materials. However, so far, it is difficult to distinguish the original mechanisms due to the overlapping nature of the processes that take place. In addition, localization of AE sources is not possible due to the heterogeneous and damping nature of the fresh material. The motivation of this study is to obtain real-time information on the different ongoing processes in fresh concrete, like settlement and shrinkage cracking, using AE and comparing the results to concrete containing SAPs. A preliminary study for 3D source localization in fresh concrete is also performed. The goal is to control concrete curing and confirm suitable final mechanical properties, resulting therefore in more sustainable materials.

***Keywords**:* Acoustic Emission, fresh concrete, superabsorbent polymers, localization.

1. Introduction

Fresh cementitious media present complex and overlapping processes due to water evaporation and cement hydration. While concrete is in the plastic state, the cement particles' movement can lead to early shrinkage cracking which can be critical for the final mechanical properties of the material. The long-term performance of concrete is closely linked to its early age properties; hence it is important to understand and isolate the different mechanisms taking place during hydration. Therefore, monitoring the early-age concrete behavior is important. Non-destructive techniques have gained a lot of attention recently for the characterization of fresh cementitious materials [1]. Acoustic Emission (AE) is a non-invasive monitoring technique that presents a high sensitivity to recording waves released by many processes simultaneously. AE has been lately used by researchers to monitor the hydration process [2,3,4,5]. According to the cumulative activity and the AE parameters, the various curing stages and cracking modes can be detected. For example,

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shear cracks are characterized by lower frequencies and longer duration, than tensile cracks, information that can be very useful when it comes to material or damage characterization.
In fresh concrete, early-age shrinkage is affected by many factors, such as thermal deformations due to the hydration reaction, moisture loss, and hardening due to changes in pore water content. Novel admixtures like SuperAbsorbent Polymers (SAPs) have been successfully used to mitigate the shrinkage phenomenon [6]. SAPs are particles that can swell by absorbing water, up to 500 times their mass, and later release it back to the cementitious matrix promoting autogenous healing [6]. According to the literature, when the action of SAPs is initiated, high bursts of AE data are observed [1]. So far, the investigation of the SAP behavior in fresh cementitious media has been limited to mortar specimens. In the present study, the behavior of a reference concrete mix is compared to that of a mix containing SAPs, to study the SAP influence on the AE behavior of fresh concrete cubes.

2. Materials and methods

2.1 Materials

A reference concrete mixture and a mixture containing SAPs were investigated for this study. Portland cement (CEM I 52.5 N Strong, Holcim, Belgium) was used, with a water-to-cement ratio of 0.35 (REF). River sand, fine stones and coarse gravel stones (sizes 4/8 and 6.3/14) were used in a proportion of 1.27:1.27:2.36 with respect to the weight of cement. The sand and the aggregates were dried in the oven for 48 hours and then let to naturally cool down at room temperature prior to mixing. Superplasticizer MasterGlenium 51 from BASF (Ludwigshafen, Germany) was added at a percentage of 0.6% by mass of cement to ensure sufficient workability.
A second composition (VP400) was made including SAPs in a percentage of 0.2% per cement weight and the same amount of aggregates and sand and cement as the reference mixture. The utilized SAP type was provided by BASF (Ludwigshafen, Germany) and is a copolymer of acrylamide and sodium acrylate with a dry particle size equal to 100 ± 21.5 μm. An additional amount of water, equal to 30 grams per gram of SAP, was added to the mix, to obtain the identical flow as the reference concrete while using the same amount of superplasticizer as the reference cube.

2.2 Specimens

The material was mixed for a total of four minutes in the laboratory concrete mixer, at 361 RPM, with one minute of dry mixing and 3 minutes of mixing with water. Then it was poured into a 150 mm x 150 mm x 150 mm (internal dimensions) metallic mold. Type-K thermocouples were used to monitor the temperature released during the hydration process. The mix was poured into the mold in two layers. Initially, the mold was filled up to the mid-height, and then the thermocouples were placed at the center of the mold. The rest of the mix was added, and the mold was vibrated at a high frequency for 20 seconds until the surface was smooth.

2.3 Acoustic emission

The AE behavior of the samples was monitored by five R15a piezoelectric sensors, with a resonance frequency of 150 kHz using the Micro-II express acquisition system by Mistras Group. Five sensors were attached in total, one on every outer side of the mold, at different heights and one at the bottom, using a coupling agent and magnetic clamps. A schematic view of the experimental setup is represented in Fig. 1.
A sensitive and low threshold was set equal to 35 dB and the AE signals were amplified using a preamplifier 1220A of 40 dB. A Pencil Lead Break (PLB) was performed near every sensor before the initiation, but also at the end of the monitoring, to ensure the coupling efficiency of the sensors to the mold. The measurements started between 10-12 minutes after water was added to the dry materials. Each cube was monitored for approximately three days.

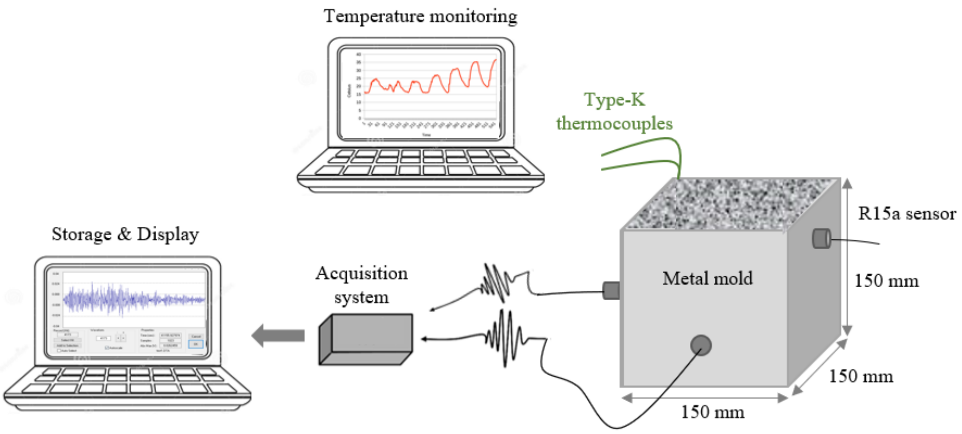


Fig. 1: Schematic view of the experimental setup.

2.4 Source localization

By considering the position of the sensors and the difference in the arrival time on each of them, the source location can be calculated, provided that the wave velocity in the medium is known. In this study, an attempt for a three-dimensional localization in fresh concrete was made for the first time, using the AE Win Software by Mistras Group. For a 3D localization, at least 4 sensors are needed for the algorithm to calculate the location coordinates. The time of the first recorded hit is considered the absolute arrival time, and it is used to calculate the delay in arrival times of the upcoming hits in the event.

Since concrete undergoes hydration and the stiffness increases, the velocity at which the elastic waves propagate changes as well. This makes the localization in the highly attenuative nature of cementitious materials complicated. To overcome this issue, different velocities were used to account for each curing stage and changing stiffness, based on ultrasonic measurements conducted by Lefever et al. [7] on mortar specimens made using the same cement as this study. Although the velocity of mortar is not the same as the one of concrete, a good approximation can be derived from the results of [7]. Early UPV measurements on concrete specimens unfortunately are not possible due to the highly attenuative nature of the material, but also due to the larger required mold thickness compared to mortar. The aforementioned factors result in a significant attenuation of the signal during the first hours of measurements when concrete is still very fresh. The three-day monitoring period was divided into four phases according to the different mechanisms of interest.

3. Results and discussion

3.1 Evolution of AE parameter and temperature during internal curing

The SAP activity was well-captured by the sensors, showing a vertical increase in the cumulative hits, as seen in Fig. 2(a). The cumulative hits for REF were approximately 5000 while for VP400 they were much higher approximately 48000. The initiation of the SAP activity took place at approximately 12 h of monitoring and lasted up to 20 h. To define the time when the SAP action was completed, the hit rate was examined. The time of the SAP activity termination was selected as the time when the hit rate dropped to 10% of the maximum hit rate. Indeed, this time is around between 20 and 21 h. As seen in Fig. 2(a), after 20 h, the slope of the cumulative hits rate starts to decrease, indicating that most of the SAP action was completed.

It is not clear if the increased AE activity is due to the SAPs releasing the entrained water or due to the consumption of the free water by the SAPs. Snoeck et al. [8] studied the release of water from the SAPs towards the cementitious matrix during the cement hydration, using the Nuclear Magnetic Resonance (NMR) method, using the same SAP and cement type as the ones used for this study. The results showed that up to 11 h, SAPs release a little amount of the entrained water after the final setting is reached. Then, up to 22 h, the free water was consumed and a slight decrease in the SAP shape was observed, due to possible debonding of the SAP from the pore wall [9]. After that, the entrained water starts to decrease again, up to 30 h.

Fig. 2b shows the temperature development at the center of the cube. The reference cube exhibited slightly higher temperatures, although the slope of the curve during the acceleration period is the same for the two mixtures. The peak temperature for the reference specimen reached 31.2 °C, while for the specimen with SAPs the peak value was 30.8 °C. The ambient temperature during monitoring varied between 28 °C and 29 °C. The raw materials were left at room temperature before mixing. The high AE activity starts around 12 h which coincides with the end of the acceleration period of hydration (peak of the temperature curve). This could indicate that most of the free water is consumed, lowering the relative humidity, hence, causing the SAPs to release their entrained water. The end of the SAP activity seems to coincide with the end of the deceleration period of hydration.

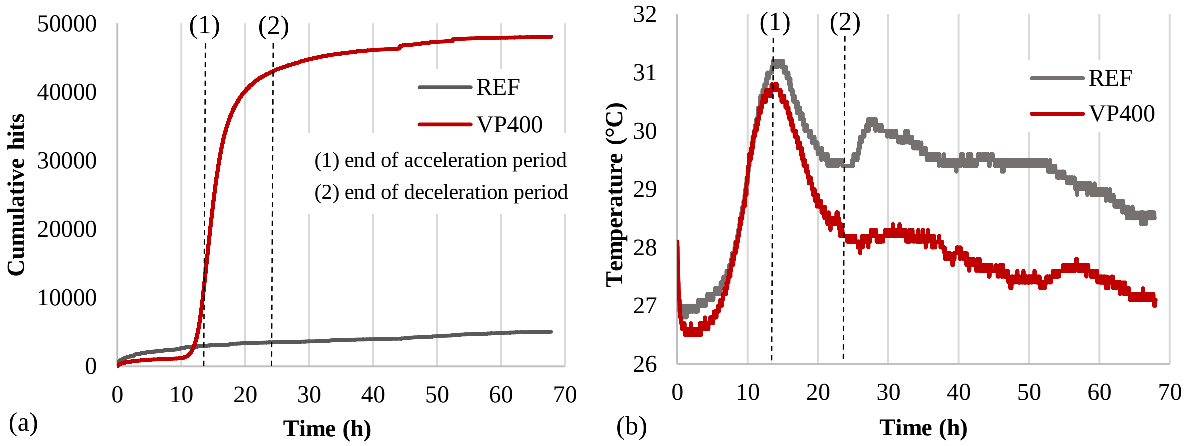


Fig. 2: (a) Cumulative activity; (b) temperature evolution.

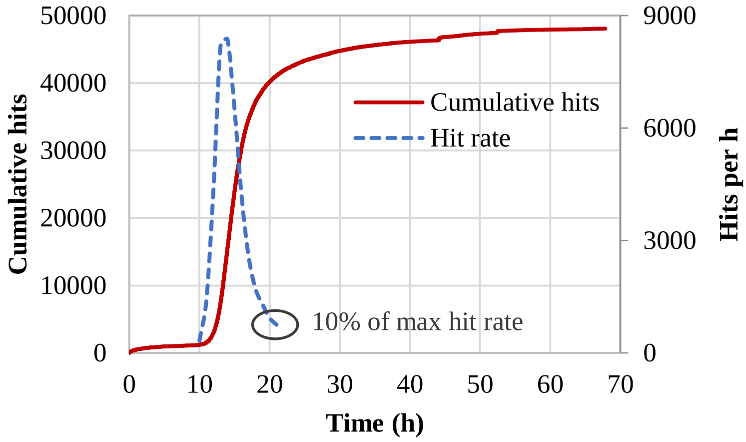


Fig. 3: Cumulative activity and hit rate of VP400.

Mechanisms such as settlement, shrinkage cracking, SAP action and detachment of the specimen from the mold can be characterized by various AE parameters. Fig. 4 shows the moving average of the amplitude and risetime of the two specimens during the monitoring period. Amplitude is one of the most important AE parameters since it is closely related to the energy that the emitted elastic waves. Risetime can be useful to characterize mechanisms such as the type of cracking.

The curing process was divided into four phases, which were subsequently used to distinguish the events during localization, as shown in Table 1. The settlement, which takes place during the first two hours after casting [2], presents higher amplitudes and a concentrated AE activity compared to the rest of the processes. The SAP activity is the denser part of the amplitude graph shown in Fig. 4a. The AE activity of the VP400 cube is generally characterized by lower amplitudes compared to the REF cube, which can be explained by the fact that SAPs mitigate the shrinkage cracking that exhibits higher amplitude bursts than the rest of the processes. This is more profound in the final stage of hardening, where shrinkage cracking is more likely to occur. The SAP cube shows again lower amplitudes, whereas the reference cube presents higher amplitude peaks, which are possibly recorded due to cracking.

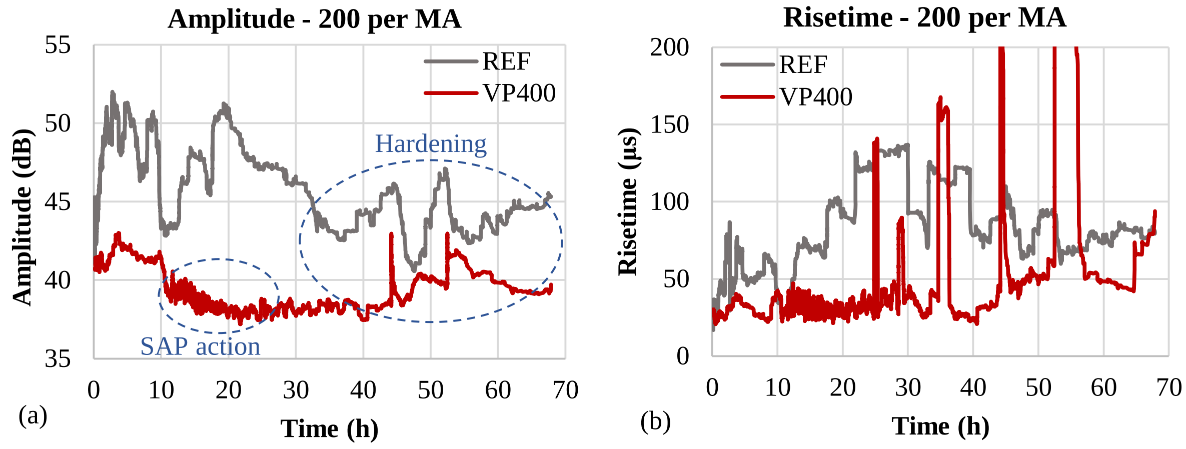


Fig. 4: 200 per moving average of (a) amplitude and (b) risetime evolution.

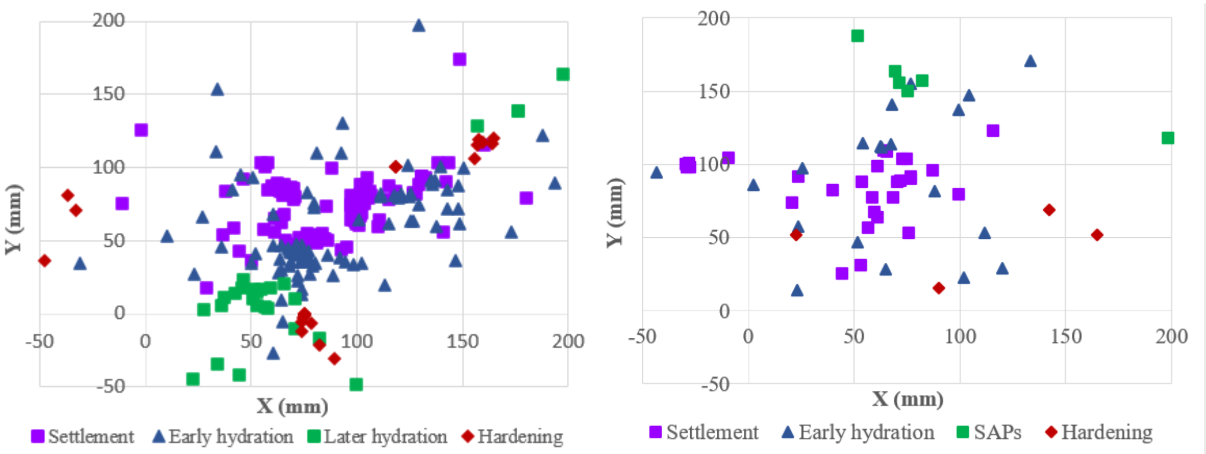
3.2 Source localization

3D source localization in fresh concrete was performed, using the localization algorithm implemented in the AE Win software. Since the sensors are attached to the metallic mold and not directly to the material itself, the waves propagate through two different materials and possibly exhibit a nonlinear path before they reach the sensors, something that is not considered in the localization algorithm. Still, localization gives a first impression of how the curing of concrete evolves in terms of AE events, while still being in the process of being optimized.

Table 1: Phases of the curing process, time frames & UPVs utilized for the distinction of the AE events.

CURING PHASE	*MONITORING TIME (H)*	*UPV(M/S)*
(1) Settlement	0-2	500
(2) Early hydration	1-12	1000
(3) Later hydration/SAP activity	12-20	2000
(4) Hardening	20 to end	3000

A top view of the AE events for each curing stage is depicted in Fig. 5, while Fig. 6 shows the 3D view. During settlement, most of the activity is concentrated near the center of the mold for the REF specimen. As concrete hardens, the events seem to move towards the outer sides of the specimen. Even though VP400 exhibited a considerably higher number of hits compared to REF, the number of AE events was higher for the REF specimen. This might be explained by the fact that the events in REF were of higher amplitude, and thus were more easily recorded by at least 4 sensors, resulting in reliable localization of the source. Another possibility for the low number of recorded events in the VP400 might be the increased porosity of the matrix due to the SAP inclusion, which makes the material even more attenuative for wave propagation. It should also be mentioned that during the internal curing period, and specifically after 12 h, the recorded hit rate is quite high, implying that several sources may be active almost simultaneously and effectively being overlapped in a single waveform, making the localization even more complicated.



(a) (b)

Fig. 5: Top view of AE events for (a) REF and (b) VP400.

When observing the 3D view of the events, it seems like the majority is located at the mid-height of the cube and towards the bottom. Sources occurring at the center of the mold are easier to localize since they have approximately the same distance from all the sensors. Moreover, the waves have to go through the metallic mold to reach the sensors, something that also impacts the accuracy of the localization.

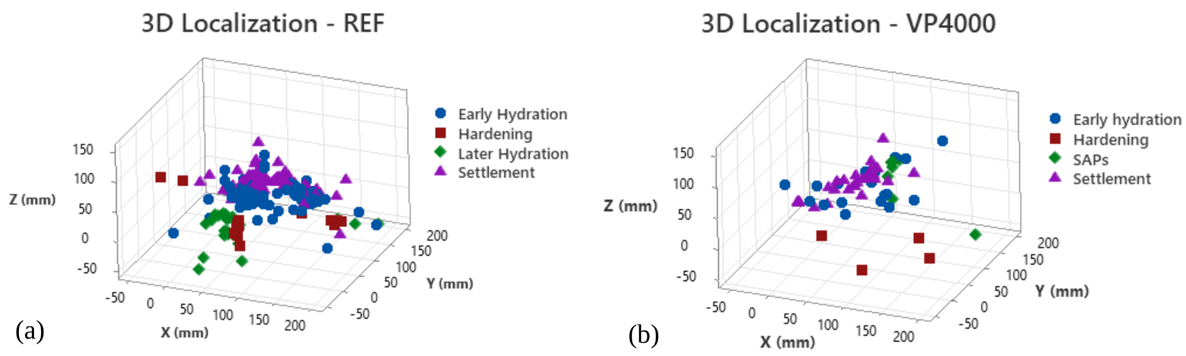


Fig. 6: 3D view of AE events for (a) REF and (b) VP400.

4. Conclusions

Acoustic emission monitoring was performed on fresh concrete cubes, with and without the presence of superabsorbent polymers to monitor the curing process. The temperature inside the specimens was also monitored. A study of three-dimensional localization in fresh concrete was done for the first time.

The specimen containing SAPs exhibited in general a lower temperature evolution, especially during the later stages of hydration, which can be linked to the delay that the SAPs cause in the hydration process. Most of the SAP activity was completed at around 20 h, although more investigation is needed to better understand the nature of the increased AE activity in SAP concrete. The end of the SAP activity seems to coincide with the end of the deceleration period of hydration, as seen from the graph of the temperature evolution.

The SAP concrete exhibited a significantly higher number of hits compared to the reference concrete. The initiation of the SAP activity was accompanied by a rapid increase in AE hits, and the water release started approximately 12 hours after mixing and lasted up to approximately 20 hours. The concrete containing SAPs was characterized by lower amplitude values throughout the monitoring period compared to the reference concrete, which confirms that SAPs mitigated shrinkage cracking that is characterized by signals with high amplitudes.

The curing process was divided into four phases, and different wave velocities were applied to account for the changing stiffness of concrete as it undergoes hydration. The 3D localization showed a wide distribution of events for the different processes, while numerical simulations should be conducted to account for possible nonlinear paths between the source and the sensors.

5. References

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