# The sensitivity of Acoustic Emission (AE) for monitoring the effect of SAPs in fresh concrete

*Eleni* Korda[1,2*], *Eleni* Tsangouri[1], *Didier* Snoeck[3], *Geert* De Schutter[2] and *Dimitrios* G. Aggelis[1]

[1]Vrije Universiteit Brussel, Department of Mechanics of Materials and Constructions, 1050, Brussels, Belgium
[2]Ghent University, Department of Structural Engineering and Building Materials, B-9052 Ghent, Belgium
[3]Université Libre de Bruxelles, BATir Department, B-1050, Brussels, Belgium

**Abstract.** Fresh concrete is characterized by numerous processes taking place simultaneously such as settlement, hydration, early-age cracking and shrinkage. Those processes have a strong impact on the strength and durability, hence monitoring the material at an early stage is essential to ensure the required performance. Acoustic Emission (AE) is a non-destructive, highly sensitive technique that records elastic waves propagating through the medium and has proven to be adequate to monitor the complex processes taking place at an early age. In this study, the method of AE is applied on fresh concrete cubes with or without the addition of SuperAbsorbent Polymers (SAPs). SAPs are particles that have been recently used for internal curing or self-healing of cementitious materials. The water-releasing action of SAPs is accompanied by high AE activity. The purpose of this study is to investigate the possibility to control the internal curing of concrete based on real-time AE data, as well as to make projections towards the final mechanical properties while still at a young age, in order to ensure the desired concrete performance.

## 1 Introduction

Concrete presents complex and overlapping processes like water evaporation, shrinkage, and cement hydration that may result in early-age cracking and influence the final mechanical properties. Physical and chemical phenomena taking place at an early stage are closely related to the final strength and stiffness of concrete. Autogenous shrinkage and early-age cracking can lead to a degradation of a structure's functionality and performance which in turn results in high-cost repair and maintenance techniques.

Even though nowadays concrete can be designed with very low porosities, high-performance concrete is more sensitive to early-age cracking than normal concrete. The need of finding alternative methods for avoiding concrete cracks in structures, to prevent failure or collapse is, therefore, a necessity. The early-age shrinkage cracking phenomenon can be mitigated with the addition of novel admixtures that promote internal curing, such as SuperAbsorbent Polymers (SAPs). These polymers act as an internal curing agent for concrete by providing water for longer, promoting therefore continuous hydration [1].

This paper is focused on monitoring the internal curing of concrete with superabsorbent polymers using the technique of Acoustic Emission (AE). SAPs are particles that can swell by absorbing water when exposed to it, and later release it back to the cementitious matrix promoting internal curing and therefore autogenous healing [2].

Autogenous healing can lead to the formation of new hydration products, that contribute to the final strength of concrete. SAPs have been proven successful to mitigate autogenous shrinkage that occurs in concrete at an early age. Besides mitigation of autogenous shrinkage, SAPs can be added to cementitious materials to increase the freeze-thaw resistance [1,3], and induce self-sealing and autogenous healing effects [1,4].

Monitoring of early-age concrete is important to understand the processes that take place in the material. Non-destructive techniques, such as AE and Ultrasonic Pulse Velocity (UPV) have gained a lot of attention recently for the characterization of fresh cementitious materials [5,6]. Acoustic emission is a passive, high-sensitivity monitoring technique that records elastic waves propagating through the medium and has been proven adequate to monitor the different processes taking place in concrete at an early stage [7,8]. AE is useful when it comes to collecting real-time data from the interior of the material and providing information just a few minutes after casting the material. The cumulative activity and the AE parameters can be used to detect and interpret different curing stages and cracking modes. However, AE is mostly used in monitoring hardened concrete and the research conducted so far on fresh concrete is limited.

Literature has shown that SAPs have a strong interaction with the cementitious matrix and this action is accompanied by high bursts of AE data [9]. The role of SAPs is to mitigate shrinkage and shrinkage cracking. However, once they are activated (due to water evaporation and capillary pressure increase) their action providing moisture in concrete has a specific duration.

* Corresponding author: eleni.korda@vub.be | eleni.korda@ugent.be

In certain cases, especially under harsh conditions, it would be desirable to extend their active period, so that the material can stay hydrated for longer. Water is proven essential for autogenous healing and internal curing through continuous hydration since it is necessary for the chemical reaction that leads to the formation of the hydration products and by maintaining the internal Relative Humidity (RH).

The increased AE activity was exploited in this study and acted as a guide to actively control the internal curing of concrete. Specifically, when AE started to increase, indicating SAP activation and internal water release, water was sprayed on the surface. The extra water is expected to decrease the capillary pressure and postpone or slow down the activity of SAPs, which will maintain their water until the pressure increases again at a later time. This way the internal curing can be prolonged in ordinary concrete. This repetitive action is shown by alternating periods of high and low AE activity (activation and de-activation of SAPs) demonstrating the capacity of AE to control the process.

Ultrasonic Pulse Velocity (UPV) is another interesting, active monitoring method to assess concrete quality at a hardened stage. Phase velocity is sensitive to frequency, aggregate, and water content, while at the same time can give important information about crack development at the hardened matrix. UPV can also be used to evaluate the grade of the self-healing and stiffness increase at a material level, but also the repair efficiency of structures, by comparing velocities before and after the treatment.

The purpose of this investigation is to control for the first time the internal curing of concrete with SAPs, based on real-time AE data. Preliminary results are shown, based on water treatment that is applied on the concrete surface, to monitor the influence on the SAPs. The de-activation and re-activation of SAPs are monitored through AE. The effect of the water treatment on the hydration process is briefly discussed. Finally, the influence on the final mechanical properties, such as compressive strength and pulse velocity is also investigated. The goal is to control internal curing and make projections towards the final mechanical properties while still concrete is at a young age, ensuring therefore the desired mechanical performance.

# 2 Materials and methods

## 2.1 Materials

Two compositions were chosen for this study. A reference mixture, and a mixture containing Superabsorbent Polymers (SAPs). The reference composition, named REF in this paper, was made with Portland cement (CEM I 52.5 N Strong, Holcim, Belgium), and water to cement ratio of 0.35. Coarse gravel stones, fine stones (sizes 6.3/14 and 4/8) and river sand were added in a proportion of 2.36:1.27:1.27 with respect to the mass of cement. The aggregates and sand were dried in the oven for 48 hours and were let to cool down naturally, at room temperature, prior to mixing. Superplasticizer (Glenium 51, conc. 35%, BASF) was added to ensure sufficient workability, at a percentage of 0.6% by cement weight.

A second composition named SAP was investigated, which contained 0.2% SAPs per cement weight while having the same amount of aggregates, cement, sand and superplasticizer as the reference mixture. The utilized SAPs were provided by Floerger SNF, and were a bulk-polymerized, cross-linked copolymer of acrylamide and acrylate, with a particle size $d_{50}$ of approximately 250 μm. This type of SAP has a swelling capacity of 308.2 ± 4.7 g/g SAP in demineralized water and 37.9 ± 1.6 g/g SAP in cement filtrate solution [10]. The determination of the swelling capacity is explained in detail in [11]. The particular SAPs were used in this study as an agent to stimulate internal curing. To obtain an identical flow as the reference mix and account for the water amount initially absorbed by the SAPs, an extra amount of water, equal to 20 grams per gram of SAPs was added to the mix. Both mixtures showed the same workability as indicated by the slump test.

For both compositions, a second series of specimens was studied, where a water surface treatment was applied at different times during monitoring. These specimens are named REF_W and SAP_W. The water used in this study was ambient-temperature tap water.

## 2.2 Specimens

The studied specimens were 150 mm concrete cubes. The mixture was prepared at a laboratory concrete mixer, where the material was mixed at 361 RPM. The total mixing time was four minutes – one minute of dry mixing, followed by three minutes of mixing with water. Then the material was poured into a 150 mm (internal dimensions) metallic mold.

Type-K thermocouples were inserted to monitor the temperature released during the hydration process. The mix was poured into the mold in two layers. Initially, the mold was filled until the mid-height, then the thermocouples were placed at the center of the mold, and finally, the rest of the mix was added. The mold was vibrated for 20 seconds between each layer, at a high frequency. Each specimen was monitored for approximately two days and then sealed and cured at ambient conditions (T = 20±1 °C, RH = 50-60%) for 28 days before being subjected to UPV and compression tests.

## 2.3 Methods

The AE method is a high-sensitivity technique that records waves released by irreversible material processes. The material is monitored by piezoelectric transducers which are placed on the surface using a coupling agent. The transient pressure changes are transformed by the piezoelectric elements into electric waveforms. Preamplifiers are used to amplify the signal before storing it on the acquisition board where the waveform parameters are analyzed [7]. To ensure the coupling efficiency of the sensor to the material, the Pencil Lead Break (PLB) test is performed. Through the PLB method, a wave signal is generated by breaking the lead of a mechanical pencil with a diameter of 0.5 mm close to the sensor. The sensor is then able to record the signal, and if the maximum amplitude of the sensor is reached, the coupling of the sensor to the mold/material is considered satisfactory.

Five R15a piezoelectric sensors of a 150 kHz resonance frequency were used to monitor the AE activity, while the acquisition was performed by Micro-II express acquisition system by Mistras Group. The sensors were placed at every outer side of the mold, at different heights, using magnetic clamps and a coupling agent. A threshold of 35 dB was set to filter out environmental noises. The signal was amplified by 1220A preamplifiers of 40 dB. The coupling efficiency of the sensor to the mold was ensured by performing PLB close to every sensor before the initiation of the monitoring, as well as at the end.

Temperature measurements were conducted using type K thermocouples at the center, but also on the surface of the concrete cubes. The acquisition started approximately 10-14 minutes after water was added to the dry material. All measurements were performed at ambient conditions (T = 20±1 °C, RH = 50-60%). A schematic view of the experimental setup can be found in Fig. 1.

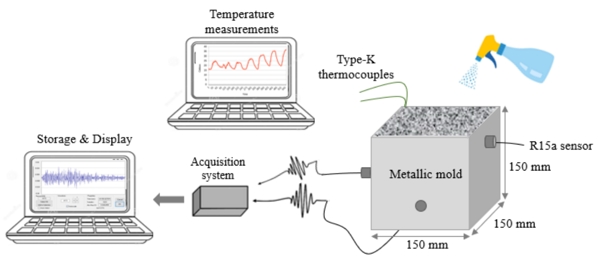


**Fig. 1**. Experimental setup.

The attempt to actively control concrete curing was performed by means of spraying water on the surface of the specimens after the AE activity started to increase due to SAPs presence. When the AE signal increased, indicating the SAP activation, the surface was wetted, and that resulted in a postponement of the SAP action. Fig. 2 shows the AE cumulative activity of a reference concrete and a SAP concrete and when SAPs are activated. The time of the surface wetting was based on the time that the SAP action initiates, which was approximately 15 hours after casting. Even when SAPs are activated, it takes a certain time for the cumulative AE curve to increase, and to give a clear view of the active phenomenon. Therefore, a layer of water equal to 20 grams was sprayed approximately an hour after SAP activation, at 16, 18, and 20 hours from the start of the monitoring.

At 28 days of curing, Ultrasonic Pulse Velocity (UPV) measurements were conducted using a commercial ultrasonic pulse analyzer of a 54 kHz frequency. The instrument is conforming to Standards EN 12504-4 and ASTM C597. Ultrasonic testing was applied directly on the hardened concrete surface, providing information on the pulse velocity and stiffness of the material. Elastic waves are generated from one sensor (emitter), travel through the medium and are captured by a second sensor (receiver), in a certain transit time, allowing for the wave velocity calculation.

After the pulse velocity was measured, specimens were subjected to a compression test to determine their strength. A hydraulic pressure machine with a maximum capacity of 5000 kN was used.

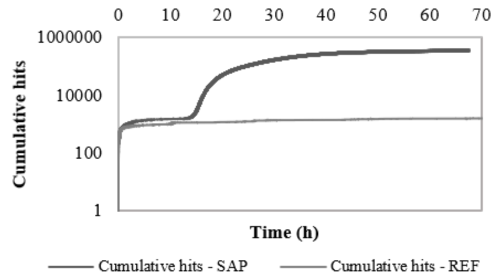


**Fig. 2.** AE cumulative activity of reference concrete vs SAP concrete.

## 3 Results

### 3.1 Impact on acoustic emission activity

#### *3.1.1 Cumulative activity*

The effect of water surface treatment on the curing of concrete containing SAPs was monitored for this study, using the AE technique. The AE cumulative activity acted as a guide for the time of the surface water treatment application. When SAPs were activated, the cumulative activity increased and water was sprayed on the surface of the specimens. After the water treatment, a change in slope can be seen in the cumulative hits curve, which indicates that the SAP action was decreased. This type of SAPs tends to release the water all at once when exposed to harsh dry conditions [12]. The rewetting of the concrete surface influences the internal RH of the matrix and forces the SAPs to retain the entrapped water for a longer time, rather than releasing it all at once, stimulating ongoing hydration, which in turn promotes autogenous healing. Preliminary results are shown below.

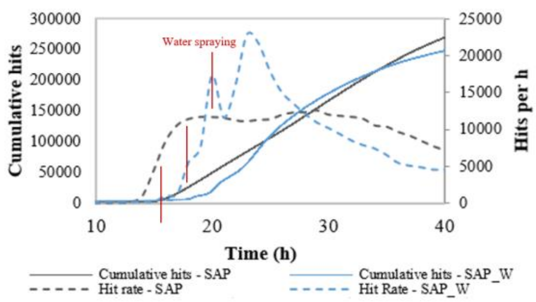


**Fig. 3.** Cumulative hits and hits rate of SAP vs SAP_W from 10-40 h.

Fig. 3 shows the cumulative activity of the monitored specimens containing SAPs. The onset of the SAP activity was in both cases around 15 hours. The red lines indicate the water spraying. For the normal SAP concrete, the hit rate is almost constant for more than 10h. However, for the SAP_W local peaks are observed, which are attributed to the external water effect, as received by AE.

The water addition resulted in a hit rate drop and delayed the rise of the cumulative activity as seen in Fig. 4. Since the rapid increase in the AE activity is connected to the water being released by the SAPs, the moderation of the AE hits indicates that the action is postponed. After the surface water is exhausted the slope increases as well, indicating the re-activation of SAPs. This way, SAPs can retain the water for a longer time, prolonging therefore internal curing and hydration, something that could result in better final mechanical properties.

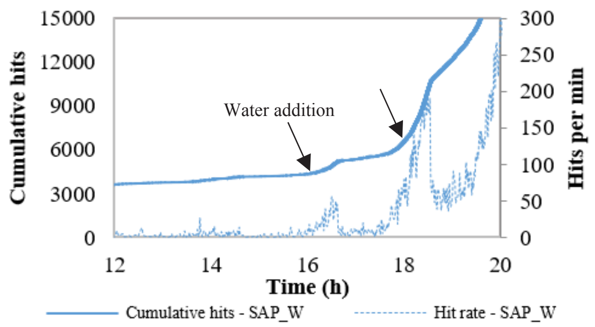


**Fig. 4.** Impact of water addition to cumulative hits and hit rate evolution.

The same treatment was applied to the reference concrete; however, no noticeable results were seen regarding AE activity, apart from a decreased overall number of AE hits as Fig. 5 shows.

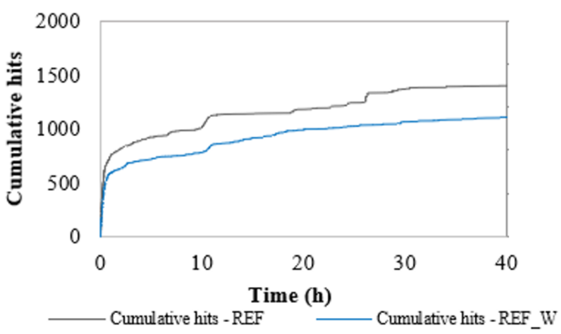


**Fig. 5**: Cumulative activity of REF and REF_W.

### 3.2 Impact on hydration

#### *3.2.1 Temperature evolution*

The temperature of the cubes was monitored in the core as well as at the surface of the cube. The evolution of temperature can give information on the hydration reaction and whether it is prolonged when the surface water treatment is applied.

Fig. 6 shows the temperature evolution of the two SAP specimens. The results showed that the temperature peak was reached at 16.18 h for the SAP specimen while for the SAP_W the first peak was reached at 17.45 h. This could be linked to the fact that the hydration reaction is partially extended when the concrete surface is treated with water. Nonetheless, the results are preliminary, and more experiments need to be conducted to confirm this behavior.

Since SAP water seems to be stored for a longer time with water surface treatment, the possibility of lowering/optimizing the amount of SAPs to minimize the impact on the mechanical properties should also be examined in the future. High amounts of SAPs increase the matrix porosity, decreasing therefore the compressive strength.

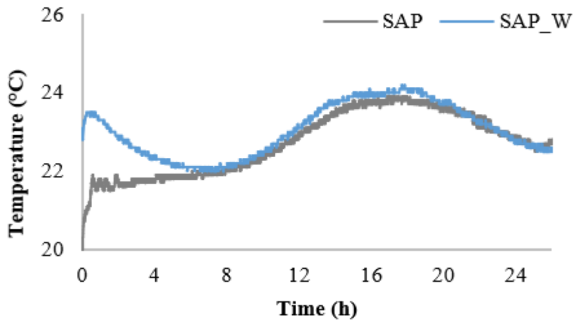


**Fig. 6**: In-core temperature evolution for the SAP specimen and the SAP with water addition after SAP activation (SAP-W).

### 3.3 Impact on the mechanical properties

#### *3.3.1 Pulse velocity and compressive strength*

To investigate further the impact of the water surface treatment on concrete curing, the final mechanical properties were studied. Better internal curing results in greater final properties. At 28 days of age, the compressive strength, as well as the ultrasonic pulse velocity, were measured. UPV can be linked to concrete's modulus of elasticity and density and provide important information regarding the efficiency of the internal curing of concrete.

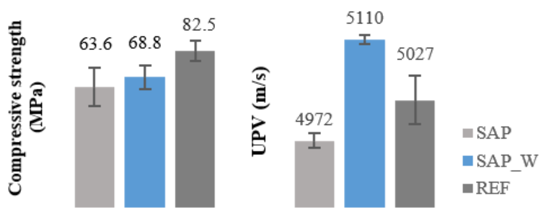


**Fig. 7**: Average compressive strength and UPV at 28 days.

The results showed that the UPV was enhanced for the SAP_W concrete as shown in Fig. 7. The compressive strength of the SAP_W concrete showed a slight increase as well. Re-wetting the surface causes the SAPs to retain their water for longer. Hence, early-age crack formation and shrinkage are less likely to occur within the matrix. Even though SAPs increase the porosity, resulting therefore in a reduction of strength, the water treatment compensates for the increased number of voids. The compressive strength and pulse velocity of the SAP concrete improved when the water treatment was applied. The pulse velocity of the SAP_W concrete showed a higher average value compared to the rest of the samples, indicating a stiffness increase. This could be attributed to the fact that continuous hydration is promoted through SAPs with the water addition, providing more efficient internal curing.

The enhancement of the mechanical properties cannot be attributed to a specific mechanism at this point. The study is preliminary, hence more experiments need to be conducted to obtain more reliable results. Methods such as the scanning electron microscope need to be used in the future to analyze further the mechanisms taking place when the concrete surface is re-wetted, by examining the hydration products being formed within the pores that are created by the SAPs.

## 4 Summary and discussion

The sensitivity of Acoustic emission (AE) to monitoring concrete with SuperAbsorbent Polymers (SAPs) was investigated in this study. The purpose is to control for the first time the internal curing of concrete containing SAPs, based on real-time AE data. Water treatment is applied on the concrete surface, to monitor the influence on the SAPs. The de-activation and re-activation of SAPs are monitored through AE and preliminary results are obtained. The effect of the water treatment on the hydration process is briefly discussed. Finally, the influence on the final mechanical properties is also investigated.

The results showed that re-wetting the concrete surface results in a decrease in the AE hit rate for the SAP concrete, which is related to the water release. The external layer of water causes changes in the pressure state within the matrix and forces therefore SAPs to retain their entrapped water for longer, extending internal curing.

The temperature peak in the core of the specimen, which is closely related to hydration, was delayed by approximately 1.5 h for the externally water-treated specimen. The more efficient internal curing provided by the SAPs seems to cause a delay in the hydration process. However, more experiments need to be conducted to have solid conclusions on this behavior.

The enhancement of internal curing was finally confirmed when the final mechanical properties were measured. The ultrasonic pulse velocity as well as the compressive strength were measured at 28 days of age. The compressive strength of the SAP concrete was improved when the surface water treatment was applied, compared to the SAP concrete with no water treatment. Ultrasonic pulse velocity exhibited similar results. The water treatment increased the UPV of SAP concrete, signifying a stiffness increase.

Active control of concrete curing using AE is a technique that provides promising results. However, more research needs to be conducted considering that this is the first attempt to actively control concrete curing. The microstructure of the matrix should be examined using a scanning electron microscope, to confirm that hydration products are formed inside the voids that SAPs create. Capillary pressure measurements should also be conducted while monitoring the specimens, to confirm that the capillary pressure drops and increases again, resulting in a deactivation and re-activation of the SAPs. Internal relative humidity measurements should also be performed to assess the water content evolution within the material.

Financial support of the Research Foundation Flanders (FWO-Vlaanderen) through Projects No G019421N, is gratefully acknowledged.

## References

1. N. De Belie, E. Gruyaert, A. Al-Tabbaa, P. Antonaci, C. Baera, D. Bajare,… & H. M. Jonkers, Advanc. Mater. Interfaces, **5**, 17 (2018).
2. D. Snoeck, L. Pel, & N. De Belie, N. Scientific reports, **10**, 1 1-6, (2020).
3. V. Mechtcherine, C. Schröfl, M. Wyrzykowski, M. Gorges, P. Lura, D. Cusson, J. Margeson, N. De Belie, D. Snoeck, K. Ichimiya, S-I Igarashi, V. Falikman, S. Friedrich, J. Bokern, P. Kara, A. Marciniak, H-W Reinhardt, S. Sippel, A. Bettencourt Ribeiro, J. Custodio, G. Ye, H. Dong, J. Weiss, Mater. Struct., **50**, 14 (2017).
4. D. Snoeck, K. Van Tittelboom, S. Steuperaert, P. Dubruel, N. De Belie, polymers, J. Intell. Mater. Syst. Struct. 25,1, 13–24 (2014).
5. T. R. Naik, V. M. Malhotra, J. S. Popovics, Handbook on Nondestructive Testing of Concrete, Second Edition, pp 8-1; 8-19 (2003).
6. S. N. Iliopoulos, Y. E. Khattabi, & D. G. Aggelis, J. Nondestruct. Eval., **35**, 3, 1-11 (2016)
7. D.G. Aggelis, C.U. Grosse, T. Shiotani, Acoustic Emission Testing, 2nd Edition, Springer, pp. 339 - 359, (2022)
8. E. D. Dzaye, G, De Schutter, D.G. Aggelis, Cem. Concr. Research, 129, 105964, (2020).
9. G. Lefever, D. Snoeck, N. De Belie, S. Van Vlierberghe, D. Van Hemelrijck, D., & D. G. Aggelis, Sensors, **20**, 10, 2959 (2020).
10. E. Gruyaert, B. Debbaut, D. Snoeck, P. Díaz, A. Arizo, E. Tziviloglou, ... & N. De Belie, Smart Mater. Struct., **25**, 8 (2016).
11. D. Snoeck, L. Pel, & N. De Belie, Scientific reports, 7(1), pp.1-14, (2017).
12. J. R. Tenório Filho, E. Mannekens, K. Van Tittelboom, S. Van Vlierberghe, N. De Belie, & D. Snoeck, J. Build. Eng. 43 (2021).