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Monitoring the reduction in shrinkage cracking of mortars containing superabsorbent polymers

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ABSTRACT

Ultra-high performance concrete (UHPC) is characterized by a low water-to-cement ratio, leading to improved durability and mechanical properties. However, the risk for autogenous shrinkage and cracking due to restrained shrinkage increases, which may affect the durability of UHPC as cracks form pathways for ingress of aggressive liquids and gases. These negative features can be prevented by the use of superabsorbent polymers (SAPs) in the mixture. SAPs reduce autogenous shrinkage by means of internal curing: they will absorb water during the hydration process and release it again to the cementitious matrix when water shortage arises. In this way, hydration can continue and shrinkage is diminished.

Keywords: Ultra-high performance concrete, Autogenous shrinkage, Superabsorbent polymers, Ring test

1. INTRODUCTION

Concrete is known to be the most used construction material, this because of its relatively low cost and high compressive strength. The drawback lies in the low tensile strength that it provides, which makes concrete prone to cracking. For this reason, concrete is mostly reinforced by steel bars. To avoid corrosion of this reinforcement, durability of concrete is a very important topic and should be improved as much as possible. UHPC is one of these 'innovative' materials, characterized by a low W/C ratio, so that a tight microstructure is formed. The problem then lies in the increase in shrinkage that occurs upon drying, since the amount of hydration water is lowered. According to G. Espinoza-Hijazin [1], concrete having a W/C ratio lower than 0.42 provides insufficient water to promote complete hydration of the cement particles. Since UHPC is characterized by a very low W/C ratio, around 0.3, self-desiccation will occur which leads to shrinkage. A solution to this shrinkage problem is given by internal curing, which can be attained by the use of superabsorbent polymers. SAPs are able to absorb large amounts of water (up to 500 times their own weight, depending on the type). They will take up water upon mixing and release it when needed to continue the hydration process. The use of SAPs has already been studied by A. Mignon [2] and it was concluded that shrinkage was indeed reduced by their addition. However, a drawback was seen in the fact that these polymers lower the compressive strength of the material: when releasing water, pores are created. This paper studies a new combined monitoring technique for autogenous shrinkage and tries to link strain data to a non-destructive measuring method, being Acoustic Emission (AE). Thanks to the monitoring of the acoustic activity, Lura et al. [3] determined the onset and duration of different shrinkage stages in cement paste. It is said that cavitation is the main source of acoustic activity, which occurs upon hydration of the cement particles when the paste has already acquired a certain stiffness. This non-destructive technique together with the measured strain will provide valuable information about the hydration kinetics of mortars and concrete, which determines the shrinkage behavior of the material.

2. MATERIALS AND METHODS

2.1. Materials

Two different mortar mixtures are made: a reference mixture (without SAPs) and one containing 0.2% of SAPs by mass of cement (0.2m%). The cement used is CEM II/B-S 52,5N produced by Diamur. It is a Portland composite cement and consists mainly of Portland clinker, in combination with blast furnace slag. Superabsorbent polymers are obtained from the chemical company BASF.

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These polymers are copolymers of acrylamide and sodium acrylate and they have a particle size of 100 ± 53 µm. Water uptake of these SAPs is around 26g of water for 1g of SAP. For this reason, the W/C ratio is slightly increased when adding them to the mortar. Also, a superplasticizer, being MasterGlenium 51 from BASF, is used to increase the workability of the paste. The composition of both mixtures can be found in the table underneath.

Table 1. Composition of mortar mixtures

	Reference mixture	**0.2m% SAP mixture**
Water/cement ratio	0.3	0.3054
Sand/cement ratio	2	2
Superplasticizer/cement ratio	0.007	0.007

2.2. Sample preparation

To measure shrinkage, hollow cylindrical specimens are casted, with an inner diameter of 330mm and an outer diameter of 406mm. The height of the ring is 152mm. Immediately after casting the rings are sealed to protect the samples from environmental conditions. They are kept like this during the full measuring period of 7days, in order to avoid drying shrinkage to occur, in a room with an ambient temperature of about 20°C. Small temperature fluctuations can occur due to entering sunlight. Three identical rings are casted per mixture. On the other hand, three small beam elements are cast per mixture, measuring 4cm x 4cm x 16cm, in order to perform a flexural strength test. Afterwards, the remaining halves of the beams are used for compression testing.

2.3. Flexural and compressive strength

The flexural strength of the beam samples is determined by means of a three-point bending test, following ASTM C 348-14 [4]. The flexural strength is calculated by Equation (1), with P the ultimate load, L the span between the supports, b the width and d the thickness.

$$S_f = \frac{3PL}{2bd^2} \tag{1}$$

Afterwards, the prisms are broken in half and can be used for compressive strength determination (ASTM C 349-14 [5]). Cubes are sawn, measuring $64cm^3$ and their compressive strength is calculated as following:

$$S_c = \frac{P}{bd} \tag{2}$$

For both mixtures, bending and compressive tests were performed. The results are shown in Table 1Table 2, by means of the average value and the standard deviation.

Table 2. Results of the flexural and compressive strength tests

	Reference	0.2m% SAPs
Flexural strength (MPa)	9.02 ± 0.41	9.64 ± 0.71
Compressive strength (MPa)	74.87 ± 3.55	69.56 ± 6.83

It can be seen that the flexural strength has slightly increased when adding SAPs. This result was unexpected, since the polymers leave pores in the hardened material. However, the presence of SAPs reduces shrinkage and crack formation. In the compressive strength, a clear reduction can be seen due to pore formation.

2.4. Testing methods

Restrained ring test

Measurement of autogenous shrinkage is done by means of a restrained ring test, based on ASTM C 1581-04 [6]. Some adjustments are made to ensure the measurement of autogenous shrinkage only. The set-up consists of two steel rings where the mortar is casted in between. Upon drying, the mortar will start to shrink, applying a pressure on the inner steel ring. This ring is equipped with 4 strain gauges, two sets of two, radially across each other. Each strain gauge is then wired in a quarter bridge configuration to measure the strain by shrinkage of the mortar specimen. A schematic representation of the ring can be seen in Figure 1 and the dimensions are described in Table 3.

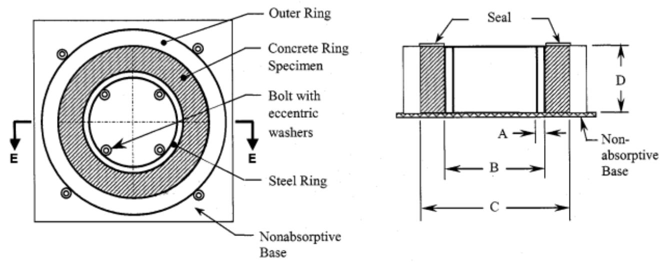

Figure 1. Schematic representation of the ring test (ASTM C 1581-04)

Table 3. Dimensions of the ring set-up

Figure dimensions	[mm]
A	12.5 ± 0.13
B	330 ± 3
C	406 ± 3
D	150 ± 6

Acoustic Emission (AE)

The strain measurements on the ring specimens are accompanied by Acoustic Emission measurements. AE is a non-destructive testing technique, based on the fact that materials emit elastic (sound) waves when subjected to stress. Also the time of cracking can be easily determined by using this measuring method. In order to obtain AE information, piezoelectric sensors are placed on the inside of the steel rings, just next to the strain gauges. The comparison of both measuring techniques (AE and strain gauges) will allow to have a certain reliability on the obtained results and conclusions made. The full set-up depicted in Figure 2.

Figure 2. Ring test with Acoustic Emission set-up

3. RESULTS

In the following, two specific rings are chosen which are representative for the respective test series. Figure 3 shows the results of ring 1, containing the reference mortar. The number of hits of acoustic emission, the amplitude and average frequency of these hits and the strain in one of the strain gauges are represented. It can be seen that the strain increases steeply from ±4h. The curve flattens gradually, until a large discontinuity is seen: a crack occurs. It should be noted that the graph only shows the result of one strain gauge, since the measurements of the second one were unusable.

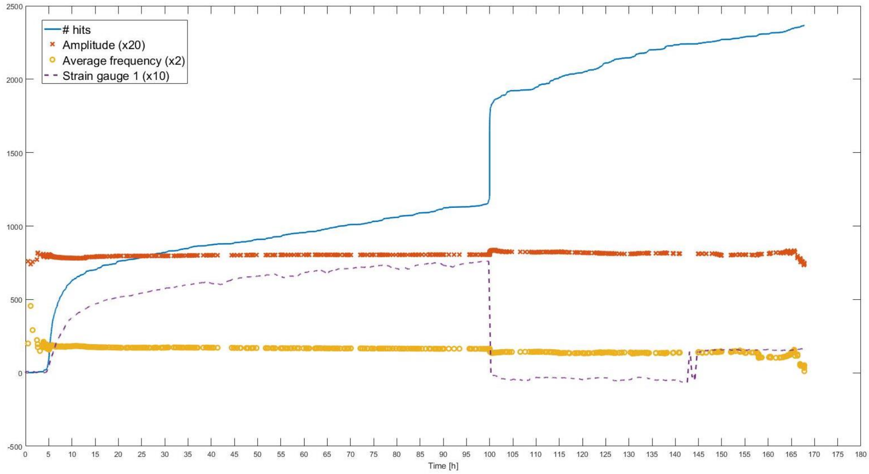

Figure 3. Overview of the results of ring 1 for the reference mortar

The curve representing the accumulated number of AE hits can be divided in 5 stages:

- *Phase 1 (start measurement -> ±4h):* The mortar is still plastic and the acoustic activity is limited. The hit rate (hits/hour) is the lowest during this stage, being 4.96.
- *Phase 2 (±4h -> ±5h):* An onset in AE activity is noticed. The mortar attains now a sufficient stiffness to sustain the first cavitations. The hit rate has increased by a multiple of 5.
- *Phase 3 (±5h -> ±11h):* As hydration progresses the stiffness of the mortar paste increases and the first stable, isolated bubbles are created. This process is represented on the cumulative hit curve by a big increase in value as most of the bubbles are created within this phase. The hit rate is here more of less 102hits/hour. The increment of AE activity slows down from the moment the energy required to expand already existing bubbles is lower than the energy needed to create new bubbles.
- *Phase 4 (±11h -> ±100h):* The acoustic activity slows down, since no new pores are created.
- *Phase 5 (±100h):* A sudden increment in AE activity is monitored. This increase can be linked to the decrease in strain, since they occur exactly at the same moment. A crack has been formed, which can also be stated by the fact that the average frequency lowers from ±165kHz to ±145kHz.

Identically as for the reference mortar, a ring test together with AE is done for a mortar containing 0.2m% of SAPs. The results are represented in Figure 4. Different from the strain data of the reference mixture is the period after 5h of the beginning of the measurement: a decrease in strain is seen. This decrease can be explained by the behavior of the SAPs. The polymers will release water for further hydration and shrink, which leads to a strain decrement. Gradually, the strain increases again due to the hardening of the mortar. No sudden cracking can be seen.

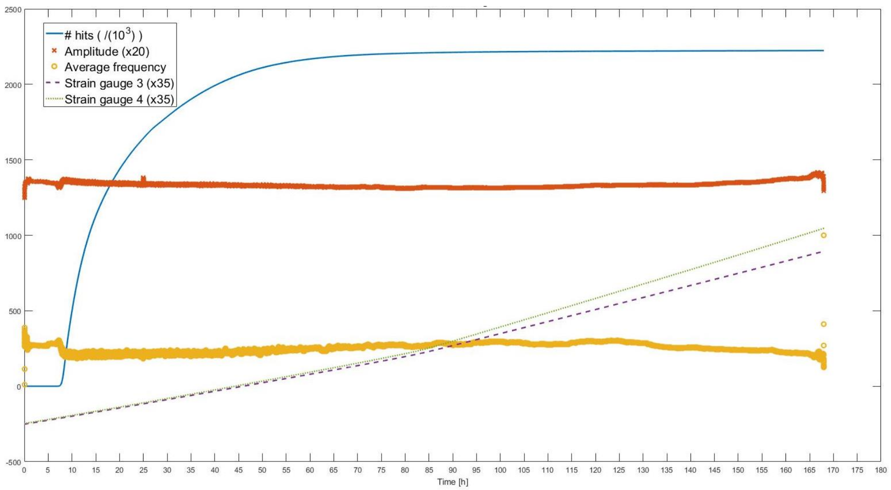

Figure 4. Overview of the results of ring 2 for the mortar with SAPs

Looking at the AE hits, the same first two phases are seen at the start of the measurement, only a bit later in time (shift of 2h). In fact, the third and fourth stage can also be seen here, but the increase in number of hits is a lot higher. A maximum hit rate of 200230 hits/hour is reached. The high number of AE hits can be explained by the presence of the SAPs, due to which more pores are formed than in the reference mortar. As was predicted and confirmed by the strain data, no cracking information is found. After demolding, no visible crack was seen.

4. CONCLUSION

The combination of the restrained ring test and AE monitoring can give us a lot of information on the behavior of a fresh mortar paste. Whereas AE shows the different steps in the hydration process, the strain gauges reveal the autogenous shrinkage of the mixture. Moreover, it was found out that cracking of the mortar is also confirmed by the number of captured hits: upon cracking, the amount of elastic sound waves emitted increases steeply and these are captured by the sensors. The goal, which was to find a way of measuring shrinkage and to characterize the differences in shrinkage behavior of mortar with and without SAPs, has been reached. Of course, the set-up can still be improved and other non-destructive techniques could accompany this measuring method.

The reduction of shrinkage cracking has been accomplished thanks to the addition of SAPs. However, this addition causes a decrease in compressive strength of the mortar, which should be counteracted.

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