# Moving towards a realistic implementation of self-healing concrete based on encapsulated polymer precursors

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## ABSTRACT

Extensive research has already been performed on self-healing concrete based on a triggered release of liquid polymer precursors from a carrier, especially during the past decade. However, tests on large concrete specimens are still seldom performed and the self-healing techniques used are often not practical or effective if implemented at a large scale.

This paper presents an analysis of the most relevant properties for carriers that are critical for moving the technology closer to a realistic implementation. The study contemplates the assessment of the dimensions of tubular glass capsules that result in a high survival rate if directly added to concrete during mixing, while still being able to rupture during realistic crack formation in the host concrete matrix.

Finally, a trial implementation of randomly dispersed glass tubular carriers in concrete beams is presented. This system is composed of a typical OPC concrete with tubular glass capsules added during the mixing process. It is shown that this system works and the crack planes cross several capsules that subsequently release the polymer precursor into the crack. However, the dosage used needs to be increased if a satisfying healed area is to be achieved.

## 1. INTRODUCTION

Numerous studies have been published on the use of polymer precursors as healing agents for self-healing concrete. For this application, the precursors need to be encapsulated, so that they are only released into the concrete matrix once a crack crosses the capsules. Most of the existing studies were however performed on proof-of-concept, small scale specimens, using pre-placed glass capsules and careful moulding of specimens. Thus, only a few publications address the actual implementation of this technology at a large scale, but even those rely on manual pre-placement of the capsules.

Dry [1] used glass tubes manually placed in large concrete decks to assess healing of shrinkage and shear cracks, but the dimensions of the tubes and their resistance to mechanical stresses during placing were not disclosed. Van Tittelboom et al. [2] used short glass/ceramic tubes embedded in cement paste bars placed at the bottom of moulds for large concrete beams. The cement paste surrounding the glass tubes protected them from the mechanical stresses experienced during casting and the flow of concrete during moulding slightly displaced the capsules into the interior of the concrete element.

It is debatable if manual pre-placement of capsules at specific locations is practical at a large scale in field sites. In that sense, capsules that could be used as a typical concrete addition and added during mixing of concrete would be preferable, as they would be compatible with current industrial production of concrete and field practice. Spherical microcapsules containing polymer precursors have already been shown to withstand the mechanically aggressive mixing of concrete [3]. However, the use of microcapsules in the context of concrete mimics their pioneering use for self-healing of a polymer matrix [4] and in both cases they target only the healing of very narrow cracks, in the order of a few micrometres.

In this study, the authors assess the possibility of using glass tubes as carriers for polymer precursors that can be directly added to fresh concrete during mixing. The dimensions of the capsules are tuned to survive mixing and be able to rupture and release the polymer precursors when crossed by realistic cracks in a concrete matrix.

## 2. MATERIALS AND METHODS

Glass tubes cut into 3 cm sections were used as capsules, which were sealed with a 2-component epoxy. The healing agent used was a commercial polyurethane precursor. Small scale tests were performed on 40x40x160 mm$^3$ mortar prisms reinforced with two Ø2 mm steel wires. The mortar consisted of a sand/cement ratio of 3, a water/cement ratio of 0.5, CEM I 52.5 N and was mixed according to the EN 196-1 requirements. Each prism contained one 3 cm long capsule placed at mid-section, where a crack was created at an age of 14 days under 3-point bending. The crack width was controlled by an LVDT at the position of the capsule. For larger specimens of 150x150x550 mm$^3$, ordinary, vibrated concrete with a slump of 45 mm was used. The mix consisted of 0/5 mm sand (640 kg/m$^3$), gravel 2/8 mm (462 kg/m$^3$), gravel 8/16 mm (762 kg/m$^3$), CEM I 52.5 N (360 kg/m$^3$) and water (165 kg/m$^3$). The components were mixed for 3 minutes in a 50 litre vertical shaft mixer. The concrete specimens were reinforced with two Ø6 mm ribbed rebars and multiple cracks were created under 4-point bending at an age of at least 3 weeks.

## 3. RESULTS

To assess whether the capsule dimensions in terms of outside diameter and wall thickness considerably affected the crack size at which they ruptured, mortar prisms with a single embedded capsule were cracked. Figure 1 shows that regardless of the capsule dimensions, glass capsules rupture for very small crack mouth openings of 15-35 μm in a mortar matrix. Given that autonomous self-healing concrete targets crack openings above 100 μm, these results prove that any of the dimensions tested are suitable regarding their ability to rupture and release the healing agent.

However, wall thickness also affects the capability for the capsules to survive under the mechanical stress experienced during mixing of concrete. To assess their survivability under these conditions, capsules were added to fresh concrete during mixing at a dosage of approximately 3 capsules per litre of concrete and mixed in for 5 minutes. The results are shown in Figure 2. Out of 10 capsules added for each series, none survived in the case of capsules with a very thin, 0.18 mm wall, regardless of their length. For 3 cm long capsules, similar results were achieved for all the other series with wall thickness in the range of 0.80 to 1.50 mm, with 8 to 10 capsules surviving, i.e. almost the total of the capsules added. In the case of 5 cm long capsules, the survivability decreased, with 6 to 7 capsules found intact and 2 capsules per series found mostly intact but damaged at the tops, which resulted in a compromised seal and potential hardening of the healing agent in the long term.

Concrete beams embedding randomly dispersed, 3 cm long capsules with an external diameter of 5 mm and wall thickness of 0.8 mm were cracked. After a period of at least 3 days, to allow curing of the polymer precursor released from the ruptured capsules, sections of the cracked planes were split to qualitatively assess the amount of polymer bridging the crack faces, while the remaining specimen was cut to assess the amount of capsules intersected in each cross section. Figure 3 shows a cut cross section, where 4 capsules could be seen intersected. Out of 10 sections, an average of 3.7±1.0 capsules were intersected. Figure 4a shows a capsule intersected in a real crack face, where polymer can also be seen surrounding it. Observation of real crack faces also showed that if a crack plane intersects a capsule along its length (Figure 4b), the capsule detaches from the concrete matrix without rupturing, although this situation was rarely found.

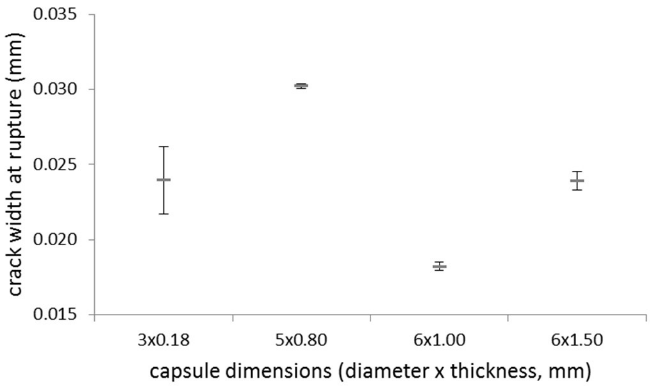


Figure 1: Crack width at which glass capsules rupture; average for 2 specimens.

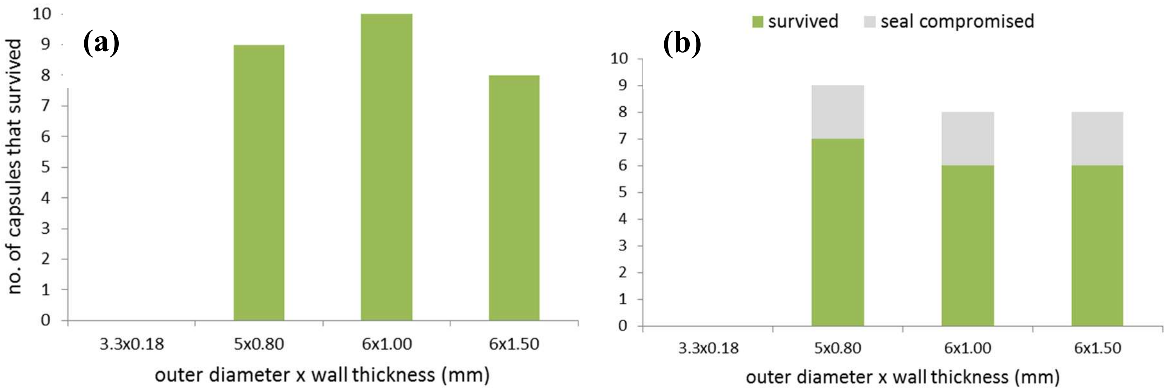


Figure 2: Survivability of glass capsules 3 cm (a) and 5 cm (b) long when added to concrete during mixing; 10 capsules were added per series.

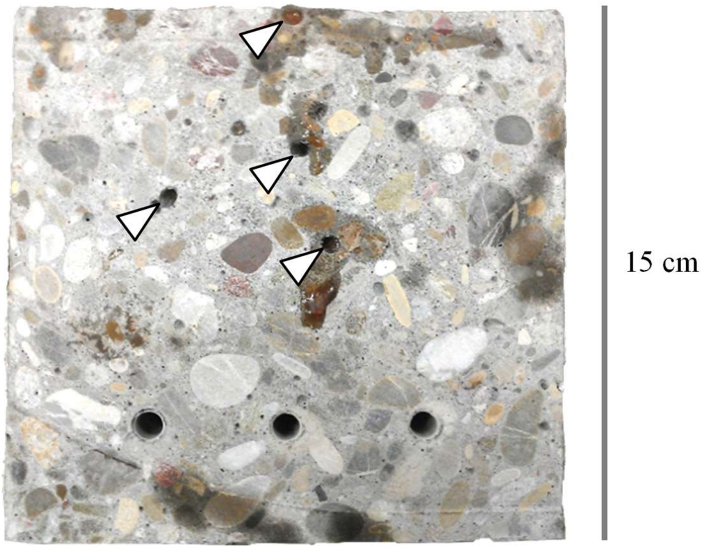


Figure 3: Cut cross section of concrete beam; arrows show capsules intersected.

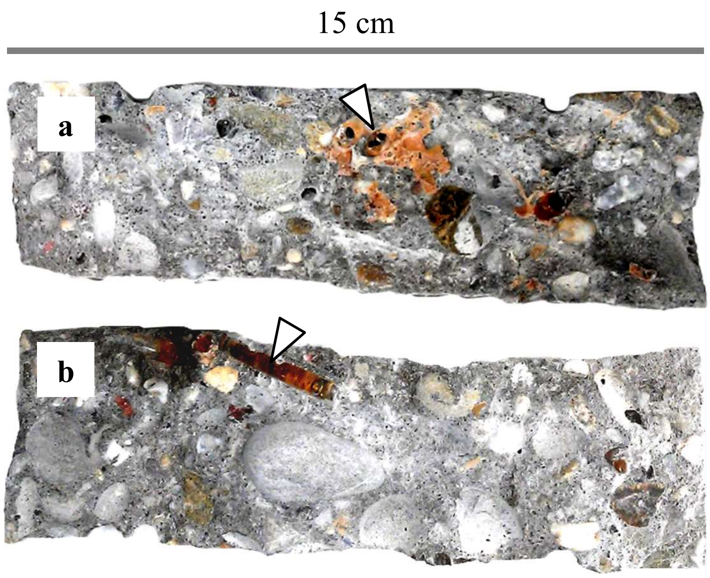


Figure 4: Sections of a split crack plane, where arrows show a ruptured capsule (a) and a capsule detached due to being intersected along its length (b).

## 4. CONCLUSIONS

Tubular glass capsules were proven to be suitable for the encapsulation and release of polymer precursors used as healing agents in the context of self-healing concrete. Capsules with very thin capsule walls of 0.18 mm did not survive the mixing process of concrete, but capsules with walls as thin as 0.80 mm had a high survival rate, while still being able to rupture if crossed by small cracks of less than 35 μm in a concrete matrix. The length of the capsules had an effect on their survival rates, with almost all 3 cm long capsules surviving, while 5 cm long capsules were more prone to being damaged.

Capsules 3 cm long with a 5 mm outside diameter and a wall thickness of 0.80 mm were added to fresh concrete during mixing to produce concrete beams with randomly dispersed capsules. The capsules were proven to crack and release the polymer precursors if crossed by realistic cracks. A dosage of 13 capsules per litre of concrete resulted in approximately 4 capsules being intersected in each cross section of the beams. A new round of tests will use a higher dosage of capsules to achieve a satisfying healed area. This dosage is estimated to be 3 to 4 times the one used in this study.

## ACKNOWLEDGEMENTS

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