# Self-healing of moving cracks in reinforced concrete based on encapsulated polymer precursors

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## ABSTRACT

While the existing research on self-healing concrete focuses mainly on the strength regain achieved with self-healing of cracks, this study aims at assessing the sealing of cracks and the strain capacity of flexible polymers fit for healing of dynamic cracks (e.g. due to traffic loads or cyclic temperature variations).

Different types of liquid polymer precursors were used as healing agents after encapsulation in cylindrical glass capsules. The precursors used cover different properties in terms of viscosity and foaming potential, leading to distinct mechanical properties after curing.

Test procedures were developed to assess the performance of the healing agents at a laboratory scale in small mortar specimens containing encapsulated precursors. Realistic cracks of approximately 250 µm were used throughout the study. The performance of the different systems varied significantly, with viscosity being an important parameter for the dispersion of the precursors and proper sealing of cracks. Moreover, it was shown that a large foaming effect is detrimental. Strain capacity was shown to be at best between 50% and 100%.

## 1. INTRODUCTION

As with other self-healing techniques for concrete, the use of encapsulated polymer precursors aims at increasing the durability or at recovering the load-bearing capacity of newly-built structures by allowing autonomous healing of microcracks, an idea borrowed from natural materials. With this technique, capsules rupture upon crack formation and polymer precursors are released, which flow to fill the crack and subsequently cure (harden) to form a cohesive polymer bonding the opposite sides of the crack.

However, polymers cover a wide range of mechanical properties and up to now, mostly stiff and brittle polymers have been used. Prior to this study, it was already thought that new cracks would develop when structural elements healed with such stiff and brittle polymers are again subjected to strain, a situation often found in field structures under cyclic loading. Flexible polymers with high elongation at break were thus selected for this study to assess their capacity to keep healed cracks sealed even after widening.

## 2. MATERIALS AND METHODS

For this study, liquid polyurethane precursors were selected and their properties are listed in Table 1. These are moisture curing products which harden when released from capsules inside the cement matrix. For encapsulation, Ø3 mm glass capsules were used.

Table 1 – Series of precursors tested.

| Series | Precursor | | Accelerator | Additional moisture |
|---|---|---|---|---|
| | Designation | Viscosity at 25° C (mPa.s) | | |
| LV | LV | 550 | - | - |
| LV.W | LV | | - | 1:1 (in 2nd capsule) |
| LV.A | LV | | 5 wt.% | - |
| SLV | SLV | 200 | - | - |
| CUT | CUT | 350 | - | 1:1 (in 2nd capsule) |

The healing performance was assessed in 40x40x160 $mm^3$ mortar prisms. The mortar mixing design consisted of cement CEM I 42.5 N, 0/4 mm sand, a cement to sand ratio of 1:3 and a water to cement ratio of 0.45. Mixing and moulding were carried out according to the procedure described in EN 196-1.

Each specimen contained 2 pairs of capsules, with only one containing precursor. The remaining capsule was filled with water for the series LV.W, to assess the effect of additional water upon rupture of the capsules. Otherwise, the remaining capsule was left empty. An accelerator was also mixed with the precursor for the series LV.A, which reduced the time for curing and induced a foaming effect.

The specimens were reinforced with two Ø3 mm threaded steel and contained a notch to guarantee a single crack. A crack of ~250 µm was created via 3-point bending tests. After cracking, the specimens were left for 3 days in a controlled climate consisting of 20° C and 60% RH to allow curing of polymers. Widening of healed cracks was achieved by reloading the specimens in the same manner.

Assessment of the water uptake through healed cracks was also performed. The cracked face of the specimens were brought into contact with water and the mass of water uptake was monitored. Before performing the test, the specimens were partially waterproofed with adhesive aluminium foil, to maximize the effect of the crack on the total amount of water uptake. The water level in the container did not exceed by more than 2 mm the top of the notch. As the specimens had to be retested following crack widening, after each absorption test, the specimens were dried in an oven at 50° C so that the total amount of water absorbed during the test was lost (within ±10% limits). The results are the average of 3 specimens and are shown in terms of sorption coefficient.

The healed crack area was determined using a different set of specimens reinforced with smooth steel bars, on which complete separation of the two halves of the specimens was performed. High resolution pictures were taken from both crack faces and the healed crack area was determined by adding the areas covered with polymer on both faces, since failure occurs mostly due to detachment from one of the faces.

## 3. RESULTS AND DISCUSSION

Specimens healed with a brittle polymer (CUT) and a polymer that fails due to ductile elongation (SLV) were bent until failure. Despite similar bending strength and stiffness of specimens of both types, the brittle failure of the specimens healed with the CUT precursor resulted in additional crack branches next to the original crack. This confirmed the initial motivation for the study and is specially significant considering that brittle failure occurred for a crack mouth widening of only ~20 μm. This implies that failure may occur even for small deformations resulting from a single daily cycle in a field structure. Figure 1 highlights the differences in the crack mouth area after failure.

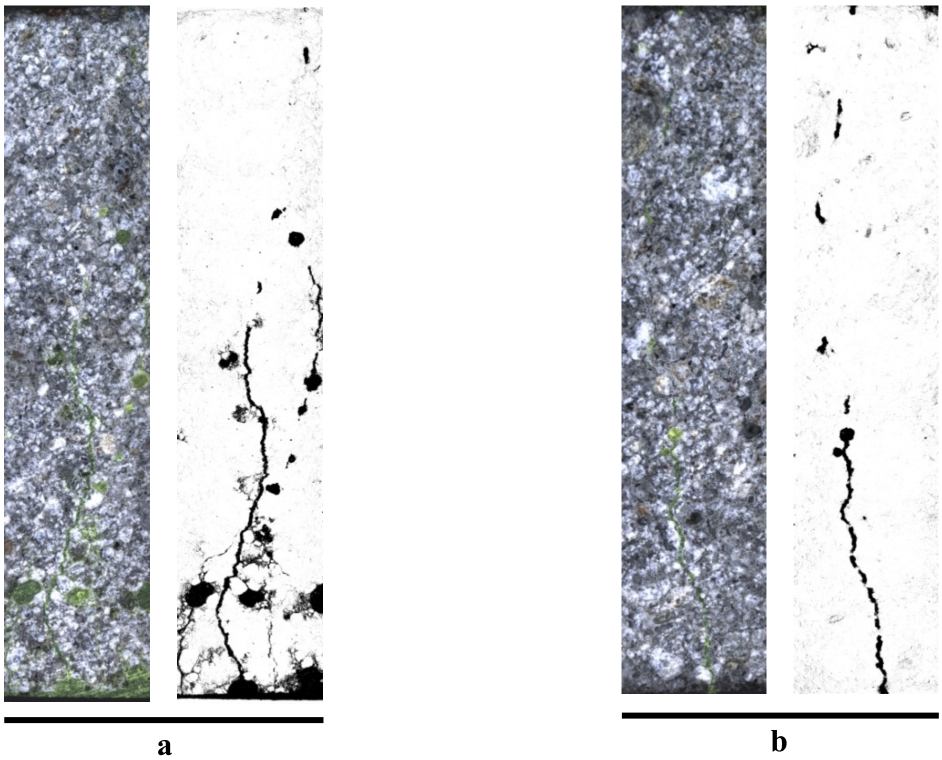


Figure 1 – Crack mouth profiles obtained in fluorescent microscope. New crack branches appeared next to the original crack after failure of the specimens healed with the brittle polymer (a) but not with the flexible polymer (b).

Overall, the use of the LV precursor did not lead to a considerable healing effect, as assessed through its sealing efficiency regarding the capillary water uptake through healed cracks. Additional water during cracking (LV.W) and foaming (LV.A) did not improve the performance of the LV precursor. However, the use of the SLV precursor considerably decreased the water uptake to a level similar to that of sound specimens. This effect remained even after a crack widening of 50%, but after 100% widening the water uptake increased and approached that of cracked, non-healed specimens. These results are shown in Figure 2. The considerably better healing efficiency achieved with the SLV precursor is thought to be due to its lower viscosity, which results in improved dispersion inside the crack and thus in a larger healed crack area. This is clearly shown in Figure 3.

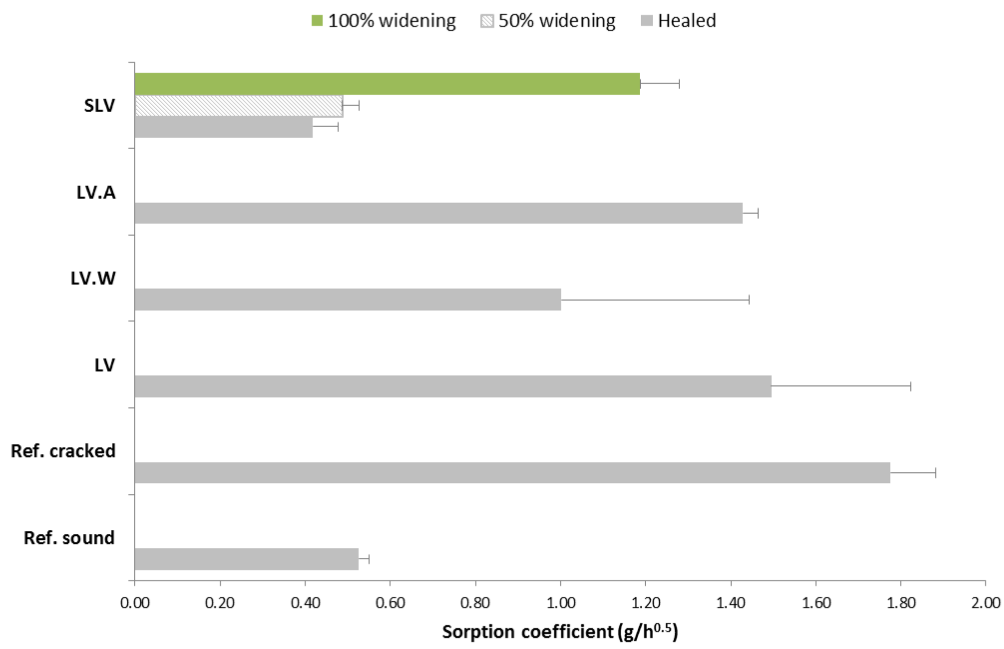


Figure 2 – Sealing efficiency and strain capacity assessed via water uptake through healed cracks.

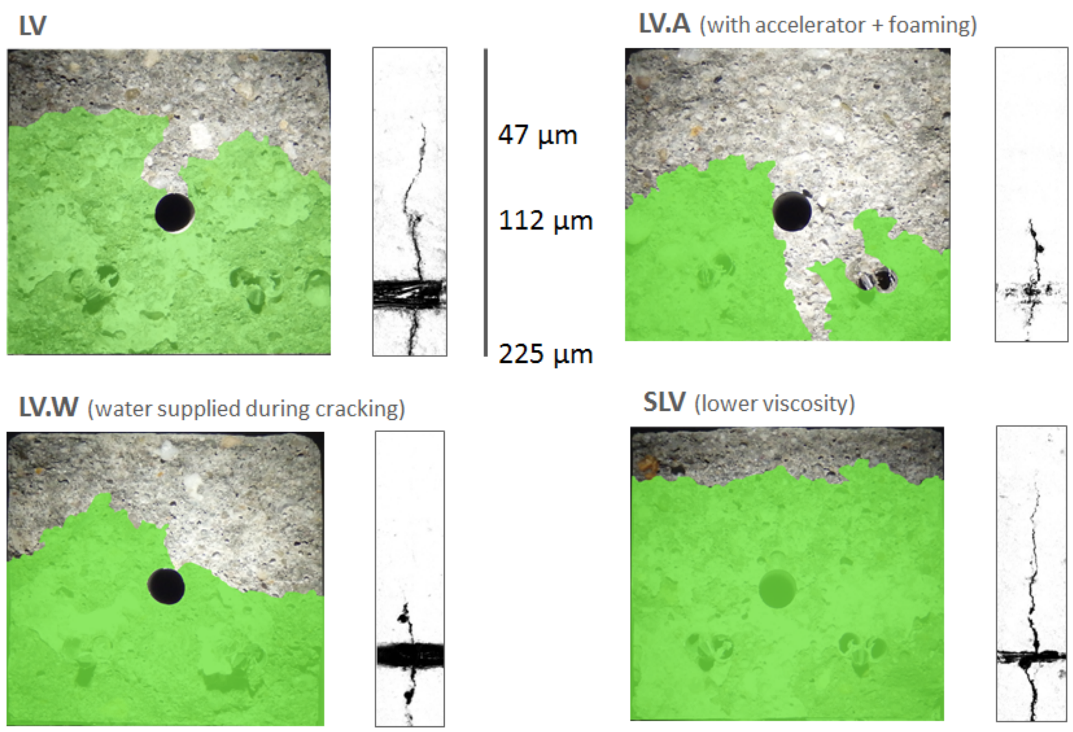


Figure 3 – Assessment of healed crack area. Crack cross-section profiles are also shown highlighting the sections filled with polymer. Average crack width is displayed at different heights.

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