Evaluation of the self-sealing effect of mortar containing polymeric healing agents

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ABSTRACT

In many studies on autonomous healing, evaluation of the self-healing efficiency focusses on the regain in mechanical properties. However, for a lot of structures like tunnels, liquid containing structures, etc., regain in liquid-tightness is the most important evaluation criterion. Within the HEALCON project, two different tests were developed by TUDelft and UGent and are recommended in order to quantitatively evaluate the sealing efficiency on lab scale. These tests evaluate whether the passage of water through the crack is blocked by the healing agent.

(1) Sealing assessment via water flow: The test is performed on cracked and water-saturated mortar prisms, containing a hole in the middle crossing the crack. Water under pressure is provided to the hole and the leakage from the (healed) crack is monitored in function of time. Comparison between the results of cracked-unhealed and cracked-healed specimens allows to quantitatively evaluate the sealing efficiency.

(2) Sealing assessment via capillary water absorption: Cracked mortar prisms which are partly waterproofed (leaving the area surrounding the crack exposed) are put in a 2 mm deep water bath and the mass of absorbed water is monitored in function of time. Based on the sorption coefficients obtained for uncracked, cracked-unhealed and cracked-healed specimens, the sealing efficiency is evaluated.

The test methods described above were applied in HEALCON and the techniques were found suitable. In this paper, the results obtained with an encapsulated elastic polymeric healing agent will be discussed in detail.

1. INTRODUCTION

One of the goals within the FP7-project ‘HEALCON - Self-healing concrete to create durable and sustainable concrete structures’ is to describe test procedures for the evaluation of the effectiveness of self-healing methods (healing agent and healing treatments) on mortar specimens at lab-scale. To validate the water permeability tests proposed, a large experimental program was executed and different parameters were varied (type of healing agent, crack widths, curing conditions, etc.). In this paper, the results obtained, using an encapsulated elastic polymeric healing agent, are presented.

2. TEST METHODS

Mortar mixes

Reference mortar mixes (containing no healing agent) as well as self-healing mortars (containing encapsulated healing agent) were made according to the composition given in Table 1 and prisms (40 mm x 40 mm x 160 mm), containing 2 reinforcement wires of Ø 1 mm, were casted. An extra hole Ø 5 mm was provided in the middle of the specimens which were used for the water flow test. The specimens were wrapped in plastic foil and stored in a room at a temperature of 20°C.

Table 1: Mortar composition for reference and self-healing specimens

	REFERENCE	SELF-HEALING
CEM I 42.5 N	450 g	450 g
water	225 g	225 g
Sand 0/2	1350 g	1350 g
Glass capsules (Ø 3 mm; l 50 mm) filled with precursor of a super low viscosity polyurethane (PU)	/	2

At the age of 28 days, the self-healing specimens were cracked in a crack-width controlled three-point bending test so that the crack width after unloading was ~ 250 μm. Moreover, also a part of the reference specimens were cracked and part of them were healed manually with the same polyurethane (PU). To allow proper curing of the PU, all specimens (uncracked reference specimens, cracked reference specimens, cracked and manually healed specimens and cracked and self-healed specimens) were stored in a climate room at 20°C and 60% RH for 3 days.

Water permeability via capillary water absorption

After curing, the specimens were dried at 40°C for 7 days. Before the capillary water absorption test started, the specimens were stored 1 day at 20°C and 60% RH, sealed with adhesive aluminum foil (except the zone of 20 x 40 mm in the middle of the specimen) and weighed. The test procedure is based on the method described in EN 13057 and consists of bringing the cracked face of the specimens into contact with water (immersion depth = 2 mm) and monitoring the mass of absorbed water (M) for 24 hours.

Water permeability via water flow

Since saturated samples are needed for the water permeability test via water flow, the specimens were stored 2 days under water. Subsequently, the hole in the middle of the specimen was sealed at one end with methyl methacrylate glue and at the other side a connection was made with a plastic tube. Via a water-column (water level at 500 mm above the middle of the specimen), water passes through the plastic tube in the 5 mm-hole and leaks out of the crack. The water outflow (W) in function of time is registered.
In addition, the test was also performed with an increased water pressure (up to 2 bar) in order to investigate the resistance of the healed specimens to high water pressure (Figure 1).

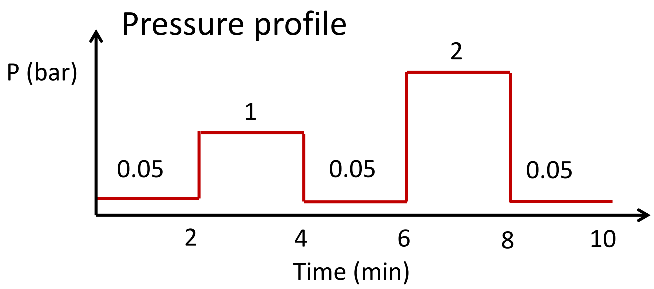

Figure 1: Pressure profile for the water flow test

3. RESULTS

Water permeability via capillary water absorption

In Figure 2, the capillary water absorption coefficients (SC) (in g/√h), calculated with equation (1) are presented. M_{1h} and M_{24h} is the mass of absorbed water (in g) respectively after 1 and 24 hours.

$$SC = \frac{M_{24h} - M_{1h}}{\sqrt{24h} - \sqrt{1h}} \qquad (1)$$

As expected the uptake of water is the highest for the cracked reference specimens. However, the uptake of water is lower for the manually and self-healed specimens than for the uncracked reference specimens. This is possibly due to the fact that healing agent leaked out of the crack and part of the surface exposed to water is covered by PU, although the surface was cleaned with sandpaper before the water absorption test started.

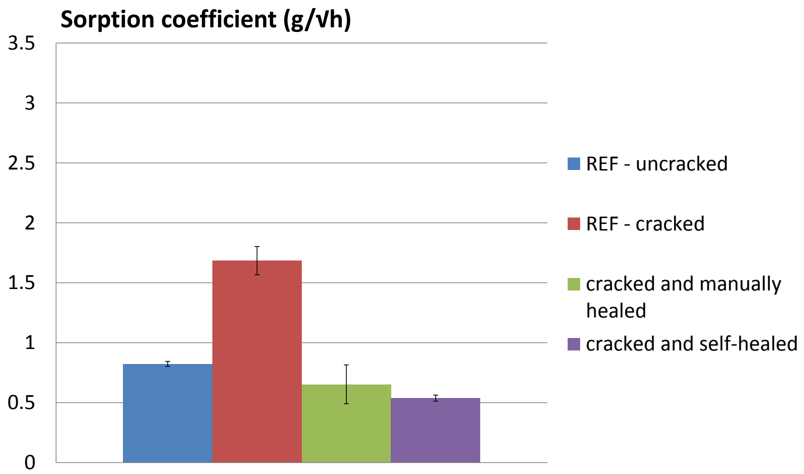

Figure 2: Capillary water absorption coefficient (mean value and standard error (n = 3)).

The average sealing efficiency (SE_{CA}), calculated with equation (2), amounts to 120% and 134% respectively for the manually healed and self-healed specimens.

$$SE_{CA} = \frac{SC_{REF-cracked} - SC_{healed}}{SC_{REF-cracked} - SC_{REF-uncracked}} \, x \, 100\% \qquad (2)$$

Water permeability via water flow

At a pressure of 0.05 bar, the water flow through the cracked reference specimens (which had an average crack width of ~200 μm) was at average 5 g/min, while no water flow was detected for both the manually and self-healed specimens with PU. This shows the good sealing capacity (SE_{WF}) (equation 3) of the polymeric healing agent which is thus 100%.

$$SE_{WF} = \frac{W_{REF-cracked} - W_{healed}}{W_{REF-cracked}} \; x \; 100\% \qquad (3)$$

All manually healed specimens could also withstand a water pressure up to 2 bar (no water flow, even at that high pressure). This was also the case for two out of the three specimens which were self-healed and subjected to the water flow test with high pressure. This means that for one self-healed specimen, a water flow was detected and due to the higher pressure the sealing was partly damaged (Figure 3). This was detected since the water flow at 0.05 bar slightly increased after application of the high pressure. In comparison to the reference, this value is still limited.

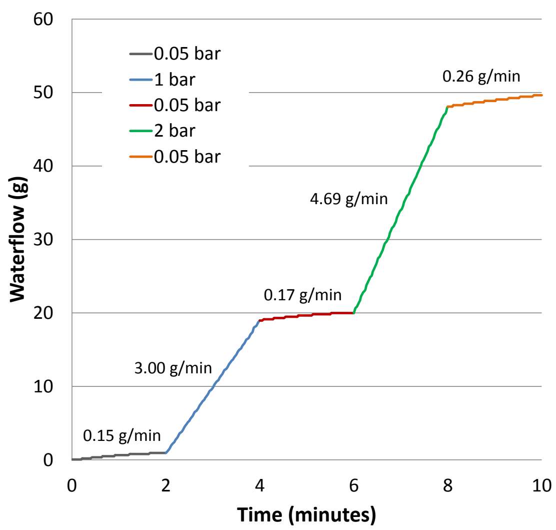

Figure 3: Water flow through a specimen that is not completely sealed.

4. CONCLUSIONS

The self-sealing efficiency of cracked mortar by using an elastic polymeric healing agent was determined based on the two test methods proposed in the HEALCON project. The water permeability test via capillary absorption as well as the water permeability test via water flow with limited pressure showed a sealing efficiency of 100% for the manually and self-healed specimens. All manually healed and almost all self-healed specimens could even withstand a water pressure of 2 bar. The proposed test methods were found suitable to test the self-sealing efficiency of healed mortar specimens.

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