NEUTRON RADIOGRAPHY, A SENSITIVE METHOD TO VISUALIZE AUTONOMOUS HEALING OF CRACKS IN CEMENTITIOUS MATERIALS

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ABSTRACT

Repair of cracks in concrete is an important issue as they may endanger durability and reduce service life of reinforced concrete structures; however, large costs are generally involved if cracks are to be repaired and sometimes repair is even impossible due to inaccessibility. Therefore, in this project, we attempt to heal cracks autonomously by embedding an encapsulated healing agent into the matrix.

Ceramic tubes were used to carry a two-component polyurethane-based healing agent. The first component is a prepolymer of polyurethane which starts foaming in moist surroundings; the second is an accelerator shortening the reaction time. Half of the tubes was filled with the prepolymer and the other half was filled with a mixture of accelerator and water. Mortar beams were cast following the procedure described by Zhang et al. [1]. Each beam was reinforced with six steel bars, three positioned close to the bottom and three at the top of each beam. For beams with self healing properties (SHC), six couples of ceramic tubes (with one tube of each filled with polyurethane and the other filled with a mix of accelerator and water) were positioned at a height of 10mm, and six at 40mm. Besides, three more test series were prepared, however, samples belonging to these series contained only reinforcement bars. Beams of the first test series were left uncracked (UNCR), the following series was used as reference (REF), which would be cracked but from which the cracks were left untreated, the last series was used for manual crack healing with polyurethane (MAN). After casting, the beams were placed in an air conditioned room and demoulded 24 hours later.

At the age of 14 days, all beams, except the beams of series 'UNCR', were cracked by means of a crack width controlled three-point-bending test. The crack width was increased until 400 μm, at that point, the beam was unloaded giving cause to a resulting crack with of 200 μm. Cracks of the specimens containing encapsulated healing agent were autonomously healed. The embedded tubes broke during crack formation and both components of the healing agent were released into the crack due to capillary forces. Upon contact of both compounds, polyurethane foam was formed, resulting in crack healing. Cracks of the samples belonging to the test series 'MAN' were treated with polyurethane after crack formation.

The crack healing efficiency of these specimens was evaluated by capillary water sorption tests. Specimens were dried and afterwards the side surfaces were covered with self-adhesive aluminium foil. Then, specimens were weighed and the cracked surface was brought into contact with water. At regular time intervals, the increase in mass, due to water sorption, was determined. The results showed that there is no difference between the efficiency of manual and autonomous crack repair (Fig. 1). The amount of water absorbed by specimens with a crack and with self-healing properties was 33% of the absorption by cracked but untreated specimens. The value measured for uncracked samples was found to be 29% of the cracked specimens. This led to the conclusion that the autonomous healed cracks were completely water tight and water uptake was due to absorption by the porous matrix only.

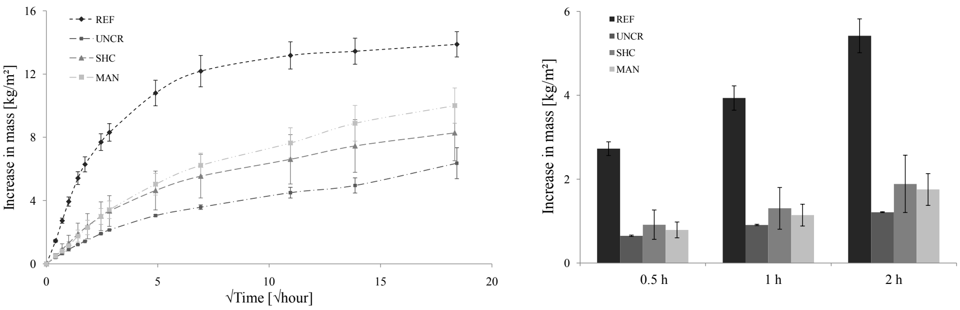

Figure 1: Increase in mass due to water sorption.

The findings mentioned above were verified by visualization of the water migration by means of neutron radiography. These experiments were performed at the neutron beam facility of Paul Scherrer Institute (PSI) in Switzerland. Similar as described above, specimens were dried and covered with a self-adhesive aluminium foil. Then, specimens were placed in a container and positioned in the neutron beam. After an image had been taken in the dry state, the container was filled with water so that the water level just touched the bottom. The kinetics of water uptake was then followed by neutron radiography. It was shown that both manually and autonomously healed cracks were water tight as no water ingress into the cracked zone could be observed (Fig. 2). Moreover, as part of the healing agent penetrated into the damaged zone near the crack surfaces, no penetration of water into the material near the crack was noticed. For untreated cracks fast ingress of water was seen along the length of the crack. It was also proven that the interface between steel and concrete was damaged due to crack formation as water penetrated into the interface perpendicular to the crack direction. From the neutron radiographs the moisture distribution could be determined quantitatively in order to compare the different test series in detail. It could be shown that neutron radiography is a very promising non-destructive test method to study the efficiency of manual and autonomous repair of cracks.

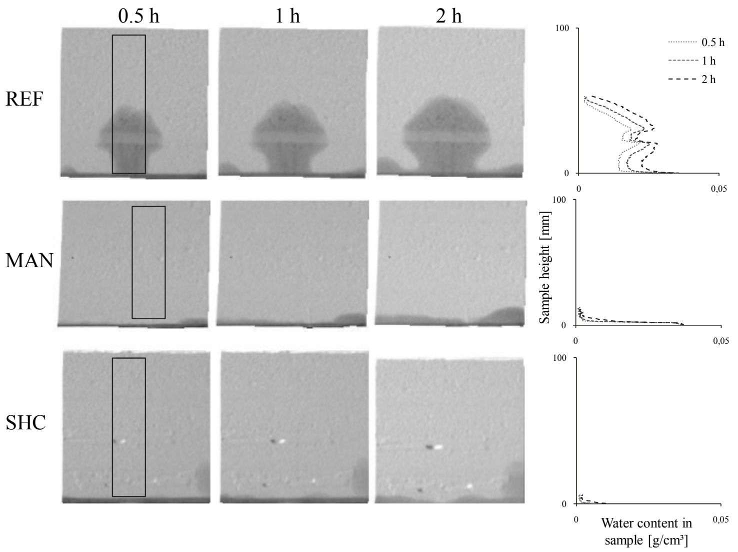

Figure 2: Neutron images of water penetration into cracked (indicated with rectangle) and healed reinforced mortar prisms during contact with water for 0.5h, 1 h and 2 h, and corresponding quantitative water profiles along a vertical axis of sample.

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REFERENCES

[1] Zhang P, Wittmann F H, Zhao T, Lehmann E H. Neutron imaging of water penetration into cracked steel reinforced concrete. Physica B: Condensed Matter. 2010;405(7):1866-71.