Development of self-repairing concrete structures by means of porous network

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Summary

Concrete, the most widely used man-made construction material, has inherent brittleness. Micro-cracks may occur due to restraint shrinkage deformations and macro-cracks when a concrete element is loaded in tension or bending. This unavoidable crack formation has been the major consideration for water retaining structures. Furthermore they form an issue for realizing a water tight connection between slab and wall of underground structures. Long term durability for reinforced concrete and prevention of reinforcement corrosion due to ingress of (chloride) ions is another field where cracks have an enormous influence. A novel self-healing / self-repairing method has been developed by introducing porous network concrete. Mimicking bone, prefabricated porous concrete was placed internally in the concrete structures. As the fracture might happen, a commercially available low viscosity polymer based resin was used as healing agent which was transported through the porous network by automatic injection. After polymerization reaction took place a dense layer was formed closing the cracks. The efficiency of crack healing was examined by mechanical recovery of cracked specimens and visual confirmation. Having porous network in the concrete interior, several self-healing / self-repairing scenarios could be performed.

Keywords: Self-healing, self-repairing, porous network concrete, biomimicry.

1. Introduction

Exponential urban population growth has caused increasing public demand of infrastructure serving their need in constant high level of service. However, many constructed infrastructures, e.g. building, concrete structure, transport facilities, built in the second half of the last century are experiencing unprecedented material deterioration causing higher annual expenditures for repair and rehabilitation. This is even problematic since a half of the field repair of concrete infrastructures require re-repairs due to short-lived poor repair action. The concepts of concrete structure (material) able to repair itself mimicking living creatures without human intervention has emerged as an alternative methods for combating civil infrastructures deterioration. This concrete is smart enough, able to sense its own 'wound' and undergo 'self-repair', thus, demonstrate 'continuous renewal' its performance resulting to longer material life time.

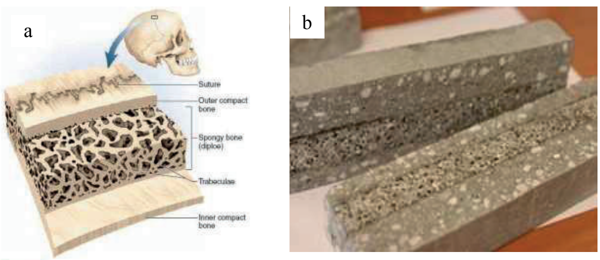

Figure 1. Bone [Saladin, 2010] and porous network concrete [Sangadji and Schlangen, 2011]

In this research the authors invented an alternative method to deliver healing agents into the crack. We imitated bone morphology by making use of prefabricated cylindrical porous concrete cores, which are placed in the interior of the concrete structures to make a porous network concrete as can be seen in figure 1.

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The porous network provides alternate means for (1) channelling temporary or permanent materials to form a dense layer and (2) distributing healing agent to cracks into the main body. By incorporating three basic aspects; sensing, actuating, and adaptive controlling to the environment into the system, we developed the self-healing mechanism which was carried out in an autonomous manner.

2. Experimental test setup, result and discussion

To create porous network concrete, a 40×40×295 mm porous concrete core was put in the centre of a wooden mould. Afterwards, concrete was cast around the core. A three point bending test was performed to create a crack in the mid span of the prism. As the LVDTs sensed that the crack opening reached a certain value (250 µm), the computer triggered the injector to push epoxy resins into the interconnected porous core. The actuator was stopped when it reached the upper bound relay. The system was maintained in the reached position for 24 hours allowing the resin to polymerize and harden. A second loading cycle was carried out after 24 hr.

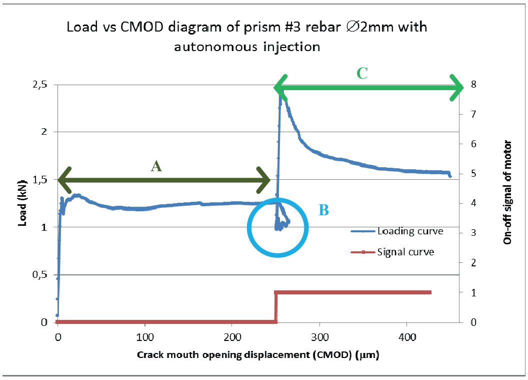

Figure 2. Graph of load vs CMOD

Figure 2 show the loading curve superposed with signal curve. An on-off control system was implemented; the signal remains zero (A) prior to the pre-set threshold value 250 µm and steps-up to 1 (B) as the triggering signal for electric Direct Current (DC) motor. After injection, healing took place with the resin hardened, creating a dense layer in the core and gluing the crack walls together. This creates a new composite action between concrete matrix and resin polymer causing twice the peak load capacity in the second loading test (C). The result shows that the second crack zone is shifted away from the first fractured area. It is assumed that the second crack formed in the new weaker area since the first crack was sealed and healed with higher stiffness and strength. Observing a wetted area larger than the crack opening itself it is realistic to assume that the resin also penetrated into the surrounding micro pores of the crack wall.

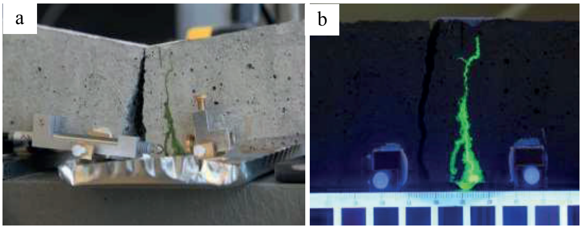

Figure 3. (a) sealed crack and second crack and (b) the prism under UV light.

Several applications are considered such as water retaining structures, like storage tanks, basement-walls, industrial floors, tunnels or aqueducts. Furthermore structure in which dense layer/barrier is formed next to the reinforcement to stop ingress of chlorides.

3. Conclusion

Imitating bone shape, a prefabricated porous concrete core is placed in the interior of concrete prisms. The interconnected void in the core was used as a media channelling the liquid healing agents. After hardening of the healing agent, the crack is sealed and mechanical recovery takes place. Visual observation of the original and newly formed cracks in the section further confirmed the conclusion. Sealing the cracks may be associated with enhancing water tightness, thus, reducing the danger form chemical ingress, reducing rebar corrosion potentials, and prolonged service life. As the porous structure is filled with hardened epoxy, thus, producing a polymer-concrete matrix composite, the mechanical regain may be expected from the healed system.