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The use of alkaliphilic bacteria-based repair solution for porous network concrete healing mechanism

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Abstract

Bacteria induced calcium carbonate precipitation based on metabolic conversion of nutrients has been acknowledged for having potentials in self-healing cement-based materials. Recent studies have shown the development of bacteria-based repair solution (liquid) for concrete surface repair. This article demonstrates the feasible application of the solution as healing agent to be injected into porous network concrete (PNC). This type of concrete has a porous core which can be used as a media to transport healing agents into the fracture zone. The repair capacity of the solution have been assessed by monitoring the bio-mineral precipitation in the porous cylinder cores. The X-ray tomography and permeability tests at certain time interval were carried out before and after injection of the solution. Polished sections were prepared and examined under ESEM after healing period to investigate healing capacity. The healing potential was then tested by injecting the solution into PNC. The injection of tap water and bacteria based solution was performed through porous network until it reached and flew out through the crack which was formed by three-point bending loading. The healing efficiency was measured by water permeability test before and after injection at several time intervals. The specimens injected with bacteria based solution and cured in wet condition showed higher healing efficiency compared to dry cured specimens.

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Keywords: Self-healing concrete; Bio-based healing agent.

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1. Introduction

For many people not well trained in biology, the word 'bacteria' means something not so friendly to human. They associate bacteria with *pathogen* – agent that cause disease and infection. Though there are several deadly bacteria, the great number of bacterial communities have no connection with human. Recent studies show that bacterial ecosystem inhabits in healthy human skin, mouth, genital areas and intestine. This human microbiome – *a complex mutualism symbiotic of host-microbe* – is essential in maintaining human basic physiological processes.

Apart from aforementioned unique intricate human-bacteria relation, countless bacterial communities have direct positive effects in human life. These bacteria help human in digestion, food fermentation, and soil fertility maintenance, to name a few.

Specific to concrete technology, the potential benefit of bacteria has been investigated. Bacteria have been utilized in improving mortar strength, cleaning weathered concrete surface, restoring deteriorated limestone, and healing / sealing concrete cracks. Bacteria based concrete healing/sealing have been carried out through carbonate precipitation.

In nature, bio-mineralization (microbiologically induced calcium carbonate precipitation, MICP) precipitates calcium carbonate in three different polymorphs, calcite, aragonite, and vaterite, where calcite is the most thermodynamically stable mineral. This CaCO3 precipitation is mediated by bacteria via different pathways – e.g. urea hydrolysis, metabolic conversion of salt and carbon, denitrification. Currently in the lab scale, several research of bacterially mediated self-healing concrete have successfully develop techniques that make use alkaliphilic calcite precipitating bacteria [1-3].

As research project spin-off, the bacteria-based repair system has been developed recently by Wiktor and Jonkers at Microlab TU Delft [4]. This bio-based system was designed in particular for repairing cracks in existing (aged) concrete. This is a liquid system comprises of three components: (a) alkaliphilic calcite precipitating bacteria, (b) nutrients and (c) transport solution. The solution is sprayed on to a concrete surface and seals the cracks leading to porosity reduction of concrete matrix.

For designing new durable building component, this contribution investigates the feasibility of the solution to block crack opening by injecting the solutions via porous core in Porous Network Concrete (PNC). PNC which was designed by imitating concrete mammalian bone morphology has pervious (porous/enhanced porosity) concrete embedded in the interior of concrete main body [5]. This air void network system constitutes an alternate means for channeling the healing agent to cracks in the main structure. Once crack mouth opens wider than a prescribed threshold value and detected by sensors, the solution may be injected automatically by the actuator.

2. Materials

2.1. Bacteria based repair solution

Jonkers and Schlangen [6], Jonkers et al. [7], and Wiktor and Jonkers [8] designed self-healing concrete by means of bacteria mediated calcite precipitation through metabolic conversion of nutrients. It is required that the bacteria resistant to alkaline environment as in fresh concrete matrix and have sufficient tolerances to oxygen. The bacteria should be able to form spores in order to be viable in very long time. As the encapsulated bacteria convert the nutrients when crack intersects the capsule, the microenvironment next to the bacteria cell is conducive for calcite to precipitate. With this mechanism bacteria help sealing crack for newly designed concrete.

On the other hand, existing aged concrete shows distress and crack due to mechanical or environmental load. This damaged concrete was not designed in first place to have self-healing capability. They demand repair using ecologically friendly repair material. This situation motivated Wiktor and Jonkers to design a bacteria-based repair system with easy and quick application [4]. The solution is applied by spraying the solution onto the surface of a cracked concrete structure, where it yields to crack closure.

For this investigation the solutions were prepared based on Wiktor and Jonkers [8]. The bacteria-based repair system consists of two types of solutions namely A which is composed of bacteria, nutrients and pH buffer compound and B containing a calcium source to promote massive calcium carbonate precipitation.