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Case Study

Field performance of bacteria-based repair system: Pilot study in a parking garage☆

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ABSTRACT

This paper presents the field performance in a parking garage of the recently developed bacteria-based repair system for concrete. This liquid-based repair system aims at the sealing of cracks and decrease of the porosity due to the production of a calcium-based biomineral. The system combines advantages of both a traditional repair system for concrete (fast reacting and short term efficiency), and bio-based methods (more sustainable, slow process, and long-term efficiency).

The bacteria-based repair system has been sprayed onto the surface of cracks and on concrete pavement. The crack-sealing efficiency and improvement of frost salt scaling were assessed by water permeability and freeze/thaw resistance tests respectively. The results were very promising as only cracks that had not been treated with the bacteria-based repair system were still heavily leaking. In addition, the freeze/thaw resistance of concrete that was treated with the bio-based repair system was higher than the untreated concrete.

1. Introduction

Concrete is the most used construction material worldwide. Indeed, even if exposed to a number of degradation processes such as carbonation or chloride ingress, concrete structures can reach a service life of more than 50 years (Emmons and Sordyl, 2006). However the presence of cracks, and the subsequent ingress of aggressive corroding substances, is a major limitation for the durability. This leads to the premature corrosion of the reinforcement and early failure of the structure. As a result, costly measures for maintenance and repair are undertaken. Nowadays a wide range of repair products, such as for instance epoxy-based fillers or silane-based water repellent, is available for concrete. However, the short term efficiency and negative impact on the environment are an issue for the repair industry.

Biodeposition, a method by which calcium carbonate ($CaCO_3$) precipitation is induced by bacteria, has been proposed as an interesting alternative approach to protect building materials. Various pathways are involved in Microbial Induced Precipitation (MIP) process. Among them, enzymatic hydrolysis of urea in a calcium rich environment is the most commonly

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used system (Dhami et al., 2012). Successfully applied as a surface treatment in practice to limestone monuments, it has been considered only on a laboratory scale for cementitious material and crack repair.

Also, besides cost issues, MIP using ureolytic bacteria might generate other problems, such as environmental nitrogen loading due to the production of ammonia during the hydrolysis of urea or negative effect to the material itself due chemical reactions with ammonium salt (Dhami et al., 2012). In addition, the time required for a substantial amount of bacterially induced calcium carbonate may hold back the acceptance of MIP as an efficient repair technique by the building industry.

Bacterially mediated calcite precipitation thanks to metabolic conversion of calcium lactate instead of urea hydrolysis has been successfully applied in self-healing concrete (Wiktor and Jonkers, 2010). The authors implemented this concept for the development of bio-based repair system for a real concrete structure. The novelty of such a system is to combine advantages of both a traditional repair system for concrete and bio-based methods (Wiktor and Jonkers, 2011, 2012a).

In this way, a silicate-based compound, which has a composition similar to concrete, is associated with MIP without involving a urea hydrolysis pathway. Instead, the metabolic conversion of organic salts through bacterial respiration is used for MIP.

The bio-based repair system as presented in this paper is a liquid-based system which transports the bio-based agent into concrete. This paper investigates and discusses the field performance of the bacteria-based system developed in the laboratory.

2. Materials and methods

2.1. Bacteria-based repair system

The repair system consists of concrete compatible bacteria (Wiktor and Jonkers, 2012b) and feed which produce calcite-based minerals decreasing concrete porosity. This system is composed of two solutions:

(i) Solution A – sodium-silicate (alkaline buffer), sodium-gluconate (carbon source for bacteria growth), alkaliphilic bacteria.
(ii) Solution B – calcium-nitrate (nitrate source for denitrification when O_2 is depleted and calcium for $CaCO_3$ precipitation), alkaliphilic bacteria.

The denitrification is the biological reduction of nitrogenous oxides to gaseous products during anaerobic (no oxygen) bacterial growth. This means that under the metabolic conversion of calcium nitrate, N_2 and $CaCO_3$ are produced.

The silicate-based compound, sodium silicate, ensures an alkaline pH in the system and the formation of a gel inside the crack. Although not very strong, this gel allows a rapid sealing of the crack (within a few hours) and an optimum environment for bacteria to precipitate calcium carbonate. By the time the gel becomes too weak, a substantial amount of $CaCO_3$ has been precipitated to seal the crack.

2.2. Test location: parking garage

The test location was a 2 storey underground parking garage with a capacity of 300 parking places.

The concrete deck was suffering from cracking which resulted in significant leakage of the structure (Fig. 1a). Also, the concrete pavement on each side of the access ramp was damaged due to freeze/thaw (Fig. 1b).

2.3. Application of the bacteria-based repair system

Part of the concrete pavement (area of 2 m × 0.5 m) and three cracks (1–3 mm wide) of the concrete deck were impregnated with the bacteria-based repair system. Solution A and solution B were each poured in a sprayer, and manually applied at the surface of the concrete in layers until saturation of the concrete treated area.

2.4. Evaluation of the efficiency of the repair system

Two months after the application of the bacteria-based repair system, 6 cores were drilled (Fig. 2a and b) from two different locations on the concrete pavement: 3 from the treated area and 3 from an untreated part on the same side of the access ramp as control specimens. The resistance of the treated and untreated concrete to freeze/thaw conditions and deicing salt was then evaluated in laboratory.

The crack-sealing efficiency of the bacteria-based repair system was assessed by means of a water permeability test performed on site on 3 treated- and 3 untreated cracks (Fig. 2c).

2.4.1. Resistance to freeze/thaw and deicing salt

The 6 concrete cores were tested according the NPR-CEN/TS 1239-9 (Testing hardened concrete – Part 9: Freeze/thaw – scaling) and NEN-EN 13877-2 (Concrete pavement – Part 2: Functional requirements for concrete pavements). The test was