

INJECTING A LIQUID BACTERIA-BASED REPAIR SYSTEM TO MAKE POROUS NETWORK CONCRETE HEALED

S. Sangadji¹, V. Wiktor¹, H. Jonkers¹, and E. Schlangen¹

¹ Delft University of Technology, Faculty of Civil Engineering & geosciences, Section of Materials & Environment – Microlab, Stevinweg 1 2628 CN Delft, the Netherland

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ABSTRACT

Bacteria induced calcite precipitation has been proven to be effective in making concrete structure self-healing. In Microlab TU Delft, the concept has been enhanced by developing a liquid bacteria-based concrete repair system. The solution contains calcite precipitating bacteria, nutrients and buffer compound which may demonstrate high potential 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 concept was tested in the 55×55×285 mm PNC prisms with 23×23×285 mm porous concrete core in the interior. Ø2 mm threaded steel rebar was installed below the core. A crack was formed by three-point bending loading and the solution was injected through porous network until it reached and flew out through the crack opening. The bacteria then precipitated calcium carbonate blocking the crack. The healing efficiency was measured by water permeability test before and after injection at several time intervals. Second cycle mechanical loading was carried out to assess regain of mechanical properties. Eventually, calcite precipitation in the crack wall was examined by polished section with ESEM.

Preliminary results showed more than 90% permeability reduction has been achieved at 11 days which appeared to be temporary since after 19 days permeability reduction drop to 70%. This could be attributed to the flushing of the solution after 11 days as the process could be not yet complete. However, bacteria imprints obtained from ESEM observation of polished section of Ø26-30 mm cylindrical porous core 21 days after injection with the solution provided strong evidence of bacterial activity and confirm the previous observation

The on-going research program has been devised implementing tap water and bacteria-based solution injected specimens with wet and dry curing. The results showed that wet cured bacteria series exhibited 99% permeability reduction while dry cured specimen only shows 60% reduction.

1. INTRODUCTION

The bacteria-based repair system has been developed recently by researchers at Microlab TU Delft [1]. This bio-based system is a liquid system containing alkaliphilic calcite precipitating bacteria, nutrients and transport solution leading to porosity reduction of concrete matrix. This system has been applied on concrete structure successfully as it yields to crack closure.

This paper investigates the feasibility to inject the solution into the fracture zone of concrete by means of porous network concrete (PNC). By mimicking bone shape,

PNC has porous (pervious/enhanced porosity) concrete in the interior of concrete structures [2]. This interconnected meso-size air void system constitutes an alternate means for distributing the healing agent to a crack or cracks in the main structure.

2. PRELIMINARY PROGRAM

The bacteria-based repair system consists of two types of solutions namely A which is composed of bacteria, feed and buffer compound and B containing a calcium source to promote massive calcium carbonate precipitation. The solutions were prepared based on Wiktor and Jonkers [1] meanwhile PNC was casted as described by Sangadji and Schlangen [2].

Initial falling head water permeability test (fig 1.a) was performed by flowing water from point (a) to the opposite point (b) prior to crack formation by means of strain controlled three point bending. Post-crack permeability test (fig 1.b) then was carried out by blocking the end connector (b) with water stop allowing water to flow out into container (c). This step then would also be used to measure post-healing permeability. After drying the excess water out from the porous core by blowing ± 0.7 bar pressurized air for ± 20 minutes, the solution was injected (fig 1.c) by means of syringe (d) which then flew out through the crack (e). Afterwards specimen was sealed with plastic for 24 hour. Then, to keep the porous core empty ± 0.7 bar pressurized air was blown through for ± 20 min. Specimen were cured under lab condition with RH $\pm 30\%$ and temperature $\pm 20^\circ\text{C}$ prior to after-healing permeability test and second mechanical three point loading.

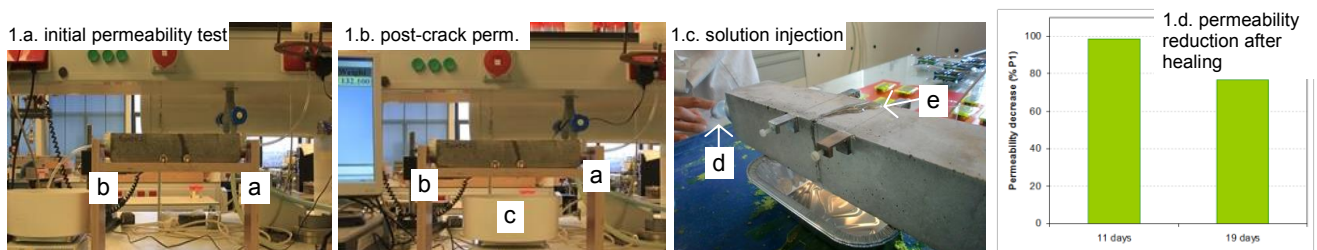


Figure 1: Preliminary experimental procedure and the result of the study

The result for permeability test after healing showed a very promising 98% reduction at 11 days assuming precipitation products were formed in the crack zone. However, lower percentage of permeability reduction was achieved after 19 days test on the same specimen, depicted in figure 1.d. This could be attributed to the flushing of the solution after 11 days. It was assumed that healing process have not yet completed. As temporary healing was observed, a preliminary investigation to assess sealing capacity of bio-based solution was conducted. The 4 ml same solution composition was then injected into $\varnothing 26\text{-}30$ mm cylindrical porous core covered with plastic film tightened with adhesive tape. One control (tap water injection) and four different series (bacteria-based solution injection) with two replicates were carried out. Bio-mineral precipitation was monitored 3, 7, 14, 21, and 28 days using several techniques; x-ray μCT Scan, water permeability test, and ESEM.

After 3 days, observations of polished sections under stereomicroscope and ESEM exhibited a cavity between porous concrete matrix and epoxy resin in the series comprising nutrients. This was attributed to the food dissolution during the grinding process with water. However, further higher magnification observation into this cavity

appears to be a good indicator for the location of bacteria-based solution and therefore to the presence of calcium carbonate precipitated due to bacterial activity. Bacteria imprints on Ca-based mineral (figure 2) observed in different spots provided the direct evidence of bacteria induced CaCO_3 precipitation. This result leads to the conclusion that bacteria-based repair solution can successfully be injected into porous network concrete as crack-healing agent.

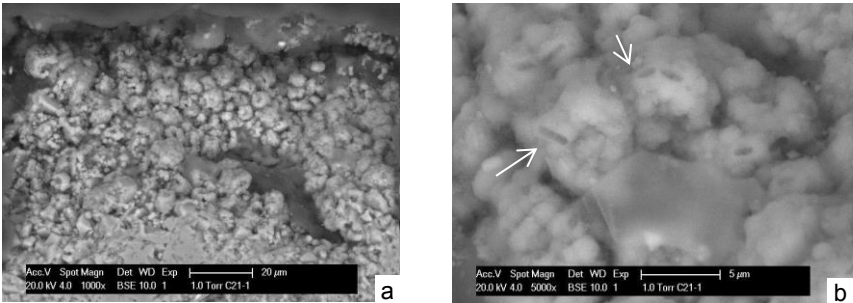


Figure 2: (a) Ca-based mineral formation of series ‘C’ at 21 days, (b) 5000x magnification shows bacteria imprints (white arrows) of spot (a).

3. ON-GOING RESEARCH PROGRAM

As a consequence of the preliminary results a research program (see table 1) has been devised to implement injection of bacteria based solution into 55×55×285 mm PNC specimen. Each specimen center interior is 23×23×285 mm porous concrete and Ø2 mm threaded steel rebar was installed under the core. The specimen was prepared as described by Sangadji and Schlangen [2]. Two type of treatment were implemented with 2 replicates. The ‘control’ series received injection of tap water and ‘bacteria’ series received injection of bacteria-based solution. Two different curing were conducted in which ‘wet’ series were cured in ± 95% RH and ± 20°C curing chamber while ‘dry’ series were cured under lab condition abovementioned.

Table 1: matrix of research program.

		Curing	
		Wet	Dry
Treatment	Control	CtrlW-1	CtrlD-1
		CtrlW-2	CtrlD-2
	Bacteria	BactW-1	BactD-1
		BactW-2	BactD-2

Similar test procedure as described in preliminary program was performed. Initial crack width in the beam bottom side was achieved around ± 250 µm [2]. Then 30 ml water was injected into PNC ‘control’ series and solution A and B were injected into ‘bacteria’ series specimens. To improve CaCO_3 formation capacity, calcium salt has been changed. Crack closure has been monitored before and 7, 14, 21, and 28 days after injection under stereomicroscope. Quantification of crack-healing has been carried out using the method as described by Wiktor and Jonkers [3]. 28 days post-healing permeability test was executed to measure permeability reduction. The results showed that wet cured bacteria series exhibited 99% permeability reduction while dry cured specimen only shows 60% reduction. By the times this abstract is written, the first replicate specimen preparation for ESEM is in

progress meanwhile the second replicates is currently cured for on-going monitoring until 100 days.

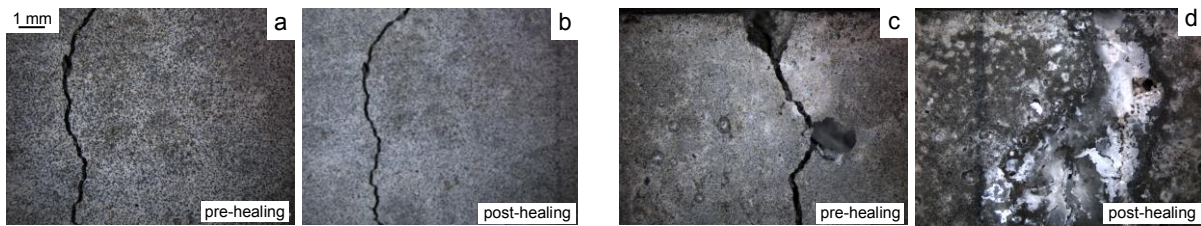


Figure 3: stereomicroscopic images of dry cured control before (a) and after (b) 28 days healing, and in wet cured 'bacteria' before (c) and after (d) 28 days healing.

Second cycle three-point loading was carried. The result was compared to the first cycle loading to assess regain of mechanical properties. The curves are presented in figure 4 which obviously showed limited strength and stiffness regain.

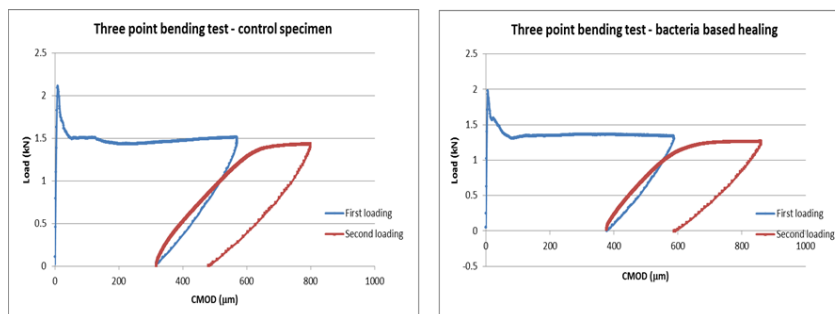


Figure 4: Load versus crack mouth opening displacement before and after healing.

4. CONCLUSIONS

As evidence of bacteria activity has been found with observation of bacteria imprints in the preliminary studies, the crack closure in the bacteria-based solution injected beam can then be allocated induced by bacteria. Even though mechanical regain in term of strength and stiffness of bacteria-based post-healing beam is quite limited, crack sealing works effectively and liquid tightness may be assured.

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