Reduction of water permeation through cracks in mortar by addition of bacteria based healing agent

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ABSTRACT

Water tightness of cracks in concrete constructions requires stringent limitations on crack widths. Practical guidelines recommend maximum crack widths of 200 µm, based on the autogenous healing capacity of the cementitious material. Here crack paths are mainly blocked by formation of calcium carbonate due to carbonatation of calcium hydroxide (portlandite) minerals present at the crack surface. Additional production of calcium carbonate may enhance the healing capability, slackening limitations on crack width for regain of water tightness. Carbonates can be formed in the alkaline cementitious environment by bacterial metabolic conversion of a precursor compound. Proposed is the addition to the cementitious mixture of a scalable healing agent, consisting of lactic acid derivatives as a microbial metabolic carbon source, nutrients for bacterial activation and bacterial spores. Healing agent particles of size 1-4 mm were produced at a 10 kg h^{-1} scale. During preparation of the cementitious mixture, particles were mixed in with the sand fraction of the dry constituents. Particles retained integrity during the mixing phase, as intact particles remained visible in the set mortar matrix. Cracked mortar samples and exposed mortar embedded healing agent particles were immersed in water, followed by oxygen measurements for establishing metabolic activity of bacteria. Mineral formation inside cracks of water immersed mortar samples was observed. Regain of functionality in the form of water tightness was indicated by reduction of water permeation through cracks after a healing regime. In this procedure, water permeation of cracked specimens was determined before, during, and after incubation in either water or exposure to 95% relative humidity up to 70 days. Mortar specimens of both control and healing agent containing series featuring crack widths below 200 µm appeared healed. However, only for healing agent containing samples significant reduction of permeability was found for specimens with reopened crack widths above 400 µm.

1. INTRODUCTION

For addition of bacteria-based healing agent to cementitious mixtures, targeted healing is in the form of crack sealing for regain of functionality in the form of water tightness. Stringent limitations exist on crack widths for water bearing structures. The critical crack width is determined by the autogenous healing capacity of concrete [1,2], regarded as 200 µm in case of insignificant water load during healing. Crack paths are mainly blocked by formation of calcium carbonate, due to carbonatation of calcium hydroxide (portlandite) [2]. Increasing the formation of calcium carbonate can enhance crack blockage, so that limitations on crack widths for water bearing structures may be slackened. Carbonates can be produced in an alkaline environment due to microbial metabolic conversion of a carbon source. Bacterial spores remain inactive until contacted by water entering through the cracked cementitious matrix. Proposed is the addition of lactic acid derived particles with embedded bacterial spores and activation nutrients to a cementitious matrix such as mortar. Healing potential is shown by regain of functionality in the form of water tightness for crack widths beyond autogenous healing capacity. Indication of scalability of healing agent, limited influence on mixture behaviour and hardening, microbial metabolic activity, mineral formation and significantly enhanced reduction of water flow through cracks show the potential for use of the proposed healing agent in water retaining structures for extended regain of water tightness.

2. MATERIALS AND METHODS

Flake like healing agent particles from lactic acid derivatives, containing bacterial spores and activation nutrients were produced at 10 kg h^{-1} scale in collaboration with Corbion Purac at the department of Chemical Engineering at Delft University of Technology. 15 kg m^{-3} healing agent particles of 1 to 4 mm were mixed in with commercially available ready mix mortar dry constituents (weber.tec SBN 175 III/4, Weber Beamix, Eindhoven, The Netherlands) prior to addition of water and mixing according to the recipe provided by the mortar manufacturer. Prisms of 4 x 4 x 16 cm^3 and cubes of 10 x 10 x 10 cm^3 were cast in two layers and compacted per layer by 15 strokes with a rod. As a control, mortar prisms and cubes were produced without healing agent addition. After one day prisms and cubes were removed from the mould and held in foil for 28 days. Prisms were tested for mechanical strength under bending and compression (NEN-EN 196-1). Subsequently half prisms were sawn in 1 cm layers and added to demineralized water in a closed vial to check for reduction in oxygen concentration to indicate microbial metabolic activity by non-invasive oxygen measurement (PSt3 sensor, Fibox 4 transmitter, PreSens, Regensburg, Germany). The other prism halves were immersed in water to indicate mineral formation in cracks by visual observation using stereomicroscopy (Leica MZ6). Cubes were sawn in half and split to various crack widths, with incorporated fibres keeping crack faces at distance. Splitting forces were exerted on short sides of the half cube. The surfaces on which the splitting force was exerted were sealed using viscous silicon glue. In this way a parallel crack remained, connected in one direction, such that the crack length was constant. An inverted polyvinyl chloride shower drain of 10 x 10 cm^2 and height 10 cm was glued on one of the cracked surfaces. A drain pipe with rubber sealed tightening was connected to the inverted shower drain to add a height of 5 cm. Water flow through cracks was measured by applying a stable 15 cm water head vertically on the cracked surface. Permeated water was collected in a tray on a weighing scale. The scale was connected to a computer in order to record accumulation of permeated water in time, determining the water flow rate through the crack. Half cubes were subsequently kept in water or 95% humidity room up to 70 days as a healing regime. During this time the crack was held in horizontal plane, to prevent influence of gravity or surface deposition. After healing the water permeation through the crack was again measured. In case of crack closure, cracks were reopened by splitting, water permeation was determined and another healing period was applied. Classification of crack widths was done by initial water flow rates, using data of spacer controlled cracked specimens from another project in the research group (D. Palin, personal communication), modified to the reported specimen size and applied water head. Water flow rates to 0.65 mL s^{-1} were regarded as cracks ≤ 200 µm and flow rates between 1.17 and 2.29 mL s^{-1} indicated cracks around 400 µm. Water flow rates above 2.29 mL s^{-1} were regarded optimal to assure crack widths above 400 µm. Visual observation confirmed the size range.

3. RESULTS AND DISCUSSION

During mixing negligible influence on mortar consistency was observed. Mortar flexural and compression tests indicated no significant influence on strength development at 28 days upon addition of healing agent. Visibility of healing agent particles upon wet sawing of hardened mortar samples indicated particle survival during the mortar mixing and hardening process. Subsequent immersion of mortar slices in water for oxygen measurements indicate bacterial activation and nutrient conversion in hardened and cracked mortar samples (Figure 1). Cracked half prisms in water containing healing agent showed abundant mineral formation at the crack mouth. For half cube specimens cracks were initially below 200 µm, for which autogenous healing was expected. Significant reduction in water permeation for both mortars with and without healing agent confirmed ability to close cracks autogenously up to a width of 200 µm. Upon reopening of cracks, widths were above 400 µm and therefore regarded beyond autogenous healing capability. After following a healing regime significant differences showed between control and healing agent containing samples. Figure 2 shows an example of samples from the two series experiencing a similar initial water flow rate, for which the healing agent containing sample shows significant reduction of water flow in time. Similar reduction is currently seen for initial flow rates up to 8.5 mL s^{-1}. Even after subsequent drying of the samples, cracks remained significantly water tight. Since results only indicate autonomous healing in case of stagnant water without water pressure, future work in which cracks heal under increased water head or water flow should indicate potential for broader application in water retaining structures. Recommended is to extend addition of healing agent to a variety of mortars and concretes at various healing agent content.

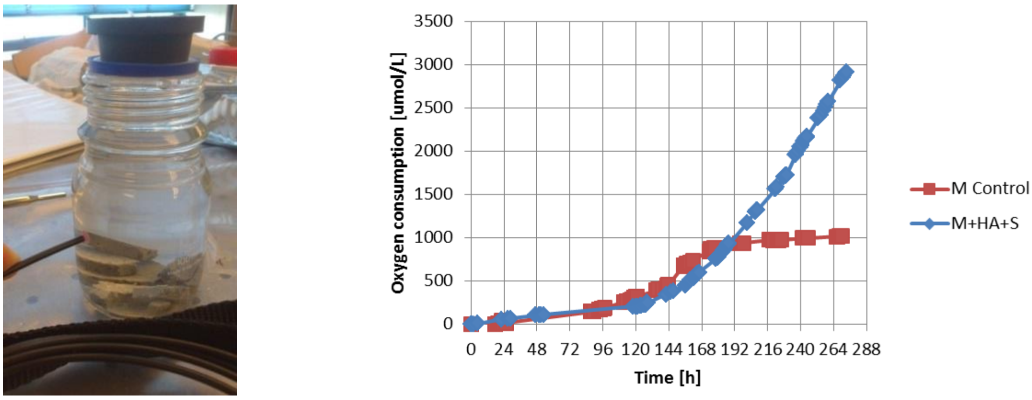

Figure 1: Non-invasive oxygen measurement for oxygen consumption in time.
M = control mortar, M+HA+S = mortar with healing agent and bacterial spores.

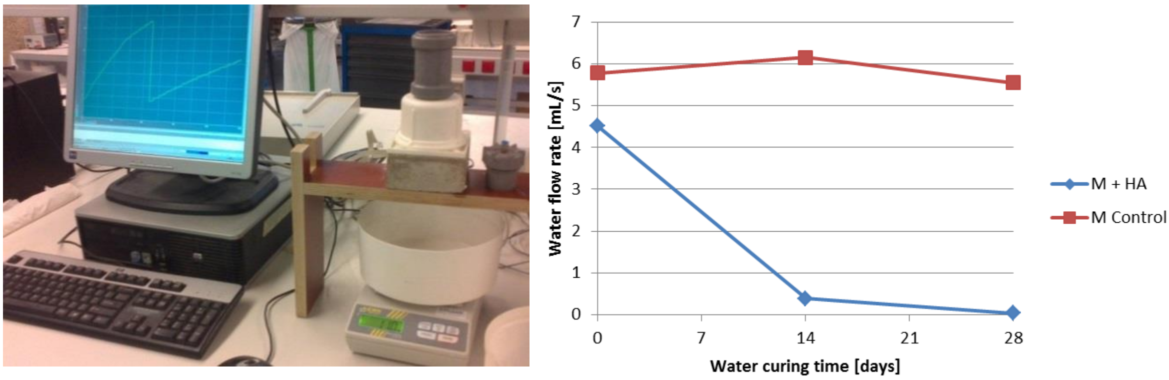

Figure 2: Water flow through crack at various water curing times.
M = control mortar, M+HA = mortar with healing agent.

4. CONCLUSIONS

Given a mortar added scalable healing agent with negligible influence on mortar mixture consistency and strength development, a promising bacteria-based additive was found for further characterisation of healing potential. From oxygen consumption measurements microbial metabolic activity for healing agent containing cracked mortar was indicated. Mineral formation was visible at the crack mouth on several occasions, but is not a necessity for regain of water tightness as the functionality. For crack widths below 200 µm significant reduction was seen for water flow through cracks upon water immersion or placement in humidity room, though no superficially visible material was formed in the cracks. For crack widths above 400 µm water tightness was restored in case samples contained bacteria-based healing agent, but not in control specimens.

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