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Bacterial carbonate precipitation as an alternative surface treatment for concrete

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Abstract

Surface treatments play an important role in the protection of construction materials from the ingress of water and other deleterious substances. Due to the negative side-effects of some of the conventional techniques, bacterial induced carbonate mineralization has been proposed as a novel and environmental friendly strategy for the protection of stone and mortar. This paper reports the effects of bacterial $CaCO_3$ precipitation on parameters affecting the durability of concrete and mortar. Pure and mixed cultures of ureolytic bacteria were compared for their effectiveness in relation to conventional surface treatments. Bacterial deposition of a layer of calcite on the surface of the specimens resulted in a decrease of capillary water uptake and permeability towards gas. This bacterial treatment resulted in a limited change of the chromatic aspect of mortar and concrete surfaces. The type of bacterial culture and medium composition had a profound impact on $CaCO_3$ crystal morphology. The use of pure cultures resulted in a more pronounced decrease in uptake of water, respectively less pronounced change in the chromatic aspect, compared to the use of mixed ureolytic cultures as a paste. The results obtained with cultures of the species *Bacillus sphaericus* were comparable to the ones obtained with conventional water repellents.

Keywords: Water repellents; Coatings; Capillary water suction; Gas permeability; *Bacillus sphaericus*; Mixed ureolytic cultures

1. Introduction

Current concern about the degradation of concrete and the economic impact of the maintenance and repair of concrete structures, have drawn the attention to processes of concrete deterioration, and to the methods to slow down or even to eliminate concrete degradation [1]. The service environment, together with the permeation properties of concrete determine the risk of damage and the speed at which it can develop. Many of the physical and chemical deterioration mechanisms of concrete are related to aggressive substances present in aqueous solution. An important measure to protect concrete against damage is then diminishing the uptake of water [2]. Surface treatments play an important role in limiting the infiltration of water – and consequently of detrimental components – into concrete. Nowadays a broad array of organic and inorganic products is available on the market for the protection of concrete surfaces, such as a variety of coatings, water repellents and pore blockers. These conventional means of protection show, however, beside their favourable influences also a number of disadvanta-

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geous aspects such as: (i) different thermal expansion coefficient of the treated layers; (ii) degradation over time and (iii) the need for constant maintenance. Furthermore the use of certain solvents contributes to environmental pollution [3–5]. To partially offset these disadvantages, more ecologically friendly methods have been suggested. Within this framework, bacterial induced carbonate mineralization has been proposed as a novel and environmentally friendly strategy for the protection and remediation of stone and mortar [6].

Microbial mineral precipitation (biodeposition) involves various microorganisms, pathways and environments. Considerable research on carbonate precipitation by bacteria has been done by using ureolytic bacteria. These bacteria are able to influence the precipitation of calcium carbonate by the production of a urease enzyme. This enzyme catalyzes the hydrolysis of urea to CO_2 and ammonia, resulting in an increase of the pH and carbonate concentration in the bacterial environment [7]. Precipitation of calcium carbonate crystals occurs by heterogeneous nucleation on bacterial cell walls once supersaturation is achieved. Biodeposition technologies have already been used for consolidation of sand columns [7–9], for repair of limestone monuments [10–12] and to a smaller extent for remediation of cracks in concrete [13–15]. Results from life-size experiments on limestone monuments have shown a protective effect of the bacterial deposited calcite layer for several years. It is suggested that a new treatment should be applied after 10 years [16].

Until now, many researchers used cultures of single bacterial strains. This paper describes the results of an innovative approach in which both the use of pure cultures of *Bacillus sphaericus*, and of ureolytic mixed cultures have been investigated for mortar and concrete remediation purposes. The influence of different kinds of nutrients on the efficiency of the treatment was also part of this investigation. To gain a better insight into the efficiency of the bacterial treatments, results were compared with those obtained from conventional surface treatments.

2. Materials and methods

2.1. Mortar and concrete specimens

Ordinary Portland cement (CEM I 52.5) was used for all mixtures. Depending on the type of experiment, concrete or mortar samples were chosen for reasons of practical convenience. Standardized mortar prisms ($40 \times 40 \times 160$ mm), prepared according to European Standard EN 196-1, were cut into cubes with sides of 40 mm for capillary water absorption experiments. Prisms were made with water–cement ratios (w/c) of 0.5, and cured for 28 days in water prior to treatment. Cylindrical specimens ($H = 50$ mm, $D = 150$ mm) were drilled out of concrete slabs ($1200 \times 700 \times 50$ mm) for gas permeability experiments. The concrete mixture had the following composition (per m^3): 300 kg cement, 670 kg sand 0/5, 1280 kg gravel 8/16, 150 kg water (w/c 0.5). The concrete slabs were cured for 28 days under humid atmosphere (95% R.H., 20 °C) prior to the drilling of the specimens and the treatment.

2.2. Micro-organisms and growth conditions

2.2.1. B. sphaericus

B. sphaericus LMG 225 57 (BCCM, Gent) was used for this study. Selection of this strain was based upon earlier work by our research group. This strain showed a high urease activity, a very negative ζ-potential and a continuous formation of dense calcium carbonate crystals in liquid medium [10]. *B. sphaericus* is unlike to cause human disease. No measurable health effects were seen in laboratory animals that were exposed to large concentrations of *B. sphaericus* by multiple routes of exposure. Cases involving human health effects following exposure to this organism are extremely rare. Mild eye and skin irritation may occur in humans following contact with *B. sphaericus* [17,18].

Liquid culture media consisted of 3 g/L nutrient broth powder (Oxoid N.V., Drongen, Belgium), 2.12 g/L $NaHCO_3$ (VWR International, Leuven, Belgium) and 10 g/L urea (VWR International, Leuven, Belgium). Liquid media were sterilized by autoclaving for 20 min at 120 °C. Cultures were incubated at 28 °C on a shaker at 100 rpm for 48 h.

2.2.2. Ureolytic mixed cultures

Ureolytic mixed cultures were obtained through specific cultivation of active biomass, in a semi-continuous reactor. The reactors were filled with 1 L activated sludge obtained from an aerobic wastewater treatment plant. After sedimentation in Imhoff cones, 0.3 L of supernatant was replaced by the same volume of tap water, containing 2 g/L nutrient broth powder, 10 g/L urea and 10 g/L SLM 1228 (Gebroeders Lambrecht, Aalst, Belgium). One g/L of the SLM 1228 represents a chemical oxygen demand (COD) of 1135 mg/L, a phosphorus concentration of 50 mg/L and a Kjeldahl N concentration of 44 g/L. The reactors were continuously mixed at 100 rpm and 28 °C. Every second day, part of the reactor content was replaced, using the procedure described above. This procedure offered the ureolytic bacteria an ecological advantage and therefore stimulated their growth [19]. An adaptation period of 7 days was respected, to obtain a system in equilibrium. The dry matter content and the concentration of volatile organic compounds amounted to 25.8 ± 1.8 g/L and 16.1 ± 0.8 g/L, respectively.

2.3. Conventional surface treatments

To gain a better insight into the efficiency of the bacterial treatments, results were compared to those obtained from conventional surface treatments. For that purpose a number of commercially available water repellents and