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# Feasibility tests toward the development of protective biological coating mortars

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## HIGHLIGHTS

- A conceptually new biological coating mortar was developed for concrete durability.
- The glycocalyx membrane by photosynthetic bacteria was used for coating approach.
- The bacterial immobilization technique was originally developed.
- We examined the optimum growth environments of bacteria in hardened mortar.
- We verified the potential of the developed coating mortar as a biomimetic material.

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## ABSTRACT

The objective of the present pioneering study is to examine the significance and limitations of the development of new biological coating mortars to protect the substrate of concrete exposed to chemical and microbiological attacks. Acting as a block membrane against the exogenous attack, the glycocalyx that is formed around the cell during bacterial cultivation and growth is introduced in the coating mortars. An inventive immobilization process using expanded vermiculite containing numerous internal pores, and a magnesium potassium phosphate composite (MKPC) as a near-neutral binder were implemented to achieve the preferable environment for growth and survival of bacteria within the hardened mortars. Based on the assessment of the productivity of the glycocalyx of various photosynthetic bacteria, the cultivated bacterium *Rhodobacter blasticus* in malic acid medium is recommended as a primary strain for the coating of mortars. The setting behavior, compressive strength development, and pH variation of the biological coating materials were evaluated as the replacement level of expanded vermiculite that contained bacterial agents varied from 0 to 10%. The population of bacteria immobilized into the expanded vermiculite and incorporated within the mortars verified that the present approach is practical to achieve the growth environment of bacteria. Overall, the developed biological coating mortar possesses significant potential toward an ideal biomimetic material for concrete structures and their maintenance.

## 1. Introduction

Even though cracking is commonly accepted as an inherent feature of concrete owing to the low tensile strength, the presence of cracks reduces the durability of materials and structures and causes the corrosion of the embedded steel reinforcement [1]. van Tittelboom et al. [2] mentioned that cracks cause severe damage and shorten the lifetime of reinforced concrete structures because they supply an easy path for the migration of moisture and gases that potentially accelerate the carbonation of hydration products and expansive reactions with cementitious matrix. Hence, cracks need to be treated in time. However, cracks would not be able to be detected easily, and the timely treatment of every single crack is unrealistic. As a result, self-healing technology has gradually attracted interest to achieve sustainable and durable concrete through the reduction of the high maintenance and repair costs of concrete structures.

Among the currently investigated self-healing strategies, the microbial-based approach has been extensively investigated in the area of crack remediation of concrete since the pioneering

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study [3] on the precipitation of calcium carbonate using a specific type of anaerobic bacteria. Zhong and Yao [4] pointed out that bacterial deposition of the calcite layer within concrete plays an important role in remediating concrete cracks, resulting in a decrease of capillary water uptake and gas permeability. Moreover, it has been reported [5,6] that the precipitation of calcium carbonate by the bacterial activity contributes to the enhancement of the compressive strength and durability of concrete through a decrease in porosity. The surface deposition of calcium carbonate crystals decreases the water absorption by as much as 85% depending on the porosity of the specimens. Thus, the use of microorganisms in concrete has led to the process of biomineralization that possesses potential for use in an extensive range of sustainable and durable concrete applications [7,8].

In recent biological self-healing concrete technologies, attention has been paid on immobilization using protective carriers or on other encapsulation approaches to ensure the long-term survival and activity of bacteria within hardened concrete [9–11]. There is a high risk that the bacterial cells or spores might be damaged during the stage of concrete mixing because of the mechanical and frictional forces generated by the blender and aggregate particles. The high temperature due to the cement hydration in the concrete mass would also be harmful to bacterial cells. The dense structure of concrete with pore sizes on the order of 0.5 μm squeeze the bacteria whose length are commonly in the range of 1–3 μm. Furthermore, the capillary water of the matrix of concrete is typically characterized by high alkalinity with pH values ranging between 11 and 13, and by the lack of nutrients needed for bacteria growth. Hence, immobilization of bacteria into a protective carrier can lead to preferable growth and a preferable survival environment further to the direct addition of bacteria during the stage of concrete mixing. Bang et al. [12] and Wang et al. [11] showed that porous polyurethane has good potential to be used as a key material of an immobilization bacterial technique for remediation of cracks in concrete. Meanwhile, Erşan et al. [9] indicated that the adverse effects on the mechanical properties of concrete should be carefully considered in the selection and addition of porous carrier materials for biological self-healing concrete applications.

Most biological concrete studies in recent times have focused on the remediation of cracks through the addition of the immobilized bacteria, or on the encapsulation materials containing bacteria agents (including bacterial cells and nutritional medium), during the stage of mixing of concrete ingredients. Meanwhile, protective coating techniques using immobilized bacteria can be accepted as a novel enlargement of biological self-healing for the concrete structures that are exposed to extreme environments, such as moist, chemical, salt, and microbiological attacks [13]. It might be expected that a protective biological coating material has sustainable and biological resistances against extreme environments, unlike the conventional coating materials, such as epoxy, which lead to a gradual deterioration under chemical or microbiological attacks. The present study is a fundamental research effort to examine the significance and feasibility to develop a new biological coating mortar to protect the substrate of concrete exposed to chemical and microbiological attacks, such as in cooling towers and drainage pipeline structures. The biological coating mortars were produced using porous expanded vermiculite, used as a bacterial carrier; natural sand; and near-neutral binder. As a block membrane against the exogenous attack, the glycocalyx is introduced as the substance generated around the bacterial cell during cultivation. To achieve a preferable environment for growth and survival for the bacteria, magnesium potassium phosphate composite (MKPC) is employed as a near-neutral binder for the protective coating mortars of concrete substrates. Overall, this fundamental study focuses on the development of recipe of biological coating mortars.

## 2. Proposals for a protective biological coating material

Fig. 1 shows a schematic diagram of a biological coating mortar designed to protect the substrate of concrete exposed to chemical and microbiological attacks. To promote a sustainable and protective biomimetic effect to the coating mortar, the bacterial glycocalyx is introduced as a block membrane. The glycocalyx, formulated during the cultivation of bacteria, is consisted of a sparse slime layer and a polymer skin capsule that tightly surrounds a cell. It is commonly estimated [14] that the primary chemical composition of the glycocalyx comprises rhamnose, mannose, galactose, glucosamine, phosphorus, and fatty acids, although the composition ratios vary according to the bacterial strain and the ingredients of the culture media. The glycocalyx in the biological activity of bacteria serves as a protecting sheath for the cell, and accelerates the interaction with other bacteria. The cultured bacteria cells that have a glycocalyx are immobilized into the pores of the porous materials, such as the expanded vermiculite, perlite, and hydrogel. To enhance the survival and activity of bacteria, and minimize odor in the immobilization stage, the culture medium is treated under an additional process. The cultured cells are washed twice and then resuspended into basic mineral media. The bacteria are immobilized by the ion-exchange reaction between bacterial anions and the cations of porous materials. To fix the porous materials containing bacterial agents on the concrete surface, MKPC is introduced as a cementitious material considering its near-neutral pH value and moderate bond strength. The primary factors to be considered in selecting the binder for biomimetic coating mortars are the activation and growth environments of bacteria, material cost, construction ability, and bond strength. Note that the porous materials containing bacterial agents are added during the mixing stage of MKPC coating mortars. The bacterial cells immobilized into porous materials mature and spread out within the hardened MKPC mortars, consistently formulating glycocalyx.

Overall, the developed biological coating approach exhibits the following differentiation and significance over the conventional biological concrete technology for crack remediation:

- The approach focuses on protecting the substrate of concrete exposed to chemical and microbiological attacks in order to enhance its durable potential.
- The glycocalyx formulated by photosynthetic bacteria is introduced for the biological technology, instead of the precipitation of calcium carbonated by bacteria.
- The bacteria are immobilized by the ion-exchange reaction between bacterial anions and porous material cations to offer bacteria proper growth environments.
- Near-neutral MKPC is used as the main binder of coating mortars to promote the survival and activity of bacteria immobilized into porous materials.

## 3. Experimental program

The present study is implemented to assess the significance and feasibility of the proposed approach. The protective biological coating mortar refers to a mixture of near-neutral cementitious materials, fine aggregates, and porous materials immobilizing bacteria with glycocalyx formation. Hence, the critical element technologies for developing the biological coating mortars need to be established in the following phases: 1) selection of bacterial strains and optimization of their culture conditions with regard to the glycocalyx production capacity; 2) implementation of a practically effective immobilization process of bacterial cells; and 3) achievement of an optimum mixture of the coating mortar compositions