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Bacteria Based Self Healing Concrete – A Bacterial Approach

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ABSTRACT: -*Concrete in most structures is designed to crack in order to let embedded steel reinforcement take over tensile stresses. Crack formation is also a typical phenomenon related to durability. Percolated cracks may lead to leakage problems or ingress of harmful materials, which can cause deterioration of the concrete matrix or reinforcement corrosion. Durability can be enhanced by preventing further ingress of water and other substances. Self-healing is characterized by regaining performance after a defect occurs. Damage targeted in bacteria-based self-healing concrete particularly relates to increased durability and leakage prevention and extending service life of concrete structures. This paper introduced a two-component healing agent to be added to the concrete mixture, consisting of bacteria and a mineral precursor compound. Upon cracking the system is activated by ingress water. Bacteria convert the mineral precursor compound into the mineral calcium carbonate, better known as limestone. Precipitation of the limestone on the crack surface enables sealing and plugging of the cracks, making the matrix less accessible to water and other deleterious materials.*
KEYWORDS: *Concrete crack-healing, permeability, bacteria, calcium carbonate formation*

I. INTRODUCTION

Concrete is the most commonly used building material which is recyclable. Concrete is used in structures to resist the compression stresses and reinforcements are used to resist the tensile stresses in concrete. Concrete does not require much water to achieve maximum strength. But a wide majority of concrete used in residential work has too much water added to the concrete on the job site. This water is added to make the concrete easier to install. This excess water also greatly reduces the strength of the concrete. Shrinkage is a main cause of cracking. As concrete hardens and dries it shrinks. This is due to the evaporation of excess mixing water. The wetter or soupier the concrete mix, the greater the shrinkage will be. This Crack formation in concrete is a phenomenon that can hardly be complete avoided due to for example shrinkage reactions of setting concrete and tensile stresses occurring in set structures. While larger cracks can potentially hamper a structures' integrity and therefore require repair actions, smaller cracks typically with a crack width smaller than 0.2 mm are generally considered unproblematic [1-2]. Although such micro cracks do not affect strength properties of structures they do on the other hand contribute to material porosity and permeability. Ingress of aggressive chemicals such as chlorides, sulfates and acids may result on the longer term in concrete matrix degradation and premature corrosion of the embedded steel reinforcement and thus hamper the structures' durability on the long term. In several studies indications have been found that concrete structures have a certain capacity for autonomous healing of such micro cracks [2-5]. The actual capacity of micro crack healing appears primarily related to the composition of the concrete mixtures. Particularly mixtures based on a high binder content show remarkable crack-healing properties [5] what is due to delayed (secondary) hydration of matrix embedded nonhydrated cement and binder particles upon reaction with crack ingress water. Autogenous self-healing of cracks in traditional but also high-binder content mixtures appear limited to cracks with a width smaller than 0.2 mm [2-5]. This somewhat limited effectiveness appears largely due to the restricted expansive potential of the small non-hydrated cement particles lying exposed at the crack surface. Another limitation to application of highbinder content mixtures solely for the purpose of increasing self-healing capacities are current policies which advocate sparse use of cement in concrete for sustainability reasons as current cement production contributes about 7% to global anthropogenic CO2 emissions [6]. For latter reasons, alternative and more sustainable self-healing mechanisms are therefore wanted. One possible mechanism is currently being investigated and developed in several laboratories, i.e. a technique based on the application of mineral-producing bacteria. E.g. efficient sealing of surface cracks by mineral precipitation was observedwhen bacteria-based mixtures were sprayed or applied onto damaged surfaces or manually inserted into cracks [7-13]. As in those studies bacteria were manually and externally applied to existing structures, this mode of repair cannot be categorized as truly self-healing. In several follow up studies therefore, the possibility to use viable bacteria as a sustainable and concrete-embedded self-healing agent was explored [14-16]. In one study spores of specific alkali-resistant bacteria related to the genus Bacillus were added to the concrete mixture as self-healing agent [16]. These spores germinated after activation by crack ingress water and produced copious amounts of crack-filling calcium carbonatebased minerals through conversion of precursor organic compounds which were also purposely added to the concrete mixture. However, in that study it was found that the bacteria-based self-healing potential was limited to relatively young (7-days cured) concrete only, as viability and related activity of bacterial spores directly (unprotected)embedded in the concrete matrix was restricted to about two months. The present study builds further on results reported in latter research paper [16]. Here, bacterial spores and organic mineral precursor compounds are packed in porous expanded clay particles prior to addition to the concrete mixture. It is hypothesized that protection of bacterial spores within porous light weight aggregates extends there viability period and thus concrete self-healing functionality when embedded in the material matrix.

II. SELF-HEALING CONCRETE

Self-healing concrete is a product which biologically produces limestone by which cracks on the surface of concrete surface heal. Selected types of the bacteria genus Bacillus, along with calcium-based nutrient known as calcium lactate, and nitrogen and phosphorous are added to the

Concrete when it is being mixed. The self-healing agents can lie dormant within the concrete for up to two hundred years. When a concrete structure damages and water starts to penetrate in the cracks present in it the bacteria starts to feed on the calcium lactate consuming oxygen and converts the soluble calcium lactate into insoluble limestone. The limestone formed thus sealsthe cracks present. It is similar to the process of how a fractured bone gets naturally healed by osteoblast cells that mineralize to reform bone. Consumption of oxygen in the bacterial conversion has an additional advantage. Oxygen which becomes an essential element for the corrosion of steel to take place is being used in the bacterial conversion. Hence the durability of steel in construction becomes higher. The process of bacterial conversion takes place either in the interior or exterior of the microbial cell or even some distance away within the concrete. Often the bacterial activities trigger a change in the chemical process that leads to over saturation and mineral precipitation. Utilization of concepts of bio mineralogy in concrete lead to invention of a newmaterial termed as Bacterial Concrete. Bacterial concrete refers to a new generation concrete in which selective cementation by microbiologically-induced $CaCO_3$ precipitation has been introduced for remediation of micro-cracks.

2.1 VARIOUS TYPES OF BACTERIA USED IN CONCRETE

- Bacillus pasteurizing
- Bacillus sphaericus
- Escherichia coli
- Bacillus subtilis
- Bacillus cohnii
- Bacillus balodurans
- Bacillus pseudofirmus

2.2 MECHANISM OF BACTERIAL CONCRETE

Self-healing concrete is a result of biological reaction of non-reacted limestone and a calcium based nutrient with the help of bacteria to heal the cracks appeared on the building.

Special type of bacteria's known as Bacillus are used along with calcium nutrient known as Calcium Lactate. While preparation of concrete, this products are added in the wet concrete when the mixing is done. This bacteria's can be in dormant stage for around 200 years.

When the cracks appear in the concrete, the water seeps in the cracks. The spores of the bacteria germinate and starts feeding on the calcium lactate consuming oxygen. The soluble calcium lactate is converted to insoluble limestone. The insoluble limestone starts to harden. Thus filling the crack, automatically without any external aide.The other advantage of this process is, as the oxygen is consumed by the bacteria to convert calcium into limestone, it helps in the prevention of corrosion of steel due to cracks. This improves the durability of steel reinforced concrete construction.

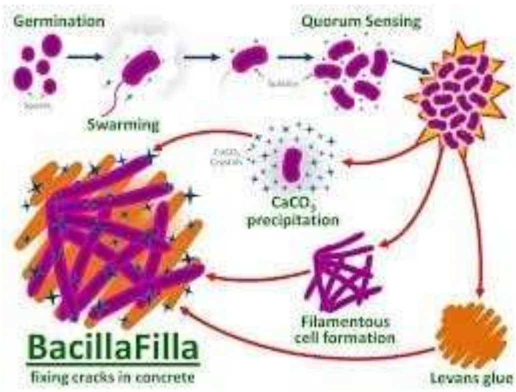


Fig1: Process of fixing crack in concrete

(Source :https://theconstructor.org/concrete/bacterial-concrete-self-healing-concrete/13751/)

2.3 PREPARATION OF BACTERIAL CONCRETE

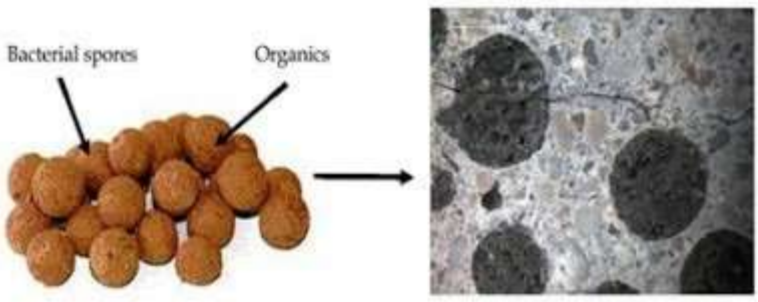
Bacterial concrete can be prepared in two ways,

- By direct application
- By encapsulation in lightweight concrete

In the direct application method, bacterial spores and calcium lactate is added into concrete directly when mixing of concrete is done. The use of this bacteria and calcium lactate doesn't change the normal properties of concrete. When cracks are occurred in the structure due to obvious reasons. The bacteria are exposed to climatic changes. When water comes in contact with this bacteria, they germinate and feed on calcium lactate and produces limestone. Thus sealing the cracks.

By encapsulation method the bacteria and its food i.e. calcium lactate, are placed inside treated clay pellets and concrete is prepared. About 6% of the clay pellets are added for making bacterial concrete.

When concrete structures are made with bacterial concrete, when the crack occurs in the structure and clay pellets are broken and the bacteria germinate and eat down the calcium lactate and produce limestone, which hardens and thus sealing the crack. Minor cracks about 0.5mm width can be treated by using bacterial concrete.



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2.4 CHEMICAL PROCESS OF SELF-HEALING OR BACTERIAL CONCRETE

When the water comes in contact with the unhydrated calcium in the concrete, calcium hydroxide is produced by the help of bacteria, which acts as a catalyst. This calcium hydroxide reacts with atmospheric carbon dioxide and forms limestone and water. This extra water molecule keeps the reaction going.

$$CaO + H_2O \rightarrow Ca(OH)_2$$

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

The limestone then hardens itself and seals the cracks in the concrete.

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IV. TEST AND RESULT OF SELF-HEALING OR BACTERIAL CONCRETE AND NORMAL CONCRETE

Standard test were conducted on normal concrete and self-healing concrete. Test conducted were Compressive and flexural strength tests on a concrete cube for 7 and 28 days.

Table:Compressive Strength Test result for 7 and 28 days for Bacterial Concrete

Sr.No	Days	Normal Concrete (N/mm^2)	Bacterial Concrete(N/mm^2)
1	7	20.85	27.10
2	28	30	38.95

Table:Flexural Strength Test result for 7 and 28 days of Bacterial Concrete

Sr.No	Days	Normal Concrete (N/mm^2)	Bacterial Concrete(N/mm^2)
1	7	3.90	4.6
2	28	7.05	7.80

V. ADVANTAGES AND DISADVANTAGES OF BACTERIAL CONCRETE

Advantages of Bacterial Concrete

- Self-repairing of cracks without any external aide.
- Significant increase in compressive strength and flexural strength when compared to normal concrete.
- Resistance towards freeze-thaw attacks.
- Reduction in permeability of concrete.
- Reduces the corrosion of steel due to the cracks formation and improves the durability of steel reinforced concrete.
- Bacillus bacteria are harmless to human life and hence it can be used effectively.

Disadvantages of Bacterial Concrete

- Cost of bacterial concrete is double than conventional concrete.
- Growth of bacteria is not good in any atmosphere and media.
- The clay pellets holding the self-healing agent comprise 20% of the volume of the concrete. This may become a shear zone or fault zone in the concrete.
- Design of mix concrete with bacteria here is not available any IS code or other code.
- Investigation of calcite precipitate is costly.

VI. FUTURE PERSPECTIVES

Currently a fully functional bacteria-based self-healing concrete system using LWA as storage reservoir is available on the laboratory scale. On-going studies in our laboratory investigate the possibility to use this system in practical applications. A next step towards widening application possibilities is the development of a more efficient and economical agent that does not negatively affect concrete strength properties. Possibility for easy application and production on industrial scale at low costs should be considered. Next to healing capacity, long-term behaviour and improvement of durability characteristics of the bacteria-based self-healing concrete material need to be determined, such as resistance to chloride penetration and freeze-thaw cycles. Long-term monitoring of larger scale experiments executed in the outdoors environment may reveal material behaviour in practice. Feasibility of implementing the material in the market should then finally be determined by a full cost-benefit analysis.

VII. SUMMARY

The goal of this paper is to introduce bacteria-based self-healing concrete, currently being developed in our laboratory. On the lab-scale a fully functional system exists. To the concrete mixture a healing agent is added, consisting of two components immobilized in expanded clay particles. Due to bacterial activity a calcium carbonate layer is deposited on the crack surface, sealing and blocking entrance to deteriorating substances. Further research and development is needed in order to make the material ready for application in practice. Since potential advantages are mainly anticipated in reduction of costs for maintenance and repair and service life extension of concrete structures, the self-healing material needs to be cost efficient and durable.

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