

A Review of Emerging Way to Enhance the Durability and Strength of Concrete Structures: Microbial Concrete

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Abstract: Concrete is an absolutely essential component of construction materials used in infrastructure and most buildings. Despite its versatility in construction, it is known to have several limitations. It is weak in tension, has limited ductility and little resistance to cracking. Based on the continuous research carried out around the globe, various modifications have been made from time to time to overcome the deficiencies of cement concrete. However, concrete is sometimes exposed to substances that can attack it and cause deterioration. The corrosion of the concrete is caused by the interaction between biological and chemical processes. When the corrosion is sufficiently occurred, it can lead to structural failures with potentially serious long term operational consequences. Due to microbial activities of the bacteria, microbiologically induced calcite precipitation (MICP), a highly impermeable calcite layer is formed which contributes to increase the performance of concrete structure and also has excellent resistance to corrosion. Recent research has shown that specific species of bacteria can be useful to enhance the durability and strength of concrete structures. This microbial concrete presents a potentially enormous lengthening in service-life of infrastructure, substantially reduces the maintenance costs and also considerably increases the safety of structures. This paper outlines the basic mechanism involved in microbial concrete on which studies were carried out to investigate the causes involved in enhancing the strength and durability of concrete.

Keywords: Concrete corrosion, Microbial concrete, Biological processes, Bacteria, MICP.

I. INTRODUCTION

Concrete is most widely used construction material used all over the world and usually considered as indestructible because of their longer service life as compared with the most constructional products. However, they can get destroyed for a variety of reasons including the material limitations, design gaps and construction practices, as well as exposure conditions. Continuous exposure of hard weathering leads to an increase of the porosity of concrete and as a result, the mechanical features decreases. It is known that the durability of concrete is related to the characteristics of its pore structure. Degradation mechanisms of concrete often depend on the way potentially aggressive substances can penetrate into the concrete, possibly causing damage. The permeability of the concrete depends on the porosity and on the connectivity and /or structure of the pores. The more open the pore structure of the concrete, the more vulnerable the material is to degradation mechanisms caused by penetrating substances. The deterioration of concrete structures usually involves movement of aggressive gases and/or liquids from the surrounding environment into the concrete, followed by physical and/or chemical reactions within its internal structure, possibly leading to irreversible damage [1]. Although many chemical and physical treatments have been applied to decrease the susceptibility to damage, these treatments are not fully useful because of their non reversible action and their limited long term performance.

Many researchers opt to find alternative material that can be incorporated inside the concrete to reduce the usage of cement and at the same time to enhance its properties. Typically, supplementary cementitious material (SCM) such as

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fly ash, silica fume and ground granulated blast furnace slag (GGBS) are commonly used to replace a portion of cement inside concrete [2]. Although it is proven that such admixtures enhances the properties of concrete upto certain extent, these materials are relatively expensive, volume required is high and its availability is limited. Recently, a novel concrete technology has been introduced, that is by incorporating biological approach in concrete. This unique way of concrete design crossbreed between biology and engineering study of concrete is called microbial concrete, which involves the utilisation of bacteria to increase the strength and durability of concrete. These microorganisms are used for calcium carbonate precipitation in concrete, it is highly desirable because the calcite precipitation induced as a result of microbial activities is pollution free and natural [3].

The Calcite precipitation occupies the voids between cement matrixes and therefore leads to denser concrete. The approach does not deplete any natural resources since the bacteria used can be easily reproduced by cultivation process. The use of biological approach in concrete is also considered as a green technology as its production does not involve greenhouse gas emission Therefore bacterial induced Calcium Carbonate (Calcite) precipitation has been proposed as an alternative and environment friendly way for improvement of strength of building materials [4].

II. MICROBIAL CONCRETE

The microbial concrete makes use of calcite precipitation by favourable bacteria. In this technique urolytic bacteria (microorganism) are used hence the concrete is called Bacterial or Microbial concrete. The “Microbial concrete” can be prepared by adding spore forming bacteria in the concrete that are able to continuously precipitate calcite, this process of production of calcite precipitation is called Microbiologically Induced Calcite Precipitation (MICP). Recently, it is found that microbial calcite precipitation resulting from metabolic activities of favorable microorganisms in concrete improved the overall properties of concrete. Bacterial Cultures improves the strength of cement sand mortar and crack repair on surfaces of concrete structures.

The basic principle for this process is that the microbial urease hydrolyzes urea to produce ammonia and carbon dioxide and the ammonia released in surrounding subsequently increases pH, leading to accumulation of insoluble calcium carbonate [5]. Calcium carbonate precipitation, a metabolic process which occurs in some bacteria, has been investigated and proven its wide range of scientific and technological implications.

Calcite formation by Bacillus species is used in making microbial concrete, which can produce calcite precipitates on suitable media supplemented with a calcium source. Bacterial spores are specialized cells which can endure extreme mechanical and chemical stresses and spores of this specific genus are known to remain viable for up to 200 years. Spores are dormant but viable bacterial spores immobilized in the concrete matrix will become metabolically active when revived by water entering freshly into the concrete [6]. Calcite precipitation is selective and its efficiency is affected by the porosity of the medium, the number of cells present and the total volume of nutrient added. The bacteria precipitate calcite in the presence of nutrients. The alkaline environment of concrete with pH around 12 is the major hindering factor for the growth of bacteria. However, some bacteria have the ability to produce endospores to endure an extreme environment, as observed by the studies. The technique is used to improve the compressive strength [7] and reduce the permeability of concrete.

There are various types of Bactria which are used for making microbial concrete and help to improve the concrete strength and durability. According to literature review, following are the some of the bacteria [8] used in the concrete.

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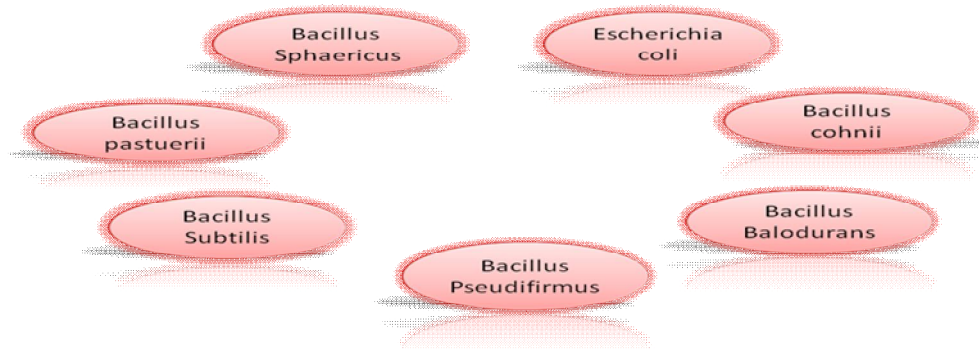


Fig. 1. Various types of Bacteria used in concrete

III. HOW DOES BACTERIA ENHANCES CONCRETE PERFORMANCE

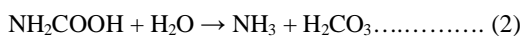
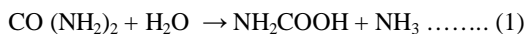
Different types of bacteria, as well as abiotic factors (salinity and composition of the medium) contribute in a variety of ways to calcium carbonate precipitation. When bacteria are exposed to the air and the food, the bacteria grow through the bio chemical process that causes them to harden and fuse, strengthening the structure of concrete. This process extends the lifespan of the concrete. When the concrete is mixed with bacteria, the bacteria go into a dormant state. When any cracks or minor damage occurred to concrete, it provides space for water and/or air entry within concrete and then spores of the bacteria initiate calcite precipitation process. Oxygen is an essential element for the corrosion of steel and when bacterial activity has consumed it then it increases the durability of steel reinforced concrete constructions.

The main role of bacteria has been ascribed to their ability to create an alkaline environment through various physiological activities. Calcium carbonate precipitation is a straight forward chemical process governed mainly by four key factors:

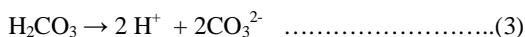
- (1) The calcium concentration,
- (2) The concentration of dissolved inorganic carbon (DIC),
- (3) The pH and
- (4) The availability of nucleation sites

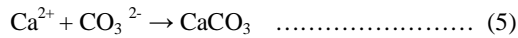
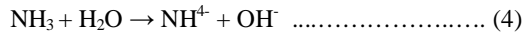
There are different pathways described in literature to achieve Calcium carbonate precipitation however due to simplicity the most commonly studied process of precipitation is urea hydrolysis via the enzyme urease in calcium rich environment.

As part of metabolism, specific bacteria produces urease, which catalyzes urea to produce CO₂ and ammonia, resulting in an increase of pH in the surroundings where ions Ca²⁺ and CO₃²⁻ precipitate as CaCO₃. During microbial urease activity, 1 mol. of urea is hydrolysed to 1 mol of ammonia and 1 mol of carbonate (Eq. 1) , which spontaneously hydrolyzes to form additional 1 mol of ammonia and carbonic acid (Eq. 2) as follows: (with bacteria) [8].



These products equilibrate in water to form bicarbonate, 1 mol. of ammonium and hydroxide ions which give rise to pH increase.





Calcite precipitation by bacterial cell –

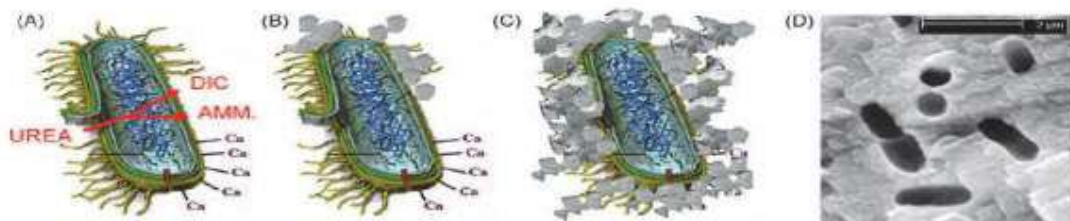
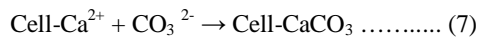
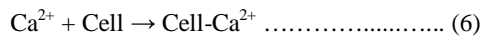


Fig.2. Key roles of pH and calcium metabolism in microbial carbonate precipitation.

Figure 2 shows simplified representation of the events occurring during the microbially induced carbonate precipitation. Calcium ions in the solution are attracted to the bacterial cell wall due to the negative charge of the cell. Upon addition of urea to the bacteria, dissolved inorganic carbon (DIC) and ammonium (AMM) are released in the microenvironment of the bacteria (A). In the presence of calcium ions, this can result in a local supersaturation and hence heterogeneous precipitation of calcium carbonate on the bacterial cell wall (B). After a while, the whole cell becomes encapsulated (C). Image (D) shows the imprints of bacterial cells involved in carbonate precipitation.

Microorganisms has cell surface charge is negative, attracts cations including Ca^{2+} from the environment to deposit on the cell surface. The following equations summarize the role of bacterial cell as a nucleation site [9]:



The bacteria act as a nucleation site which facilitates in the precipitation of calcite which can eventually plug the pores and cracks in the concrete and enhance the durability of concrete. This microbiologically induced calcite precipitation (MICP) comprises of a series of complex biochemical reactions. These create calcium carbonate crystals that further expand and grow as the bacteria produce the calcium lactate food. The crystals expand until the entire gap is filled. This inherent and bio-chemical process helps to improve performance of concrete.

The actual role of the bacterial precipitation remains, however, a matter of debate. Some authors believe this precipitation is an accidental by-product of the metabolism while others think that it is a specific process with ecological benefits for the precipitating organisms.

IV. FUTURE POTENTIAL AND CHALLENGES AHEAD

The carbonation of structures in urban and coastal regions of any country is generally very high. Carbonated concrete loses protective power of steel. Therefore it accelerates steel corrosion and related problems. Hence, the efficiency of calcite deposition in resisting carbonation and reduction in permeability to improve the corrosion resistance must be studied in detail. Most of the studies based on MICP were carried out to evaluate compressive strength, water absorption and crack remediation of mortars and concretes [10]. The role of MICP in reducing the corrosion rate of reinforced concretes has shown potential, but need to be studied in detail.

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The promising results on the use of microorganisms for the improvement of the durability of building materials have drawn the attention of research groups all over the world but until now, work on such bioremediation was mainly confined in some countries. A lot of work needs to be done before the technology can be implemented. The temperatures, humidity, type of concrete, control of various parameters such as type of mix, concentration of bacteria vary considerably from place to place and country to country, hence a consolidated recommendation of any one's result cannot be arrived [11]. Apart from these, survival of microorganisms isolated from other parts of the world under different environmental conditions also needs to be considered. No published work to date has described a sufficient degree towards enhancement in the durability of building structures using microbes by their MICP process. Hence, lot of research is necessary before such technology is ready for field applications. Moreover, long term effect of such treatment is not yet reported.

In the literatures, it has been shown that Bacteria treated concrete samples gave the lower sorptivity and porosity values compared to conventional concrete [12]. It indicates that the time taken for the water to rise by capillary action in microbial concrete are longer and thus proved that these concrete are less porous compared to the normal concrete. However, detail study of permeation properties and the extent of permeability reduction must be studied in detail.

As reported, bacterial material is a smart material than conventional materials so it can be utilised in various construction activities to improve the performance including self healing of concrete.

Advantages of Microbial Concrete –

- Improvement in compressive strength of concrete
- Better resistant towards freeze thaw attack reduction [13]
- Reduction in permeability of concrete
- Reduction in corrosion of reinforced concrete
- Eco friendly

Dis-advantages of Microbial Concrete –

- Cost is high
- Growth of bacteria is not good in any atmosphere [14]
- Design of mix concrete with bacteria is not there in IS code of any design standards
- Investigation if calcite precipitation layer is complex study
- It is great concern to know when bacteria task is complete
- Very limited research work is done across the globe
- No substantial commercial applications hence long term reference not available

V. CONCLUSION

Many researchers have recorded the benefits of microbial concrete which includes the enhancement of compressive strength, reduction in permeability and reinforced corrosion in construction materials. The use of microbial concrete in Civil Engineering has become increasingly popular.

Microbial concrete technology has proved to be better than many conventional technologies because of its eco- friendly nature, self-healing abilities and very convenient for usage. This novel and innovative concrete technology will soon provide the basis for an alternative and high quality structures that will be cost effective and environmentally safe but, more work is required to improve the feasibility of this technology from both an economical and practical viewpoints. The application of microbial concrete to construction may also simplify some of the existing construction processes and revolutionize the ways of new construction processes.

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