Effects of MICP in Self-Healing of Bacterial Concrete

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Abstract

Concrete being the most widely used construction material in the world also have some drawbacks such as, it is very prone to cracking due to a variety of environmental and mechanical reasons but also due to its low tensile strength and it is a very common known fact that these cracks allows the chemicals and moisture to penetrates into the concrete and degrades it even leading to corrosion into the reinforcement resulting in reduced performance of the structure which at times becomes very expensive to repair and maintain. As these cracks in the surface layer mainly affects the durability of concrete, as such cracks also acts as the pathways for the movement of liquids and gases which may potentially contains deleterious substances, but on the other side concrete has some unique properties of healing itself i.e. the potential to repair the micro-cracks on its own. This practice of self-healing of concrete can be done in many waves such as by using synthetic polymers like epoxy treatments, application of Precipitating bacteria or by bio-mineralization of bacteria in concrete. This study is all about discussing self-healing mechanism of bacteria, classifying different bacteria's on the basis of their shape and gram-stain, chemical processes involved in sealing of cracks, advantages and disadvantages of bacterial concrete technique and its uses in construction industry.

Keywords: Calcium Carbonate, self-healing concrete, MICP (Microbiologically Induced Calcite Precipitation), DCI (Dissolved Inorganic Carbon).

Introduction

Dissolved Inorganic Carbon Microbiologically Induced Calcite Precipitation (MICP) is a series of complex bio-chemical reactions including concomitant precipitation of Bacillus Pasteurii, Urease and high pH. It is a process in which alchophilic soil microorganisms plays an important role by producing urease which hydrolyze urea into ammonia and carbon dioxide. The ammonia increases the pH in surroundings which in turn induces precipitation of CaCO3 mainly in the form of calcite. (Kadian M. , 2018) As concrete is inexpensive and is easily available worldwide becomes the most widely used construction materials in whole construction industry but, it is also week in terms of tensile strength and forms cracks under loading and also due to environmental factors and mechanical usages. The self-healing mechanism of concrete includes production of calcium carbonate crystals which seals the cracks appeared on the surface of the concrete structure, as rapid crack healing is also necessary because due to cracks it becomes easier for aggressive substances to enter the concrete. It is desired that concrete heals itself by releasing the healing agents inside its matrix on their own when cracks appears. (J.Y. Wang et al,2010) To overcome this, MICP technique is adopted, which falls under an even broader category of science called as biomineralization. MICP is a durable technique because its microbial activities are natural as well as pollution free. This technique of healing also helps in improving the compressive strength of the concrete, as compared to those commonly used repairing techniques used currently at most places in which synthetic polymers such as epoxy treatments are used for repairing the concrete which are very harmful to both environment as well as human health, that's why this study forces the use of bacterial concrete. (Kadian A., Bio-Concrete: The Future of Concrete Science, 2018)

Literature Review

The Writing accessible uncovers that microbes can be utilized to upgrade the execution of the solid. The idea of bacterial cement was first presented by V.Ramakrishnan, a novel procedure in remediating cracks in concreted by using microbiologically prompted calcite (CaCO3) precipitation. The pioneering work on repairing concrete with

microbiologically prompted calcite precipitation (MICP) is accounted for by the exploration gathering of Ramakrishnan V. what's more, others at the South Dakota School of Mines and Innovation, USA.

(kadian, 2018) said MICP (Microbiologically Induced Calcite Precipitation)system is considered for the study by utilizing Bacillus Subtilis and its nutrients which later acts as the food for the microorganisms or bacteria's such as Sodium BiCarbonate (NaHCO3), Ammonium Carbonate (NH4CL), Calcium Chloride Dehydrate (CaCl2). Generally, they are mixed in a proportion of 1:2.5:5, Liquid form of Bacillus Subtilis is also added to the proportion (35 ml approx.) with the cell concentration of approximately 100cells/ml. The tests are performed on a cubical concrete section of 150mmx150mmx150mm for calculating and testing the compressive and tensile strength. As a result, it is found that there is a considerable increase in the strength and quality of concrete with added bacteria's/ Bacillus Subtilis and (kadian & Pannu, A Study of Durability Properties of Bacterial Concrete, 2018) Bacterial concrete refers to a new generation of concrete in which selective cementation by microbiologically-induced CaCO3 precipitation has been introduced for remediation of micro cracks. One possible mechanism is currently being investigated and developed in several laboratories. A technique based on the mineral-producing applications of bacteria. Efficient sealing of surface cracks by mineral precipitation was observed when bacteria-based mixtures were sprayed or applied onto damaged surfaces or manually inserted into cracks. As in those studies bacteria were manually and externally applied to existing structures. In several methods the possibility to using viable bacteria as a sustainable and concrete-embedded self-healing agent was explored.

Sakina Najmudd in Saifee et .al1 distributed a paper on Basic evaluation on Bacterial Cement. In this paper they talked about the diverse kinds of microbes and their applications. The bacterial cement is particularly helpful in expanding the durability of cemetous materials, repair of limestone landmarks , fixing of solid splits to exceedingly strong breaks etc.It additionally valuable for development of ease sturdy streets , high strength structures with all the more bearing limit, disintegration anticipation of free sands and minimal effort tough houses. They have additionally advised about the working rule of bacterial concrete as a repair material. It was likewise seen in the examination that the metabolic exercises in the bacteria's occurring inside the solid outcomes into expanding the general execution of cement including its compressive strength. This examination likewise discloses the synthetic procedure to remediate breaks.

(Kadian A., Bending Concrete: Balanced, Under-Reinforced and Over-Reinforced Beam Sections, 2018) in his paper stated while working in laboratory performing tests regarding the strength of concrete at different loads and other factors if satisfactory results are not obtained or the quality example fails to give appropriate results additional testing of concrete setup is required and (Singh & kadian, 2018) said when studied deeply at microscopic level, various changes in concrete properties are observed such as electrical and acoustical properties even leading to the complete failure of the structure.

Role of Bacteria in Self-Healing Mechanism

As we know, concrete is a building material which is highly alkaline y nature so, the bacteria to be added in the concrete at initial stages must follows certain criteria, such as the survival rate of used bacteria in high alkaline environment for longer period with the ability of forming spores. A bacteria used for such purposes must also have the potential to withstand the mechanical as well as environmental forces for preparing a concrete mixed with bacteria's, Alkali-resistant soil bacteria's such as Bacillus Subtilis should be used with its nutrients, which will acts as their food for the bacteria's to survive for decades because Bacillus Subtilis JC3 is a typical soil bacterium which can instigate the precipitation of calcite. (Kadian & Pannu, 2018) Bacteria's like Bacillus Subtilis are generally gram-positive bacteria's with

thick outer cell membranes which allows them to work successfully unless and until favorable environment is available to grow.

Some commonly used bacteria's in concrete are as follows

- Bacillus Subtilis
- Bacillus Sphaericus
- Escherichia Coli
- Bacillus Pasteurii etc.

Chemical Reactions

As the water to penetrate cracks will not dissolve the particles of calcite (CaCO₃) in the mortar matrix, but will react with the carbon dioxide present in the atmosphere with partially hydrated lime constituents like calcium oxide and calcium hydroxide.

 $CaO + H2O \rightarrow Ca(OH)2$

 $Ca(OH)2 + CO2 \rightarrow CaCO3 + H2O$

The resultant minerals from the above chemical reactions, the re-crystallized calcite particles precipitates on the surface, hence, sealing the cracks. Following are the factors on which relies the precipitation of calcium carbonate:

1. Concentration of Calcium.

2. DIC Concentration (Dissolved Inorganic Carbon).

- 3. The pH.
- 4. Nucleation sites.

Classification of Bacteria

• On the basis if shape -



Cocci Bacteria

Staphylococci Bacteria





Streptobacillus bacteria

Spirillium Bacteria

• On the basis of Gram Stain -







Gram Negative Bacteria's

Advantages & Disadvantages of Self-Healing Bacterial Concrete

Advantages:

- 1. Better Compressive Strength.
- 2. More Resistance to Freeze-Thaw Cycle.

3. Less Permeability as compared to conventional concrete.

4. Less chances of Corrosion in Reinforcement.

5. Low Maintenance costs.

Disadvantages:

1. Very expensive as compared to the regular concrete.

2. Limited Growth of Bacteria.

3. Unavailability of Designs of Concrete mix in IS Codes and other available Codes.

4. The cost for Research on Calcite Precipitation is very high.

Conclusions

i. Due to the unique qualities of bacterial concrete like the ability of self-healing, improved compressive strength and overall durability and its eco-friendly nature makes it much better as compared to the conventional concrete.

ii. Limitations of its biotechnical applications should be studied from past researches.

iii. More Researches are needed for the improvement in the capabilities of this technique in both practical and economical point of views.

iv. The calcium carbonate precipitations increases with the increase in the concentration of the bacteria's.

v. The ingress rate of aggressive chemicals and moisture containing deleterious substances decreases with the reduced permeability.

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