International Journal Of Engineering Research & Management Technology
ISSN: 2348-4039
July- 2014 Volume 1, Issue-4
Email: editor@ijermt.org www.ijermt.org

Study on the Effect of Calcite-Precipitating Bacteria on Self-Healing Mechanism of Concrete (Review Paper)

S.Soundharya
Student M.E. Structural Engineering,
Kongu Engineering College,
Perundurai
Erode, Tamil Nadu

Dr.K.Nirmalkumar
Professor,
Department of Civil Engineering
Kongu Engineering College
Perundurai
Erode, Tamil Nadu

ABSTRACT
Concrete is a construction material that is used world-wide because of its first-rate properties. However, the drawback of this material is that it easily cracks due to its low tensile strength. It is a well-known fact that concrete structures are very susceptible to cracking which allows chemicals and water to enter and degrade the concrete, reducing the performance of the structure and also requires expensive maintenance in the form of repairs. In this paper, the following notable points regarding classification of bacteria, self-healing of cracks in concrete, chemical process for crack remediation, self-healing mechanism of bacteria, application of bacteria in construction field, Advantages and disadvantages of bacterial concrete etc., are observed and identified from the other research works. Cracking in the surface layer of concrete mainly reduces its durability, since cracks are responsible for the transport of liquids and gases that could potentially contain deleterious substances. On the other hand the concrete structures show some self-healing capacity, i.e. the ability to heal or seal freshly formed micro-cracks. When micro-cracks growth reaches the reinforcement, not only the concrete itself may be damaged, but also corrosion occurs in the reinforcement due to exposure to water and oxygen, and possibly CO2 and chlorides too. Self-healing of concrete can be done by many ways such as application of specific calcite precipitating bacteria for concrete repair, usage of synthetic polymers such as epoxy treatment, bio-mineralization of bacteria in concrete etc.,

Keywords: Calcium Carbonate, self-healing, strength

1. INTRODUCTION

Mortar and concrete which forms major component in the construction industry as it is cheap, easily available and convenient to cast. But, these materials are weak in tension, so it cracks under sustained loading and due to aggressive environmental agents which ultimately reduces the life of the structures which are built using these materials (Mayur Shantilal Vekariya and Jayeshkumar Pitroda, 2013). Self-repairing concrete biologically produces calcium carbonate crystals to seal the cracks that appear on the surface of the concrete structures. Cracks often occur in concrete because of the low tensile strength of this material. Rapid crack-healing is necessary since it is easier for aggressive substances to ingress into concrete through cracks than through the concrete matrix. It would be desirable if concrete cracks could be healed autonomously by releasing healing agents inside the matrix when cracks appear (J.Y.Wang et al, 2010).

A novel technique is adopted in re-mediating cracks and fissures in concrete by utilizing Microbiologically Induced Calcite or Calcium Carbonate (Cacao)3 Precipitation (MICP) is a technique that comes under a broader category of science called bio mineralization. MICP is highly desirable because the Calcite precipitation induced as a result of microbial activities is pollution free and natural. The technique can be used to improve the compressive strength and stiffness of cracked concrete specimens. Research leading to microbial Calcium Carbonate precipitation and its ability to heal cracks of construction materials has led to many applications like crack remediation of concrete, sand consolidation, restoration of historical monuments and other such applications. Often, bacterial activities simply trigger a change in solution chemistry that leads to over saturation and mineral precipitation. Use of Bio mineralogy concepts in concrete leads to potential invention of new material called Bacterial Concrete (Mayur Shantilal Vekariya, Jayeshkumar Pitroda, 2013).

.

2. CLASSIFICATION OF BACTERIA

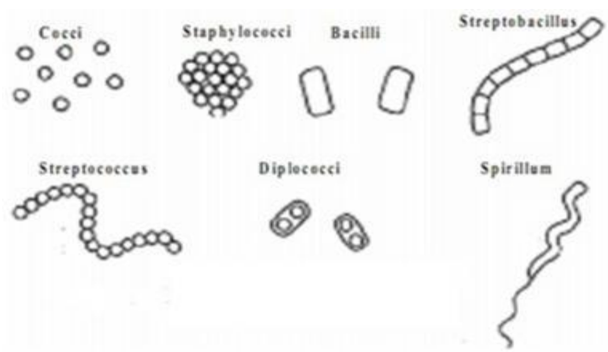
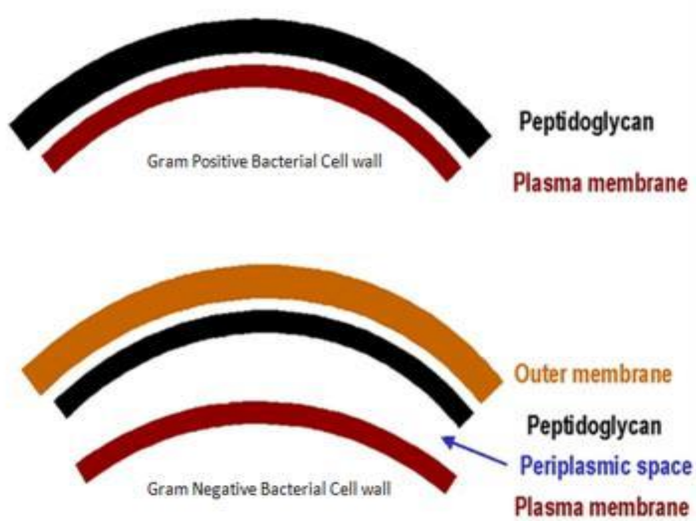


Fig.2.1 Classification Based on Shape



.**Fig.2.2 Classification Based on Gram Stain**

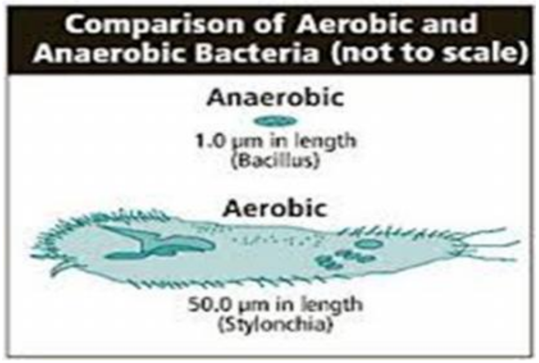


Fig.2.3 Classification Based on Oxygen Demand

3. USING BACTERIA TO SELF-HEAL CRACKS IN CONCRETE

Bacteria added to concrete mix in suspension state must meet certain criteria. Concrete is highly alkaline building material, so bacteria used as self-healing agent should be able to survive in this high alkaline environment for long durations and be able to form spores, withstanding the mechanical forces during concrete mixing. A bacterial concrete mix is prepared by using alkali-resistant soil bacteria Bacillus subtilis, along with nutrients from which the bacteria could potentially produce calcite based bio-minerals. Such bacteria are Gram-Positive Bacteria and have extremely thick outer cell membrane that enables them to retain viable until a suitable environment is available to grow. The only factor need to be checked is the effect of nutrients media on the setting time of cement (M.V.Seshagiri Rao et al, 2013).

4. VARIOUS TYPES OF BACTERIA USED IN CONCRETE

From literature review:

- Bacillus pasteurii
- Bacillus sphaericus
- Escherichia coli
- Bacillus subtilis
- Bacillus cohnii
- Bacillus halodurans
- Bacillus pseudofirmus etc.,

5. SELF-HEALING OF BACTERIA

5.1. Chemical process to remediate cracks by bacteria

Crack-penetrating water would not only dissolve calcite ($CaCO_3$) particles present in mortar matrix, but would also react together with atmospheric carbon dioxide with not fully hydrated lime constituents such as calcium oxide and calcium hydroxide according to the following reactions:

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

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

The freshly produced minerals from the above stated reactions and from dissolved and re-crystallized calcite minerals, precipitated on the surface of cracks what resulted in crack-sealing and concomitant reduction Permeability of the mortar. The healing potential of this system was directly related to the amount of non-reacted lime particles within the set mortar (Henk M. Jonkers & Erik Schlangen, 2008).

Calcium carbonate precipitation is a straight forward chemical process governed mainly by four key factors:

1) Calcium concentration
2) Concentration of dissolved inorganic carbon (DIC)
3) The pH
4) Availability of nucleation sites

(Mayur Shantilal Vekariya and Prof. Jayes kumar Pitroda, 2013).

The concentration of carbonate ions is related to the concentration of DIC and the pH of a given aquatic system. The precipitation of Calcium Carbonate crystals occurs by heterogeneous nucleation on bacterial cell walls once super saturation is achieved. The fact that hydrolysis of urea is a straight forward microbial process and that a wide variety of microorganisms produce urease enzyme and makes it ideally suited for crack remediation for building material applications. This precipitation forms a highly impermeable layer which can be used as crack remediation for concrete or any other building material. The precipitated calcite has a coarse crystalline structure that readily adheres to the concrete surface in the form of scales. In addition it has the ability to continuously grow upon itself and it is highly insoluble in water (Jagadeesha Kumar B.G et al, 2013).

5.2 Mechanism of Self-Healing Bacteria

The microbial organism used for manufacturing of bacterial concrete should be able to possess long-term effective crack sealing mechanism during its lifetime serviceability. The principle behind crack healing mechanism is that the bacteria should be able to transform soluble organic nutrients into insoluble inorganic calcite crystals, which seals the cracks. For effective crack healing, both bacteria and nutrients incorporated into concrete should not disturb the integrity of cement sand matrix pore-diameter and should not negatively affect other important fresh and hardened properties of concrete. In concrete cracks up to 0.2mm wide are healed autogenously. Such micro cracks are acceptable as these do not directly influence the safety and strength of concrete. The in-built bacteria-based self-healing process was found to heal cracks completely up to 0.5mm (M.V.Seshagiri Rao et al, 2013).

6. APPLICATION OF BACTERIA IN CONSTRUCTION FIELD

From enhancement in durability of cementations materials to improvement in sand properties, from repair of limestone monuments, sealing of concrete cracks to highly durable bricks, microbial concrete has been successful in all such cases. This new technology paves way for low cost and durable roads, high strength buildings with more bearing capacity, long lasting river banks, erosion prevention of loose sands and low cost durable housing.

Another issue in conventional building materials is the high production of greenhouse gases and high energy consumed during production of these materials and these greenhouse gases leads to global warming. High construction cost of building materials is another drawback in such cases. These drawbacks have lead to use of novel, eco-friendly, self-healing and energy efficient technology where microbes are used for remediation of building materials and enhancement in the durability characteristics (Mayur Shantilal Vekariya, Prof. Jayeshkumar Pitroda, 2013).

7. ADVANTAGES AND DIS ADVANTAGES OF BACTERIAL CONCRETE

7.1 Advantages

i. Microbial concrete in crack remediation.
ii. Improvement in compressive strength of concrete.

iii. Better resistance to freeze-thaw cycle.
iv. Reduction in permeability of concrete.
v. Reduction in corrosion of reinforced concrete.

7.2 Disadvantages

i. Cost of bacterial concrete is double than that of conventional concrete.
ii. Growth of bacteria is not good in any atmosphere and media.
iii. Design of concrete mix with bacteria is not available in IS codes or any other codes.
iv. Study on investigation of calcite-precipitation is costly.

8. CONCLUSIONS

1. Due to its eco-friendly nature, self-healing abilities and increase in durability of many building materials, the bacterial concrete is found to be more advantageous than that of the conventional concrete.
2. Limitations of biotechnological applications on building materials could be clearly understood from the past literature studies.
3. Many cementitious and stone materials are capable of exhibiting enhanced compressive strength and reduction in permeability, water absorption, corrosion of reinforcement etc.,
4. Cementation by bacteria is very easy and convenient for usage. This will soon provide the basis for 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 economical and practical point of views.
5. Increase in compressive strength is mainly due to the consolidation of the pores inside the cement mortar with microbiologically induced calcite precipitation.
6. When bacterial concentration increases, the Calcium Carbonate ($CaCO_3$) precipitation increases.
7. A lower permeability due to healing of cracks would result in a decreased ingress rate of the aggressive chemicals.

REFERENCES

1. Henk M. Jonkers & Erik Schlangen., “Development of a bacteria-based self-healing concrete”, Journal of Tailor Made Concrete Structures, Page 425-429, 2008.
2. Jagadeesha Kumar B.G, Prabhakara.R, Pushpa.H., “Effect of Bacterial Calcite- Precipitation on Compressive Strength of Mortar Cubes”, International Journal of Engineering and Advanced Technology (IJEAT), Vol 2, Issue 3, Page 486-491, 2013.
3. Mayur Shantilal Vekariya, Prof. Jayeshkumar Pitroda., “Bacterial Concrete: New Era For Construction Industry”, International Journal of Engineering Trends and Technalogy(IJETT), Vol 4, Issue 9, Page 4128-4137, 2013
4. .Nirmalkumar.K and Sivakumar.V, “A Study on the Durability Impact of Concrete by Using Recycled Waste Water”, JIPC Journal, Vol 24, No.1, Page 17-22, 2008.
5. Nirmalkumar.K and Sivakumar.V, “Corrosion Studies on Concrete Using Treated and Untreated Textile Effluent and Impact of Corrosion Inhibitor”, Journal of Sustainable Development, Vol 1, No.1, Page 68-72, 2008.
6. Nirmalkumar.K and Sivakumar.V, “Durability Studies on Concrete by Using Tannery and Textile Effluents”, IJEST Journal, No.2, Page14-19, 2008.
7. Seshagiri Rao.M.V, Srinivasa Reddy.V, Hafsa.M, Veena.P and Anusha.P, “Bioengineered Concrete – A Sustainable Self- Healing Construction Material”, Research Journal of Enginering Sciences, Vol 2, No.6, Page 45-51, 2013.
8. Wang.J.Y, Van Tittelboom.K, De Belie.N and Verstraete.W, “Potential of Applying Bacteria to Heal Cracks in Concrete”, Journal of Second International Conference on Sustainable Construction Materials and Technologies, June-2010

Author Biography

1) Soundharya.S

Ms.Soundharya.S, obtained her B.E. (Civil Engineering) from Erode Builder Educational Trust's Group of Institutions in 2013 and currently pursuing M.E. (Structural Engineering) in Kongu Engineering College.

2) Dr.Nirmalkumar. K

Dr.Nirmalkumar.K obtained his B.E (Civil Engineering) from the Bharathiyar University in 2000, M.E (Structural Engineering) from the Annamalai University in 2001, PhD (Civil Engineering) from the Anna University, Chennai in 2009 and M.B.A (General Administration) from the Periyar University in 2013. At present he is working as Professor in the Department of Civil Engineering, Kongu Engineering College, Perundurai, Erode. He is the recipient of "Career Award for Young Teachers" for the year 2011-12 from AICTE, New Delhi, "P. K Das Memorial Best Faculty Award" for the year 2011-12 from Nehru Group of Institutions, Coimbatore and "Kongu Engineering College - Best Staff Award in Civil Engineering" for the year 2010-11. He had published about 50 technical publications in various International and National, Journals and Conferences. At present he is reviewer of nine international and national journals and reviewer of one national and two international conferences. He is the principal investigator of a 3 R&D Projects, funded by DST, New Delhi under Fast Track Scheme, UGC's Major Research Project Scheme and AICTE. He had visited the countries such as Brazil, Hong Kong, Malaysia, Macau, Philippines, Singapore, Sri Lanka, Thailand and United Ara Emirat