

# Bacterial Concrete: New Era For Construction Industry

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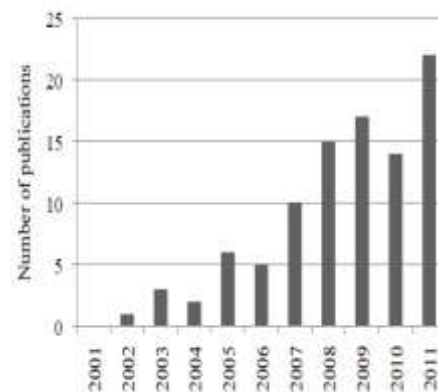
**ABSTRACT--** *Micro-cracks are the main cause to structural failure. One way to circumvent costly manual maintenance and repair is to incorporate an autonomous self-healing mechanism in concrete. One such an alternative repair mechanism is currently being studied, i.e. a novel technique based on the application of bio-mineralization of bacteria in concrete. The applicability of specifically calcite mineral precipitating bacteria for concrete repair and plugging of pores and cracks in concrete has been recently investigated and studies on the possibility of using specific bacteria as a sustainable and concrete -embedded self-healing agent was studied and results from ongoing studies are discussed. Synthetic polymers such as epoxy treatment etc. are currently being used for repair of concrete are harmful to the environment, hence the use of a biological repair technique in concrete is focused. Recently, it is found that microbial mineral precipitation resulting from metabolic activities of favourable microorganisms in concrete improved the overall behaviour of concrete. Hence in this paper define the bacterial concrete, its classification and types of bacteria, chemical process to fix the crack by bacteria, advantages and dis-advantages and possibilities of application of MICP (Microorganism used for Calcium Carbonate Precipitation in Concrete) in construction area by literature review are discussed*

**Key words:** bacterial concrete, types of bacteria, MICP, construction, chemical process,

## INTRODUCTION

Concrete which forms major component in the construction Industry as it is cheap, easily available and convenient to cast. But drawback of these materials is it is weak in tension so, it cracks under sustained loading and due to aggressive environmental agents which ultimately reduce the life of the structure which are built using these materials. This process of damage occurs in the

early life of the building structure and also during its life time. Synthetic materials like epoxies are used for remediation. But, they are not compatible, costly, reduce aesthetic appearance and need constant maintenance. Therefore bacterial induced Calcium Carbonate (Calcite) precipitation has been proposed as an alternative and environment friendly crack remediation and hence improvement of strength of building materials. In **Fig. 1** shows the concept was first introduced by Ramakrishna. Journal publication on self-healing concrete over the last decade



**Fig. 1** Archived journal publication on self-healing concrete over the last decade  
(Source: Google scholar-online)

A novel technique is adopted in re-mediating cracks and fissures in concrete by utilizing Microbiologically Induced Calcite or Calcium Carbonate ( $\text{CaCO}_3$ ) 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. so it can be define as “The process can occur inside or outside the microbial cell or even some distance away within the concrete. Often bacterial activities simply trigger a change in solution chemistry that leads to over saturation and mineral precipitation. Use of these Bio mineralogy concepts in concrete leads to potential invention of new material called —Bacterial Concrete”

**CLASSIFICATION OF BACTERIA**

Bacteria is generally classified in three category Basis on Shape, Basis on Gram Stain and Basis on Oxygen Demand which shown in Fig. 2 and sub types of each category also can be shown in Fig. 3, Fig. 4, and Fig. 5.

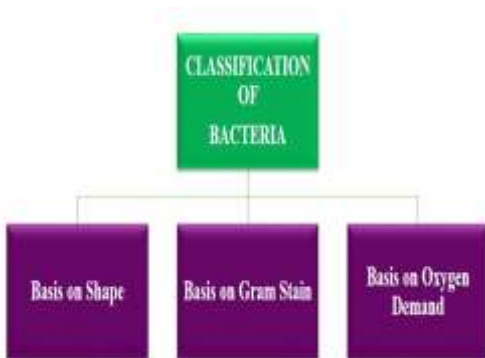


Fig.2 Classification of Bacteria

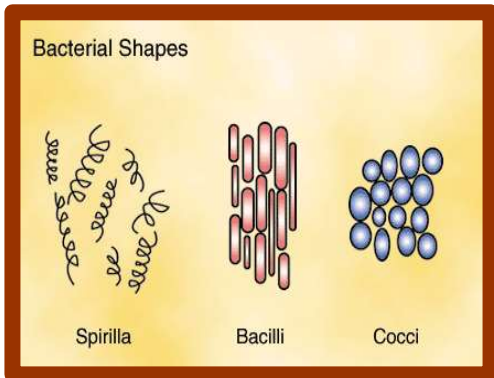


Fig.3 Classification on Basis of shape

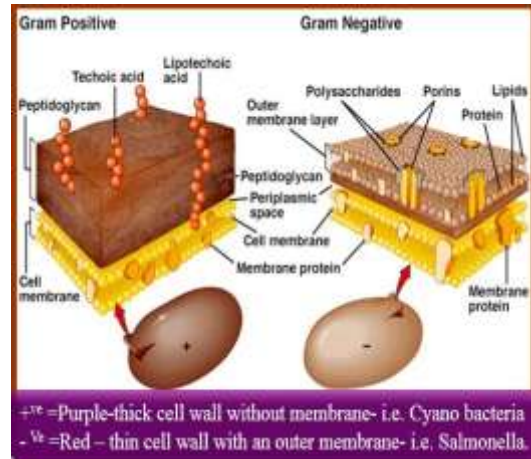


Fig.4 Classification on Basis of Gram Stain

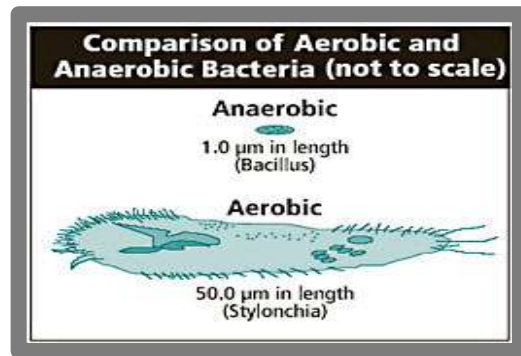


Fig. 5 Classification on Basis of oxygen demand

**VARIOUS TYPES OF BACTERIA USED IN CONCRETE**

There are various types of bacteria were used in construction area, from literature review it is as shown in Fig. 6 and other application of bacteria are shown in Table.1 and Table 2



Fig. 6 various types of Bacteria used in concrete

Table-1 Overview of various Construction Materials made using MICP

Application	Micro organism	Metabolism	Nutrients	REF.
Biological mortar	Bacillus cereus	oxidative deamination of amino acids	Growth media (peptone, extract yeast, KNO <sub>3</sub> , NaCl) + CaCl <sub>2</sub> .2H <sub>2</sub> O, Actical, Natamycine	De Muynck W 2008
Crack in concrete remediation	Bacillus subtilis	Hydrolysis of urea	Nutrient broth, urea, CaCl <sub>2</sub> .2H <sub>2</sub> O, NH <sub>4</sub> Cl, NaHCO <sub>3</sub>	Ramachandran S.K., 2001
Crack in concrete remediation	Bacillus sphaericus	Hydrolysis of urea	Extract yeast, urea, CaCl <sub>2</sub> .2H <sub>2</sub> O	De Muynck W., 2010
Bacterial concrete	Bacillus subtilis	Hydrolysis of urea	Nutrient broth, urea, CaCl <sub>2</sub> .2H <sub>2</sub> O, NH <sub>4</sub> Cl, NaHCO <sub>3</sub>	De Muynck W 2008
Bacterial concrete	Bacillus subtilis	oxidative deamination of amino acid	Peptone: 5 g/lit., NaCl: 5 g/lit., Yeast extract: 3 g/lit.	Seshagiri Rao M.V., 2012

**Table-2 Microorganism used for Calcium Carbonate Precipitation in Concrete**

Type of Microorganism	System	Crystal type	Ref.
Photosynthetic organism : Synechococcus GL24	Meromictic lake	Calcite (CaCO <sub>3</sub> )	Tai C.Y. and Chen F.B., 1998
Photosynthetic organism :Chlorella	Lurcene Lake	Calcite (CaCO <sub>3</sub> )	Sanchez-Moral S., Canaveras J.C 2005
Sulphate Reducing Bacteria: Isolate SRB LVform6	Anoxic hypersaline lagoon	Dolomite (Ca(Mg) CO <sub>3</sub> )	González-Muñoz M.T. 2000
Nitrogen cycle Bacillus subtilis	Urea degradation in synthetic medium	Calcite (CaCO <sub>3</sub> )	Castanier S. 2000
Nitrogen cycle Bacillus cereus	Ammonification and nitrate reduction	Calcite (CaCO <sub>3</sub> )	Castanier S. 1999
Nitrogen cycle Bacillus subtilis JC3	Ammonification (Ammono acid degradation)	Calcite (CaCO <sub>3</sub> )	Seshagiri Rao MV 2012

Self-healing concrete is a product that will biologically produce limestone to heal cracks that appear on the surface of concrete structures. Specially selected types of the bacteria genus *Bacillus*, along with a calcium-based nutrient known as calcium lactate, and nitrogen and phosphorus, are added to the ingredients of the concrete when it is being mixed. These self-healing agents can lie dormant within the concrete for up to 200 years.

However, when a concrete structure is damaged and water starts to seep through the cracks that appear in the concrete, the spores of the bacteria germinate on contact with the water and nutrients. Having been activated, the bacteria start to feed on the calcium lactate. As the bacteria feeds oxygen is consumed and the soluble calcium lactate is converted to insoluble limestone. The limestone solidifies on the cracked surface, thereby sealing it up. It mimics the process by which bone fractures in the human body are naturally healed by osteoblast cells that mineralise to re-form the bone.

The consumption of oxygen during the bacterial conversion of calcium lactate to limestone has an additional advantage. Oxygen is an essential element in the process of corrosion of steel and when the bacterial activity has consumed it all it increases the durability of steel reinforced concrete constructions.

The two self-healing agent parts (the bacterial spores and the calcium lactate-based nutrients) are introduced to the concrete within separate expanded clay pellets 2-4 mm wide, which ensure that the agents will not be activated during the cement-mixing process. Only when cracks open up the pellets and incoming water brings the calcium lactate into contact with the bacteria do these become activated.

Testing has shown that when water seeps into the concrete, the bacteria germinate and multiply quickly. They convert the nutrients into limestone within seven days in the laboratory. Outside, in lower temperatures, the process takes several weeks.

**PROCESS OF FIXING CRACKS IN CONCRETE BY BACTERIA**

**HOW DOES BIO-CONCRETE WORK?**

Process of fixing cracks in concrete by bacteria in such a process can be shown in Fig.7

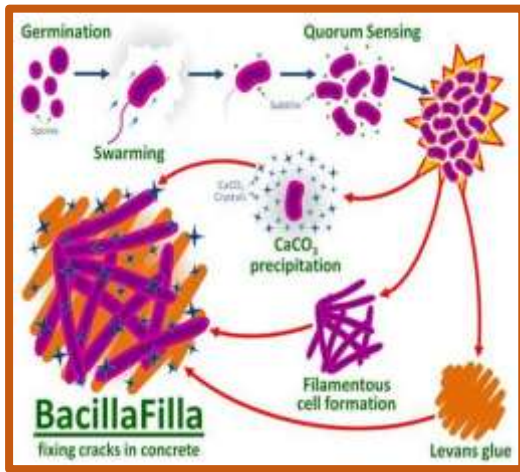


Fig. 7 Process of fixing cracks in concrete by bacteria

In the crack fixing process the anaerobic type bacteria which can be using along with concrete can be fix that crack by step by step.

At first germination of germs by spores and swarming themselves and quorum sensing and growing from proper medium in large amount in particular time and from the metabolism process - levans glue is produce and making such type of filamentous cell formation and precipitation CaCO<sub>3</sub>. This both material combine with each other and making cementations material.

**CHEMICAL PROCESS TO REMEDIATE CRACKS BY BACTERIA**

Bacteria from various natural habitats have frequently been reported to be able to precipitate calcium carbonate both in natural and in laboratory conditions (Krumbein, 1979; Rodriguez et al., 2003).

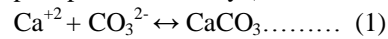
Different types of bacteria, as well as abiotic factors (salinity and composition of the medium) seem to contribute in a variety of ways to calcium carbonate precipitation in a wide range of different environments (Knorre & Krumbein, 2000; Rivadeneyra et al., 2004).

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 (Hammes & Verstraete, 2002).

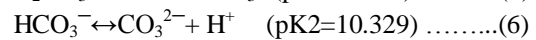
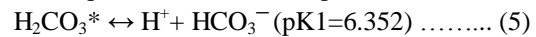
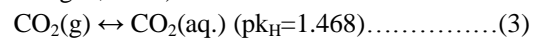
CaCO<sub>3</sub> precipitation requires sufficient calcium and carbonate ions so that the ion activity product (IAP) exceeds the solubility constant (K<sub>so</sub>) (Eqs. (1) and (2)). From the comparison of the IAP with the K<sub>so</sub> the saturation state (Ω) of the system can be defined; if Ω > 1 the system is oversaturated and precipitation is likely (Morse, 1983):



$$\Omega = a(Ca^{+2}) a(CO_3^{2-}) / K_{SO} \dots \dots \dots (2)$$

$$\text{With } K_{SO_{\text{calcite}, 25^\circ\text{C}}} = 4.8 \times 10^{-9}$$

The concentration of carbonate ions is related to the concentration of DIC and the pH of a given aquatic system. In addition, the concentration of DIC depends on several environmental parameters such as temperature and the partial pressure of carbon dioxide (for systems exposed to the atmosphere). The equilibrium reactions and constants governing the dissolution of CO<sub>2</sub> in aqueous media (25°C and 1 atm) are given in Eqs. (3)–(6) (Stumm & Morgan, 1981)



$$\text{With } H_2CO_3^* = CO_2(aq.) + H_2CO_3$$

Microorganisms can influence precipitation by altering almost any of the precipitation parameters described above, either separately or in various combinations with one another, (Hammes & Verstraete, 2002).

Different pathways appear to be involved in calcium carbonate precipitation.

**The first pathway** involves the sulphur cycle, in particular sulphate reduction, which is carried out by Advanced Topics in Bio mineralization sulphate reducing bacteria under anoxic conditions.

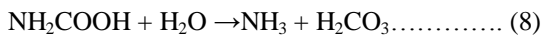
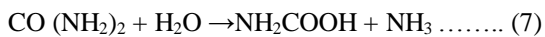
**A second pathway** involves the nitrogen cycle, and more specifically,

- (1) The oxidative deamination of amino acids in aerobiosis,
- (2) The reduction of nitrate in anaerobiosis or microaerophily and
- (3) The degradation of urea or uric acid in aerobiosis (by ureolytic bacteria).

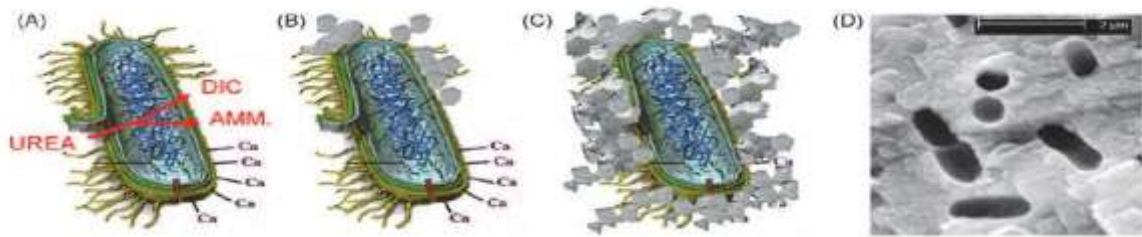
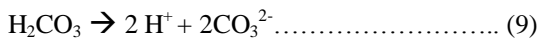
Another microbial process that leads to an increase of both pH and the concentration of dissolved inorganic carbon is the utilization of organic acids

(Braissant et al., 2002), a process which has been commonly used in microbial carbonate precipitation experiments. The precipitation pathways described in the aforementioned are generally found in nature which accounts for the common occurrence of microbial carbonate precipitation (MCP) and validates the statement by Boquet et al (1973) that under suitable conditions, most bacteria are capable of inducing carbonate precipitation. Due to the simplicity, the most commonly studied system of applied MICCP is urea hydrolysis via the enzyme urease in a calcium rich environment.

Urease catalyses the hydrolysis of urea to CO<sub>2</sub> and ammonia, resulting in an increase of pH and carbonate concentration in the bacterial environment. During microbial urease activity, 1 mol. of urea is hydrolysed intracellularly 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)



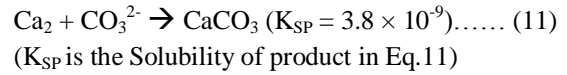
These products equilibrate in water to form bicarbonate, 1 mol. of ammonium and hydroxide ions which give rise to pH increase



**Fig. 8 calcite precipitation by bacterial cell**

Source: “Key roles of pH and calcium metabolism in microbial carbonate precipitation,-Hammes, F. &Verstraete,W. (2002).

**Fig.8** 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



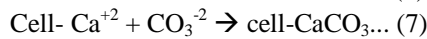
Hammes & Verstraete (2002) investigated the series of events occurring during ureolytic calcification emphasizing the importance of pH and calcium metabolism during the process (**Fig. 8**). The primary role of bacteria has been ascribed to their ability to create an alkaline environment through various physiological activities.

Bacterial surfaces play an important role in calcium precipitation (Fortin et al., 1997). Due to the presence of several negatively charged groups, at a neutral pH, positively charged metal ions could be bound on bacterial surfaces, favouring heterogeneous nucleation (Douglas, 1998; Bauerlein, 2003). Commonly, carbonate precipitates develop on the external surface of bacterial cells by successive stratification (Pentecost & Bauld, 1988; Castanier et al., 1999) and bacteria can be embedded in growing carbonate crystals (Rivadeneira et al., 1998;Castanier et al., 1999).

negative charge of the latter. 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). Limiting nutrient transfer, resulting in cell death. Image (D) shows the imprints of bacterial cells involved in carbonate precipitation

Possible biochemical reactions in urea-CaCl<sub>2</sub> medium to precipitate CaCO<sub>3</sub> at the cell surface can be summarized as follows



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 latter. 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 super saturation and hence heterogeneous precipitation of calcium carbonate on the bacterial cell wall
- B. After a while, the whole cell becomes encapsulated
- C. Limiting nutrient transfer, resulting in cell death.
- D. Shows the imprints of bacterial cells involved in carbonate precipitation




The actual role of the bacterial precipitation remains, however, a matter of debate. Some authors believe this precipitation to be an unwanted and accidental by-product of the metabolism (Knorre & Krumbein, 2000) while others think that it is a specific process with ecological benefits for the precipitating organisms (Ehrlich, 1996; Mc Connaughey & Whelan, 1997).

**APPLICATION OF BACTERIA IN CONSTRUCTION AREA**

The use of microbial concrete in Bio Geo Civil Engineering has become increasingly popular.

From enhancement in durability of cementitious 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 one and all. Application of various bacteria in construction area by various author shown in **Table 3** and other application of bacteria in construction area shown in **Fig.8**

**Table 3 application of various bacteria in construction area**

APPLICATION	ORGANISM	REFERENCE
Cement mortar and Concrete 	Bacillus cereus	Le Metayer- Leverel et al (1999)
	Bacillus sp. CT-5	
	Bacillus pasteurii	Achal et al., 2011b
	Shewanella	Ramachandran et al (2001)
	Sporosarcina pasteurii	Ghosh et al (2005) Achal et al (2011a)
Remediation of cracks in concrete 	Sporosarcina pasteurii	Bang et al (2001)
	Bacillus pasteurii	Ramachandran et al (2001)
	Bacillus pasteurii	Ramakrishnan (2007)
	Bacillus sphaericus	De Belie et al (2008)
	Bacillus sphaericus	De Muynck et al (2008a, b)
Self-Healing 	Bacillus pseudifirmus	Jonkers et al (2007)
	Bacillus cohnii	



Fig, 8 application of bacteria in construction area

This new technology can provide ways 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. The next section will illustrate detailed analysis of role of microbial concrete in affecting the durability of building structures.

Another issue related with conventional building materials is the high production of green house gases and high energy consumed during production of these materials. The emission of greenhouse gases during manufacturing processes of building materials is contributing a detrimental amount to global warming. Along with this, high construction cost of building materials is another issue that needs to be dealt with.

The above mentioned drawbacks of conventional treatments have invited the usage 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. This technology may bring new approaches in the construction industry.

Thus, bacterial material as a smart material than it can be utilise in various construction area to improve the performance if structure in new era

#### ADVANTAGES AND DIS ADVANTAGES OF BACTERIAL CONCRETE:

##### ➤ ADVANTAGES:

###### 1. Microbial concrete in Crack Remediation:

- Specimens were filled with bacteria, nutrients and sand. Significant increase in compressive strength and stiffness values as compared to those without cells was demonstrated.

###### 2. Improvement in Compressive Strength of Concrete:

- Compressive strength test results are used to determine that the concrete mixture as delivered meets the requirements of the job specification. So, the effect of microbial concrete on compressive strength of concrete and mortar was studied and it was observed that significant enhancement in the strength of concrete and mortar can be seen upon application of bacteria.

###### 3. Better Resistance towards Freeze-Thaw Attack Reduction:

- Application of microbial calcite may help in resistance towards Freeze-thaw Reduction due to bacterial chemical process and also it can reduce the permeability than freezing process decreased.

#### 4. Reduction in Permeability of Concrete:

- Effect of microbial concrete on permeation properties was studied by different researchers. Permeability can be investigated by carbonation tests as it is increasingly apparent that decrease in gas permeability due to surface treatments results in an increased resistance towards carbonation and chloride ingress. Carbonation is related to the nature and connectivity of the pores, with larger pores giving rise to higher carbonation depths..

#### 5. Reduction in Corrosion of Reinforced Concrete:

- Application of microbial calcite may help in sealing the paths of ingress and improve the life of reinforced concrete structures (Jonkers et al., 2007). Mukherjee et al (2010) reported four fold reduction in corrosion of reinforced concrete specimens upon application of *Bacillus* sp. CT-5. The same group observed reduction in water and chloride ion permeability upon use of calcite by *Sporosarcina pasteurii*. Qian et al (2010) used *B. pasteurii* to check its effect on permeability resistance and acid attack and reported that bacterial calcite improves surface permeability resistance and resist the attack of acid (pH> 1.5).

#### ✚ DIS-ADVANTAGES:

##### 1. Cost of Bacterial Concrete is Double than Conventional Concrete- (Dr. Henk Jonkers-2011)

- Cost of bacterial concrete is double than conventional concrete said by Dr. Henk Jonkers in 2011 but it can be reduce this cost by growth of this techniques

##### 2. Growth of Bacteria is not good in any Atmosphere and media

- Different types of nutrients and metabolic products used for growing calcifying microorganisms, as they influence survival, growth, biofilm and crystal formation. More work should be done on the retention of nutrients and metabolic products in the building material.

##### 3. Design of mix Concrete with Bacteria there is no available any IS-code or other code.

- Due to it is a new research material and not famous to use in construction area hence no any code is provided to use it so, it is hard to calculate the doses of bacteria use in concrete to get optimum performance

##### 4. Investigation of calcite precipitation is costly studied

- Different types bacteria have different properties to produce an amount calcite precipitation to identify this amount it should be require investigation of bacteria and for that "Scanning by Electron Microscopy" and this method is costly and require good skill to carry out this test.

#### RECOMMENDATIONS FOR FURTHER STUDIES

- ✚ As the many researchers found out this superior and smart material although due to its various limitation, further study is require to get a more benefit from this material.
- ✚ Rodriguez-Navarro et al (2003) reported that fast precipitation of bacterial carbonates could result in a lower efficiency of the calcite deposition. Along with this, the presence of well-developed rhombohedra calcite crystals result in a more pronounced consolidating effect compared to the presence of tiny acicular vaterite crystals.
- ✚ So, detailed studies need to focus on different types of nutrients and metabolic products used for growing calcifying microorganisms, as they influence survival, growth, and bio-film and crystal formation.
- ✚ More work should be done on the retention of nutrients and metabolic products in the building material. Detailed microbial ecology studies are also needed in order to ascertain the effects of the introduction of new bacteria into the natural microbial communities, the development of the communities at short, mid and long-term,
- ✚ And the eventual secondary colonization of heterotrophic microorganisms using bacterial organic matter and dead cells, such as actinomycetes, fungi, etc.

#### CONCLUSIONS

- ✚ Microbial concrete technology has proved to be better than many conventional technologies because of its eco- friendly nature, self-healing abilities and increase in durability of various building materials.
- ✚ Work of various researchers has improved our understanding on the possibilities and limitations of biotechnological applications on building materials.
- ✚ Enhancement of compressive strength, reduction in permeability, water absorption, reinforced corrosion have been seen in various cementitious and stone materials.
- ✚ Cementation by this method 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 an economical and practical viewpoints.

#### REFERENCES

- 1) Annie Peter.J, Lakshmanan.N, Devadas Manoharan.P, Rajamane.N.P& Gopalakrishnan.S —Flexural Behaviour of RC Beams Using Self Compacting Concretel. The Indian Concrete Journal, June 2004, PP 66-72.
- 2) Bachmeier KL, Williams AE, Warmington JR, Bang SS., “Urease activity in microbiologically-induced calcite precipitation.” *Journal of Biotechnology* 93, 2002, pp. 171-181.
- 3) Benini S, Rypniewski W, Wilson KS, Miletti S, Ciurli S, Mangani S., “A new proposal for urease mechanism based on the crystal structures of the native and inhibited enzyme from *Bacillus pasteurii*: why urea hydrolysis costs two nickels.” *Structure*7, 1999, pp.205-216.
- 4) Ciurli S, Marzadori C, Benini S, Deiana S, Gessa C., “Urease from the soil bacterium: *Bacillus pasteurii* immobilization on Ca-polygalacturonate.” *Soil Biol Bio chem* 28, 1996, pp. 811-817.
- 5) De Muynck W., Cox K., De Belie N. and Verstraete W.”Bacterial carbonate precipitation as an alternative surface treatment for concrete”, *Constr Build Mater*, **22**, 875 - 885 (2008)
- 6) F. Hammes, N. Boon, J. De Villiers, W. Verstraete, S. D. Siciliano, and J. De Villiers, “Strain-Specific Ureolytic Microbial Calcium Carbonate Precipitation,” *Applied And Environmental Microbiology*, vol.69, no.8, 2003, pp. 4901–4909.
- 7) Ghosh P, Mandal S, Chattopadhyay BD, Pal S., “Use of microorganism to improve the strength of cement mortar.” *Cement and Concrete Research* 35, 2005, pp.1980-1983.
- 8) González-Muñoz M.T., Ben-Chekroun K., Ben-Aboud A., Arias J.M. and Rodriguez-Gallego M., Bacterially induced Mg-Calcite formation: Role of Mg<sup>2+</sup> in development of crystal morphology, *Journal of Sedimentary Research*, **70**, 559-564 (2000)
- 9) H. M. Jonkers and E. Schlangen, “A two component bacteria-based self-healing concrete,” *Concrete Repair, Rehabilitation and Retrofitting II*, 2009, pp. 215–220.
- 10) Horner-Devine MC, Carney KM, Bohannon BJM, “An ecological perspective on bacterial biodiversity”. *Proceedings Royal Society Biological Science B* 271, 2004, pp.113–122.
- 11) J. G. Holt, Ed., *Bergey’s Manual of Determinative Bacteriology*, 9th ed. Williams & Wilkins, Baltimore, 1994.
- 12) J. L. Day, A. V. Ramakrishnan, and S. S. Bang, “Microbiologically Induced Sealant For Concrete Crack Remediation,” *16th Engineering Mechanics Conference*, 2003, pp.1–8.
- 13) J. P. Prescott and M. Harley Lansing, *Laboratory Exercises in Microbiology*, Fifth edit. The McGraw–Hill, 2002, pp. 57–77.
- 14) K. D. Arunachalam, K. S. Sathyanarayanan, B. S. Darshan, and R. B. Raja, “Studies on the characterization of Bio sealant properties of *Bacillus sphaericus*,” *International Journal of Engineering Science and Technology*, vol.2, no.3, 2010, pp. 270–277.
- 15) Muynck W, Dick J, De Graef B, De Windt W, Verstraete W, De Belie N., “Microbial ureolytic calcium carbonate precipitation for remediation of concrete surfaces.” *Proceedings of International conference on concrete repair, rehabilitation and retrofitting*, South Africa, Cape Town, 2005, pp. 296-297.
- 16) N. Chahal, R. Siddique, and A. Rajor, “Influence of bacteria on the compressive strength, water absorption and rapid chloride permeability of fly ash concrete,” *Construction and Building Materials*, vol.28, no.1, 2012, pp.351-356
- 17) N. De Belie and W. De Muynck, “Crack repair in concrete using bio deposition,” *Concrete Repair, Rehabilitation and Retrofitting II*, 2009, pp.777–782.
- 18) P. Tiano, L. Biagiotti, G. Mastromei, “Bacterial biomediated calcite precipitation for monumental stones conservation: methods of evaluation”, *Journal of Microbiological Methods*, Vol.36, Issues 1–2, 1999, pp.139-145.
- 19) S. S. Bang, J. J. Lippert, U. Yerra, S. Mulukutla, and V. Ramakrishnan, “Microbial calcite, a bio-based smart nanomaterial in concrete remediation,” *International Journal of Smart and Nano Materials*, vol.1, no.1, 2010, pp. 28–39.
- 20) Sanchez-Moral S., Canaveras J.C., Laiz L., Saiz-Jimenez C., Bedoya J., and Luque L.

Biomediated precipitation of calcium carbonate metastable phases in hypogean environments: A short review, *Geomicrobiology Journal*, **20(5)**, 491-500 (2003)

- 21) Seshagiri Rao M.V., Ch Sasikala V. and Srinivasa Reddy, "A Biological Approach To Enhance Strength And Durability In Concrete" Structures, *International Journal of Advances in Engineering and Technology (IJAET)*, Sept 2012 **4(2)**, 392-399 (2012)
- 22) Stocks-Fischer, S., Galinat, J.K., and Bang, S.S."Microbiological Precipitation of CaCO<sub>3</sub>," *Soil Biology and Biochemistry*, 31, 1999, 1563-1571.
- 23) Tai C.Y. and Chen F.B., Polymorphism of CaCO<sub>3</sub> precipitated in a constant-composition environment. *AIChE Journal*, **44(8)**, 1790-1798 (1998)
- 24) V. Bang, S.S., Galinat, J.K., and Ramakrishnan, "Calcite Precipitation Induced by Polyurethane Immobilized Bacillus Pasteurii," *Enzyme and Microbial Technology*, vol.28, 2001, pp. 404-409.
- 25) V. Ramakrishnan, R. K. Panchalan, S. S. Bang, and R.City, "Improvement of Concrete Durability By Bacterial Mineral Precipitation," *International Conference on Fracture*, 2005.

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