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PERFORMANCE ENHANCEMENT OF CONCRETE THROUGH BACTERIAL ADDITION-A NOVEL TECHNIC

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ABSTRACT

Concrete is the major building material largely used in building construction but it has many limitations with respect to its durability aspect. Cracks, the major reason for deterioration, occur due to various mechanisms like shrinkage, freeze and thaw action, mechanical tensile and compressive forces etc., lead to the failure of the structure. For enhancing the performance of concrete a new method of using bio mineralization in concrete is evolved. The calcite precipitating spore forming bacteria is introduced to concrete and when water comes in contact with the bacteria through the cracks, it will react with it and produce calcium carbonate as a byproduct which heals the cracks. This type of concrete prepared with bacteria is called as Bacterial Concrete. A summary of the major research developments is outlined here.

Keywords: concrete, bio mineralization, *bacillus, u*rease hydrolysis, durability, strength.

1. INTRODUCTION

Large number of researches being carried out all over the world about how to make concrete, the most common building material, more durable and eco friendly. Durability aspect of concrete is a major headache not only to civil engineers but also to the society as large amount of money is involved in construction industry. Cracks occur in concrete due to several reasons like shrinkage, freez-thaw reactions; low tensile strength of concrete etc., the formation of cracks during the process of concrete hardening is leading to the deterioration of the building. Water enters through this crack and will cause corrosion of reinforcements which accelerates the deterioration of structures. Researchers are trying to find a material or a process which can enhance the performance of concrete. Synthetic materials like epoxies are used to remediate but they are costly, not compatible and need constant maintenance. Using chemicals is also causing damage to the environment. The need for an environment friendly and effective alternate crack remediation technique leads to the development of using the bio mineralization method in concrete.

Bacterial concrete is comparatively a new area of research in this category. Here we are incorporating calcite precipitating bacteria to concrete in certain concentrations so that the bacteria will precipitate calcium carbonate when it comes in contact with water and this precipitate will heal the cracks. Micro biologically Induced Calcite Precipitation (MICP) is the process behind bio mineralization. The basic principle in the process is that the microbial urease, hydrolyzes urea, to produce ammonia and carbon dioxide and the ammonia released in surroundings subsequently increases the pH, leading to accumulation of insoluble calcium carbonate [1].

MICP involves various micro organisms but not all bacteria is suitable to be incorporated with concrete as the environment inside it is very alkaline ie., pH of around 12. Another major worry is whether the bacteria is able to live there for long time as the development of cracks may be a long term process involving several years. Researchers in this area identified that only spore forming gram positive strain bacteria can survive in this high pH environment and it is found that *Bacillus* species can perform better in this environment. The *Bacillus* spores, specialized thick walled dormant cells, have been shown viable for over 200 years under dry condition [2].

2. WORKING PRINCIPLE OF SELF HEALING PROCESS

As part of metabolism the bacteria produces urease which catalyzes urea to produce CO_2 and ammonia which results in an increase of pH in the surroundings and Ca^{2+} and CO_3^{2-} precipitate $CaCO_3$. During this activity 1mol. of urea is hydrolyzed to 1 mol. of ammonia and 1 mol. of carbonate, which spontaneously hydrolyses to form additional 1 mol. of ammonia and carbonic acid [3]. The equation is as follows:

$$CO(NH_2)_2 + H_2O \longrightarrow NH_2COOH + NH_3 \quad \text{----------(1)}$$

$$NH_2COOH + H_2O \longrightarrow NH_3 + H_2CO_3 \quad \text{----------(2)}$$

These products equilibrate in water to form bicarbonate,1 mol. of ammonium and hydroxide ions which increases the pH.

$$H_2CO_3 \longrightarrow 2H^+ + 2CO_3^{2-} \quad \text{----------(3)}$$

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$$NH_3 + H_2O \longrightarrow NH^{4+} + OH^- \quad (4)$$

$$Ca^{2+} + CO_3^{2-} \longrightarrow CaCO_3 \quad (5)$$

Further Microorganisms has negative cell surface charge which attracts cations including Ca^{2+} from the environment to deposit on the cell surface .The equation for the same is given below.

$$Ca^{2+} + Cell \longrightarrow Cell\text{-}Ca^{2+} \quad (6)$$

$$Cell\text{-}Ca^{2+} + CO_3^{2-} \longrightarrow Cell\text{-}CaCO_3 \quad (7)$$

The bacteria acts as nucleation site which facilitates the precipitation of calcite which can eventually plug the pores and cracks in the concrete and enhance the durability of concrete.

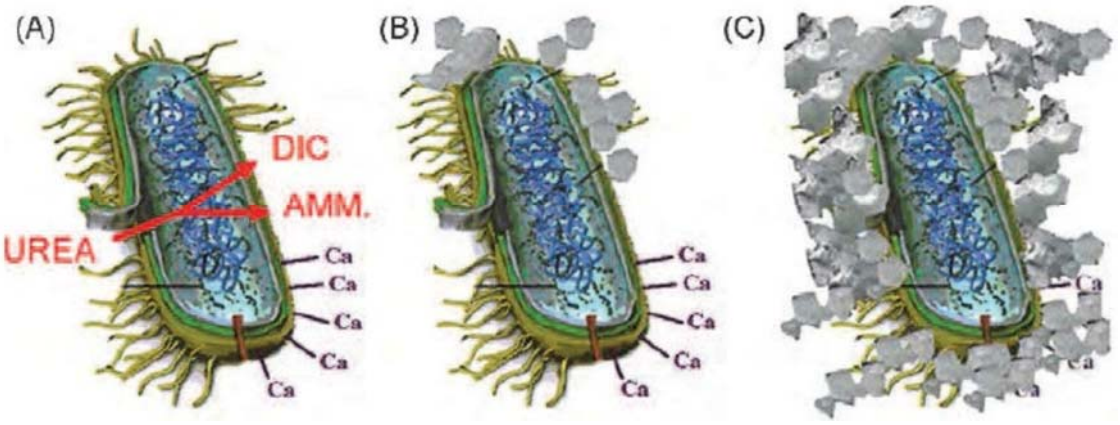

Figure-1. Calcium Carbonate precipitation mechanism induced by urease enzyme activity in microorganism.

The MICP has application in areas like crack remediation of concrete, sand consolidation, restoration of historical monuments etc., and thus bacterial concrete can definitely enhance the performance of concrete.

Figure-2. Concrete sample before and after self healing.

3. HISTORY OF RESEARCH WORK

Bacterial concrete is an active area of research in Civil Engineering. The studies are not only limited to concrete structures but also to different areas like improvement in sand properties, improvement in durability of bricks etc.,

To be an effective self healing agent a bacteria should be

- resistant to high pH atmosphere of concrete
- able to produce sufficient amount of minerals($CaCO_3$) to plug the cracks
- viable upto the life span of building ie, around 50 to 100 years
- oxygen brilliant and
- non pathogenic.

The strength and durability aspects of bacterial concrete are studied as the standard measure for the effectiveness. Basic principle behind this is the $CaCO_3$ precipitate which clogs the pores and hence it increases density, strength and decreases permeability which is the main reason for durability. Based on the above requirements the studies had suggested the use of alkaliphilic spore forming bacteria and in this category the Bacillus species tops the list. Mainly the research works are differentiated on the basis of i) types of bacteria used and its concentrations ii) mediums in which it is immersed iii)applying bacteria into concrete in immobilized form etc.,

3.1 Types of Bacteria

Bacteria are unicellular micro organisms found in abundance in the atmosphere. They are of different shapes like spheres, rods, spirals etc., and the size also varies from 0.5 to 5 µm in length [4].The bacteria used for bio mineralization should have the above said qualities and mostly the soil bacteria species Bacillus fit into this range. Researchers are experimenting with a variety of bacteria and most of them have resulted in effective crack healing. The effectiveness of the bacteria is also studied by doing

strength tests like compressive strength, split tensile strength and flexural strength besides the durability tests to find the resistance to acid, alkali, sulphur etc., the high alkaline environment inside concrete provides room only for alkali resistant bacteria in research.

Table-1. Depicts the various types of bacteria used by various researchers and also the effects using them.

S. No.	Bacteria Used	Conclusion	Researcher /Journal /Year
1.	Bacillus subtilis	The optimum cell concentration is 10^5cells/ml.	M.V. SeshagiriRao*et al*, Research Journal of Engineering Sciences(2013)[5]
		The addition of The species increases compressive strength by 14.92% at 28 days and also better acid attack factor.	Sunil Prathap Reddy *et al*,Asian Journal of Civil Engineering(2010)[6]
2	Bacillus sphericus	Higher concentration of bacteria produced more $CaCO_3$.	J.Y. Wang et al,Second International conference on Sustainable construction materials and Technologies(2010)[7]
		Can heal the cracks and improves strength and durability	C.C.Gavimath*et al*,International journal of Advanced Biotechnology and Research(2012)[8]
3	Bacillus cereus	Improved the strength by 38% and high chloride penetration resistance.	S.Maheswaran*et al*,Current Science(2014)[9]
4	Bacillus flexus	Can perform better than all other microorganism in terms of strength and durability.	Jagadeesha Kumar B. G. *et al*,International Journal of Engineering and Advanced Technology(2013)[10]
5	Bacillus pseudoforms	Can potentially act as self healing agent with out affecting strength.	Henk.M. Jonkers*et al*,Proceedings of first International Conference of Self HealingMateirals(2007)[11]
6	Bacillus pasteurii	Bacteria immersed in Phosphate - buffer shows better performance with respect to strength and durability.	V.Ramakrishnan*et al*,Proceedings of SPIE,Australia(2001)[12]

There are broadly speaking two different types of cell wall in bacteria, called Gram-positive and Gram-negative. The names originate from the reaction of cells to the Gram strain, a test long-employed for the classification of the bacterial species. The spore forming gram negative bacteria with thick cell membrane makes it a best choice for MICP. *Bacillussubtilis* and *Bacillus sphericus* are found giving better results in this context. Some researchers are even trying the combination of two or more bacteria instead of one.

The concentration of bacteria also plays a major role in producing sufficient quantity of copious material. The concentrations are mainly adopted in 10^n cells/ml. Different bacterium had different effective concentrations also.For instance *Bacillus subtilis* effective concentration is 10^5cells/ml. More research work is being carried on to find the maximum effective concentration.

3.2 Immersed medium

Effect of Bacteria suspended in different mediums like water,phosphate buffer and Urea $CaCl_2$was studied by researcher V. Ramakrishna *et al*,the durability aspects of different concentrations of bacteria immersed in the mediums showed that the phosphate buffer resulted in maximum efficiency when compared with that suspended in water. All the specimens showed better performance than control specimen. The economy part of the phosphate buffer immersed bacterial concrete and its effective concentration needs more research to establish. The research work of Syed AfzalBasha*et al*[13] reaffirms the results.

3.3 Applying Bacteria in immobilized form

Researcher Van Tittelboom*et al* [14]l, used silica gel as immobilization agent and the results is not that much promising. Later Bang *et al*[15], J.Y. Wang *et al*, viz, used polyurethane as filling material. Bacteria and Poly Urethane (PU) were encapsulated in glass tubes in three components and was embedded inside mortar specimens. When a crack appears in the mortar matrix, the glass tubes break and all components mix together in the crack and first polymerization of PU happens followed by $CaCO_3$ precipitation by bacteria which fills the pores of PU and heals the cracks resulted in enhanced strength. H.M. Jonkers *et al* tried with clay pellets to introduce bacteria into the concrete and found effective. All the research revealed the enhanced life of bacteria when immersed in immobilized form but the cost and technical skill needed is the worrying part.

4. CONCLUSIONS

Review of the papers done and following conclusions can be driven

1) Bacterial concrete is effective in increasing the strength and durability of concrete.
2) Bacterial concrete can heal the cracks by $CaCO_3$ precipitation.
3) Different types of bacteria can be used to prepare bacterial concrete and spore forming gram positive bacteria gives the most effective results.
4) The concentration of bacteria also plays a major role in it effectiveness.
5) Lot of studies are done with bacteria suspended in water, phosphate -buffer and Urea $CaCl_2$ and it was found that bacteria suspended in phosphate buffer gives best result.
6) SEM analysis of bacterial concrete proves the presence of $CaCO_3$ precipitation.
7) Bacteria applied in clay pellets, glass tubes and PU forms are also studied and found they are not effective methods economically.
8) The spore forming bacteria can remain in concrete for 200 years and it can be an effective method as $CaCO_3$ precipitation is a byproduct of urease hydrolysis,so the reactant will remain even after the completion of one reaction. The other chemicals that are used for crack healing will remain for one application only.
9) Bacterial concrete prepared with admixtures like silica fume, fly ash etc. also gives better strength and durability.
10) The $CaCO_3$ precipitation fills the pores of the concrete and reduces permeability, increases density, reduces water absorption and better results with rapid chloride penetration tests.
11) Bacterial concrete shows better resistance to drying shrinkage, resistance to acid attack,better sulphate resistance.
12) Bacillus species give better adaptability to the high alkaline concrete environment.
13) Even surface treatment with bacterial cement paste can enhance durability.
14) Bacterial concrete can play a major role in modern construction which needs precise technologies to enhancedurability and also heal cracks by itself as maintenance cost is high in case of pipe lines, underwater structures etc.
15) Self healing of cracks is very effective in case of cracks up to 0.2mm size.

5. SCOPE FOR FUTURE RESEARCH

Even though the works going on in the field of bacteria concrete has resulted in enormous effective outcomes, but still lot of queries are need to be addressed. The major queries are

a) The availability of dormant bacteria after 5 to 10 years needs to be studied as most of the cracks appear after years.

b) The pathogenic effect of bacteria is a major health issue that needed thorough investigation.

c) The cost of bacterial concrete remains on the higher side and it should be brought downto affordable range.

d) Possibility of incorporating waste materials and economic materials to bacterial concrete.

e) Possibility of using Msand, Fly ash, Silica Fume, GGBS, Metakaoline etc., so that the cost can be reduced, need to be studied.

f) More research is needed to identify more effective and less pathogenic bacteria from alternate or waste materials.

g) Effectiveness of bacteria in high grade, high strength concrete needs to study.

h) Self compacting concrete is an area where the research has not yet been done.

i) Effectiveness of using combination of bacteria need to studied.

j) The biological process of $CaCO_3$ precipitation needs more research as the task is verycomplex.

k) Codal provision is not available.

l) More usage of it in field will give long term effects and drawbacks.

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