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Biomimetics Materials: A New Approach to Sustainable Environment

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Abstract—*The principal objective of the research is to highlight the importance of developing self-healing concrete composites by the help of bacteria as a healing agent. Since ages, architects worldwide have focused on usage of durable concrete for construction of beautiful historic monuments as Roman, European Cathedrals and Greek temples, Taj Mahal etc. To preserve these structures for coming years is a matter of great concern nowadays as they are continuously degrading and deteriorating by biotic and abiotic factors. Biotic and abiotic factors affect the aesthetic appearance, deterioration of durability and strength of these structures. The concrete used for the structures, monuments, modern buildings, roads, base wall, tunnel lining, bridges are generally weak in tension having very less ductility and less resistance to cracking. The concrete structures are generally exposed to variant atmospheric conditions that may develop surface deterioration and invisible cracks with the time. Small cracks in concrete may lead to development of large cracks with passage of time which in turn decreases the service life of these concrete structures. Natural, Chemical and Biological processes, such as dynamic atmospheric conditions, faults, landslides, earthquakes and human activities create splits of cracks and fractures in concrete structures which decreases the life of these structures. This study briefly explains the use of biomimetic materials which provides a self healing mechanism in infrastructure engineering and durability and strength characteristic of building structures. This paper also highlights the concept of attaining sustainability in built-up infrastructure by assessing the repairing mechanism. In addition this paper also focuses on the applicability of biomimetic materials in Indian context as well as across the globe as a mode to achieve sustainable infrastructure.*

Keywords*: Sustainable Infra-structure, concrete, durability, biomimetic*

Introduction

Self-healing may refer to automatic, homeostatic processes of the body that are controlled by physiological mechanisms inherent in the organism. Disorders of the spirit and the absence of faith can be self-healed. The idea of self- healing concrete was inspired from the natural phenomenon by organism such as trees or animal. Damaged skin of trees and animals can be repaired autonomously. Remediating crack in concrete structure is important for its service durability and safety of structure. Recently, developing self-healing concrete technology has become an important for its service durability and safety of structure. Recently, developing self-healing concrete technology has become an important objective for researchers in biotechnology and civil engineering science. During the 1980's, only very few articles can be discovered technologies containing (1) Natural process (2) Chemical process (3) Biological process. The complete taxonomy for self-healing concrete operation of making observation. A latest paper on self-healing concrete was by Wu et al [2012]. Who high light on the natural and man-made self-healing their paper also covered complete account on the chemical and biological method. Siddique and Chahal (2011) detailed the use of ureolytic bacteria for the designing of self-healing building material made of small stone, sand, and cement. Toohey et al (2007) had look into micro-vascular as self-healing material. Jonkers (2007) gone over again on biological method design self-healing solid, special, fact based on calcium carbonate precipitation. Al-thawadi (2011) identified the mechanism to enhancement the strength of sand using ureolytic bacteria and calcium carbonate structuring. Although several papers have been made public on self-healing facts, as against ideas, a complete gone over again on physical, chemical and biological processes have not yet been stated. For a biologist, the importance of a complete paper is to make certain a quick great scale quick-shot from the body of knowledge. In this way, this paper try to present a complete paper on self-healing solid, special, fact based on three key taxonomy, i.e. natural self-healing, chemical self-healing and biological self-healing.

Self-healing of concrete

Natural Self-healing process

As shown in Fig.3, Several natural processes can not completely, partly get in good condition again concrete crack as shown in fig 3(A). In natural processes, four supporter's processes can solid mass crack.

- The structuring of calcium carbonate or calcium hydroxide is another process to solid mass crack.

- Crack is got in the way of by other substances in the existence of water as shown in fig 3(B).
- Crack is future got in the way of by hydration of the unreacted cement or cementitious material as shown in fig 3(C).
- Crack is got in the way of by the expansion of hydrated cementitious matrix in the crack goes round site (getting greater of calcium silicate hydrate soft paste) as shown in fig 3(D).

In many cases, more than one of these process or mechanisms (Fig. 3A to 3D) can come about at the same time.

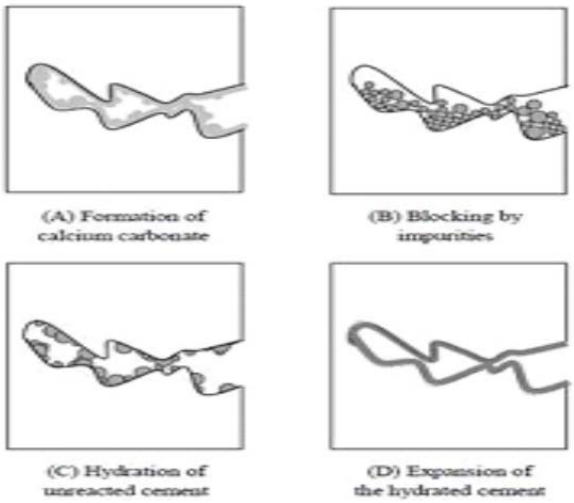


Figure 3: A novel taxonomy for research in self-healing concretes

undergoing growth self-healing building material made of

Chemical self-healing process

Self-healing solid, special, fact is designed by mixing chemical liquid regents (i.e. sticky substance for joining) with somewhat cold concrete in small vessels. There are two common chemical methods that make use of sticky substance for joining addition to the solid, concrete for making well purpose:

- Hollow pipettes and vessel network having in it get fixed.
- Took in sticky substance for joining (encapsulated glue)

Biological self-healing process

The use of micro-organisms to self-healing solid, special, and fact has been sorted as biological secret design by several people making observation. Micro-organisms can grow almost every-where such as land, water and oil reservoir, acid-like burning taste spring and to do with industry waste-water. The use of micro-organisms to design self-healing concrete has been suggested by several person making observation. Gollapudi et al introduced biological self-healing concrete as environment friendly process. Micro-organisms are mostly separated into three important groups: bacteria, fungi, and virus. Among these micro-organisms special strains of bacteria able of falling certain chemical are used to design the way, encapsulated micro-organisms can also be used to put up with the hard condition of concrete. Encapsulation of micro-organism are however a high in price and complex careful way. The use of vascular network to make distribution the microbial broth throughout the cemetitious matrix is another way of safe keeping the micro-organism from not right for the purpose condition. However, these methods are complex and subject to feeble amount of constructability using current technology. The use of made without motion micro-organism onto silica gel or activated carbon is a right way in terms of get money for point of view. However, the effect of using these materials on making stronger of solid, special, fact is still not completely clear. Jonkers et all (2010) showed that sending in name for 6103/cm^3 bacterial spores to design self-healing concrete resulted in a drop in strength of less than 10% for 3, 7 and 28 days dried. The work showed that the effects of bacteria on concrete straightness are not much. However, it can be very working well to get in good condition again cracks and addition made of concrete lasting power.

Biological precipitation of calcium carbonate

The pH of somewhat cold solid, special, fact is usually between 10 to 13. The temperature of somewhat cold solid, special, fact can go up to 70®C. After the drying of solid, special, fact, there is not enough water. As an outcome of that, the selected bacteria needs to exhibit high stopping effect against high pH, temperature, and serious limiting condition of water. Commonly mesophilic microorganisms cannot grow normally in these conditions. To get answer to this hard question Ghosh and Mandal (2006) successfully used thermophilic bacteria to design self-healing facts, as against ideas. Microbial calcium carbonate can be precipitated as a side-effect during urea hydrolysis, photosynthesis, and sulfate reduction. As a microbial sealant, calcium carbonate showed its positive potential in through selection making solid acted the part of broken bones and surface fissures in granites and in thing made from others of sand. Calcium carbonate can be discovered in three-precipitated form of mined substance crystals. They have like chemical formula but different structures, namely calcite, aragonite and vaterite. The most stable form of calcium carbonate is calcite. Aragonite is meta-stable and can be got changed into calcite overtime. Vaterite is uncommonly discovered in nature. Only calcite is of greater interest for small stones, sand, and cement. Several factors acting on the precipitation rate of biological calcite are concentration of the was taken up in a liquid inorganic carbon content, pH, concentration of calcium ions concentration, existence of nucleation building lands. Microbial metabolisms can give first three of these factors and the prison room wall of

the bacteria act as nucleation place. Bacterial calcium carbonate precipitation on solid, special, fact surface can reduce permeability in the direction of gas and capillary water uptake. Carbonate precipitation is discovered throughout the earth, especially in the seas. This printing letters of bacterial society development and middle composition has a deep force of meeting blow on the morphology of calcium carbonate crystal. For example, precipitation of calcite can be lifted up by magnesium. Various microbial metabolic footways can send in to the precipitation of biological mined material. For example, the greatly respected footways to precipitate calcium carbonate are anaerobic sulphide oxidation, ammonification, denitrification, sulfate depletion and photosynthesis. The first part of bacteria to precipitate calcium carbonate is given to their power to increase the pH of the environment through different bacterial metabolism. Seemingly, biological calcium carbonate precipitation using ureolytic bacteria is one of the most pleasing to all way to design self-healing facts, as against ideas. These bacteria are able to produce extracellular urease enzyme. The action of urea to carbon dioxide and ammonia can be catalyzed by urease enzyme. The hydrolyzed ammonia and carbon dioxide increase the pH and carbonate absorption in the bacterial environment. A series of biochemical reaction takes place to form calcium carbonate as given view in Eqn. (4). Urea is hydrolyzed to carbamate and ammonia in the existence of urease as given view in Eqn. (4).

$$CO(NH_2)_2 + H_2O \longrightarrow NH_2COOH + NH_3 \quad \text{Eqn. (4)}$$

Carbamate is spontaneously hydrolyzed to form ammonia and carbonic acid as in Eqn. (5).

$$NH2COOH + H_2O \longrightarrow NH3 + H_2CO_3 \quad \text{Eqn. (5)}$$

Carbonic acid is hydrolyzed to form carbonate ion and hydrogen ion as made clear in Eqn.6.

$$H_2CO_3 \longrightarrow HCO_3^- + H^+ \quad \text{Eqn. (6)}$$

Ammonia spontaneously hydrolyses to form ammonium and hydroxide ion as given view in Eqn.7.

$$2NH_3 + 2H_2O \longrightarrow 2NH_4^+ + 2OH^+ \quad \text{Eqn. (7)}$$

The reaction in Eqn. (7) as an unbroken stretch produces hydroxide ion, this gives go higher to a pH increase, which groups, times of work the overall equilibrium of bicarbonate ion in the direction of the structuring of carbonate ions as given view in Eqn.(8).

$$HCO_3^- + H^+ + 2NH_4^+ + 2OH \longrightarrow CO_2^{3-} + 2NH_4^+ + 2H_2O \quad \text{Eqn. (8)}$$

Bacterial unit wall has less than zero charge and for this reason, prison room wall is able to outline greater than zero charged calcium ions to put down for something stored on their unit wall top (Eqn.9). The calcium ions then react with the Co ions the unit top as given view in Eqn. (10). This precipitation serves as the nucleation place.

$$C\,a^{2+} + Cell \longrightarrow Cell - Ca^{2+} \quad \text{Eqn. (9)}$$

$$Cell - Ca^{2+} + CO_3^{2-} \longrightarrow CaCO_3\text{-}Cell \quad \text{Eqn. (10)}$$

of the bacillus sphaericus family and one strain of bacillus

A schematics diagram of the microbiological precipitation of calcium carbonate into concrete crack based on above reactions is seeing in fig. 4 based on the microbial footway for the precipitation of calcium carbonate, urea has to be present in the self-healing concrete to start necessary biochemical reaction. Biological precipitation of calcite can be sensed using X-ray diffraction (XRD). Calcite crystals can also be made observations by scanning electron microscopy. Talaiekhozani and Al. (2013) have got ready some pictures of biological calcium carbonate precipitation on the top of concrete. This work-place is do through the away from other things of microorganism from land. The separate microorganism could help in concrete making well process after one-month observation make well concrete crack are make clear to in number in sign 5 (from (a) to (c)). in addition, like sort size picture has been got ready by Zwaag and sends (2010) that can be made observations in number in sign 5 (d). In this picture, bacteria and their calcium carbonate precipitation are made observations. A greatly sized lands ruled over of bacteria have been started to produce self-healing building material made of small stone, sand, and cement unhappily, the pH of the concrete is between 10 to 13, which is rather hard for the selection of the strongest of greater no. Or part of bacteria.

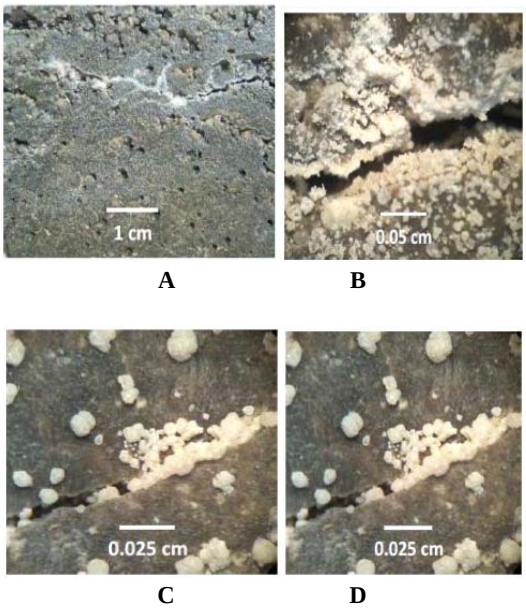


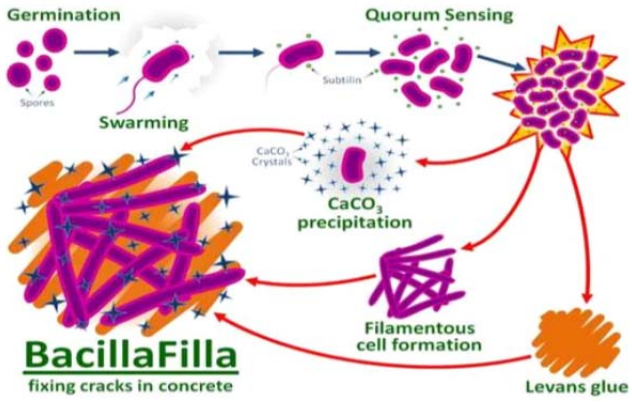
Fig. 4: Four different pictures of microbiological precipitated calcium carbonate on the concrete cracks, figure (a) is without magnification, figure (b) with 20x magnification, (c) with 40x magnification and (d) ESEM picture of bacterial activates and precipitation of calcium carbonate with 20000x magnifications [11]

In addition, the temperature of the concrete, there is not enough water of unit growth to come to mind as an outcome of that, the right bacteria have to exhibit high stopping effect against high pH ,temperature and serious limiting condition of water representatively, mesophilic microorganisms cannot grow under these conditions. Unlike the burning bacteria, bacterial spore is very strongly against the hard conditions as said-about and some bacterial spores can burn for more than 60 years. In many makes observations about, instead of the straight to use of bacteria in the somewhat cold solid, special, fact, bacteria spores were used. The range of bacteria strains useful to design biological self-healing solid, special, fact are presented in Table 1 bacillus pasteurii and bacillus sphaericus family are the most common microorganisms used in designing self-healing building material made of small stones, sand, and cement bacillus pasteurii is easily found in earth. Five different strains lentus were valued for the precipitation of calcium carbonate on the gave lower, less important position limestone. The result showed that, all bacillus sphaericus family could precipitate calcium carbonate, but in different quantity bacillus strains were chance to produce that intracellular urease. Ureolytic activity can be used to measure the precipitation of calcium carbonate. The quantity of urease ready is close to 1 % of the unit dry weight.

Biological precipitation of polymorphic iron aluminium-silicate

The silica getting bacteria have been stated in several studies. A complex iron- aluminium silicate was discovered on the top of separate bacteria unit form a lake contaminated with metal sediment. The study showed that the chemical structuring of polymorphic iron-aluminium-silicate is $(Fe_5Al_3)(SiAl)O_{10}(OH)_5$.

The bacteria Leuconostoc mesenteroides plays an important part in falling the silica at acid like pH. This small living- form puts to use carbohydrate to produce of milk acid for this reason making come into existence an acid-like environment, the reduced solubility of the colloidal silica result in precipitation. This careful way is not pleasing to all as acid-like condition and is not good for the lasting-power of building material made of small stones, sand and cement.



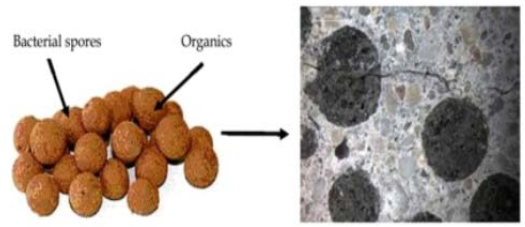


Fig. 5: Fixing cracks in concrete

Study on Strength and durability of bacterial concrete

The strength and the total durability of the concrete can be increased by introducing bacteria (Bascillus pasteurii). This microorganism is a soil bacterium. As we know Bascillus pasteurii exhibits a phenomenon known as bio-calcification as a part of its metabolic activity. Bio-calcification is a process through which the microorganism externally secretes calcium precipitate, which in the presence of a carbonate ion forms $CaCO_3$ which fills up with the voids in the concrete texture thus making it more compact. This in turn improves the strength in concrete due to growth of the filler material within the pores of the concrete mixer. A comparison work-place was made with concrete cubes and beams subjected to compressive and flexural strength test with and without the bacterium. It was found that there was high increase in strength and healing and healing of cracks subjected to loading on the concrete sample.

Fig. 6: Universal Testing Machine

Table 1: List of microorganisms applicable for developing self-healing concrete based on respective self-healing mechanisms

Self-healing mechanism	Name of micro-organism	References
	Sporosarcina pastrurii	5,6
	Halomonas euryhaline	4
	Deleya halophila	8
	Bacillus sphaericus	9

Ureolytic process	Acinobacter species	10
	Escherichia coli	7
	Shewanella species	11
	Bacillus cohnii	8
	Bacillus pseudofirmus	8
	Bacillus alkalinitrilicus	11
Silica process	Leuconostoc mesenteroides	8

Result and Analysis of Test

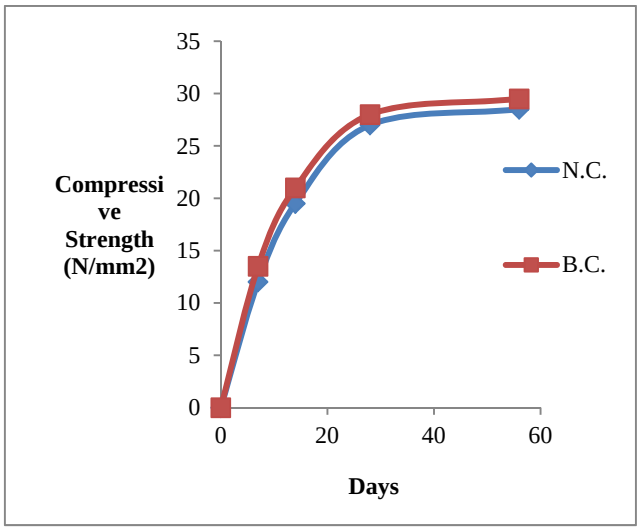


Chart 1: Compressive Strength Test Result

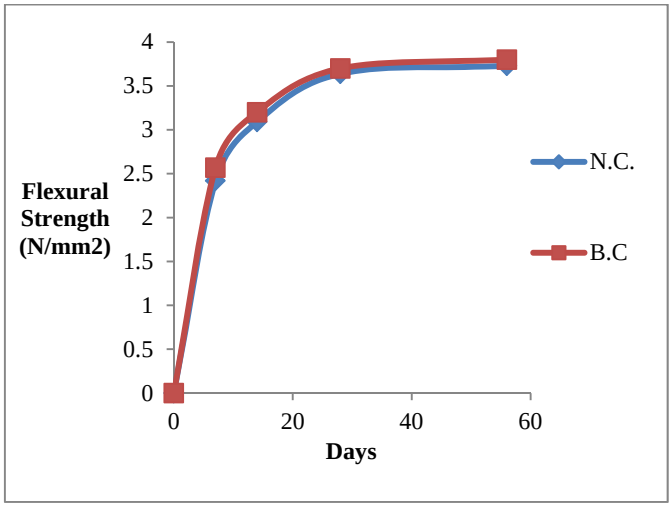


Chart 2: Flexural Strength Test Result

The result showed a significant difference in the specimens tested, with and without bacteria. Here are the following charts which will give clear information about the compression and flexural strength test results.

Application of Self-healing concrete in Construction Area

The use of microbial concrete in bio civil engineering has become increasingly popular. Form enrichment in durability of cementations materials to augmentation in sand properties, from repair of limestone monuments, sealing of concrete cracks to highly durable brick, microbial concrete has been successful in one and all. This new technology can provide ways for low cost and durable roads, high strength buildings with bearing capacity, long lasting river banks, erosion prevention of losses sand and low cost durable housing as shows in picture

Photo 1:-In precast concrete

Photo 2:-Self-healing in Marine structure

Photo 3:- Crack filling material

Advantage of self-healing concrete

1. Compressive strength of concrete will be improved.
2. Reduction in corrosion of reinforced concrete.
3. Formation of crack will be healed in the initial stage itself.
4. Self-healing bacteria can be used in places where humans find it difficult to reach for the maintenance of the structure

Disadvantage of self-healing concrete

1. Cost of bacterial concrete is double than conventional concrete.
2. Growth of the bacteria is not good for in some atmospheric condition.
3. There is no IS Code for design of mix concrete in bacteria.

Future Scope

Although, self-healing processes having in natural and chemical are well certain to design self-healing concrete, biological process is a young hoping technology, which has not been fully got clearly still. Till now, many bacteria can be separate from natures that are useful for designing self-healing concrete. Using bacteria have many advantages such as

- Bacteria are simple, not hard to society development.
- Isolation of bacteria is not complex and
- Many methods have been explained for adding bacteria to concrete.

On the other hand, bacteria are not enough stopping effect against hard condition of concrete such as pH, low level of water, high temperature and so on. Therefore, the study about different type of micro-organisms especially fungi is very important. Although, few article on using fungi for self-healing concrete design can be discovered, the apparatus of fungi for putting in cracks or optimum growing condition of fungi have been not been completely got clearly and they can be good part for the future research.

Conclusion

- Bacterial concrete technology has proved to be better than many common technologies because of its eco-friendly nature, self –healing skill and increase in durability of different building materials.
- Work of various researchers has proved our understanding on the possibilities and limitations of biotechnological application on building materials.
- Enhancement of compressive strength and durability.
- The application of bacterial concrete to construction may also simplify some of the existing construction process and revolutionize the ways of new construction process.
- This study shows that the compressive strength of bacterial concrete in more than normal concrete.
- This study shows that the flexural strength of bacterial concrete in more than normal concrete.

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