EFFECT OF BACTERIA ON THE PROPERTIES OF CONCRETE- A REVIEW

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ABSTRACT. Concrete, a widely used building material, is quite prone to crack formation (a phenomenon that allows water, chemicals into the concrete structure). The chemicals along with water and CO_2 cause a decrease in strength, ductility, durability and also have adverse effects on reinforcement. In absence of immediate measures, the cracks may further expand giving rise to bigger problems. Therefore, to tackle such issues, self-healing concrete, a revolutionary idea and a building material of future is introduced. Self-healing is the property where the parent material is capable of healing the cracks itself. It is possible with the help of bacteria. The underlying principle of self-healing nature is the production of calcium carbonate crystals with the help of a bacterial solution having calcium carbonate precipitate that helps in blocking the pores and cracks. This introduction of bacterial concrete paves the way to production of more durable, sustainable, crack free and more efficient concrete. The introduction of bacteria in concrete gave it a new name: microbial concrete or bio concrete. This bio concrete is more or less pollution free and economic. This paper aims at defining bacterial concrete, its effects on concrete properties and describing its merits and demerits.

Keywords: Strength, Ductility, Durability, Sustainabile, Crack free.

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INTRODUCTION

In 2^{1st} century concrete is the major construction material in infrastructural world. The reason behind concrete being used as a worldwide building material is: the ingredients for concrete are easily available, concrete can be provided desired strength with economy, its mould can be cast into any required shape, and it can withstand high temperature. Concrete is strong in compression but has many drawbacks like it haslow crack resistance, less tensile strength, less ductility. Fierce environmental factors along with consistent sustained pressure results in declination of self-life of concrete. While designing a concrete structure, strength and durability must be kept in mind. A major problem in concrete is the crack formation on its surface, which is due to the low tensile strength of concrete [1, 2]. Cracks in concrete lead to the reduction of strength, durability and make concrete sensitive to deleterious environment [3]. Also cracks pave way to chloride attack, carbonate attack and sulphate attack, as a result of which corrosion of steel reinforcement and deterioration of concrete take place. Formation of crack is generally intercepted by manual examination and repairs by using synthetic fillers or cement [4]. But these repairs are not cost effective and not possible for deep cracks [5,6]. Thus, emerging a favourable and inventive way to heal the cracks of concrete is the call of nature i.e., self-healing concrete. Many self-healing techniques like adhesive-based, autogenous, bacteria-based, mineral admixtures based have been introduced [7].Among these methods bacteria-based self-healing of cracks is the most effective one [1-3, 5, 8-16].

Ureolytic bacteria was first time used as healing agent by Gollapudi et al. (1995) for cracks which assists the enzymatic hydrolysis of urea to ammonia and carbon dioxide [9]. On the other hand, Ramakrishnan et. al. (2001) first introduced the concept of utilizing microbiologically induced calcite ($CaCO_3$) precipitation [17]. When bacterial techniques were applied in fresh concrete, it produces calcite precipitation in the void of concrete which decreases the permeability and increases the strength of concrete. Deposition of calcite on concrete specimen by the bacteria leads to the reduction of gas permeability and uptake of capillary water. Crystals of calcium carbonate deposition on the concrete specimen results in the decrease in water absorption upto 85%. Bacterial carbonate precipitation affects the durability of concrete specimen with different porosity.Due to bacterial calcite precipitation, permeability and sorptivity of concrete decreases. Dependingupon porosity, water absorption is reduced from 65-90% due to bacterial carbonate precipitation [18]. Due to the execution of bacterial approach in concrete, durability property of concrete has been improved effectively [10, 13, 19-22].

This paper describes about bacteria and its self healing mechanism, analyses its merits like advantageous effect on mechanical properties of concrete and it also highlights some of the demerits

BACTERIA, ITS GROWTH AND REPRODUCTION

Bacteria are unique species having simple structure but large diversity. Bacteria is the plural form of bacterium. The plasma membrane of bacteria having all the properties acts as cell membrane. It serves as the area of transport of protein and nutrients. Bacterial species were the first to evolve in non-oxygenic atmosphere. They are prokaryotes as they do not have membrane bound cell organelles in their body.

In case of prokaryotic unicellular organisms reproduction and cell growth are two mutually inclusive events, i.e. reproduction takes place by means of cell growth. cell growth is the most common method of asexual reproduction among unicellular organisms. The bacterial cells grow up to a certain amount by taking nutrients from their surrounding atmosphere and then the parent cell divides into two new daughter cells by binary fission. DNA, mesosomes and other cell organelles divide into two equal parts.Each cell is a duplicate of the other.

Bacteria can be cultured in laboratory by using suitable growth medium (solid or liquid). Culture means letting the bacteria grow and reproduce in predetermined condition in a medium inside a laboratory. Agar plates are the most commonly used solid growth medium which contains all required nutrients for bacterial growth.Selective nutrient medium is required for detecting specific organisms. Liquid mediums are helpful for culture of enormous volumes of bacteria. Naturally it becomes difficult for bacteria to grow and to do cell division in artificial conditions which becomes unsuitable for them, but usage of gel or liquid media containing natural resources are quite helpful in speeding up their rate of cell division, i.e. they do not have to struggle for collecting nutrients, they get ready made nutrients.

There are four stages in which bacterial growth in a nutrient medium takes place. First, bacteria need to adopt to their new environment, which is a quite slow phase, as they require some time to comprehend the condition they are in. This phase is known as the lag phase, where the rate of growth is slow and bacterium prepares itself for upcoming high growth rate. The second phase is the log phase. In this phase bacteria take up the nutrient in a faster rate and metabolism is done at higher speed. Third phase is the stationary phase. Here the growth curve becomes horizontal. Due to heavy usage of nutrients, now the nutrient medium starts depleting. The cellular activity along with metabolism keeps on decreasing. The final phase is the death phase in which all of the nutrient medium is finished and bacteria die due to lack of nutrients.

SELF HEALING MECHANISM

The underlying principle of bacterial concrete is the formation of calcium carbonate precipitation around particles to bind quite loosely attached particles that helps in strengthening of concrete. Commonly, urease producing bacteria serve this purpose [23,24].
1 mol of urea when hydrolysed, gives rise to 1 mole ammonia (NH_3) and 1 mole of carbamic acid (NH_2COOH) [25]. Further carbamic acid when reacts with water produce 1 mole of bicarbonate and 2 moles of ammonia. Bicarbonate gets reduced to bicarbonate ion and H^+ ion. Also, the 2 moles of ammonia when reacts with water gives ammonium ion and OH^-.
The last reaction results in an increase in pH, due to which the reaction shifts towards right producing more carbonate ions (law of mass action), which is shown Eq. 1.

$$HCO_3^- + H^+ + 2NH_4^+ + 2OH^- \leftrightarrow CO_3^{2-} + 2NH_4^+ + 2H_2O \quad (1)$$

We know that the cell wall of bacteria is negatively charged. Therefore, it attracts Ca^{2+} cations from the surrounding environment. The previously deposited CO_3^{2-} ions react with these Ca^{2+}cations forming $CaCO_3$ precipitation at the cell wall which acts as the site for nucleation, which is shown in Eq. 2.

$$Cell\text{-}Ca_2^+ + CO_3^{2-} \rightarrow Cell\text{-}CaCO_3\downarrow \quad (2)$$

The amount of deposited or non- reacted lime particles determine the potential of the concrete for self-healing.

EFFECT ON MECHANICAL PROPERTIES OF CONCRETE

Increase in Compressive Strength

Compressive strength plays a vital role in determining the durability of concrete. Hence research in bio concrete is an essential field from application point of view. When bacteria species are injected into concrete and mortar, it shows significant increase in compressive strength of concrete. By using bacterial sample *Bacillus sp CT-5* author observed that bacterial specimen gives strength of 31Mpa and compressive strength increases about 36% with respect to concrete without bacteria after 28 days of curing [23].In the concrete containing *Bacillus Sphaericus*, increase in compressive strength of 30.76%, 46.15% & 32.21% at 3,7 & 28 days occurs. In case of split tensile strength 13.75%,14.28% & 18.35% increases in a period of 3,7 & 28 days respectively [26]. Bacillus subtilis bacteria was introduced in concrete by using various bio influenced self- healing technique such as carrier compound namely light weight aggregate and graphite nano platelets.For carrier compound light weight aggregate there is increase of 12% of compressive strength as compared to concrete without bacteria and by graphite nano platelets there is 9.8% increase in compressive strength as compared to concrete without bacteria [27].Bacillus *Haloduransstrain KG1* was used along with replacing Cement Kiln Dust with cement from 0 to 20%. With 10% CKD7.15% and 26.6% increase in strength at 28 & 91 days of test was observed [28]. By using *Bacillus cereus* 38% and by *Bacillus pasturii* 29% increase in compressive strength takes place after 28 days curing [29].*Bacillus Subtilis JC3* was used with cell concentration of 10^4,10^5,10^6,10^7 cells per ml. Highest strength was achieved by cell concentration 10^5 cells/ml, which gives 23% increase in strength after 28 days of curing [30]. Addition of bacteria*Bacillus Subtilis JC3* lead to increase in the compressive strength by 13.93% at a curing period of 28 days where as in case of split tensile strength there is an increase in strength by 12.60% at 28 days [31].By adding *B. Subtilis* compressive strength of the structure increases about 23% at a curing period of 28 days for ordinary concrete when compared to controlled concrete [32]. Both dead & live bacterial cell of *B. Pasturii*were used with different cell concentrations and found that the live cells having less number of cells per ml, if allowed to grow for a longer period then it tends to increases the compressive strength of cement mortar. As per results a marginal increase up to 10% of compressive strength was observed by adding *B. Pasturii*[33].

Reduction in Permeability

Permeability is one of the key features by which the durability of concrete is affected. Concrete having very high amount of permeability results in percolation of water and pollutants, which affects the concrete durability along with integrity. Hence, low permeability is a must for having long activity period. Using bacterial concrete helps in decreasing the permeability of concrete. Since the calcite precipitation because of bacterial concrete mainly occurs at the surface of concrete, it acts as the covering system that helps in covering the pores [34]. Carbonation test (surface treatment results in decrement in gas permeability which leads to a method of examining the permeability because it is known that decrease in gas permeability which further leads to increment in resistance for carbonation and chloride entry. An increment in resistance of concrete for alkali, drying shrinkage, freeze thaw attack by addition of bacterial cells was observed. The impact of calcite precipitation on permeability was a part of study, who used S. *Sphaericus*and reported a significant amount of decrement in concrete permeability [13]. Research has been done on the effects of *Bacillus pasteurii* bacteria on the permeability of concrete and observed a significant reduction in permeability of water in cement cubes incorporated with the bacterial species [35]. It also observed the same effects when they used *Sporosarcina pasteurii* in concrete cubes. Many believe that this reduction in water permeability of concrete specimen with bacteria content is due to the calcite deposition in the voids of concrete [23]. When concrete specimen were treated with *Bacillus* sp. CT-5, they showed reduction upto six times in water absorption of concrete in comparison to control specimen [36]. When the effect of *Sporosarcinapasteurii* was studied on concrete with fly ash, it showed reduction upto 8 times in chloride permeability. This might be possible because of the deposition of calcite in concrete. When mortar specimen were incorporated with *Bacillus sphaericus* spores that are hydrogel encapsulated, the permeability reduces upto 68% [37].Concrete with fly ash content incorporated with bacteria showed decrement in water absorption upto four times. As bacteria concentration increases capacity for absorption of water decreases. When bacteria contain 10^5 cells/ml bacterial concentration, then reduction in water absorption is maximum. Overally with respect to control specimen, there is decrease in water absorption in the presence of bacteria [38]. The deposition of a layer of calcium carbonate on the surface and inside pores of the concrete specimens resulted in a decrease of water absorption.When the quantity of carbonation is higher in concrete containing bacteria, the surface reaction causes increment in resistance to chloride attack, which in turn helps in decreasing the permeability along with porosity[39-41].

Reduction in Corrosion of Concrete Reinforcement

Failure of structure occurs mainly due to the steel corrosion in concrete which arises as reinforced concrete exposes to chloride ion. In order to avoid corrosion, sufficient measures are necessary to reduce the permeability of concrete. Because permeability is nothing but a way to allow water, chloride ions and other chemicals into the concrete which results in corrosion of steel and reduce. The permeability property of concrete was reduced effectively by the bacterial precipitate of calcium carbonate. This precipitation blocks any path available for passage of water and other impurities into the concrete [42]. When microorganisms like *Sporosarcina pasteurii* and *Bacillus* sp. CT-5 [23] were injected into the concrete mixture, it was observed that, corrosion of steel reinforcement decreased by a large amount. Using bacteria, the concrete shows a reduction in corrosion of reinforcement bar. The calcite precipitation formed by bacteria, blocks the path of water absorption, thus provides longer activity period to the reinforcement bars [43-46]. Chemical process by bacteria offers great resistance towards the freeze and thaw attack. [8,47].

DRAWBACK

Although bacterial concrete helps in reducing the future wastage of money in repairing the cracks in concrete, it costs 7 to 28% more than the usual concrete [43,48,49]. In general, there are no perfect designs for bacterial concrete to get the best possible performance. The perfect amount of bacteria and type always keeps changing and is dependent on its usage[43,50,51]. Some bacteria like *Shewanella species,Leuconostoc mesenteroides, Pseudomonas aeruginosa, Escherichia coli, Acinetobacter species* etc. are harmful to human health as they cause various diseases [52]. So many people believe that it is harmful for them to live in an environment filled with bacteria due to health concern. But bacteria like *Bacillus pasteurii, Bacillus sphaericus, Bacillus lentus*are used in concrete because they do not cause any harm to human health [43-45].

CONCLUDING REMARKS

Recently, self-healing concrete is in a lot of talks because of its microbiological techniques. Calcite precipitation by micro-organisms is an effective solution to the cracking problem in concrete. Using pure bacterial culture resulted in more profound results.Metabolic steps occurring inside of microorganisms are the main reason of all-round development of quality of concrete. Metabolic processes occurring in most of the bacteria species such as photosynthesis, sulphate reduction, and urea hydrolysis result in production of calcium carbonate as one of the by-products. Using self-healing concrete containing bacteria has positive effects on various parameters like durability, self-life strength, permeability, water and chloride absorption. It has been observed that using biotechnology in designing self-healing concrete effectively increases the durability, strength and decreases the permeability of concrete. There is a myth existing regarding the use of microorganisms in houses and offices. Many have a belief that an environment filled with bacteria is not good for their health, it may bring unseen diseases. It is hoped that in future, people will understand the value of using self-healing bio concrete and realise its importance and start using it widely as a substitute of conventional concrete.Moreover, usage of self-healing concrete is a reassuring method for having better quality infrastructure.

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