BIO-CONCRETE: SUSTAINABLE SELF-HEALED BACTERIAL CONCRETE: A REVIEW

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ABSTRACT

Concrete though being used and adopted as an ideal construction material because of its easy availability, low cost, good viscosity, good compressive strength etc. but it has some drawback also, the major drawback of concrete is its low tensile strength due to which micro-cracks occur when the structure is subjected to sustained loading and exposed to aggressive environmental conditions in to decreasing the life of the structure. The service life of buildings is determined by the durability of concrete. Aggressive environmental conditions, on the other hand, may weaken it. The presence and operation of microorganisms that develop sulphuric acid to form sulphate degradation of concrete materials, for example, causes bio-corrosion. The shortage of suitable concrete materials is to blame for the issues with durability and repair systems. The use of bacteria for concrete repair and pore plugging and cracking has been investigated. Bacillus species are oxygen consuming spore shaping gram positive microorganisms with particular thick-walled torpid cells, live for over 200 years as they are spore forming bacteria. Structure and the compressive characteristics of the developed materials with bacterial concentrations are investigated.

Keywords: Bacterial Concrete, Bacterial Characteristics, Concrete Cracking, Self-Healing.

I. INTRODUCTION

Cracks in concrete are unavoidable and are one of the characteristic shortcomings of concrete. Water and different salts leak through these splits, erosion starts, and therefore diminishes the life of concrete. So there was a need to build up an innate biomaterial, a self-fixing material which can remediate the splits and gaps in concrete. Bacterial concrete is a material, which can effectively remediate splits in concrete. This strategy is profoundly attractive in light of the fact that the mineral precipitation incited because of microbial exercises is sans contamination and regular. As the cell mass of microscopic organisms is anionic, metal gathering (calcite) on the outside of the divider is generous, in this way the whole cell gets crystalline and they in the end plug the pores and cracks in concrete. Cracks in concrete are unavoidable and are one of the characteristic shortcomings of concrete. Water and different salts leak through these splits, erosion starts, and therefore diminishes the life of concrete. So there was a need to build up an innate biomaterial, a self-fixing material which can remediate the splits and gaps in concrete. Bacterial concrete is a material, which can effectively remediate splits in concrete. This strategy is profoundly attractive in light of the fact that the mineral precipitation incited because of microbial exercises is sans contamination and regular. As the cell mass of microscopic organisms is anionic, metal gathering (calcite) on the outside of the divider is generous, in this way the whole cell gets crystalline and they in the end plug the pores and cracks in concrete.

A. Need of Study

The needs of following study are listed below:

a) Because of cracks generation in concrete under sustained loading and also due to aggressive environmental agents that reduces the life of the structure which are built using these materials. To counter these problems, a new revolutionized concept has come into limelight which is "Bacterial Concrete".

b) Bacterial concrete has recently gained popularity due to benefits such as self-healing, increased longevity, and increased strength. Many factors are expected to affect the behavior of living organisms when they are incorporated into cementation materials. The survival and intended behavior of bacteria in concrete require a conductive environment, which includes temperature, nutrients, pH, and other factors.

c) The emerging technologies towards the evolution of concrete from ordinary concrete to bacterial concrete, is developing at the faster rate to achieve the goal in terms of strength and durability.
II. LITERATURE REVIEW

The evaluation text includes the analysis of multiple scholars and the findings of separate study articles. The studied Ph.D thesis, reviews and books have been released in different national and foreign journals, and their main findings are described and shown at the end of this article. This improves knowledge of the subject and offers extensive background in the right flow of work.

V. Ramakrishnan et al. (2001) conducted study use of microbiologically induced calcite precipitation (MICP) to mitigate crack and fissure. MICP is the biomineralization technique in which living organisms shape inorganic solids. They use as a microbial sealant bacillus pasteurii. The MICP was found to be cost-effective and is a natural process for calcite production. This technique is used to improve strength and resistance. With the presentation of cell grouping of microscopic organisms in concrete, the solidness is improved. By XRD (X-Ray Diffraction) study, they quantified and visualized calcite precipitation by SEM (Scanning Electron Microscope). Researchers claim that the presence of bacteria in various media enhances shrinkage and other chemical attacks. Bacillus pasteurii was used by writers as a microbial sealant. (1)

E Schlangen et al. (2010) studied the overview of techniques of self-healing in three different materials. Bacteria are used for the first use to precipitate calcite into concrete cracks. This approach can be used to fill relatively large gaps in reinforced concrete. The technique does not lead in structure strength changes, but the path to reinforcement is blocked by filling the gap. It prevents the penetration of liquids and ions beginning to intensify corrosion and thus increases the structure’s resilience. In addition, this approach is useful for structures that retain water. It helps cracks to be filled and leakage can be prevented. It is troublesome or difficult to fix splits in concrete, especially in underground structures around then bacterial cement is exceptionally helpful. In the second application SHCC (strain solidifying concrete composites) materials are examined, which because of their little split widths as of now have a high potential for self-mending. New increases, for example, microfibers and SAP (Super Absorbent Polymers) seven further upgrade this limit with regards to self-mending The third application is for black-top cement with the utilization of epitomized oil and miniaturized scale steel filaments to improve on self-mending capacity. The last strategy has demonstrated to be powerful in the research center and will be executed in the Netherlands in 2010 on a genuine street. (5)

Van Tittelboom et al. (2010) studied that the introduction of bacteria to the concrete matrix against the water permeability and also up-to 10 mm deep cracks can be cured under the bacterial action. (6)

Fernando Pacheco-Torgal et al. (2010) There were also four blends made of ceramic powder replacing 20% of the cement. Ceramic bricks (CB), White stoneware twice-fired (WSTF), sanitary ware (SW), and White stoneware once-fired (WSTF) are the names of the different types of ceramic waste (WSOF). All of the mixes have lower vacuum water absorption than the control mixture, and all of the concrete mixtures that use ceramic waste as a cement substitute outperform the control mixture. The water permeability of various ceramic wastes varies. (21)

Wiktor et al. (2011) It was discovered that the viability of a bacterial strain could also be determined by the rate at which oxygen is consumed, which decreases when bacteria are immobilised. The FTIR Analysis aids in the detection of calcite formation by bacteria, which is a vital factor in crack remediation. As compared to a managed concrete sample with bacterial immobilised concrete sample, the 100-day curing of samples showed 0.46 mm crack width sealing. (7)

Rafat Siddique et al. (2011) presented a description of the types of bacteria depending on the classification. Even the impact of bacteria in concrete on different parameters is proving beneficial. The microbial mineral precipitation seems, by all accounts, to be a promising system at this phase of advancement dependent on the contemplated properties, for example, compressive quality, penetrability, water retention, chloride ingestion. The sort of bacterial culture and medium piece were found to profoundly affect the morphology of calcium carbonate precious stones. The use of pure culture had a more substantial effect. Metabolic activity of certain specific concrete microorganisms is responsible for enhancing concrete behaviour. It has been accepted that practically all microbes are fit for delivering CaCO3 in light of the fact that precipitation happens as a side-effect of explicit metabolic procedures. Indeed, even the effect of microorganisms in concrete on various parameters is demonstrated to be gainful advancement and the compressive quality is improved essentially. (8)
Navdeep et al. (2012) investigated the capability of Bacillus megaterium to create calcite and upgrade the properties of Fly debris blocks and Rice husk debris blocks. They found that the treated blocks had fundamentally expanded compressive quality and diminished ice assault, water ingestion because of the amassing of calcite superficially, and block voids. Checking electron micrographs unveiled extracellular affidavit on the outside of the blocks of calcite gem by the microbes. X-beam diffraction and vitality dispersive X-beam investigation announced that the accelerates shaped as calcite precious stones are CaCO3. These perceptions recommend that this innovation can possibly deliver building hinders that are supportable and ecologically well disposed. Analysts saw that the Bacillus megaterium was seen as productive on the outside of debris blocks in calcite statement, bringing about decreased porousness, diminished water ingestion, bringing about expanded sturdiness. Through including bacterial calcite, the quality of debris blocks can be essentially expanded. Bacteria's bio-calcification process can serve as an important tool for improving the resilience of ash-brick-built civil structures. (10)

V. Achal et al. (2013) studied the function of Bacillus sp. bacteria. On the properties of stability and remediation of cracks in reinforced structures. Induced by a Bacillus sp. 'Biocement'. Lead a decrease of in excess of 50 percent in mortar porosity while chloride Concrete porosity has changed from "moderate" to "low" as demonstrated by the quick chloride penetrability test. The microscopic organisms effectively relieved the reproduced profundity cracks, remembering 27.2 mm for concrete mortars, with an improvement in the compressive quality as high as 40% of the force. The results clearly showed that microbially induced precipitation of calcium carbonate can be applied to different building materials for crack remediation and durability enhancement. They showed that the efficacy of precipitation of calcium carbonate microbially induced was used to remedy cracks in building materials. The crack sealing method increases building structures' strength and durability. This prompts a decrease in penetrability of water and chloride particles. It additionally ties the particles of the sand together and goes about as concrete. In addition, the reported system has the potential to provide structures with the ability to self-heal. (11)

Mayur et al. (2013) presented that the analysis of bacterial concrete with its advantages, drawbacks and various application of calcite bacteria to improve concrete efficiency. To improve concrete strength, they researched the new microbially induced material. In light of the investigation, they found that the most conservative, self-fixing building material is the microbial movement. Various analysts' work has fortified our comprehension of the conceivable outcomes and restrictions of biotechnology applications on development materials. Different concrete and stone materials have seen an improvement in compressive quality, decline in porosity, water ingestion, and strengthened erosion. Cementation is exceptionally simple and advantageous for use with this structure. This system is perfect, yet more research is required, and some positive condition is essential for the microorganism. This bacteria is important to increase the durability as well as the compressive strength of concrete. (13)

Jagadeesha Kumar et al. (2013) Effect of Bacterial Calcite Precipitation on Mortar Cube Compressive Strength was published in this paper. This paper details the results of experiments on mortar cubes that were subjected to bacterial precipitation by various bacterial strains, as well as the effect of bacterial calcite precipitation on the compressive strength of the mortar cube after 7, 14, and 28 days of bacterial treatment. Bacillus flexus, isolated from a concrete setting, Bacillus pasturii, and Bacillus sphaericus were used in the study. The cubes were immersed in bacterial and culture medium for the days specified, with control cubes immersed in water, and compressive strength was determined. The results showed that the compressive strength of cubes improved over time, but that the compressive strength of cubes decreased over time. Cubes treated with Bacillus flexus, which has not been identified as a bacteria for calcite precipitation, had the highest compressive strength of the three bacteria strains compared to the other two bacterial strains and control cubes. The rise in compressive strengths was found to be primarily attributable to the consolidation of pores inside the cement mortar cubes caused by microbially induced Calcium Carbonate precipitation. The amount of ammonia released from urea was measured using the phenol-hypochlorite assay method to determine the urease activity of all bacteria in Urease media. Urease activity was checked in all three bacteria strains. The media changed colour from yellow to pink, indicating that it was urease positive. Urease was present in all three strains. The chemical composition of the precipitation that resulted from bacterial mineralization was also determined using X-ray diffraction analysis. (16)

Amitkumar D. Raval et al. (2013) When up to 30% of the weight is replaced by weight, the Compressive Strength of M20 grade Concrete increases, and as the weight is replaced further, the Compressive Strength
decreases. Concrete on 30% replacement, Compressive Strength obtained is 22.98 N/mm² and vice-versa the cost is reduced up to 12.67% in M20 grade. (22)

Electricwa Fatima et al. (2013) Compressive strength, split tensile strength, and flexural strength have all increased with the addition of ceramic waste. Ceramic waste concrete has a slump value of 75 to 100 millimetres. The average 28-day compressive strength for various proportions of concrete shows that the strength of concrete increases as the amount of ceramic waste increases by up to 20%. With the removal of 20% ceramic wastes, the cube strength increased by 3.9 percent at a w/c ratio of 0.46, resulting in a w/c ratio of 0.46. (23)

Wang et al. (2014) The bacteria with microencapsulation had a higher impact on crack repair than bacteria with direct immobilisation, according to the report. Crack healing rates vary from 48 to 80 percent. In terms of the feasibility of bacteria penetration into concrete, microencapsulation is a safer methodology. (17)

Ravindranatha et al. (2014) have published a paper on Self-Healing Material Bacterial Concrete. A comparative analysis was conducted with concrete cubes and beams that were subjected to compressive and flexural strength tests with and without Bacillus pasteurii. The concrete cubes and beams were prepared by adding calculated quantity of bacterial solution and they were tested for 7 and 28 day compressive and flexural strengths. It was found that there w The concrete cubes and beams were prepared by adding a measured amount of bacterial solution, and their compressive and flexural strengths were tested after seven and twenty-eight days. On the concrete specimens, there was a significant improvement in strength and healing of cracks subjected to packing. As a result of the loading on the concrete specimens, there was a significant improvement in strength and healing of cracks. By achieving a very high initial strength improvement, the microbe proved to be successful in improving the properties of the concrete. The bacteria's calcium carbonate has filled a portion of the void volume, rendering the texture more compact and resistant to seepage. (19)

Francis Kenna Et Al. (2014) This is most likely due to a higher water absorption rate of the ground ceramic particles. A noticeable decreasing effect on the amount of bleed water which appeared on the concrete surface during the test. This effect can be attributed to both the water absorption rate of the SCC powder and to its particle packing effect. (24)

Dr. M. Swaroopa Rani (2016) On 10% replacement of cement with ceramic waste, compressive strength obtained is more, hence it is more economical without compromising concrete strength. It becomes technically and economically feasible. By the use of waste material such as ceramic waste, usage of concrete industry's waste products is increased by 20%. (25)

JM. Irwan et al. (2017) recently studied the use of bacteria for concrete repair and cracks plugging and concrete cracking. Scientist additionally expressed that past examinations had shown the probability of utilizing explicit microscopic organisms as a maintainable technique for improving solid properties by bio concrete. The examination was completed and the utilization of microscopic organisms in solid generation was researched. Bio-concrete is more durable as it increases the concrete's properties. However, in order to implement bio-concrete technology, a comprehensive study on bio-concrete should be performed. (35)

**Table 1.** Different types of microbes with changing in concentration used by researchers to develop the compressive strength and reduce water absorption of mortar or concrete.

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Author</th>
<th>Country</th>
<th>Bacteria used</th>
<th>Bacterial concentration</th>
<th>Compressive Strength Increase/Decrease/Desirable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ramchandran et al.</td>
<td>South Dakota</td>
<td>Bacillus pasteurii</td>
<td>10⁵ cells/mm</td>
<td>Increase</td>
</tr>
<tr>
<td>2</td>
<td>Achal et al.</td>
<td>India</td>
<td>Bacillus sp. CT-5</td>
<td>5×10⁷ cells/mm³</td>
<td>Increase</td>
</tr>
</tbody>
</table>
III. BACTERIAL CONCRETE

A. Selection of bacteria
As cement and water are combined, the pH value rises to as high as 13, creating a hostile atmosphere for life. The majority of species die in conditions with a pH of 10 or higher. As a result, finding bacteria that can survive in an extremely alkaline environment is critical. Since a lot of heat is produced during the hydration phase of cement, the bacteria chosen should be mophilic. Bacillus bacteria strains were discovered to survive in this alkaline climate. Bacteria that formed spores similar to plant seeds were the ones that were able to survive. These spores have incredibly thick cell walls, allowing them to live for up to 200 years while waiting to germinate in a better environment.

Bacillus is the only bacterial species that can live in such an alkaline climate. It took a long time to find a suitable food source for bacteria that could live in concrete, and several different nutrients were tried until calcium lactate was discovered to be a carbon source that provided biomass. Calcium lactate does not affect the concrete’s setting time if it begins to dissolve during the mixing phase. Jonker et al. used Bacillus cohnii bacteria to precipitate CaCo3 and other researchers used various types of bacteria to study bacteria.

B. Majorly Used Bacteria in Concrete
Following are various types of bacteria used in construction sector:

- Bacillus megaterium
- Bacillus sphaericus
- Escherichia coli
- Bacillus subtilis

<table>
<thead>
<tr>
<th>No.</th>
<th>Authors</th>
<th>Country</th>
<th>Species</th>
<th>Concentration</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Chaurasia et al.</td>
<td>India</td>
<td>B. megaterium</td>
<td>3 x 10⁷ cells/ml</td>
<td>Increase</td>
</tr>
<tr>
<td>4</td>
<td>Krishnapriya et al.</td>
<td>India</td>
<td>B. megaterium</td>
<td>10⁵ cells/ml</td>
<td>Desirable</td>
</tr>
<tr>
<td>5</td>
<td>Nosouhian et al.</td>
<td>Iran</td>
<td>B. pasteurii with B. subtilis</td>
<td>2 x 10⁹ cells/ml</td>
<td>Desirable</td>
</tr>
<tr>
<td>6</td>
<td>Maheswaran et al.</td>
<td>India</td>
<td>Bacillus cereus</td>
<td>10⁶ cells/ml</td>
<td>Increase</td>
</tr>
<tr>
<td>7</td>
<td>Chaurasia et al.</td>
<td>India</td>
<td>B. cohnii</td>
<td>3 x 10⁷ cells/ml</td>
<td>Increase</td>
</tr>
<tr>
<td>8</td>
<td>Biswas et al.</td>
<td>India</td>
<td>Thermo-anaeroba</td>
<td>10⁶ cells/ml</td>
<td>Increase</td>
</tr>
<tr>
<td>9</td>
<td>Chahal et al.</td>
<td>India</td>
<td>Bacillus pasteurii</td>
<td>10⁵ cells/ml</td>
<td>Increase</td>
</tr>
<tr>
<td>10</td>
<td>Siddique et al.</td>
<td>India</td>
<td>Bacillus aerius</td>
<td>10⁵ cells/ml</td>
<td>Desirable</td>
</tr>
<tr>
<td>11</td>
<td>Park et al.</td>
<td>South Korea</td>
<td>E. coli K12</td>
<td>(OD) of 0.8 at 600 nm.</td>
<td>Desirable</td>
</tr>
<tr>
<td>12</td>
<td>Kaur et al.</td>
<td>India</td>
<td>Eupenicillium Crustaceum (fungal)</td>
<td>1.7 x 10⁷ cells/ml</td>
<td>Increase</td>
</tr>
<tr>
<td>13</td>
<td>Li &amp; Jin et al.</td>
<td>China</td>
<td>Sporosarcina pasteurii</td>
<td>2.8 x 10⁷ cfu/ml</td>
<td>Desirable</td>
</tr>
<tr>
<td>14</td>
<td>Andalib et al.</td>
<td>Malaysia</td>
<td>Bacillus megaterium</td>
<td>30 x 10⁵ cfu/ml</td>
<td>Increase</td>
</tr>
<tr>
<td>15</td>
<td>Siddique et al.</td>
<td>India</td>
<td>Bacillus aerius</td>
<td>10⁵ cells/ml</td>
<td>Desirable</td>
</tr>
<tr>
<td>16</td>
<td>Maheswaran et al.</td>
<td>India</td>
<td>Bacillus pasteurii</td>
<td>10⁵ cells/ml</td>
<td>Increase</td>
</tr>
</tbody>
</table>
Bacterial Concrete

Concrete is a material that is by far the world's most widely used building material. Concrete has a high compression load bearing capacity, but the material is low intensity. This is why in order to build buildings; steel reinforcement bars are inserted in the material. When the concrete cracks in tension, the steel bars take over the load. On the other side, the concrete protects the steel bars from environmental attacks and avoids corrosion. The cracks in the concrete, however, are a concern. Here the water and ions join and the degradation of the metal begins with the steel corrosion. To order to increase the structure's resilience, either the cracks that are formed will be fixed later or additional reinforcement will be installed in the structure during the design phase to ensure that the crack width stays within a certain amount. A reliable self-healing concrete process will lead to a new way of constructing long-lasting concrete structures, which would be beneficial to the national and global economies. It is possible to make the "Bacterial Concrete" by embedding bacteria into the concrete that can continuously precipitate calcite. This occurrence is called Microbiologically Induced Calcite Precipitation (MICP).

D. Need of Bacterial Concrete

Concrete is a material that is by far the world’s most widely used building material. Concrete has a high compression load bearing capacity, but the material is low intensity. This is why in order to build buildings; steel reinforcement bars are inserted in the material. When the concrete cracks in tension, the steel bars take over the load. On the other side, the concrete protects the steel bars from environmental attacks and avoids corrosion. The cracks in the concrete, however, are a concern. Here the water and ions join and the degradation of the metal begins with the steel corrosion. To order to increase the structure's resilience, either the cracks that are formed will be fixed later or additional reinforcement will be installed in the structure during the design phase to ensure that the crack width stays within a certain amount. A reliable self-healing concrete process will lead to a new way of constructing long-lasting concrete structures, which would be beneficial to the national and global economies. It is possible to make the "Bacterial Concrete" by embedding bacteria into the concrete that can continuously precipitate calcite. This occurrence is called Microbiologically Induced Calcite Precipitation (MICP).

Because of its wide range of scientific and technological consequences, calcium carbonate precipitation, a common phenomenon among bacteria, has been investigated. The use of bacterial concrete to cause precipitation of CaCO3. The basic principles for this application are that microbial urease hydrolyzes urea to produce ammonia and carbon dioxide, and that the ammonia released in the atmosphere raises pH, causing insoluble CaCO3 to accumulate. In a concrete, the favorable conditions do not exist directly, but must be created. How to establish the ideal environment for bacteria to not only live in concrete, but also to thrive and generate as much calcite as needed to fix cracks and improve the concrete's durability.

With industrial materials such as fly ash, blast furnace slag, silica fume, and metakaolin, ongoing research in the
field of concrete technology has led to the production of special concrete that considers the pace of construction, the strength of concrete, the durability of concrete, and the environmental friendliness of concrete.

Concrete is the mixture of cement, fine aggregate, coarse aggregate and water. It is an excellent building material but it is imperfect because micro cracks form in concrete makes the structure damage. Repair in conventional concrete is time consuming and expensive. Bacterial concrete is one of the solutions to problems in the concrete.

E. Effect of Bacteria on Characteristics of Concrete
   a. Hydration Process
   The expansion of microbes spore powder in concrete either quicken or hinder the setting time of concrete contingent upon the calcium source provided. The supplements to microscopic organisms are provided as calcium lactate, calcium nitrate, and calcium design. The expansion of calcium lactate can impede the setting time, calcium configuration and calcium nitrate can quicken the setting time of concrete.

   b. Compressive Strength
   The strength of the normal concrete has been improved by a Bio-innovative strategy dependent on calcite precipitation. Microbial cells accomplished great sustenance during starting relieving period, as the concrete mortar was porous. Be that as it may, these cells were adjusting to another climate. Because of the high pH of concrete, there is an opportunities for bacterial cells to develop gradually in the underlying time frame and accustoms to high pH conditions in the restoring time frame. During the procedure of cell development, calcite accelerates on surface of the phone and furthermore in the concrete mortar framework, which might be because of the nearness of different particles in the media. This outcomes in less porosity and porousness of the concrete mortar. The progression of supplements and oxygen to the bacterial cells gets halted if a considerable lot of the pores in the network are stopped at once. At the appointed time, the cell either gets dead or transforms into endospores. Along these lines the conduct of expanded compressive strength with microbial cells can be clarified. By presenting Bacillus megaterium microbes of concentration 105 cells/ml in concrete, precipitation of calcite was higher in higher evaluation concrete when contrasted with the lower grade concrete in this way, higher evaluation concrete gives more strength when contrasted with the lower grade concrete. The most extreme advance concrete speed of hardening for the most elevated strength of 50 MPa concrete is as high 24% in strength. Concrete was supplanted with 10% of fly debris and the considerations of 105 cells/ml Bacillus megaterium microorganisms were incorporated. 20% upgrade in compressive strength of auxiliary fly debris concrete was watched, which is because of the testimony of calcium carbonate on cell surfaces of microorganism.

   The compressive strength of the microorganisms added to silica smolder concrete improved because of the precipitation of calcite. Microstructure investigation of concrete utilizing XRD, SEM affirmed that calcium carbonate was available in the concrete. The compressive strength of concrete with bacillus megaterium went with bacillus subtilis microbes (2x10^9 cells/ml) is 20% more than concrete without microscopic organisms as watched for 28 days. The 28 days compressive strength expanded when contrasted with control concrete mortar by fusing the receptive spore powder in concrete mortar. Statement of calcite on the cell surfaces and in the pores of concrete sand framework connects the pores the mortar and causes improvement in the compressive strength by bacillus megaterium gives the subtleties of microorganisms utilized, bacterial focus and the estimations of compressive strength these may change contingent upon the calcium source provided to the microscopic organisms. Although any of the calcite precipitating bacteria has been never utilized in concrete grade above M50.

F. Preparation of Bacterial Concrete
   Bacterial concrete can be made up by two methods,
   1. Direct Application Method
   2. Encapsulation Method

   In the direct application method, bacterial spores and calcium lactate is included into concrete legitimately when mixing of concrete is ongoing. The utilization of this microorganisms and calcium lactate doesn't change the ordinary properties of concrete. At the point when pores are forms in the structure because of evident reasons. The microbes are presented to environmental changes. At the point when water interacts with this microbe, they grow and feed on calcium lactate and creates calcite. Hence fill up the pores.
By encapsulation method the microscopic organisms and its food for example calcium lactate, are put inside rewarded dirt pellets and concrete is readied. About 6% of the earth pellets are included for making bacterial concrete. At the point when solid structures are made with bacterial solid, when the crack happens in the structure and dirt pellets are broken and the microscopic organisms sprout and eat down the calcium lactate and produce calcite, which solidifies and along these fill up the pores.

![Bacterial spores Embedded in Clay Particles](image)

**Fig. 2.** Bacterial Spores Embedded in Clay Particles

G. Advantages and Limitations of Bacterial Concrete

Bacterial concrete is very unique and new approach in construction industry. Bacterial calcite improves the various properties of concrete and it is already being effectively utilized for surface treatment of the concrete. Although it has some downsides as well. Various advantages and limitations of bacterial concrete area as described below:

a. Advantages of Bacterial Concrete
   1. Various advantages of bacterial concrete are as follows:
   2. Self-healing of cracks without adding any external assistant.
   3. Noteworthy increasing in compressive strength and flexural strength compared to normal concrete.
   4. Confrontation towards freeze-thaw attacks.
   5. Decrease in permeability of concrete.
   6. Decrease the corrosion of steel thanks to the cracks formation and improves life span of steel concrete.
   7. Bacillus bacteria are harmless to human life and hence it are often used effectively.
   8. For major structures are that the lifespan is extended and also the structure are significantly improved. This eases the carbon footprint and also the whole cost of structures and also means they're safer.
   9. Self-healing approaches may also reduce costly disruption by reducing the amount and extent of repairs which are mandatory.
   10. Amalgamation of the agent within the concrete are relatively cheap also as easy when the mix is immobilized in porous light weight aggregate before adding to the concrete mix.
   12. Oxygen is a cause that might encourage corrosion, as bacteria feedstuffs on oxygen tendency for the corrosion of reinforcement are frequently decline.
   13. Self-healing bacteria are often employed in places where humans find it difficult to attain for the upkeep of the structures.
   14. Overall maintenance cost of this concrete is low.
   15. Lesser water absorption when put next to traditional concrete.

b. Limitations of Bacterial Concrete

Various limitations of bacterial concrete are as follows:

1. Cost of bacterial concrete is more than conventional concrete. But it is often reducing this cost by developing this method.
2. Design of mix concrete with bacteria isn't available any IS code or other code.
3. Examination of calcite precipitate is costly.
4. Very limited research work is done across the world till now.
5. No substantial commercial applications hence long run reference not available.

H. Research to be done on Bacterial Concrete

Although bacteria are already utilized effectively for surface treatment and crack healing purpose in construction industry still bacterial concrete is very unique and a new approach in construction sector especially when it is directly utilized in concrete mix to increase its various mechanical properties. By referring numerous works done by various researchers in the field of bacterial concrete, it has been observed that when bacteria are added in the concrete its increase the various mechanical property of the concrete. Also, it has been observed that as the concrete grade goes higher than the contribution of bacterial calcite to the concrete's strength also increases. The maximum highest concrete grade of investigation on bacterial concrete was M50. So, there is a scope of check the contribution of bacterial calcite to the concrete’s strength in high strength concrete which is M60 or above. One can performed comparative study by selecting different types of bacteria in the concrete and determine that which bacteria gives maximum increase in the strength and durability parameters of the concrete and most suitable bacteria can be identify for utilizing it in the bacterial concrete. Also one can study the effect of different types of bacterial nutrients on the strength and other parameters of bacterial concrete and determine the suitable type and optimal dosage of bacterial nutrients.

IV. CONCLUSIONS

The following conclusion are based on case study and literature review. From the discussions above, utilization of the eco-friendly bacillus bacteria in the construction industries would help to increase the durability of the structure as well as the compressive strength of the concrete. The compressive strength results also support the use for same in establishing sustainable concrete. Further study required to overcome on the limitations of bacillus bacteria.

More work should be done on the long term effect of bacteria on human life. The concept of to make a durable concrete is still a thing of the future for commercial and residential buildings due to the production cost. As this technology continues to develop in the future, the bacterial concrete could make a huge impact on the construction industry, as well as the environment.

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