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Eco-concrete: Opportunities and Challenges

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Abstract—Concrete is the most commonly used material in building construction, but the cracks in concrete is one of the essential weakness of concrete. So, the goal of this research is to deals with the micro-crack in concrete which occurs due to the low tensile strength under the application of load. This causes settlement, shrinkage and expansion in concrete which leads to the failure of whole structure. These micro-cracks reduce the strength and durability of concrete. In recent time, a self-healing technique is adopted to remediate this problem. In this paper, the study is carried out on bacteria which are based on the self-healing property of concrete by using bacillus species "Bacillus Subtilis". Adding bacteria to the concrete increases the compressive strength and tensile strength of the concrete as compare to the conventional concrete. For remediating cracks and fissures in the concrete bacillus subtilis precipitate calcite ($CaCO_3$) during the process of their metabolic activities. Microbiologically induced calcite precipitation technique comes under the heading of science called as "Bio-Mineralization". This technique also minimizes the adverse effect of CO_2 which causes global warming to the environment during the manufacturing process of cement and conserve energy. Subtilis is non-pathogenic, gram positive bacteria, rod shaped and eco-friendly to the atmosphere. Bacterial concrete is also known as "Eco-concrete".

Keyword*: Bacterial Concrete/Eco-concrete, Bacillus Subtilis, Strength, Durability, Self-healing concrete, $CaCO_3$ precipitation.*

1. INTRODUCTION

Concrete is extremely used building construction material which is reusable. Numerous researches have been performed in the past year on the concrete to make it stronger, durable and eco-friendly. The most common problem in concrete is crack which reduces the strength and durability of the structure. For healing the cracks in concrete many methods has been adopted like filling the crack with epoxy based fillers, latex binding agents etc. Yet, they are expensive, not reconcilable, decreases the aesthetic of the structure and needed continuous maintenance. To overcome come these problems or to remediate cracks in concrete a new technique has been adopted. In this technique, bacteria are used for self-healing of cracks in concrete and also to enhance the compressive strength, flexure strength, tensile strength and durability of concrete. The process of self-healing of crack is done by the metabolic activity of the bacteria in concrete which precipitate calcite($CaCO_3$). The phenomenon of the process is called microbiologically induced calcite precipitation. This technique heals up to 0.2mm crack in concrete.

Fig. 1: Bacterial concrete specimen

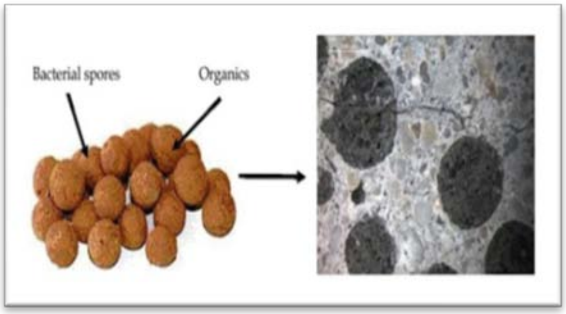


Fig. 2: The self-healing admixture is composed of expanded clay particles (left) which is loaded with bacterial spores and organic bio mineral precursor compound (calcium lactate) when embedded in the concrete matrix (right).

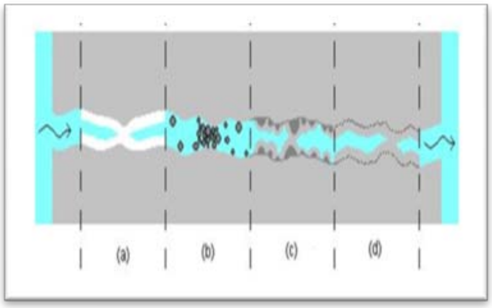


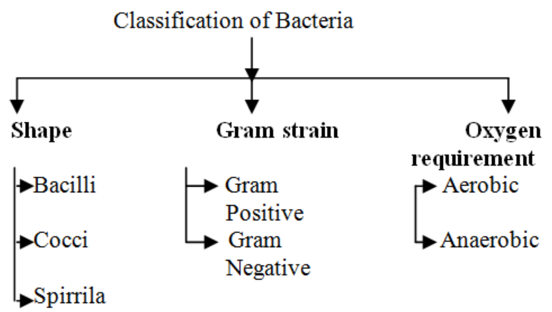
Fig. 3: Possible causes of self-healing are as follows: (a) Formation of calcium carbonate or calcium hydroxide, (b) Sedimentation of particles, (c) Continued hydration, (d) Swelling of the cement matrix.

1.1. Bacteria used in concretes

The various other types of bacteria used in concrete are as follows:

a) Bacillus pasteurii
b) Bacillus sphaericus
c) Escherichia colli
d) Bacillus subtilis
e) Bacillus cohnii
f) Bacillus pseodofirrius
g) Bacillus halodurais

1.2. Classification of Bacteria



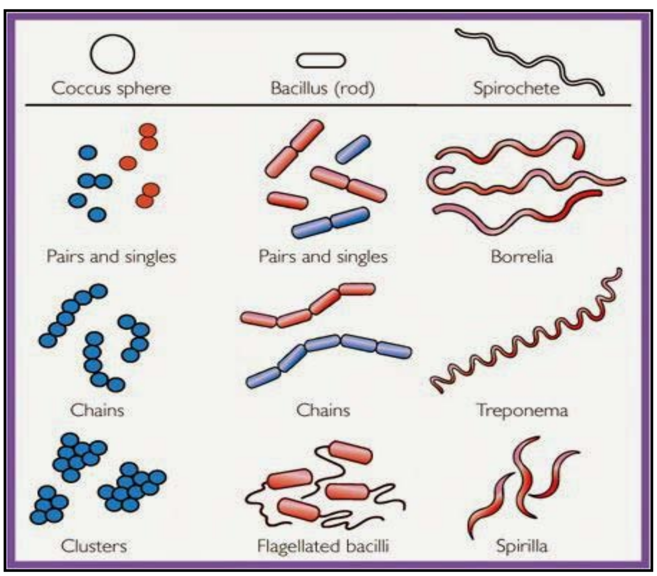


Fig. 4: Bacilli, Cocci and Spirilla

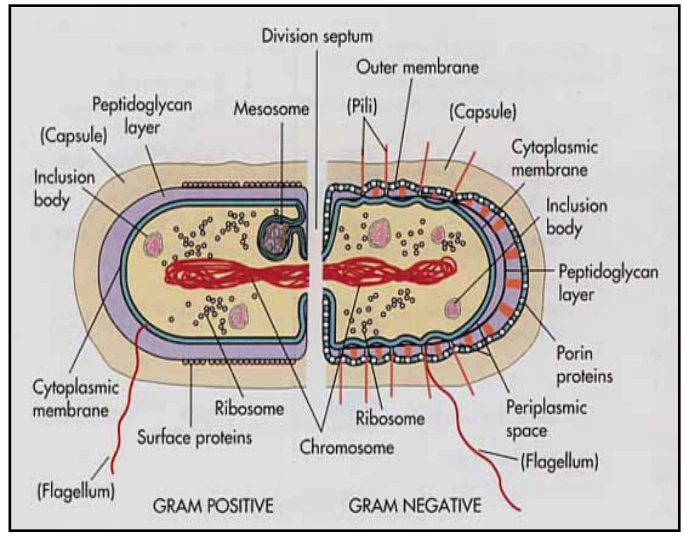


Fig. 5: Gram positive and Gram negative

2. LITERATURE REVIEW

Henk M. Jonkers (2011), have published a paper which gives an overview about the durability of bacterial concrete. This paper shows the self-healing mechanism of crack in concrete. In his paper he came to the conclusion that bacterial concrete is useful in healing the cracks up to sub millimetres (0.15mm size of crack). Bacterial concrete is more advantageous in wet environment and helpful in restraining the corrosion in the steel.

L.Soundariet[3], have published a paper which gives an overview about the experimental study on the strengthening of concrete by practicing with precipitate of bacterial mineral. In his paper the nutrient broth agar and the chemicals are mixed with water and boiled by autoclaving process. The boiled water must be of reddish colour to which appropriate bacterial cell is transferred and the liquid media is shielded by aluminium foil and shake constantly as far as it turns to light yellow colour which reveals the presence of bacillus subtilis. The specimens of concrete is prepared by mixing the coarse aggregate, fine aggregate, cement and appropriate amount of bacterial water in electrically operated mixer. For concrete grade of M25, after the addition of bacteria the percentage increase in the compressive strength ranges from 12.32% to 30.05% at the different days, the percentage increase in the split tensile strength ranges from 13.80% to 18.45% at the different days, the percentage increase in the flexural tensile strength ranges from 13.19% to 15.56% at the different days.

Smitha. M et.al (9), in this paper he gives an overview about the compressive strength and durability of concrete with different concentration of bacteria (10^4, 10^5 and 10^6 cells/ml) to compare with the specimen of M25 grade of concrete to distinguish the optimum concentration. In this the bacteria adopted is Bacillus megaterium. In this the fine aggregate was completely replaced by M-sand. The increase in the compressive strength of concrete at 7 days is 11.30% and at 28 days is 22.58%.

Table 1: Average water absorption of concrete at 28 days

SI. No.	Cell Concentration (Cells/ml)	Water absorption (%)
1	0	1.153
2	104	0.961
3	105	0.576
4	106	0.76

S. Maheswaran et.al(2014), in this paper he shows the comparison between compressive strength of bacillus species Bacillus Cereus and Bacillus pasteuri. In this paper he shows that the compressive strength of Bacillus Cereus is greater than the Bacillus pasteuri and conventional concrete. It is mostly used in marine environment.

3. SELF-HEALING PROCESS TO REMEDIATE CRACKS USING BACTERIAL CONCRETE

The crack in the structure caused due to the application of load through which water penetrate into the crack and damage the structure. The cracks can be filled by using micro-organism which precipitates calcium carbonate ($CaCO_3$). When water enters into the crack the bacteria present in it get activated which heals the crack in concrete by yielding the calcium carbonate precipitation.

The calcium carbonate precipitation is produced

by the equation given below:

$$Ca^{2+} + Cell \rightarrow Cell - Ca^{2+}$$

$$Cell - Ca^{2+} + CO_3^{2+} \rightarrow Cell - CaCO_3 \downarrow$$

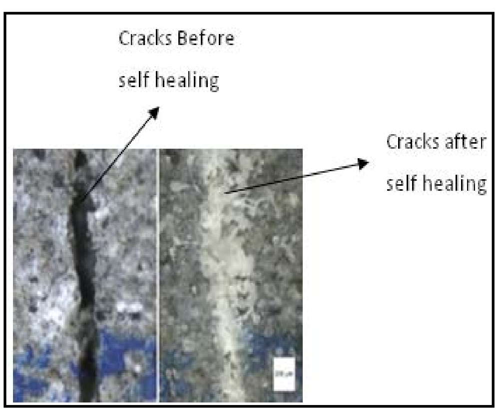


Fig. 6: Healing of cracks

4. MATERIAL AND METHODOLOGY

4.1 Material

Materials used are as follows:

1. **Cement:** The type of cement which is used in the investigation is Ordinary Portland Cement of 53 grade which is easily available in local market.
2. **Coarse Aggregate:** 20mm size of coarse aggregate is used.
3. **Fine Aggregate:** Fine aggregate which is used in investigation is Natural river sand.
4. **Water:** Normal water as specified in IS 456-2000 is used.
5. **Bacteria:** Bacillus Subtilis is used which can be cultured in laboratory.

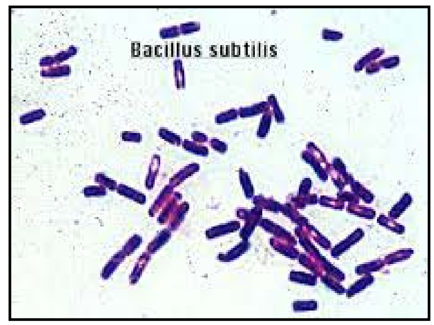


Fig. 7: Bacillus Subtilis

Table 2: Characteristics of Bacillus Subtilis

Characteristics	Bacillus Subtilis
Shape, size, gram strain	Long rods, 2.0 to 3.0 µm in length and 0.6 to 0.8 µm in width gram positive
Colony morphology (on nutrient agar plate)	Irregular, dry, white, opaque colonies
Dextrose	No acid, no gas
Sucrose	No acids, no gas
H2S production	Acids and gas
Nitrate reduction	-
Indole production	-
Starch hydrolysis	+
Gelatin liquefaction	+

4.2. Methodology:

4.2.2. Preparation of Bacterial Concrete

Bacteria are added to the concrete in suspension form at the time of mixing. Bacillus subtilis have the capability to withstand in unfavourable environment of concrete. Thick cell membrane of bacillus subtilis is used to give better resistance against high pH. Accordingly to this, the bacillus genus bacteria can remain in concrete for up to 200 years as far as it gets the appropriate environment. As the crack appears on the concrete surface water and air enters into the structure which decreases the pH of concrete environment and activate the bacteria. A peptone based nutrient is equipped along with bacterial content which helps in enlarging the production of calcite precipitate.

4.2.3. Culturing and Maintenance of Bacteria

The pure culture is to be maintained constantly on nutrient agar slant and is taken from soil sample. After this, the bacteria cultivate the irregular dry white colonies on the nutrient agar. Whenever there is the requirement of a single colony of the culture it has to be inoculated into the nutrient broth of 200ml in 500ml conical flask and the condition of the growth is maintained at $37°C$ temperature and is placed in the 125rpm orbital shaker. For the growth of culture the required medium composition are Peptone, NaCl and Yeast extract.

Fig. 8: Cultured Bacteria

After 2 to 3 days of growth, slant culture has to be cured under refrigerator ($4°C$) for further use. The Sub culturing has to be performed for every 90 days. Contamination from other bacteria was analyzed repeatedly by streaking on the nutrient agar plates.

5. TEST ON BACTERIAL CONCRETE

a) Compressive strength and tensile strength: Compressive strength of concrete mix of M30 grade with and without addition of bacteria is performed by using compression testing machine at 7 days, 28 days and 56 days. The split tensile strength with bacteria is performed at 28 days.

b) Durability assessment: An experiment is performed on M30 grade concrete cubes of size $150mm * 150mm * 150mm$ with and without the addition of bacteria. For Acid Durability Tests the specimens were immersed in 5% solution of H_2SO_4, for Chloride Test 5% solution of$NaCl$ and for Water Absorption Test in distilled water.

c) Scanning Electron Microscopy (SEM): The deposition of calcite by bacteria in micro cracks of concrete is determined by using SEM.

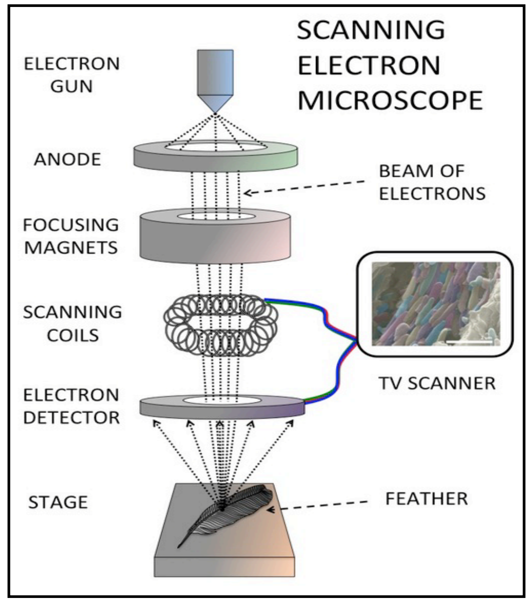


Fig. 10: Scanning Electron Microscopy (SEM)

6. APPLICATIONS OF BACTERIAL CONCRETE IN CONSTRUCTION AREA

The following application of bacterial concrete are as follows:

1. For the improvement in the sand properties bacteria enhanced the durability of cementations material.
2. Helps in repairing of limestone monuments.
3. In sealing of cracks in concrete to highly durable bricks.
4. Used for low cost durable roads.
5. For high strength buildings with increased bearing capacity.
6. Used for long lasting river banks.
7. To prevent loose sands from erosion.
8. In the construction of low cost durable housing.
9) It helps in reduction of permeability by which freezing process is decreased.

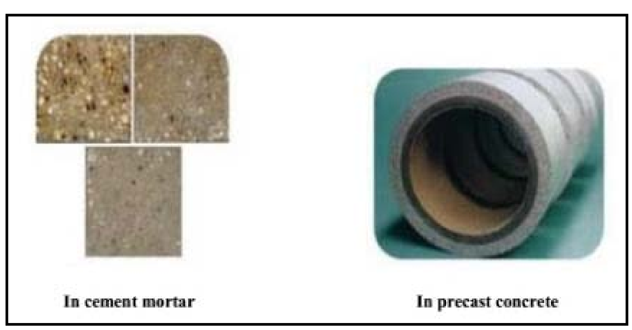


Fig. 11: Applications of bacterial concrete in the construction area

7. ADVANTAGES

1. Bacterial concrete remediates cracks quickly.
2. Compressive strength of concrete is improved.
3. Provides better resistance against freeze-thaw attack.
4. Reduces the corrosion in reinforced concrete.
5. Reduces the permeability of concrete.
6. It can be applicable in spray form to existing buildings.
7. Repair and maintenance cost is low.
8. Gives good aesthetic appearance to the structure.
9. Bacterial concrete is pollution free, eco-friendly and natural.
10. Enhanced the durability of concrete.

8. DISADVANTAGES

1. As compare to the conventional concrete the cost of the bacterial concrete is more.
2. In any atmosphere and media the growth of bacteria is not good.
3. The design of concrete mix with bacteria is not present in any IS codes.
4. The study of calcite precipitation is very costly.

9. LIMITATIONS

There are following limitations of bacterial concrete, they are as follows:

1. The eco-concrete has less resistance to the chemical attacks.
2. The eco-concrete offers less resistance to the fire accidents.

10. FUTURE SCOPE

The scope of the bacterial concrete in future are as follows:

a) In the construction of bridges, aircraft runways and dam reducing the maintenance cost.
b) In the construction of retaining wall.
c) In the construction of rigid pavement.
d) Use of rice husk ash with bacterial concrete.
e) Use of lime surki mortar with bacterial concrete.

11. RESULT AND DISCUSSION

According to the previous research which has been done in the last few years, shows the significant results when the specimens are tested with and without bacteria at 7 days, 14 days and 28 days for M25 grade of concrete.

Table 3: Compressive Strength Test

No. of Days	Conventional Concrete N/mm^2	Bacterial Concrete N/mm^2
7	21.52	24.17
14	25.36	30.05
28	32.24	41.93

Table 4: Split Tensile Strength Test

No. of Days	Conventional Concrete N/mm^2	Bacterial Concrete N/mm^2
7	2.78	3.16
14	3.62	4.14
28	3.85	4.56

Table 5: Flexural Tensile Strength Test

No. of Days	Conventional Concrete N/mm^2	Bacterial Concrete N/mm^2
7	2.88	3.26
14	3.73	4.28
28	3.92	4.53

12. CONCLUSION

The paper concluded that the use of bacteria in concrete increases the compressive strength and tensile strength with decrease in the permeability, water absorption and corrosion in reinforcement as compared to the conventional concrete. Bacterial concrete influences the durability characteristic of the structure by filling the cracks in the structure. Due the ability of continuously precipitating calcite bacterial concrete is also called as "Bio material". It can be easily produced in the laboratory which proved to be safe and cost effective. Bacterial concrete is eco-friendly in nature for the atmosphere. Bacterial concrete is convenient to use because it is more effective from economical and practical point of views.

13. ACKNOWLEDGEMEN

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