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Microbes: A Remedy for Micro Cracks of Concrete

Avinash Tupe[1], Hari Thombre[2], Atif Baig Mirza[3], Prof. Dipa Dudhani[4]

[1,2,3]Student, Department of Biotechnology, Yashwantrao Chavan College, Sillod Dist. Aurangabad (M.H)

[4]Professor, Department of Biotechnology, Yashwantrao Chavan College, Sillod Dist. Aurangabad (M.H)

Abstract

Crack formation is a very common phenomenon in concrete structures, which allows the entry of water and different type of chemicals into the concrete through the cracks and decreases their durability, strength and, which also affect the reinforcement when it comes in contact with water, CO_2 and other chemicals. For repairing the cracks developed in the concrete, it requires regular maintenance and special type of treatment which will be very expansive. To overcome this problem autonomous self-healing mechanism is introduced in the concrete cracks which helps to repair the cracks by producing calcium carbonate crystals that fills the micro cracks and pores in the concrete. During the present investigation *Bacillus megaterium* is identified for alkaline environment based on their survival.[1][2][3][4]

Keywords: Concrete, *Bacillus megaterium*, Bio-cement, $CaCO_3$ precipitation.

Introduction

Concrete:

A building material made from a mixture of broken stone or gravel, sand, cement, and water, which can be spread or poured into mould and forms a mass resembling stone on hardening which is called as Concrete.

When aggregate is mixed together with dry Portland cement and water, the mixture forms a fluid slurry that is easily poured and molded into shape. The cement reacts chemically with the water and other ingredients to form a hard matrix that binds the materials together into a durable stone-like material that has many uses.[2][4]

There are three basic ingredients in the concrete mix: Portland Cement, Water and Aggregates (rock and sand)

1. **Portland Cement -** The cement and water form a paste that coats the aggregate and sand in the mix. The paste hardens and binds the aggregates and sand together.
2. **Water -** Water is needed to chemically react with the cement (hydration) and to provide workability with the concrete. The amount of water in the mix in pounds compared with the amount of cement is called the water/cement ratio. The lower the w/c ratio, the stronger the concrete (higher strength, less permeability). Water is mixed with the dry powder and aggregate, which produces a semi-liquid slurry that can be shaped, typically by pouring it into a form. The concrete solidifies and hardens through a chemical process called hydration. The water reacts with the cement, which bonds the oth-

er components together, creating a robust stone-like material.

3. **Aggregates-** Sand is the fine aggregate. Gravel or crushed stone is the coarse aggregate in most mixes. The paste, composed of Portland cement and water, coats the surface of the fine (small) and coarse (larger) aggregates. Through a chemical reaction called hydration, the paste hardens and gains strength to form the rock-like mass known as concrete.

Micro crack in concrete:

Concrete is very good material to resist the compressive load to a limit but if the load applied on the concrete is more than their limit of resisting load, it causes the strength reduction of concrete by producing the cracks in the concrete.

Microcracking in concrete is very important issue which is formed in microstructure. The causes of microcracking are manifolds; in simple word, the main causes are:

- Large variation in mechanical properties of constituents (specially hydrated cement paste and coarse aggregate)
- Thermal and shrinkage movement

The first one is the main cause; as this cracking is formed at interface between mortar and embedded aggregate. When failure is initiated the cracking pattern follows this interface. This zone is known as interface zone, sometimes also called transition zone. [1][3][4]

Solution to repair micro crack:

The self-healing ability of concrete has been improved by the incorporation of bacteria, which can induce calcium carbonate precipitation through their metabolic activity. These precipitates can build up and form an effective seal against crack related water ingress.

As regular manual maintenance and repair of concrete constructions is costly and, in some cases, not at all possible, inclusion of an autonomous self-healing repair mechanism would be highly beneficial as it could both reduce maintenance and increase material durability.

The mechanism of crack healing in bacterial concrete presumably occurs through metabolic conversion of calcium lactate to calcium carbonate what results in crack-sealing. [2][3]

How these cracks are repair by Microbes:

The actual capacity of micro crack healing appears primarily related to the composition of the concrete mixtures. Autogenous self-healing of cracks in traditional but also high-binder content mixtures appear limited to cracks. One possible mechanism is currently being investigated and developed in several laboratories, i.e. a technique based on the application of mineral-producing bacteria. E.g. efficient sealing of surface cracks by mineral precipitation was observed when bacteria-based mixtures were sprayed or applied onto damaged surfaces or manually inserted into cracks as in those studies bacteria were manually and externally applied to existing structures, this mode of repair cannot be categorized as truly self-healing. In one study spores of specific alkali-resistant bacteria related to the genus Bacillus were added to the concrete mixture as self-healing agent. These spores germinated after activation by crack ingress water and produced copious amounts of crack-filling calcium carbonate-based minerals through conversion of precursor organic compounds which were also purposely added to the concrete mixture.

The principle mechanism of bacterial crack healing is that the bacteria themselves act largely as a catalyst, and transform a precursor compound to a suitable filler material. The newly produced compounds such as calcium carbonate-based mineral precipitates should than act as a type of bio-cement what effectively seals newly formed cracks. Thus, for effective self-healing, both bacteria and a bio-cement precursor compound should be integrated in the material matrix. [6][7][8]

- **Reaction:**

$$CO(NH_2)_2 + H_2O\ NH_2 \longrightarrow COOH + NH_3 \quad (1)$$

$$NH_2COOH + H_2O \longrightarrow NH_3 + H_2CO_3 \quad (2)$$

$$H_2CO_3 \longleftrightarrow HCO_3^{-} + H^{-} \quad (3)$$

$$2NH_3 + 2H_2O \longleftrightarrow 2NH_4^{-} + 2OH^{-} \quad (4)$$

$$HCO_3^{-} + H^{+} + 2NH_4^{+} + 2OH^{-} \longleftrightarrow CO_3^{2-} + 2NH_4^{+} + 2H_2O \quad (5)$$

Since the cell wall of the bacteria is negatively charged, the bacteria draw cations from the environment, including Ca_2^{+}, to deposit on their cell surface. The Ca_2^{+}-ions subsequently react with the CO_3^{2-}-ions, leading to the precipitation of $CaCO_3$ at the cell surface that serves as a nucleation site {Eq. (6) and Eq. (7)}.

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

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

Bacillus Megaterium:

Bacillus megaterium is a rod-like, Gram-positive, mainly aerobic spore forming bacterium found in widely diverse habitats. With a cell length of up to 4 µm and a diameter of 1.5 µm. *B. megaterium* is amongst the biggest known bacteria. The cells often occur in pairs and chains, where the cells are joined together by polysaccharides on the cell walls. *B. megaterium* grows at temperatures from 3 °C to 45 °C, with the optimum around 30 °C.

We have selected *Bacillus megaterium* since these bacteria produces Calcium carbonate. It is also formally known as “Hay Bacillus” of grass Bacillus, a Gram positive, catalase-positive bacterium, found in soil and the gastrointestinal tract of ruminants and humans. A member of the genus Bacillus, *Bacillus megaterium* is rod-shaped, and can form although, protective endo-spores, allowing it to tolerate extreme environmental condition. [5][9]

MATERIALS AND METHOD

MATERIALS:

The materials and methods used during this study are elaborated under the following heads.

1. Aggregate: Small Aggregate, Beaker, Conical flask, cotton, Hand gloves, Perti plates, Pippete, pH meter, Rubber band, spreader, Test tubes, etc.

2. Cement: Raw material used in the Portland cement manufacturing (Percentage Composition)

Raw material	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO
Limestone	52	3	1	0.5	0.5
Chalk	54	1	0.5	0.2	0.3
Cement rock	43	11	3	1	2
Clay	1	57	16	7	1
Slag	42	34	15	1	4

3. Nutrient Agar: The Composition of Nutrient Agar for gram per liter is Peptic digest of animal tissue (5.00gm), Sodium chloride (5.00gm), Beef extract (1.50gm), Yeast extract (1.50gm).

4. Sand: The local Maharashtrian River sand.

METHOD:

1. Isolation of *Bacillus megaterium*

The Bacterial colonies were isolated by serial dilution and platting technique. One gram of garden soil was separately suspended in 10 ml of distilled water and mixed well for 15 minutes and vortexed. Each suspension was serially diluted from 10^{-1} to 10^{-6}. 0.1ml each was pipette out and spreaded on agar plates. Incubated the plates at 30^0 C for 48 hrs. [5]

2. Concrete model Preparation

a. Cement: Ordinary Portland cement of 53 grade available in local market is used in the investigation.

b. Sand: In our investigation we used local Maharashtrian River sand.

c. Coarse Aggregate- The coarse aggregate is strongest and porous component of concrete. Presence of coarse aggregate reduces the drying shrinking and other dimensional changes occurring on account of movement of moisture. In our investigation we had used the aggregate passing through 20mm IS-sieve and retaining on 12.5 mm sieve.

- All the necessary requirements were collected to prepare concrete model i.e. Aggregate, sand, cement in 2:4:4 proportion respectively. By adding water mixed it well and by using that mixture cube were prepared as model and small cracks were made on the model.[6]

Fig.no.1. Concrete model

3. Inoculation of culture on concrete model

The isolated bacteria i.e. *Bacillus megaterium* are sub-cultured in nutrient broth. After the growth was observed as turbid solution the culture was inoculated on model

4. Incubation of concrete model with bacteria

The model was incubated after the adding of culture to it for 17 days, during incubation water was supplied to it after every 24 hrs.

RESULTS AND DISCUSSION

1. Identification of isolated bacteria

Bacterial colonies were observed in plates no. 10^{-3}, 10^{-4} and 10^{-5}. It was appeared white and shiny colonies. Isolated Bacteria were belonging to the *Bacillus Megaterium* which were identified by performing the characterizations and confirmational tests.[5][9]

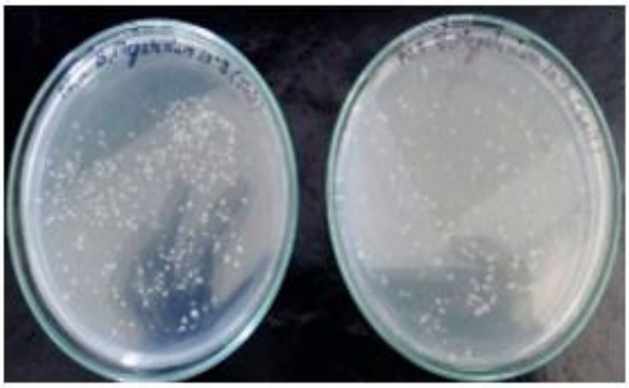

Fig.no.2. Isolated Bacillus megaterium plates

Biochemical tests

1. Catalase Test

A small amount of bacterial colony transferred to a surface of clean and placed a drop of 3% H_2O_2 on to the slide and mixed. A positive result is observed on the slide as evidenced by bubbling. [9]

Fig.no.3. Positive -Catalase test

2. Starch Hydrolysis test

24 hours incubated plates of starch agar with pure culture of bacteria. Iodine reagent is then added to flood the growth. Presence of clear halos surrounding colonies is positive for their ability to digest the starch and thus indicates presence of alpha-amylase. [9]

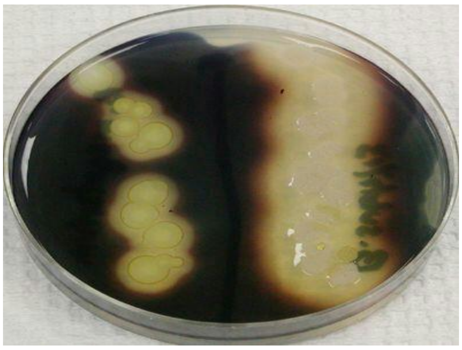

Fig.no.4. Positive -Starch hydrolysis test

3. Gram staining

When bacteria stained with Gram stain, *Bacillus megaterium* appears purple because it is a Gram-positive bacterium.

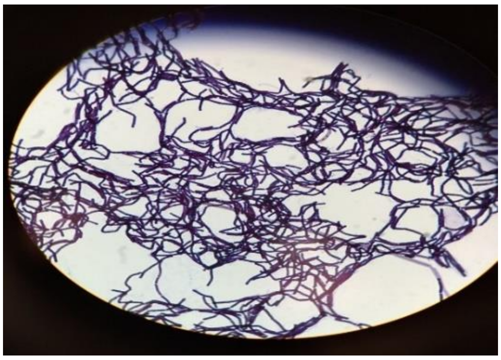

Fig no.5. microscopic view of Bacillus Megaterium

4. Activity of microorganism on Concrete model after incubation

Prepared concrete model containing isolated culture i.e. *Bacillus megaterium*, before bacterial incubation cracks were measure about 2 mm, whereas after 17 days of incubation cracks were appeared in narrow in shape approximately 1 mm, because bacteria produce calcium carbonate crystals to block crack. therefore, it shows that introducing bacteria has a property of crack healing.[3][6][7][8]

17 days of Incubation →

Fig no.6. Concrete before inoculation of culture (crack size- 2 mm)

Fig no.7. Concrete after inoculation of culture (crack size- 1 mm)

This is the first to detect and isolate pure culture of *Bacillus megaterium*. The newly isolated pure culture of bacteria inoculated on concrete and incubated with it, which can show the healing activity towards concrete. Further study on bio-cementing property of more microbes, how we can commercialize it? The Plant based; study also light up the possibility of milestone.

CONCLUSION

Introducing the bacteria into the concrete makes it very beneficial to improves the property of the concrete which is more than the conventional concrete. Bacteria repair the crack in concrete by producing the calcium carbonate crystal which block the cracks and repair it.

APPLICATION

Why the need?

Concrete will continue to be the most important building material for infrastructure but most concrete structures are prone to cracking. Tiny cracks on the surface of the concrete make the whole structure vulnerable because water seeps in to degrade the concrete and corrode the steel reinforcement, greatly reducing the lifespan of a structure. Concrete can withstand compressive forces very well but not tensile forces. When it is subjected to tension it starts to crack, which is why it is reinforced with steel; to withstand the tensile forces. Structures built in a high-water environment, such as underground basements and marine structures, are particularly vulnerable to corrosion of steel reinforcement. Motorway bridges are also vulnerable because salts used to de-ice the roads penetrate into the cracks in the structures and can accelerate the corrosion of steel reinforcement. In many civil structures tensile forces can lead to cracks and these can occur relatively soon after the structure is built. Repair of conventional concrete structures usually involves applying a concrete mortar which is bonded to the damaged surface. Sometimes, the mortar needs to be keyed into the existing structure with metal pins to ensure that it does not fall away. Repairs can be particularly time consuming and expensive because it is often very difficult to gain access to the structure to make repairs, especially if they are underground or at.

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