Assessing the Properties of Bacterial Concrete

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Abstract

Concrete is made up of a mixture of broken stone or gravel, sand, cement, and water, which can be spread or poured into moulds and once it gets hardened it form a stone like mass. In today's time it is widely used in construction as it is cheap, easily available, easy to cast and maintenance cost is negligible. It makes an application in residential, commercial as well as in industrial construction project. It possess a very high compressive strength but is extremely poor in tensile strength .It cannot handle tensions at all and develop cracks and fissures when load is applied beyond its limit. These cracks provides way for water along with other dissolved salts to enter the concrete which makes an entire structure prone to corrosion and further leads to failure. To treat this type of failure due to cracks and fissures, a new method of inducing bacteria in concrete has evolved in recent years. This method introduces the calcite precipitating spore forming bacteria in concrete which increases its performance. When water enter through cracks, it reacts with bacteria and forms precipitates of calcium carbonate, as a by-product, which fills up the cracks and makes a crack free concrete .This type of concrete prepared with bacteria is called as Bacterial Concrete also called self-healing concrete.

Keywords: Bacteria, Calcite precipitating, self-healing.

1. Introduction

Cement concrete is one of the most widely used materials for construction works in the field of civil engineering. It has a large capacity to bear compressive load, but it is weak in tension. Because of this steel reinforcement is provided and the steel bars take over the load when the concrete cracks in tension. But the cracks in the concrete pose a problem. If water seeps through these cracks then it can damage the steel reinforcement present in the concrete member. When this phenomenon occurs, the strength of the concrete decreases which results in the decay of structure. Synthetic materials like epoxies are used to treat, but they are costly and need frequent maintenance. Using chemicals also cause damage to the environment. Therefore, the need for an environment friendly and effective alternate crack treatment technique leads to the development of using self-healing method in concrete. In this we introduce calcite precipitating bacteria to concrete in certain concentrations so that the bacteria will precipitate calcium carbonate when it comes in contact with water and this precipitate will heal the cracks.

2. Materials and Methods

2.1. What is the need of bacterial concrete?

Since we know the nature of concrete, it is excellent in bearing compressive load and highly poor in taking tension. To make it strong in taking tension, steel bars are implanted in material. Steel increases its capacity to take tensile load and on the other hand concrete protects the reinforcement from external environmental conditions. However, cracks still develop in concrete which paves way for water and other chemicals to enter concrete. The traditional method to keep crack width within limit is to provide extra steel so that structure remains durable or cement mortar is applied on cracks to keep the surface damage free .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 perform repair works especially if they are underground or at a great height. Other reasons are water tightness of structure, loss of stiffness and aesthetic reasons. Therefore, we need a method which could automatically repair cracks. This could be made possible by infusing bacteria into the concrete called as bacterial concrete or self-healing concrete.

2.2. Choosing correct bacteria.

Cement and water have a pH value of up to 13 when mixed together, usually hostile environment for life. Most organisms die in an environment with a pH value of 10 and above. So, it is essential to find bacteria capable of surviving an extreme alkaline environment. Also the bacteria selected should be thermophilic, because during hydration process of cement large amount of heat is developed. Strains of the bacteria genus Bacillus were found to thrive in this high alkaline environment. The only group of bacteria that were able to survive were the ones that produced spores. Spores have extremely thick cell walls that enable them to remain intact for up to 200 years while waiting for a better environment to germinate. Bacillus is the only group of bacteria's that are able to survive this high alkaline environment. It was discovered that calcium lactate was a carbon source that provides biomass. If it starts to dissolve during the mixing process, calcium lactate does not interfere with the setting time of the concrete. Some of the bacteria which come under Bacillus genus are:-

Bacillus Subtilis
Bacillus Spharecius
Bacillus Pasteurii
Bacillus Pseudofirmus

2.3. How do bacteria work?

Self-healing concrete (bacterial concrete) is a product that will biologically produce limestone to heal cracks that appear on the surface of concrete structures .Specially selected types of the bacteria along with calcium based nutrient known as calcium lactate is added to the ingredients of the concrete when it is being mixed. These self-healing agents can lie dormant within the concrete for up to 200 years. However, when a concrete structure is damaged and water starts to seep through the cracks that appear in the concrete, the spores of the bacteria germinate on contact with the water and nutrients. Under favourable conditions, Bacillus bacteria in concrete continuously precipitate a new highly impermeable calcite layer over the surface of the already existing concrete layer. Calcite has a coarse crystalline structure that readily adheres to surfaces in the form of scales .In addition to the ability to continuously grow upon itself; it is highly insoluble in water. Cracks in concrete significantly influence the durability characteristics of the structure. The bacterial remediation technique can be used for repairing structures of historical importance to preserve the aesthetics value.

2.4. Mechanism of Production of Calcite (CaCO3)

In natural environments, chemical CaCO3 precipitation accompanied by biological processes, both of which often occur simultaneously or sequentially. This microbiologically induced calcium carbonate precipitation (MICP) comprises of a series of complex biochemical reactions. As part of metabolism, bacteria produce urease, which catalyses urea to carbonate and ammonium, resulting in an increase of pH and carbonate concentration in bacterial environment .These compounds further hydrolyses to ammonia and carbonic acid that leads to the formation of bicarbonate.

Finally calcite is precipitated over the cell surface.

REACTIONS:

$$CO(NH_2)_2 + H_2O \longrightarrow NH_2COOH + NH_3 \quad (1)$$

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

$$NH^{+}\ 2H_2O \longrightarrow NH^{4+} + 2OH^{-} \quad (3)$$

$$2OH^{-} + H_2CO_3 \longrightarrow CO_3^{\ 2-} + H_2O \quad (4)$$

$$Ca^{2+} + cell \longrightarrow cell\text{-}\ Ca^{2+} \quad (5)$$

$$Cell^{-}\ Ca^{\ 2+} + CO_3^{2-} \longrightarrow cell\text{-}\ CaCO_3 \quad (6)$$

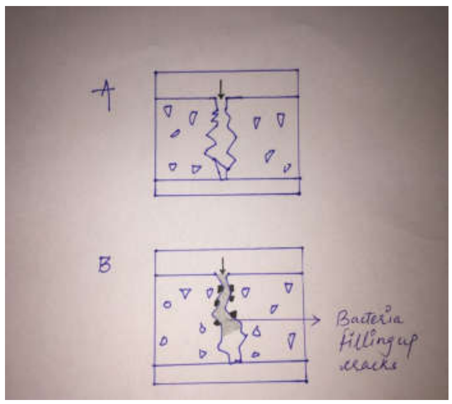

Figure 1. Self-healing process

In A, water enters into a micro cracks activating the embedded bacterial spores. In B, the active bacteria seal the cracks with the production of limestone, protecting the embedded steel.

2.5. Bacteria Used

2.5.1. Bacillus Subtilis

Originally named Vibrio subtilis in 1835 and was renamed Bacillus subtilis in 1872.

Bacillus Subtilis bacteria were one of the first bacteria to be studied. These are naturally found in soil and water and are rod shaped. The optimal temperature is 25-45^{o} c. Stress and starvation is common in this environment, therefore, Bacillus subtilis can survival under these harsh conditions due to its spore forming tendency which makes it stress-resistance.

Bacillus subtilis can also gain protection more quickly against many stress situations such as acidic, alkaline, osmotic and heat.

Bacillus subtilis bacteria are non-pathogenic. It is used as a fungicide and fortunately it does not affect humans

Figure2 .Bacillus Subtilis

Figure 3. Rod Shape Bacillus under Microscope

3. Experimental Study

Bacillus Subtilis is the major microbe producing bacteria used in the experiment and results were compared with conventional concrete.

3.1. Materials used

- Cement

  Ordinary Portland cement of 53 grade available in local market is used. The cement used has been tested for various properties as per IS: 4031-1988 and found to be confirming various specifications of IS: 12269-1987 .
- Coarse aggregate

  Locally available crushed granite angular aggregate of size 20mm and 10mm were used having specific gravity 2.89 and 2.82 respectively
- Fine aggregate

  natural sand river is used of specific gravity 2.67
- Water

  Locally available portable water confirming to IS 456 is used.
- Microorganism

  Bacillus Subtilis .

- Water-cement ratio 0.47

3.2. Test Procedure

Mix design can be defined as the process of selecting suitable ingredients of concrete and determining their relative proportions with the object of producing concrete of certain minimum strength and durability as economically as possible.

The mix design of grades M25 is carried out to achieve specified age, workability of fresh concrete and durability requirements by using IS 10262-2009.

Calculated quantity of Sand and cement was mixed in electrically operated concrete mixer and different percentage of water was replaced with bacillus subtilis bacteria.A conventional concrete cube and beam of M-25 grade was casted and a bacterial concrete cube and beam in which water was replaced at different percentage 5%,10%,20% and 25% by bacteria Subtilis.

Standard cubes of size 150mm × 150mm × 150mm and beams of dimension 700mm x 150mm x 150mm were casted and compacted using vibration machine. All the specimens were cured in water. The compressive strength test,flexural strength test and non destructive test (ultrasonic pulse velocity)of conventional and bacterial concrete was determined at 28 days.A comparative study was done between the conventional and bacterial concrete based on these tests.

3.3 Test Performed on Fresh Concrete

3.3.1 Slump Cone Test

This is the simplest test performed to find the workability of fresh concrete. Fresh concrete is that stage of concrete in which concrete can be moulded and is in plastic state. Workability is defined as an ease by which concrete can be placed, transported and compacted. Workability of concrete depends very much on compaction rate.

Mould for slump test consist of non- porous base plate, measuring scale, tamping rod. The mould for the test is in the form of the frustum of a cone having height 30 cm open at both the ends.

The bottom diameter is 20 cm and top diameter is 10 cm. The tamping rod is of steel 16 mm diameter and 60cm long and rounded at one end.

3.4 Test Performed on Hardened Concrete.

3.4.1. Compressive Strength Test

Compressive strength test is a mechanical test which measures the maximum amount of compressive load a material can bear before fracturing. The test piece is in the form of a cube, prism, or cylinder and is compressed between the plates of a compression-testing machine by a gradually applied load. The mould should be made of metal or cast iron, with sufficient plate thickness to prevent spreading or warping. The testing machine may be of sufficient capacity for the testing and rate of loading as specified.

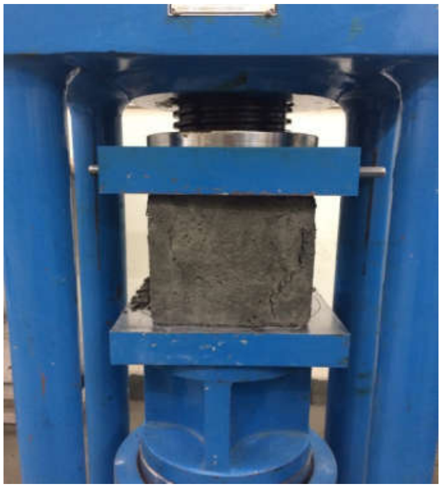

Figure 4. Compressive test on Bacterial Concrete

3.4.2. Ultrasonic Pulse Velocity Test

This comes under a non-destructive test which is performed to check the strength durability of structure without demolishing it. It works on a principle of reflection and refraction just as light wave. If there are certain discontinuities present in specimen it will detect and locate the flaws. Therefore it is used to detect uniformity, cavities, cracks and other defects in concrete. It tells us about the quality of concrete and severity of deterioration in structure. The equipment consists of transducer, a receiver and an indicator which shows the time of travel from transducer to receiver.

Figure 5. Ultrasonic Pulse Velocity Equipment

3.4.3. Flexural Test

Flexural testing is used to determine the bending properties of a material. flexure test is more affordable than a tensile test the material is laid horizontally over two points of contact (lower support span) and then a force is applied to the top of the material through either one or two points of contact (upper loading span) until the sample fails. The maximum recorded force is the flexural strength of that particular sample.

Figure 6. Flexural testing Machine

4. Results and Discussions

4.1. Compressive strength

A comparative study was done between conventional concrete and bacterial concrete and following results were obtained.

Table no.1 Results for compressive strength and workability

S.no	Grade	% of Bacteria	Compressive strength in 28 days in KN	Workability (mm)
1	M-25	0	829	30
2	M-25	5	1040	25
3	M-25	10	683	20
4	M-25	20	500	20
5	M-25	25	410	15

It is observed by experimental studies that there is significant increase in compressive strength when water is replaced by 5% bacteria as compared to convention concrete whose.

After replacing more water by bacteria the compressive strength declines as compared to conventional concrete.

4.2. Ultrasonic Pulse Velocity (Non-Destructive Test)

Ultrasonic test was performed on each percentage of Bacterial concrete as well as on conventional concrete. If reading is in Between 3-3.50 – Medium

Above 3.50-4.50 – good

Above 4.50 - Excellent

Table no.2 Results for Non-Destructive Test

S.no.	Grade	% of bacteria	Ultrasonic reading	Remark
1	M-25	0	4.45	Good
2	M-25	5	4.54	Excellent
3	M-25	10	4.36	Good
4	M-25	20	4.32	Good
5	M-25	25	4.11	good

It is observed that in non- destructive test it showed an excellent result at 5% water replacement with bacteria.

4.3 Flexural Strength Test

Table no. 3 Results for Flexural Strength

S.no	Grade	% of Bacteria	Flexural Strength (KN)
1	M-25	0	34
2	M-25	5	44
3	M-25	10	37
4	M-25	20	34
5	M-25	25	38

5. Conclusion

The experimental studies showed a high compressive strength, high flexural strength and high ultrasonic pulse velocity value at 5% replacement of water by bacteria Bacillus Subtilis after 28 days. It can be concluded that by adding a small amount of bacteria, it acts like an admixture and increases a significant amount of compressive and flexural strength. The concrete-incorporated bacterium can produce copious amounts of minerals which can potentially seal freshly formed cracks and therefore it justifies been called as self-healing concrete. Also it is environmental friendly hence there are no chances of pollution.

The only drawback is its cost when used in large scale but can prove to be economical if produced on large scale in industries and if it finds a place in Indian standard code provision.

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