Experimental Evaluation of Self-Healing Concrete's Performance Properties

[1]Mr Shashank P, [2]Mrs Jyothi D N, [3]Mr Rudresh A N, [4]Mrs Bharathi B

[1]Assistant Professor, Department of Civil Engineering, ATMECE, Mysuru, Karnataka
[2]Assistant Professor, Department of Civil Engineering, ATMECE, Mysuru, Karnataka
[3]Assistant Professor, Department of Civil Engineering, ATMECE, Mysuru, Karnataka
[4]Assistant Professor, Department of Civil Engineering, ATMECE, Mysuru, Karnataka

Abstract: Due of its resilience, toughness, and affordability relative to other construction materials, concrete is the most commonly utilized engineering material in construction. Concrete's main flaw is that it has a low tensile strength, which makes microcracks more likely to form and spread, resulting in weaker construction. These tensile stresses may result from expanding chemical reactions, plastic shrinkage, or tensile loading. Concrete becomes more susceptible to harmful environmental factors due to its higher propensity for cracking, which also reduces strength. The entry of toxic substances through these fissures may cause concrete to deteriorate chemically and may also cause steel reinforcing to corrode. This corrosion causes fracture damage to increase, which reduces the strength and stiffness of concrete buildings. The deterioration of reinforced concrete results in significant maintenance costs for both the concrete and the reinforcement. The goal of the current study is to create a self-healing concrete that, upon setting, repairs cracks caused by a variety of factors, reducing the need to find and fix interior damage without outside assistance.
Keywords: Strength, Durability, micro-cracks, Self-healing.

1. Introduction

Concrete that has the ability to self-heal can provide concrete with a dense microstructure and decrease the occurrence and spread of cracks. As a result, structural concrete that is more durable and requires less upkeep can be made. Different methods are employed to slow the spread of fractures and span them, increasing the longevity of concrete. But the majority of methods—including epoxy systems, acrylic resins, and silicone-based polymers—involve the use of pricey, frequently toxic components that clash with concrete. Recent research has led to the development of bio concrete, also known as bio-influenced self-healing concrete, as a potential method for limiting fracture propagation.

A product called "bio concrete" uses microbial activity in order to produce mineral compounds that help fissures heal. Due to autonomous healing, durability is increased through a decrease in concrete fractures, and in the later part, the maintenance needed for reinforced concrete structures is decreased. Because bio mineralization is a natural process that is environmentally benign and increases the compressive strength of broken materials, it is recommended.

The creation of calcium carbonate, which is influenced by set of variables and one among them is concrete's pH, the dissolved inorganic content of carbon, the combination contains calcium ions throughout, and nucleation sites, is directly tied to the self-healing process.

The kind of bacteria present, their differing concentrations, the curing methods employed, and the material utilized to integrate the bacteria which influences concrete to repairs on its own. For improved performance in deep concrete and in order to maintain bacterial availability, these bacteria and an organic mineral chemical precursor are blended along with concrete during mixing process, as opposed to being applied externally. Among various bacteria which is capable of fixing cracks and its inclusion practices are adopted in achieving self-healing, the usefulness of a specific bacteria named "Bacillus subtilis," introduced by various incorporation procedures, must be determined.

It is also crucial to consider the methods that affect the size of fracture healing which in turn affects the concrete strength. Most commonly, self-healing concrete refers to a material's capacity to fill in gaps Self-repairing concrete naturally or automatically is another name for it. Concrete that heals itself mimics how cracks naturally close up by secreting limestone with the aid of microbes and calcium carbonate. Self-healing concrete is produced by dispersing bacteria and calcium carbonate into matrix in fibers or capsules form. When a crack appears, the fibers or capsules will rupture, exposing the bacteria-containing liquid to air and water. The bacteria then break down the calcium carbonate to create limestone, which cures the crack. In contrast to tensile force, it can tolerate compressive force quite well. These bacteria are found in soil and water and have characteristics including being shaped like a road and being aerobic or anaerobic.

These gaps make concrete less durable because they make it simple for gases and liquids that might contain toxic compounds to travel. Concrete may undergo some ill-effects, as well as the steel reinforcement bars, if microcracks spread and eventually reach the reinforcement. Therefore, it's crucial to keep crack width under control and to have them repaired as soon as feasible. Concrete structures' service lives would be extended by self-healing fissures, which would also increase the material's durability and sustainability.

They mostly consist of the following techniques: autogenous self-healing, capsule-based self-healing, vascular self-healing, electrodeposition self-healing, microbiological self-healing, and self-healing techniques utilizing embedded shape memory alloys (SMAs). Concrete that is self-healing using bacteria aims to repair cracks and regain its water tightness

"Bacterial Concrete" made of concrete which contains bacteria that continuously precipitate calcite. Surface cracks can be repaired with a product called bacterial self-healing concrete, which uses limestone that is organically manufactured by bacteria. Specifically, strains of the Bacillus bacterium, calcium lactate, a calcium-base nutrient, nitrogen, and phosphorus are blended along with concrete during mixing stage. For as long as 200 years, these self-repairing substances can lie latent in concrete. But when a concrete building cracks and water concrete bleeds, the bacteria's spores begin to grow when comes in contact with nutrients and water. Bacteria begins to produce calcium lactate once they are activated. The soluble calcium lactate is converted to insoluble limestone as the bacteria fixates oxygen during feeding. The fracture is sealed when the limestone on the fractured surface hardens. To ensure that the self-healing agent doesn't activate during cement mixing, the two components of the agent—the calcium lactate-based nutrients and the bacterial spores—are supplied to the concrete in separate, 2-4 mm wide extended clay pellets. Only when the pellets crack and incoming water comes into touch with the calcium lactate does the bacteria become active.

1.1 Selection of Bactria

Higher pH, dryness, and lack of nutrients, bacteria cannot thrive in concrete environment. The pH of ingredients together is 13, too low for living things to survive. It was found by researchers that in this extremely alkaline environment, only certain types of Bacillus bacteria can live. They would get activated when the concrete began to fracture. The mineral precipitation process lowers the value of pH of high alkalinity concrete to between 10 and 11.5, which is required for the activation of bacterial spores.

Bacterial Type

The single-celled, generally basic organisms known as bacteria. These are categorized according to three factors: shape, gram stain, and oxygen consumption.

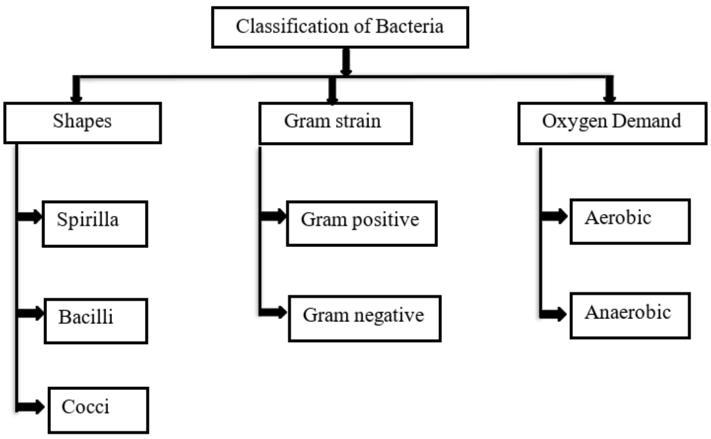

Fig 1: Types of bacteria

2 Literature Review

Dr. Henk Jonkers designed a bacterial based concrete which blends certain Bacillus bacteria with calcium lactate, nitrogen, and phosphorus ensures a healing agent within concrete. If left untouched, these compounds can stay inactive in concrete for longer periods. However, if water seeps into the crevices, the bacteria's spores begin to germinate and begin feeding on the calcium lactate. The calcium lactate turns into limestone as a result of the oxygen being used up, solidifying and sealing the surface. The elimination of oxygen results increased durability of reinforcement.

Thirumalai Chettiar's research on biological concrete discusses a special method for filling concrete cracks and fissures. This method makes use of precipitation of calcite (CaCo3) generated by microbes. The field of study known as bio mineralization includes the procedure known as microbiologically induced calcite precipitation (MICP). This process converts living organisms into an inorganic solid. Bacillus Pasteruii, a common soil bacterium, may precipitate calcite.

V. Ramakrishnan, R. K. Panchalan, and S. S. Bang, studied biological concrete where calcite precipitation was induced using a common soil bacterium. Due to mineral precipitation produced by microbial action is organic and pollution-free, this approach is especially beneficial. Researchers were able to evaluate the therapy effectiveness by comparing the strength and stiffness of the bacteria-repaired fractured specimens than that of concrete without bacteria. Experimental research was also done on the ability of fractured beams to regain strength following remediation with different bacterial concentrations. This report presents the endurance of mortar beams inclusive of bacteria treated with under alkaline, sulphate, and freeze-thaw conditions. Multiple bacterial concentrations were employed in the study. The role of biologically induced mineral precipitation in enhancing the modulus of rupture, durability, stiffness, and concrete strength was documented using SEM. It is observed that adding bacteria to concrete increased its durability, modulus of rupture, compressive strength, and stiffness.

3. Methodology

3.1 Cement

The most often used type of cement is Portland cement. It is a fundamental component of plaster, mortar, and concrete. The parameters of cement utilized in the current investigation, OPC 43 grade, are enlisted below

Table 3.1: Properties of Cement

Properties	Values
Specific Gravity	3.05
Fineness	9%
Standard Consistency	31%
Initial Setting Time	33min
Final Setting Time	600min

3.2 Aggregates

Crushed fine aggregate is referred to as "manufactured sand" and is generated from a source material with the intention of being used in concrete or other particular products. Coarse aggregates are made up of crushed stones that are suitable and larger than 4.75mm. Table below lists the characteristics of M Sand and Coarse Aggregates.

Table 3.2: Properties of Fine Aggregate

Properties	Values
Specific Gravity	2.55
Fineness Modulus	3.6
Bulk Density	1250kg/m^3

Table 3.3: Properties of Coarse Aggregate

Properties	Values
Specific Gravity	2.60
Fineness Modulus	472
Bulk Density	1340kg/m^3

3.3 Water

A cement paste is created when water and a cementitious substance are combined during the process of hydration. The specific gravity is assumed to be 1.

3.4 Bacillus Megaterium

A rod-shaped, Gram-positive, primarily aerobic, spore-forming bacteria called Bacillus Megaterium can be found in a wide variety of settings. It is quite huge for a bacterium, with a cell length of up to 4 m and a 1.5 m diameter. The polysaccharides on the cell walls of the cells, which frequently occur in pairs and chains, allow the cells to cooperate. The ideal temperature for megaterium growth is between 30 °C and 45 °C. Some isolates from a geothermal lake in Antarctica were discovered to thrive at temperatures as high as 63 °C. It has been identified as an endophyte and may be used as a biocontrol agent for plant diseases. It has been proven that some B Megaterium strains can fix nitrogen.

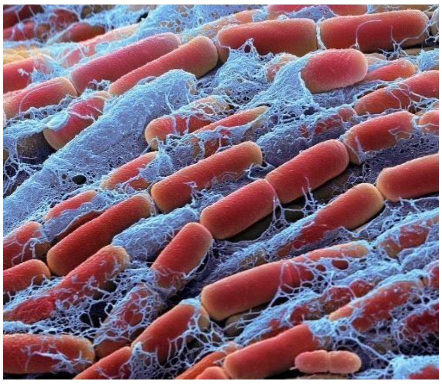

Fig 2: Bacillus Megaterium under microscope

An important industrial bacterium for many years has been Bacillus Megaterium. It creates a variety of enzymes, including amylases used in the baking industry and glucose dehydrogenase used in blood glucose tests, as well as penicillin amidase, which is used to synthesize synthetic penicillin. A number of amino acid dehydrogenases are also produced along with enzymes for corticosteroid modification. Additionally, it is utilized to make molecules with fungicidal and antiviral effects, pyruvate, vitamin B12, and other compounds. The families of surfactin, iturin, and fengycin lipopeptides, which are also produced by numerous additional Bacillus species, include cyclic lipopeptides, which include multiple of these beneficial chemicals.

3.5 Preparation of Bacterial Concrete

Two ways of manufacturing Bacterial Concrete

a) By direct application
b) By encapsulation in lightweight concrete

Direct Application Method

In the direct application approach, bacteria’s are applied along with calcium lactate immediately to the mixed concrete. The use of these microorganisms and calcium lactate does not change the typical properties of concrete. when the reasons for a structure's fissures are obvious. The bacteria are subjected to climate change. These bacteria grow in the presence of water, use calcium lactate as food, and produce limestone. Treated clay pellets are added to the concrete combined with bacteria and calcium lactate, which acts as the bacteria's food source, to fill up the cracks. Roughly 6 % of clay pellets are blended in order to create bacterial concrete.

4. Results & Discussions

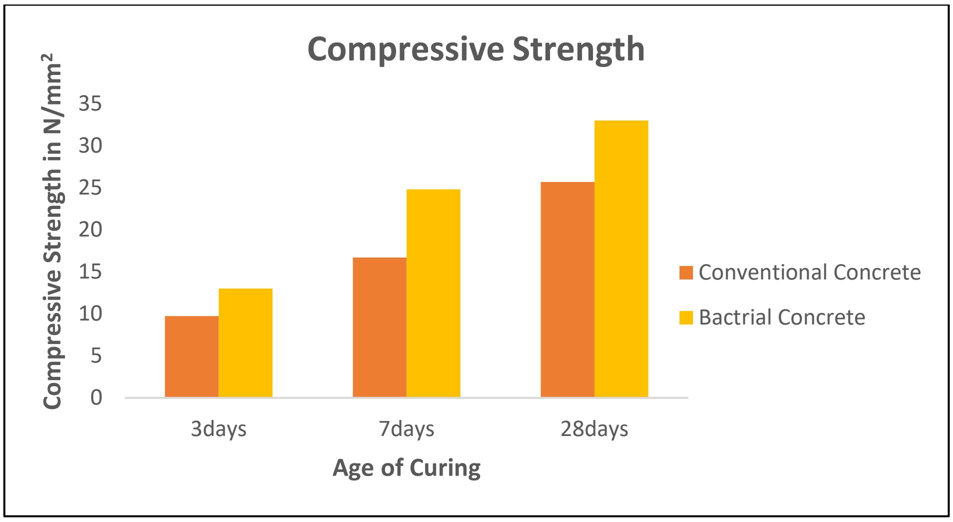

Fig 4: Variation of Strength for Conventional & Bacterial Concrete

The fluctuation in compressive strength values obtained after 3, 7, and 28 days of curing is displayed in the above graph. It has been noted that the compressive strength values increase linearly with increasing curing age. After 28 days of curing, strength values of bacterial concrete is 0.77 times more than that of ordinary concrete.

5. Conclusions:

1. After 28 days of curing, the average compressive strength test results of microbiological concrete differ from those of conventional concrete by 0.77 times.
2. Concrete that can repair itself could lessen the substantial CO2 emissions from producing concrete. For mining, transportation, and concrete plants combined, concrete production is very energy-intensive, accounting for nearly 10% of all CO2 emissions. Self-healing concrete might cut maintenance costs and extends structural life, which would minimize the need to produce extra concrete and consequently CO2 emissions.
3. Due to its eco-friendliness and ease of application, bacterial concrete has become a superior to many conventional methods.
4. In the near future, this ground-breaking concrete technology will serve as the foundation for alternative, high-quality structures that are both affordable and environmentally friendly.
5. By using microbial concrete, construction processes might be streamlined and new method of construction could be used.
6. Because Bacillus bacteria do not endanger human life, they can be used effectively.

References:

[1] P.K. Mehta, P.J. Monteiro, Concrete: Microstructure, Properties, and Materials, McGraw-Hill,New York, 2006.

[2] H.-W. Reinhardt, M. Jooss, Permeability and selfhealing of cracked concrete as a function oftemperature and crack width, Cem. Concr. Res. 33 (7) (2003) 981– 985.

[3] P. Hewlett, Lea's Chemistry of Cement and Concrete, fourth ed., Butterworth-Heinemann,2003.

[4] Federal Highway Administration, Preventive Strategies in The United States, Report by CCTechnologies Laboratories, Inc. to Federal Highway Administration (FHWA), Office of Infrastructure Research and

Development. Report FHWA-RD-01-156, 2001.

[5] M. De Rooij, K. Van Tittelboom, N. De Belie, E. Schlangen, Self-healing phenomena in cement-based materials. Draft of State-of-the-Art report of RILEM Technical Committee, 2011.

[6] M.S. Vekariya, J. Pitroda, Bacterial concrete: New Era for Construction Industry, Int. J. Eng.Trend Technol. 4 (2013) 4128–4137.

[7] Ellie Zolfagharifar; “Biological concrete new era of self-healing civil structures”; ISBN 978-0-415-59316-8; 2015; pp. 840-847.

[8] H. M. Jonkers; "Bacteria-based self-healing concrete"; Microlab, Delft, the NetherlandsHERON; Volume 56; 2011; pp. 1-2.

[9] Thirumalai chettiar; Percolation Modeling of Self Damaging of Composite Materials; DOI: 10.1109/COMSWA; 2015; pp. 1-5.

[10] Ramachandran SK, Ramakrishnan V, Bang SS (2001) “Remediation of concrete usingmicro-organisms”, ACI Materials Journal volume 98; pp. 3–9