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Bio-Concrete: The Self Healing Concrete

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Abstract: *Concrete is vital and basic material used in construction industry from foundation of the building to structure of bridges and underground passages. It has high tendency to form cracks when subjected to tension or due to external atmosphere. It leads to reduction of concrete life. Repairs of conventional concrete structures usually involve use of big machines and instruments which has to be highly maintained. Repairs can particularly be time consuming and has high maintenance cost. Thus, treatment methods that are eco-friendly and long lasting are in high demand.Bacterial Self-healing concrete is in development now, which has enhanced property than that of conventional concrete. It consists of a Bacillus species combined in the concrete in the form of bacterial solution and bacterial beads along with its food and silica gel. Bacteria heals the crack formed. Bacterial self-healing concrete has more compressive strength than that of conventional concrete. Mainly micro cracks have been noticed healing within. The mechanism and study of this healing property is briefly described in this paper*

Keywords *–Concrete, Self-healing, cracks, bacterial solution, bacterial beads, precipitate, compressive strength.*

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I. Introduction

Concrete is basic ingredient used in construction and has high tendency to form cracks. A typical durability-related phenomenon in many concreteconstructions is crack formation which result in short lifespan and increased matrix permeability[1]. Such problem has led to the progress of special concrete knownas Bacterial Concrete. Use of Bacillus bacterial species in the concrete to selfhealthe cracks formed in the structure by its own metabolic activity.

Bacillus species are rod-shaped, endospore-forming aerobic or facultatively anaerobic, Gram-positive bacteria; in some species cultures may turn Gram-negative with age. The many species of the genus exhibit a wide range of physiologic abilities that allow them to live in every natural environment. The spores are resistant to all type of atmospheric conditions, radiation, desiccation and disinfectants. It has life span of about 200 years. It has property to give out calcium carbonate precipitate in presence of calcium lactate. So, Bacillus species with its required food is used in the project work which are found in sand as well and are non-pathogenic.

Nutrient Broth is a basic media needed by bacillus to grow. It is composed of a simple peptone and a beef extract. Peptone contributes organic nitrogen in the form of amino acids and long-chained fatty acids. Beef Extract provides additional vitamins, carbohydrates, salts and other organic nitrogen compounds. When bacteria is subjected to concrete, bacteria go into a dormant state, a lot like seeds.Bacteria needs exposure to the surrounding atmosphere to activate their functions. Any cracks that occur provide the necessary exposure. When a crack is formed, the cracks were observed healing which were in range

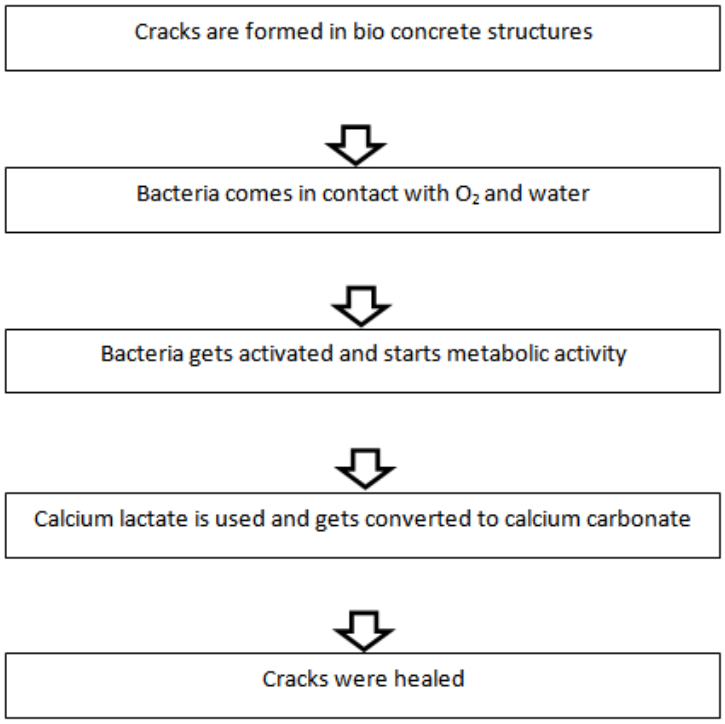
When cracks are formed, moisture from the surrounding starts to seep through the cracks that appear in the concrete, the spores of the bacteria germinate on contact with the moisture, water and nutrients. Having been activated, the bacteria start to feed on the calcium lactate nutrient. Such spores have extremely thick cell walls that enable them to remain intact for up to 200 years while waiting for a better environment to germinate. Crack-healing capacity of concrete has been recognized that micro cracks with widths typically in the range of 0.05 to 1 mm have been observed to become completely sealed.

II. Objectives

- To heal the crack by bacterial precipitation.
- To investigate the effect of bacterial species in achieving strength in contrast to conventional concrete.
- To improve durability and compressive strength of concrete.

- Use of silica gel as moisture absorbing agent to rapid the self healing activity.

III. Mechanism



When the concrete is mixed with bacteria the bacteria go into a dormant state, a lot like seeds. Bacteria does need exposure to surrounding atmosphere to activate their functions. When the cracks are formed, bacteria which are close to proximity, starts precipitating calcite crystals. 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 when comes in contact with the water and nutrients. Having been activated, the bacteria starts to feed on the calcium lactate nutrient.

As the bacteria feeds oxygen is consumed and the soluble calcium lactate is converted to insoluble limestone. The limestone solidifies on the cracked surface, thereby sealing it up. Oxygen is an essential element in the processcorrosion of steel and when the bacterial activity has consumed it all it increases the durability of steel reinforced concrete constructions.

IV. Material

The following below mentioned materials were used for the making of concrete mix of self-healing concrete. The concrete grade of M25 was adopted for the mix.[2][3]

4.1 Cement

In this project the cement used was Ordinary Portland Cement (OPC) of 53 GRADE Ultratech cement.[2][3]

4.2 Aggregates

Coarse aggregates:The aggregates passing through 20mm IS sieve and retaining on 10mm IS sieve and aggregates passing through 10mm and retaining on 4.75mm IS sieve were used.

Fine aggregates: Crushed sand passing through 4.75mm & retaining on 2.36mm sieve was used.

The aggregates used should be rounded and angular and rebounded to improve strength and workability. Use of flaky aggregates should be avoided.

4.3Water

Portable tap water should be used in the casting of the cube. The temperature of water should be maintained at room temperature. The water used for casting the concrete should have pH 6-8 according to the IS CODE 456-2000. For casting water cement ratio of 0.4 was adopted.

4.4 Bacterial species

Bacillus species used in the research work are **B. subtilus**, **B. mesentri**,**B. laussi**which are found in sand as well and are non-pathogenic. [4]

4.5 Media used

Nutrient Broth is a basic media needed by bacillus to grow. It is composed of a simple peptone and a beef extract. Peptone contributes organic nitrogen in the form of amino acids and long-chained fatty acids. Beef Extract provides additional vitamins, carbohydrates, salts and other organic nitrogen compounds.

4.6 Sodium alginate and Calcium Chloride

Gelling agent and solidifying agent to make beads.

4.7 Silica Gel

Silica gel acts as a moisture absorbing agent and hence it is introduced in the concrete so that the process of healing initiates at an early stage itself[5].

V. Methodology

1. Growth of bacteria and its media.
2. Introduction of bacteria in concrete.
3. Casting of concrete cubes.
4. Performing tests to check changes in quality.

5.1Growth of bacteria

13 gms of Nutrient broth powder is dissolved in 500 ml distilled water. Autoclave it at 121℃ and15 psi for 15 to 20 minutes to sterilize it. Let it cool and add loopful of each of bacillus culture to it in aseptic condition. Incubate it at 37℃ for 24 hours. Bacterial solution is prepared. 12 such batches were prepared to cast 9 cubes of bacterial solution form as well for beads form respecticely and 4 cubes of silicon gel form.

5.2Introduction of bacteria in concrete

5.2.1 In solution form**:** Directly pour the prepared bacterial solution in the concrete mixture while mixing is carried on [6].

Figure 1: Bacterial Solution

5.2.2In beads form: Prepare 1000 ml each of 5% sodium alginate and 2000 ml of 6% calcium chloride. Autoclave at 121℃ for 20 minutes. Cool sodium alginate and calcium chloride and add 1000 ml of nutrient broth solution (bacterial solution) to sodium alginate solution. Mix well. Take calcium chloride solution in a conical flask. Mixture of sodium alginate and nutrient broth solution. Make beads with the help of syringe or pipette in. Drop by drop add it to the chilled calcium chloride solution. Beads will get formed. Refrigerate it for 12 hours. Remove access of calcium chloride and dry them. And add it in the concrete mixture while mixing.

Figure 2: Bacterial Beads

5.3Casting of self-healing concrete

Concrete mix of M25 (1:1:2) grade was used. Mix design of concrete (1:1.96:3.24) was adopted [2][3]. Casting of 56 cubes was done. The standard IS moulds of size 15 × 15 ×15 cm was used for casting. At the time of casting, the aggregates and cement in required quantity were mixed on a clean platform. Then the required amount of water was added to the mix. The mix is thoroughly mixed till uniform color is obtained. The mixing is done by machine. The surface of block is levelled properly using a trowel. These blocks were kept submerged in water for curing for 28 days after casting. The temperature of water used in curing tank was room temperature.

5.4 Tests performed

Compressive strength test was performed using compressive test machine on 7^{th}, 14^{th} and 28^{th} day after suitable curing of the cubes with bacterial solution and bacterial beads. The cubes in which silica gel was added as moisture absorbing agent were tested only on 28^{th} day.

Figure 3: Casting of cubes

.**Figure 4:** Curing of cube

VI. Observations

Below given images are observations of healed cracks from bacterial beads and bacterial solution.

Figure 5: Healed crack of bacterial solution.

Figure 6 : Healed cracks of Bacterial Beads&Silica gel.

VII. Results

Table I. Comparison between conventional concrete and bacterial concrete in solution form

No of Days	Conventional Concrete (N/mm^2)	Bacterial Solution Concrete (N/mm^2)	Percentage Increase (%)
7 days	18.6	20.15	8.24
14 days	25.2	28.53	13.2
28 days	27.25	32.6	19.6

Graph 2: Graphical representation of compressive strength of conventional and solution form concrete

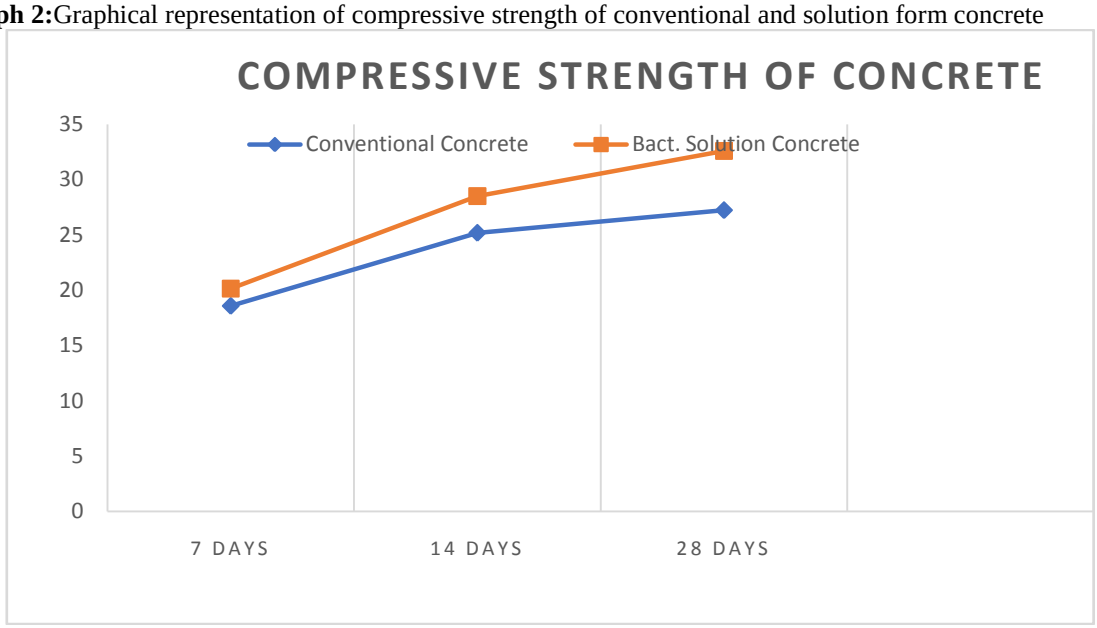


Figure 7: Graphical representation of conventional and solution form concrete

TableII. Comparison between conventional concrete and bacterial concrete in bead form

No of Days	Conventional Concrete (N/mm^2)	BacterialBead Concrete (N/mm^2)	Percentage Increase (%)
7 days	23.94	26.097	9.02
14 days	26.514	30.457	14.87
28 days	29.415	35.328	20.1

Graph 2: Graphical representation of conventional and bead form concrete

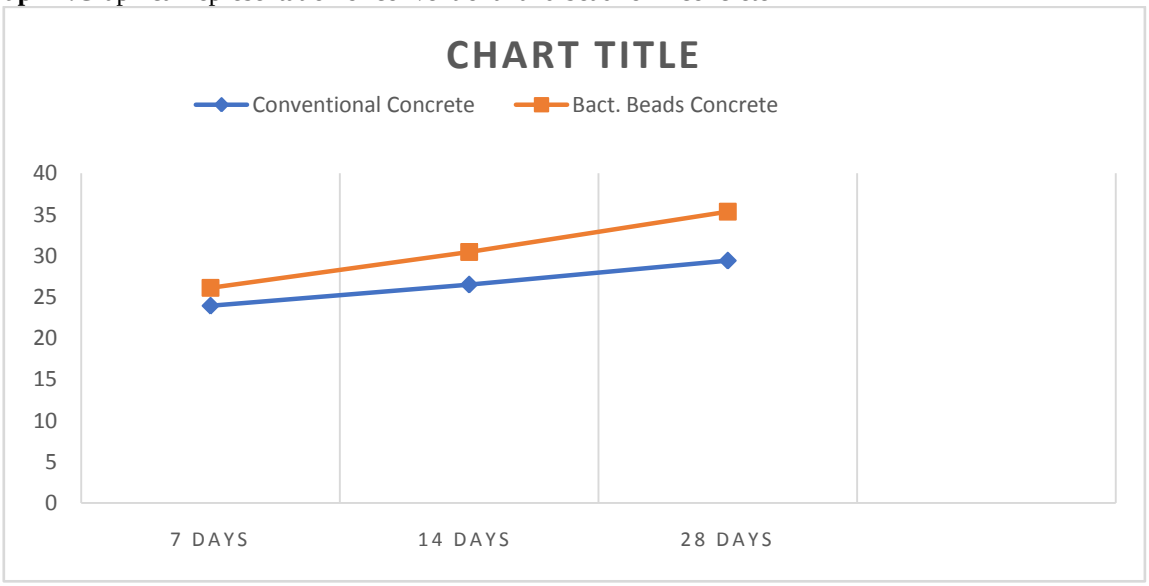


Figure 8: Graphical representation of conventional and bacterial beads form concrete

Table 4: Compressive strength after addition of Silicone gel

Days	Conventional concrete	Bacterial concrete using solution form	Bacterial concrete using beads form
28 days	30.63	27.33	29.81

VIII. Conclusions

Cracks up to 1 mm were healed with help of bacteria present in it due to bacterial precipitation. When bacteria are present in the form of solution, crack was observed to get healed within 28 days and when bacteria are present in the form of beads, crack was observed to get healed completely by 18th day. With the addition of silicone gel in concrete it was found that the cracks were healed in less duration. Calcium carbonate layer was formed on the concrete surface[7]. The compressive strength of concrete cubes in which the bacteria was introduced in the solution form was increased by **19.6** %. The compressive strength of concrete cubes in which the bacteria was introduced in beads form was increased by **20.1** %.

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