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# Self-healing concrete: A bacterial approach

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## ABSTRACT

***Self-healing concrete received an attention in previous few decades. This paper reviews the analysis conducted on self-healing in previous two decades. Self-healing approaches, differing types of healing agents used, incorporating procedures, and analysis techniques square measure highlighted during this paper. The development of cracking and crack- healing, materials used for crack-healing and also the strategies and techniques utilized throughout the method, the outcomes of experiments mentioned by numerous researchers from their work square measure highlighted. From the literature review, it had been terminated that the crack breadth sizes up to 0.1mm can be healed with self-produced self- healing mechanism, whereas, crack scrutinize to 1 mm are often well with autonomous self- healing mechanism. it had been determined that the healing potency was entirely smitten by the concrete exposure to corresponding surroundings, the kind of healing agent used, procedures and techniques followed.***

***Keywords***— *Self-healing, Cracks, Self-healing approaches, Durability*

## 1. INTRODUCTION

Concrete is used in construction industries for various construction projects, because it provide compressive strength to resist different kind of loads, which acts on the structure. Concrete has very high bearing capacity against compressive loads but it is weak in tension, when the tensile loads acting on the concrete member exceeds its tensile load carrying capacity, the concrete member starts to crack. The presence of cracks have a high impact on the durability of the concrete structure. The cracks provide a path way through which various harmful agents like chloride, moisture, carbon dioxide etc. may enter and corrode the reinforcing steel bars which are embedded in concrete member to sustain the tensile forces acting on the concrete member. The existence of these cracks can reduce the serviceability of the concrete structure as it affects the concrete properties like permeability, durability and strength of the concrete. Due to the increase in permeability water easily passes through the concrete and meets the reinforcement of the concrete structure and after some time the onset of rust will occur, due to this stiffness of the concrete structure will decrease and therefore you will need to repair cracks. By introduction of the bacterium in concrete it manufactures carbonate crystals that block the small cracks and pores within the concrete. In concrete small cracks square measure perpetually avoided however to some extent they're accountable to their failure in strength. The choice of the bacterium is rely upon the survive capability of bacterium within the base-forming surroundings. Most of the microorganisms die in associate degree surroundings with pH scale worth of ten.

Different types of bacterium employed by totally different researchers for the study of bacterium like Jonker et al.[3] used Bacilllus cohnii bacterium to precipitate CaCo3, Santhosh et al.[6], Day et al.[5], Bang et al.[7] used B pasteurii whereas B lintus employed by Dick et al. [4]. First, 1 mol of urea is hydrolyzed intracellular to 1 mol of ammonia ( (Eq. (1)). Carbonate ad libitum hydrolyses to make to boot 1mol of ammonia and acid (Eq. (2)). These merchandise later kind 1mol of carbonate and 2mol of ammonia and hydroxide ions (Eq. (3)) and (4)). The last a pair of reactions make to a pH increase that successively shifts the carbonate equilibrium leading to the formation of carbonate ions (Eq. (5)).

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

$$NH_2COOH + H_2O \rightarrow NH3 + H_2CO_3 \quad (2)$$

 

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

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

$$HCO_3^- + H^+ + 2NH_4 + + 2OH^- \longleftrightarrow CO3^{2-} + 2NH_4 + + 2H_2O \quad (5)$$

Since the cytomembrane of the bacterium is charged, the bacterium draw cations from the setting, together with Ca2+, to deposit on their cell surface. The Ca2+-ions later react with the CO32−-ions, resulting in the precipitation of CaCO3 at the cell surface that is a nucleation site (Eqs. (6) and Eqs. (7)).

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

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

## 2. TYPES OF BACTERIA USED AS SELF HEALING

Most of the studies shows that bacillus bacteria from "genus Bacillus" has widely used as self-healing bacteria , because of ability to survive in high alkalinity concrete medium . The study show that the bacillus bacteria can precipitate CaCO3 after being activated by water.

## 3. EFFECT OF BACTERIA ON CONCRETE PROPERTIES

### 3.1. Compressive and Tensile Strength

According to study the increase of compressive strength and flexural strength is observed when bacterial spores are added directly in concrete mix by about 8 to 10 percent by utilizing calcium lactate and calcium glutamate in mortar. The test shows the result of increase in strength.

### 3.2. Hydration Kinetics

Experiments results showed that addition of bacteria spore powder and nutrients significantly affect setting time of concrete. Setting time is found to be reduced by addition of calcium lactate and calcium format also, and it can be accelerated by addition of calcium nitrate as nutrient.

### 3.3. Water Permeability

It is one of the fundamental properties of concrete, it determines penetration of aggressive substances and which further affects the durability of concrete.

Water absorption and permeability of bacterial concrete decreases after CaCO3 precipitation by bacteria as pores are filled with it. According to study if bacteria along with fly ash is added the water absorption reduces by four times as conventional concrete

### 3.4. Cost

The initial cost of the bacterial concrete is high for construction but overall cost of structure reduces as maintenance and repair cost is quit less.

## 4. METHODS OF ADDITION OF BACTERIA IN CONCRETE

When spores of bacteria, fine aggregate, course aggregate and cement are mixed together, it is called as self-healing concrete. But while mixing one must take care of bacteria and cement are not allowed to mix together with the help of clay pellets. Bacterial concrete can be prepared in two ways,

1. Direct application
2. Encapsulation in lightweight concrete

### 4.1 Direct application method

- In the direct application method, bacteria spores and calcium lactate is added into concrete directly when mixing of concrete is done.
- The use of bacteria and calcium lactate doesn't change the normal properties of concrete.
- When cracks are occurred in a structure due to obvious reasons, the bacteria are exposed to climatic change.
- When water comes in contact with this bacterium, they germinate and feed on calcium lactate and produces limestone. Thus sealing of crack is done.

### 4.2 Encapsulation method

- By encapsulation method the bacteria and its food i.e. calcium lactate, are placed inside the treated clay pellets and then the concrete is prepared.
- About 6% of the clay pellets are added for making bacterial concrete.
- When the crack occurs in the bacterial concrete structure, clay pellets are broken and the bacteria germinate and eat down the calcium lactate and produce limestone, which hardens and thus sealing the crack.
- Minor cracks about 0.5mm width can be treated by using bacterial concrete.
- Among this two-methods encapsulation method is commonly used, even though it's costlier than direct application.

## 5. TESTING OF CONCRETE

Three tests were carried out: 1. compressive strength test, 2. Water absorption test and 3. Slump cone.

### 5.1 Method of performing tests

**Slump cone test**

1. Clean the internal surface of the mould and apply oil.
2. Place the mould on a smooth horizontal non- porous base plate.

 

3. Fill the mould with the prepared concrete mix in 4 approximately equal layers.
4. Tamp each layer with 25 strokes of the rounded end of the tamping rod in a uniform manner over the cross section of the mould. For the subsequent layers, the tamping should penetrate into the underlying layer.
5. Remove the excess concrete and level the surface with a trowel.
6. Clean away the mortar or water leaked out between the mould and the base plate.
7. Raise the mould from the concrete immediately and slowly in vertical direction.
8. Measure the slump as the difference between the height of the mould and that of height point of the specimen being tested.

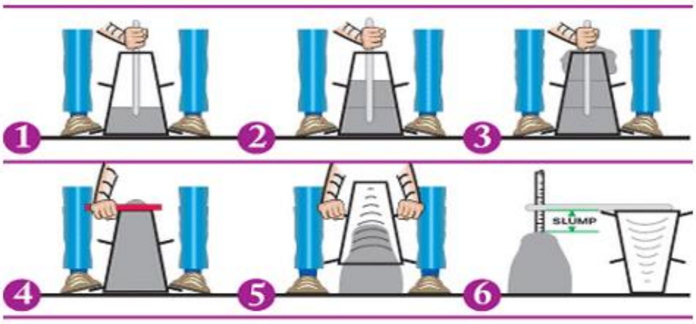


**Figure 1: Slump Cone Test.**

**RESULTS**

1. Slump of conventional concrete was found to be 45mm.
2. Slump value of bacterial concrete was 60mm.

**5.2 Water Absorption Test**

For concrete block, the test procedure involves drying a specimen to a constant weight, weighing it, immersing it in water for specified amount of time, and weighing it again. The increase in weight as a proportion of the first weight is expressed as its absorption (in percent). The average absorption of the test samples shall not be greater than 5% with no individual unit greater than 7%.

**RESULTS:**

| SR NO | STANDARD CONCRETE | BACTERIAL CONCRETE |
|---|---|---|
| 1. | 3.6% | 2.7% |

**5.3 Compressive Strength Test of Concrete Cubes:**

1. Concrete is poured into the moulds of size 15*15*15cm. compaction should be done in order to avoid honey combing and to reduce the voids.
2. After 24 hours the moulds are removed and test specimens are kept in water or immersed in water to ensure proper.
3. After the desired curing period the testing of cubes is performed.
4. Specimen is placed under CTM and loaded until failure.
5. Divide the failure load by the cross-sectional area of cube. Tabulate the results

**RESULTS:**

| SR NO | STANDARD CONCRETE (7 days compressive strength) | BACTERIAL CONCRETE (7 days compressive strength) |
|---|---|---|
| 1. | 13.8 N/mm2 | 15.2 N/mm2 |
| 2. | 14.1 N/mm2 | 16.1 N/mm2 |

**Figure 2: Cube concrete Mould**

**5.4 Effect on the strength test**

Various physical test was carried out on the concrete specimen by Salmabanu Luhar at. el.[1].

The compressive test and split tensile test on standard concrete specimen, both Traditional and bacterial are mentioned below in Table 1 and Table 2.

 

**Compressive strength:**

**Table 1. Comparison of compressive strength of traditional concrete and bio concrete**

| S. No | No. of days | Split tensile strength of traditional concrete cylinders, N/mm2 | Split tensile strength Bio Concrete cubes, N/mm | % increase in Strength |
|---|---|---|---|---|
| 1. | 3 | 3.78 | 4.30 | 13.75 |
| 2. | 7 | 4.62 | 5.28 | 14.28 |
| 3. | 28 | 4.85 | 5.74 | 18.35 |

**Split Tensile Strength:**

**Table 2. Comparison of Split Tensile strength of standard concrete and bio concrete**

| S. No | No. of days | Split tensile strength of traditional concrete cylinders, N/mm2 | Split tensile strength Bio concrete cubes, N/mm | % increase in Strength |
|---|---|---|---|---|
| 1. | 3 | 19.24 | 25.16 | 30.76 |
| 2. | 7 | 23.66 | 34.58 | 46.15 |
| 3. | 28 | 34.52 | 45.72 | 32.21 |

## 6. RECOVERY OF DURABILITY PROPERTIES

Efficient self-healing in concrete would mean that the sturdiness and mechanical strength area unit recovered totally or on the point of that of the first specimen. Sturdiness is usually measured by water permeability and water absorption tests. Healing of cracks would to boot mean block of any void or interconnected pores through, which foreign chemicals might penetrate from air or water. That successively reduces water permeability and water absorption. Reduction in permeability fully by microorganism action is thanks to pore preventative by carbonate that is found to own terribly low solubility. Luo et al.[2] (2015) determined that healing magnitude relation born from eighty three for 0.1–0.3 metric linear unit crack breadth to 30% once crack breadth was 0.8 mm. once crack breadth is high healing product tend to urge washed far away from the crack face by wetness or any incoming fluid. The come by healing magnitude relation is also thanks to loss of repair agent from the crack face or shy quantity of healing agent to bridge wider cracks. Such findings is also true as a result of microorganism metabolism and precipitation is also restricted by concentration of microorganism, nutrients and precursor compound at the crack web site. The precipitation rate is slow and thus if the crack breadth is giant precipitates is also washed off by water or alternative chemicals before the crack is sealed. it had been additionally found that concrete samples submerged in water had higher healing magnitude relation compared to samples subjected to wet hardening which can result to raised transport of healing agent because of concentration distinction between the matrix and therefore the surface in submerged condition. Within the study, highest healing magnitude relation for water hardening was determined at early age which implies that ample water might penetrate within and become on the market for microorganism metabolism

## 7. ADVANTAGES OF SELF-HEALING CONCRETE

- This concrete has comparatively much lower permeability, greater durability and stress carrying capacity than conventional concrete.
- It can be applied to existing buildings in the form of spray which can reduce the overall repair and maintenance costs of the buildings.
- This is an environmentally friendly technique because the carbon dioxide produced is prevented due to the low use of concrete.
- SHC is a more effective shock-absorber that protects it during earthquakes because it has a polymer membrane on its surface.
- It can operate at internal levels which means that the smallest cracks can be reached.
- Un-hydrated cement that does not contribute to strong participation can be used.
- Helps to fill the crack.
- Improvement in the compressive strength of concrete.
- Better resistance to freeze-melting attack reduction.
- Permeability reduction of concrete.
- Corrosion reduction of reinforced concrete.
- Helps reduce maintenance and repair.

## 8. DISADVANTAGES OF SELF-HEALING CONCRETE

- The cost of self-healing concrete is double that of conventional concrete.
- The growth of any bacteria is not good in any atmosphere media.
- Calcite precipitation investigations are expensive.
- Skilled labour is required.

## 9. APPLICATIONS OF SELF- HEALING CONCRETE:

- It can be actively used in the case of roads to reduce traffic jams.
- Also used by the oil and gas industries, preventing small cracks from spreading.
- It can be used to strengthen both existing and new types of structural building.
- It is effective in areas where buildings undergo freezing and thawing.
- This can prove to be economical in case of irrigation works, dams etc. which are directly in contact with water.
- This concrete can be used for sectors such as tunnel-linings, structural basement walls, highways, bridges, concrete floors, and marine structures.

 

- It is new technology that can give way to sustainable roads.
- In high strength buildings with more bearing capacity.

## 10. CONCLUSION

Introducing the bacterium into the concrete makes it terribly useful it improves the property of the concrete that is over the traditional concrete. Bacterium repair the cracks in concrete by manufacturing the carbonate crystal that block the cracks and repair it. several researchers done their work on the self-healing nature of concrete and that they had found the subsequent result that bacterium improves the property of standard concrete like increase in 14% strength augmented in three days, 14.28% in seven days and 18.3% in twenty-eight days. the event of carbonate crystal Decreases the water porosity by decreasing the dimension of cracks from 0.5 mm to 0.35 mm. Compressive strength was will increase by 30.7% in three days, 46.1% in seven days and thirty 22.2% in twenty eight days and in mathematical modal it absolutely was found that the microorganism concrete shows the higher price of stress and strain as compared to controlled concrete for the high strength grade of concrete.

However, the construction cost of gets doubled with the inclusion of bacteria as compared to that of traditional concrete.

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