EXPERIMENTAL STUDY ON STRENGTH OF SELF-HEALING CONCRETE

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Abstract

In this paper an overview of new development obtained in experimental study on self-healing concrete. Strength and durability of concrete is mainly affected due to the formation of cracks. Micro cracks are the main cause for structural failure. While larger cracks affect structural integrity, micro cracks result in durability problems. Ingress of water and chemicals can cause premature matrix degradation and corrosion of embedded steel reinforcement. Also concrete fails due to insufficient tensile strength. In order to overcome this, an attempt is made in Bacterial concrete with non-pathogenic, spore forming, calcite mineral precipitating bacterium "Bacillius subtilis". M20 grade concrete is prepared with different bacterial cell concentration of 10^4, 10^5 and 10^6 cells per millilitre of water and polyethylene fibre kept at constant as 0.4%. The overall development of strength and durability of self-healing concrete using Bacillius subtilis and polyethylene fibre has investigated and compared with control concrete. The optimum strength is obtained at 10^5 cells concentration and polyethylene fibre were bridging over the crack and crystallization products became easy to be attached to a large number of polyethylene fibre. The optimum strength is obtained at 10^5 cells concentration, which increases the compressive strength by 13.2%, split tensile strength by 21.4% and flexural strength by 16.04%. The percentage of increment in strength clearly shows that the self-healing concrete is advantageous.

Key Words: *Bacillius subtilis JC3, Calcium carbonate precipitating, Crack, Strength and Durability properties.*

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1. INTRODUCTION

Concrete is the most common material used for all types of construction. Due to its strength and durability, concrete became inevitable. The only defect in the use of concrete is that it is weak in tension. Since the concrete is weak in tension the Possibility of formation of crack is more. Apart from this, freeze–thaw action and shrinkage also leads cracking in concrete. Durability of concrete is highly affected due to cracks and it leads corrosion of reinforcing bars. So it is very essential to find the suitable repair mechanism for regain the strength of concrete. In concrete structures, repair of cracks usually involves applying a cement slurry or mortar which is bonded to the damaged surface. Repairs can particularly be time consuming and expensive. For crack repair, a variety of techniques is available like impregnation of cracks with epoxy based fillers [1], latex binding agents such as acrylic, polyvinyl acetate, butadiene styrene, etc. But traditional repair systems have a number of disadvantageous aspects such as different thermal expansion coefficient compared to concrete and also have impact on environment and health. Therefore, bio based calcite precipitation has been proposed as an alternative and sustainable, environmental friendly crack repair technique [2].

Bacterially induced calcium carbonate precipitation has been proposed as an alternative and environmental friendly crack repair technique. Microbial calcite precipitation is mainly due to unrealistic activity and carbonate bio mineralization of bacteria. The strains of the bacteria genus Bacillus were found to thrive in the high-alkaline environment [3].Salt tolerance, temperature range, pH range and extracellular products are important taxonomic criteria which are used in different species in the genus *Bacillus* [4].

In our study, bacterial species Bacillius Subtilis is used to improve the strength of concrete. Researchers have shown that the microbiologically induced endospore forming bacteria is able to heal cracks effectively. The principle behind in bacterial crack healing mechanism is that the bacteria should able to transform soluble organic nutrients into insoluble. Inorganic calcite crystals which seal the cracks [5].

When cracks appear in a concrete structure and water starts to seep in through, the spores of the bacteria starts microbial activities on contact with the water and oxygen. In the process of precipitating calcite crystals through nitrogen cycle, the soluble nutrients are converted to insoluble $CaCO_3$. The $CaCO_3$ solidifies on the cracked surface, thereby sealing it up.

$$CaO + H_2O \longrightarrow Ca(OH)_2 \quad (1)$$

$$Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 + H_2O \quad (2)$$

The bacterial degradation of urea locally increases the pH and promotes the microbial deposition of Calcium carbonate in a calcium rich environment. Through this process, the bacterial cell is coated with a layer of calcium carbonate [6]. It mimics the process by which bone fractures in the human body are naturally healed by osteoblast cells that mineralize to reform the bone [7].

A. Selection of Bacteria

Due to high internal pH, relative dryness and lack of nutrients the common bacteria cannot survive in the concrete environment. The pH of cement and water when mixed is 13, which is not suitable for organisms to survive. Researchers found that only the strains of bacterial genus bacillius are suitable to thrive in this high alkaline environment. It is also found that, bacillus is the only genus that is able to form spore in the hostile environment. Such spores have extremely thick cell walls that enable them to remain unbroken for up to 200 years while waiting for a better environment to germinate. They would become activated when the concrete starts to crack. The process of mineral precipitation lowers the pH of the highly alkaline concrete to values in the range (pH 10 to 11.5) where the bacterial spores become activated.

B. Polyethylene Fiber

Polyethylene is a polymer. Many no. of ethylene monomers join with each in the synthesis of polyethylene. Polyethylene is a hard, stiff, strong and a dimensionally stable material that absorbs very little water. It has good gas barrier properties and good chemical resistance against acids, greases and oils. It can be highly transparent and colorless but thicker sections are usually opaque and off-white. It has a round cross section and mixed with the concrete at contents of up 4% by volume or a continuous network of fibrillated fiber to produce high fiber content composite.

Fig.1 Polyethylene fiber

Properties of Polyethylene fiber

- ✓ Density – 0.97 g/cc
- ✓ Fiber Diameter – 0.012 mm
- ✓ Length – 6 mm
- ✓ Tensile strength – 2580 Mpa
- ✓ Elastic modulus – 73 Gpa

2. MATERIALS AND METHODS

I. Culture of Bacteria

The bacteria used in this study are Bacillius subtilis. The bacteria are cultured in mass on the culture medium. The culture medium is prepared using nutrient broth which consist of Peptone -2 gram, Glucose - 2 gram, Beef extract - 2gram and Sodium chloride-0.8 gram. The culture medium is sterilized in autoclave at 121°C at the pressure of 15lps.The bacteria is then introduced, mass cultured and diluted as per requirements. Staining is done to find the suitability and morphology of bacteria. Only gram positive bacteria are suitable for concrete. Bacterial count is measured using haemocytometer under microscope. The culture of bacteria is described in the following figures.

Fig.2 Incubation of bacillus subtilis bacteria

II .Test On Bacteria

Concentration of cells is measured by Haemocytometer and Gram staining method is used to determine the morphology of the bacterial strains.

Test	To determine	Result
Haemocytometer test	Cell concentration	10^5 cells/ml of bacterial solution
Gram staining	Morphology	Gram positive
Urease test	Calcite precipitation	Color change – yellow to pink
$CaCO_3$ test	Quantity of calcite precipitation	3 mg/l

Table1. Various test on bacteria

III. Properties of Materials

- The cement used in this study is OPC, 53 grades Chettinad cement which satisfies IS: 12269-1987.
- The fine aggregate of zone II with specific gravity 2.6, fineness modulus 3.1 and moisture content 2.5% is used and they are found as per IS: 383-1970.
- The coarse aggregate of 20 mm size with specific gravity 2.85, fineness modulus 3.69 and moisture content 0.26 % is and they are found as per: 383-1970.
- Distilled water is used for this study. The properties of water are satisfied as per 3025 – 1964 part 22, part 23 and IS: 456 – 2000.

IV. Mix Design

Concrete mix proportion is designed as per IS 10262-2009 and the mix ratio is 1: 1.63: 2.84 with the water cement ratio 0.45.

V. Details of specimen

About 24 cubes of size 150X150x150mm were cast to test the compressive strength on 7th and 28^{th} day. 12 sample of cylinders of size 150x300mm and prism of size 100x100x500mm were cast to find the split tensile and flexural strength respectively. The details of specimen are given in table 2.

SI. No.	Mix ID	Description
1	CC	Control concrete
2	SHC1	Bacteria 10^4cells per millimeter of water and 0.4% of Polyethylene Fiber.
3	SHC2	Bacteria 10^5cells per millimeter of water and 0.4% of Polyethylene Fiber.
4	SHC3	Bacteria 10^6cells per millimeter of water and 0.4% of Polyethylene Fiber.

Table 2 Details of specimen

s3. EXPERIMENTAL PROCEDURE

The slump test was carried out on fresh concrete to check the workability of all concrete mixes. It can be tested as per IS: 1199-1959.

a. Compression test:

The compressive strength of concrete is tested on cubes using compression testing machine. The rate of 140 kg/cm^2/min as per IS 516: 1964 and the ultimate loads were recorded.

The bearing surface of machine was wiped off clean and the surface of the specimen was cleaned. The specimen was placed in machine and the axis of the specimen was carefully aligned at the center of loading frame. The load was applied at a constant rate of 140 kg/cm^2/min until the specimen fails and the maximum load applied on specimen was recorded.

The compressive strength of the concrete was calculated using the following formula and the results are tabulated.

$$\text{Compression strength} = \frac{P}{A}$$

Where,

P - Load in (N)

A – Area in (mm^2)

Fig.3 Experimental setup for Compressive strength test

b. Split tensile test:

Split tensile strength of concrete is tested on cylinder using compression testing machine. The split tensile strength test for cylinders was carried out as per IS 516: 1964. Specimen was kept horizontally between the loading surfaces of a universal testing machine and the load was applied until failure of the cylinder. The failure load was noted and strength was calculated using the following formula.

$$\text{Split Tensile Strength} = \frac{2P}{\pi LD}$$

Where,

P = Ultimate load (N)

L = Length of cylinder (mm)

D = Diameter of cylinder (mm)

Fig.4 Experimental Setup for Split Tensile Strength Test

c. Flexural test:

Flexural strength is measured using universal testing machine. The flexural strength is the ability of a beam or slab to resist failure in bending. It is measured by loading un-reinforced concrete beams with a span three times the depth (usually 100 x 100 x 500 mm). The flexural strength is expressed as “Modulus of rupture” in N/mm^2.Modulus of Rupture is about 12 to 20 percent of compressive strength. However, the best correlation for specific materials is obtained by laboratory tests. The specimens are subjected to external curing are tested after the 28 days.

The flexural strength test for beam was carried out as per IS 516:1964.Specimen was kept horizontally between the loading surfaces of a universal testing machine and the load was applied until failure of the cylinder. The failure load was noted and shorter length from crack to support strength was measured. Then flexural strength was calculated using the following formula.

When a ≥ 133 mm

$$R = \frac{PL}{bd^2}$$

When 110 < a ≤ 133 mm

$$R = \frac{3Pa}{bd^2}$$

Where,

R - Modulus of rupture in N/mm^2

P - Maximum Load in N

L - Span in m

a - Shorter length from crack to support in mm

b - Average width in mm,

d - Average depth in mm.

Fig.5 Experimental Setup for Flexural Strength Test

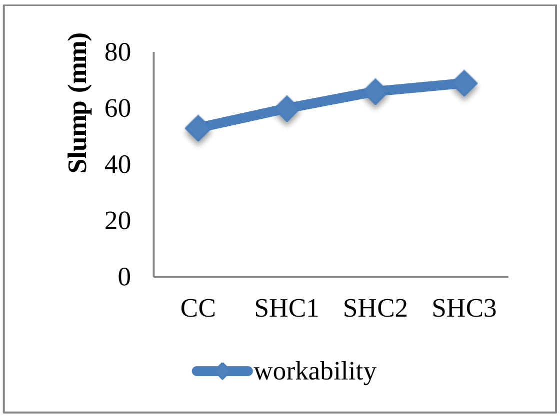
4. RESULT AND DISCUSSION

A. Workability

Graph.1.shows the variation of workability in terms of slump value. The slump values lies between 53 and 69. From the results, Among all mixes the maximum workability is obtained for SHC3specimen, whereas the workability of specimens SHC1 and SHC2 are nearer to control specimen. The observation on fresh concrete shows that there occurs little bleeding in the concrete specimen SHC3.It is found that there is an increase in slump with the increase in concentration of bacterial cells. Thus the workability of concrete is increased with the increase in bacterial concentration. The result of slump test reveals that all the concrete mixes have medium workability.

Mix	Slump (mm)
CC	53
SHC1	60
SHC2	66
SHC3	69

Table3. Slump Value of Specimens



Graph.1.Variation of Slump value

B. Compressive Strength

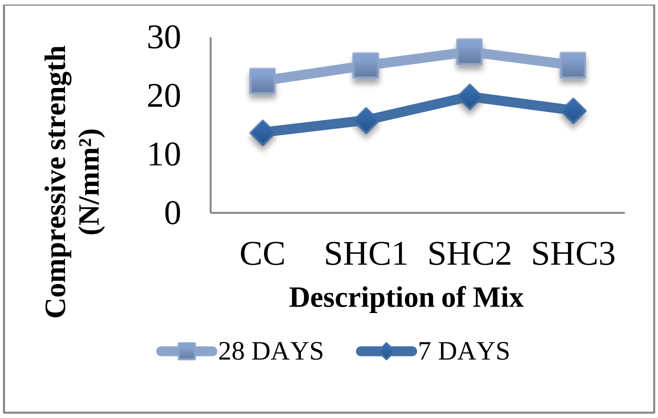
Graph.2.shows the variation of compressive strength of concrete on 7 days and 28days. The results showed that the strength of Self-healing concrete has marginally higher than the control concrete. The maximum strength is obtained for SHC2 concrete. The percentage of increment in strength of SHC2 concrete is 13.2%. The increment in strength is due to the growth of filler material within the concrete and the dead cells present in the concrete. The presence of dead cells also reduces the porosity and crack formation in concrete.

Mixes	Compressive Strength (N/mm^2)				
	1	2	3	Average	% Increase in strength
CC	13.6	13.9	13.7	13.73	-
SHC1	17.3	15.9	17.6	16.94	23.37
SHC2	20.8	19.4	19.35	19.85	44.57
SHC3	18.5	16.42	17.6	17.50	27.45

Table4. Compressive strength of concrete cubes at 7 days

Mixes	Compressive Strength (N/mm^2)				
	1	2	3	Average	% Increase in strength
CC	21.9	23.5	22.16	22.52	-
SHC1	24.6	25.3	25.5	25.13	11.58
SHC2	27.5	25.41	29.5	27.47	21.98
SHC3	26.8	24.6	24.1	25.2	11.90

Table5. Compressive strength of concrete cubes at 28 days



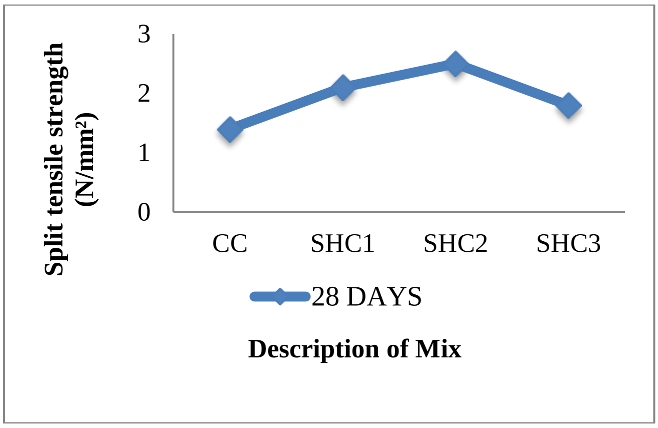
Graph.2. Variation of Compressive strength of concrete

C. Split Tensile Strength

Graph.3.shows the variation of split tensile strength of concrete. The results showed that the tensile strength of Self-healing concrete of SHC1, SHC2 and SHC3 are increased compared to the control concrete. Maximum strength is obtained on SHC2 concrete and the percentage of increment in strength is 21.4% compared with control concrete. Higher bacterial concentration in concrete leads to more decomposition of urea, which contains higher concentration of Ca^{2+}. This helps to improve the strength.

Mixes	Split tensile Strength (N/mm^2)				
	1	2	3	Average	% Increase in strength
CC	1.5	1.3	1.4	1.4	-
SHC1	2.4	1.8	2.1	2.1	50
SHC2	2.7	2.5	2.3	2.5	78.57
SHC3	1.9	1.8	1.7	1.8	28.57

Table6. Split tensile strength of cylinders for 28 days



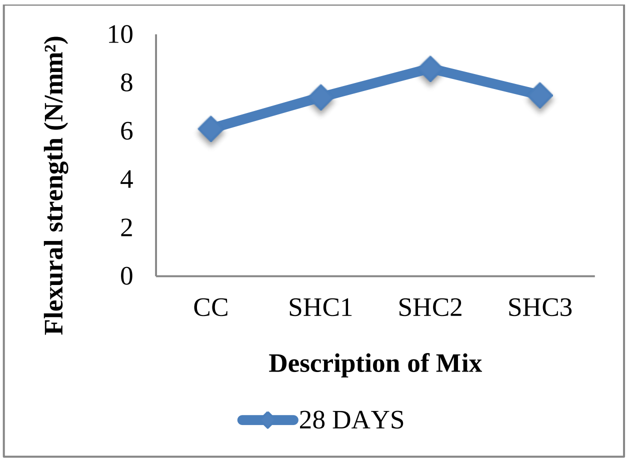
Graph.3. Variation of Split tensile strength of concrete

D. Flexural Strength

Graph.4. shows the variation of flexural strength of concrete. The percentage of increment in strength compared to control specimen is 16.04%.It is increased with the addition of bacterial cell. This was due to the reason that bacillus subtilis has more calcium precipitation to heal crack in concrete. The results showed that the flexural strength of Self-healing concrete of SHC1, SHC2 and SHC3 are increased than the control.

Mixes	Flexural Strength (N/mm^2)				
	1	2	3	Average	% Increase in strength
CC	5.8	6.2	6.3	6.1	-
SHC1	7.6	7.1	7.5	7.4	21.31
SHC2	8.7	8.4	8.7	8.6	40.98
SHC3	7.4	7.4	7.7	7.5	22.95

Tables7. Flexural strength of prisms at 28 days



Graph.4. Variation of Flexural strength of concrete

5. CONCLUSION

- Microbial concrete technology has proved to be better than many conventional technologies because of its eco-friendly nature, self-healing abilities and increase in durability of various building materials.
- The overall development of strength and durability of Self-healing concrete by using Bacillius subtilis bacteria and polyethylene fibre has investigated and compared with control concrete.
- The greatest improvement of 10^5cells/ml for all ages. The showed that a 13.2% increase in 28 day compressive strength, split tensile strength by 21.4% and flexural strength by 16.04% was achieved.
- The more $CaCO_3$ precipitations, the better the self-healing effect will be. The concentrations of bacteria and Ca^{2+} will greater the amount of precipitated $CaCO_3$.
- Polyethylene fiber can be increased its mechanical properties of the concrete.

This process results in the precipitation of substantially higher amounts of calcium carbonate inside the crack to be healed.

- The reason for this can be explained by the strictly chemical processes in the control and additional biological processes in the Self-healing concrete.
- Optimum strength is obtained on SHC2 concrete specimen. Bacillus subtilis strain can improve the characteristics of cement composites.

6. REFERENCES

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