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Strength and Durability Assessment of Bacteria Based Self Healing Concrete

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ABSTRACT: Crack formation is very common phenomenon in concrete structure which allows the water and different type of chemical into the concrete through the cracks and decreases their durability, strength and which also affect the reinforcement when it comes in contact with water, CO₂ and other chemicals. For repairing the cracks developed in the concrete, it requires regular maintenance and special type of treatment which will be very expensive. So, to overcome from this problem autonomous self-healing mechanism is introduced in the concrete which helps to repair the cracks by producing calcium carbonate crystals which block the micro cracks and pores in the concrete. The selection of the bacteria was according to their survival in the alkaline environment. The condition of growth is different for different types of bacteria. For the growth, bacteria were put in a medium containing different chemical at a particular temperature and for a particular time period. Bacteria improves the structural properties such as tensile strength, water permeability, durability and compressive strength of the normal concrete which was found by the performing different type of experiment on too many specimens had varying sizes used by different researchers for their study of bacterial concrete in comparison with the conventional concrete. So, I used Bacillus Subtilis bacteria in concrete of different cell concentrations and found optimum cell concentration by performing strength, durability and crack healing studies.

KEYWORDS: Text detection, Inpainting, Morphological operations, Connected component labelling.

I. INTRODUCTION

1.1 General

Concrete is very good material to resist the compressive load to a limit but if the load applied on the concrete is more than their limit of resisting load, it causes the strength reduction of concrete by producing the cracks in the concrete and the treatment of the cracks in very expensive. Some of the property like durability, permeability and strength of the concrete structure is also decreases. Due to increase in the permeability of the concrete the water easily pass through the concrete and come in contact with the reinforcement of the concrete structure and after some time corrosion start due to this strength of the concrete structure will decreases so it will be necessary to repair the cracks. By introduce the bacteria in concrete it producing calcium carbonate crystals which block the micro cracks and pores in the concrete. In concrete micro cracks are always avoided but to some extent they are responsible to their failure in strength. The selection of the bacteria is depend on the survive capability of bacteria in the alkaline environment. Most of the micro-organisms die in an environment with pH value of 10 or above. Strains of the bacteria genus Bacillus will be found to succeed in high alkaline environment. The bacteria survive in the high alkaline environment that formed spores comparable to the plant seeds. The spores are of very thick wall and they activated when concrete start cracking and water transude into the structure. The pH of the highly alkaline concrete lowers to the values between the range 10 to 13 where the bacterial spores become activated.

1.2 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.

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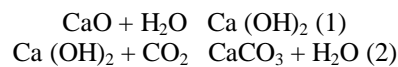
Researchers found that only the strains of bacterial genus bacillus are suitable to thrive in this high alkaline environment. It is also found that, bacillus is the only genus that is able to form spore in the hostile environment. Such spores have extremely thick cell walls that enable them to remain 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

1.3 Bacillus Subtilis Bacteria

In our study, bacterial species Bacillus 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 be able to transform soluble organic nutrients into insoluble inorganic calcite crystals which seal the cracks.

1.4 Mechanism of Self Healing

When cracks appear in a concrete structure and water starts to seep in through, the spores of the bacteria start 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 CaCO₃. The CaCO₃ solidifies on the cracked surface, thereby sealing it up.



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. It mimics the process by which bone fractures in the human body are naturally healed by osteoblast cells that mineralize to reform the bone.

II. METHODOLOGY

This deals with the details of methodology used for the study of Bacterial Concrete. The following methodology has been followed in this experimental investigation.

- Literature Survey.
- Collection of Required Raw Materials.
- Preliminary tests on cement, fine and coarse aggregate, Bacteria.
- Designing of concrete M30 Grade mix as per IS 10262-2009
- Fresh property tests were conducted for concrete without Bacteria.
- Casting and Curing of concrete specimens for finding out strength and durability characteristics without Bacteria.
- Dilution of Calcite Depositing Bacillus Subtilis Bacteria.
- PH Test on concrete specimen for the survival of bacteria.
- Fresh property tests were conducted for concrete with Bacteria.
- Casting and Curing of concrete specimens for finding out the strength and durability characteristics with Bacteria for different cell concentrations (10⁵, 10⁷, 10⁹ cells/ml)
- Creating a fault plane on Bacterial concrete and analyzing how long it will take to heal the crack effectively.
- Ultrasonic pulse velocity test for checking the effectiveness in crack closure.
- Microstructure analysis for Bacterial concrete using SEM
- Comparison of strength and durability characteristics of conventional concrete and bacterial concrete.

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III. EXPERIMENTAL TESTS AND RESULTS

3.1 Test on Bacteria

In my study, bacterial species *Bacillus 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 be able to transform soluble organic nutrients into insoluble inorganic calcite crystals which seal the cracks. The concentration of cells is measured by Hemocytometer Test and Gram Staining Method is used to determine the morphology of the bacteria strains. The test and their results obtained is as follows:

a. Hemocytometer Test:

The hemocytometer (or haemocytometer) is a counting-chamber device originally designed and usually used for counting blood cells. The hemocytometer consists of a thick glass microscope slide with a rectangular indentation that creates a chamber. This chamber is engraved with a laser-etched grid of perpendicular lines. The device is carefully crafted so that the area bounded by the lines is known, and the depth of the chamber is also known. By observing a defined area of the grid, it is therefore possible to count the number of cells or particles in a specific volume of fluid, and thereby calculate the concentration of cells in the fluid overall. I performed this test in Environmental Lab at Anna University Regional Campus, Tirunelveli. The result says that the solution contains 2×10^9 cells/ml

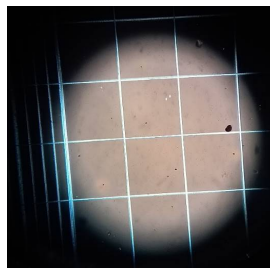


Fig. 3.1 Hemocytometer Test on Bacteria

b. Gram Staining Test:

Gram staining is a common technique used to differentiate two large groups of bacteria based on their different cell wall constituents. The Gram stain procedure distinguishes between Gram positive and Gram negative groups by coloring these cells red or violet. Gram positive bacteria stain violet due to the presence of a thick layer of peptidoglycan in their cell walls, which retains the crystal violet these cells are stained with. Alternatively, Gram negative bacteria stain red, which is attributed to a thinner peptidoglycan wall, which does not retain the crystal violet during the decoloring process. After the testing our bacteria is found as Gram positive bacteria.

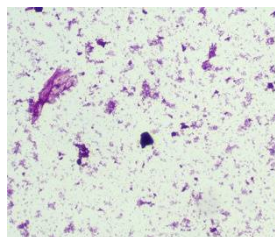


Fig. 3.2 Microscopic image of Gram Staining Plate

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3.2 Compressive Strength

The compressive strength tests of the specimens were conducted to determine the compressive strength of specimen. For each curing period, three identical specimens were prepared and the average of the strengths was reported as the compressive strength of the mix. Specimens are tested to determine the average compressive strength at the ages of 7, 14 and 28 days. All specimens were prepared, cured and tested under room temperature.

Table 3.1 Compressive Strength of Conventional and Bacterial Concrete

Specimen	7 Days Strength (mpa)	14 Days Strength (mpa)	28 Days Strength (mpa)	Average 28 Days Strength (mpa)
Conventional	23.66	35.15	39.44	39.94
	23.18	37.33	41.15	
	21.43	35.32	39.25	
10 ⁵ Cells/ml	22.96	35.82	38.28	39.04
	23.88	30.78	34.12	
	20.47	34.45	39.80	
10 ⁷ Cells/ml	25.02	39.69	44.10	43.24
	26.35	38.53	41.70	
	26.46	39.52	43.92	
10 ⁹ Cells/ml	23.72	33.86	38.77	38.64
	22.57	34.89	39.54	
	23.26	35.58	37.63	

3.3 pH Test on Concrete

pH test on concrete is one of the vital test in bacterial concrete because if the pH value of concrete exceeds 13, the bacteria will not survive inside the concrete. To confirm the survival of bacteria inside the concrete this test should be conducted. The pH value of Conventional and Bacterial concrete is 12.

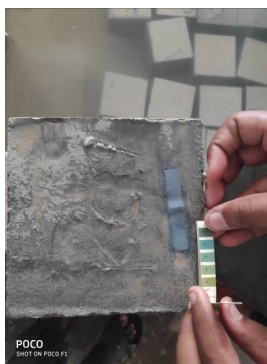


Fig. 3.3 pH Test

3.4 Creation of Fault Plane Using Leaf Spring Machine

Creating cracks on the beams of size 100x100x1000mm using Leaf Spring Machine for the study of Crack closure. The Maximum Load applied on the beams were 12 KN. The generated cracks size varies from 0.1 to 1.5mm. The cracked Beams are kept under normal room temperature for about 40 days to observe crack closure.

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Fig. 3.4 Creating Fault Plane Using Leaf Spring

3.5 Ultrasonic Pulse Velocity Test

An ultrasonic pulse velocity (UPV) test is an in-situ, nondestructive test to check the quality of concrete. In this test, the quality of concrete is assessed by measuring the velocity of an ultrasonic pulse passing through a concrete structure. This test is conducted by passing a pulse of ultrasonic through concrete to be tested and measuring the time taken by pulse to get through the structure. Higher velocities indicate good quality and continuity of the material, while slower velocities may indicate concrete with many cracks or voids. This test is carried out on the 4th and 42nd day after the generation of crack on the beam specimen. The obtained velocities are listed below., Based on the results, the velocities increased with time for the bacterial concrete. It shows that the internal cracks are closed.

Table 3.2 UPV Test Results

Specimen Code:	Velocity Obtained (m/s) after 4 th day of Cracking	Velocity Obtained (m/s) after 42 nd day of Cracking
Conventional	1433	1434
10 ⁵ Cells/ml	1617	2234
10 ⁷ Cells/ml	720	2671
10 ⁹ Cells/ml	3656	3845



Fig. 3.4 UPV test

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3.6 SEM Analysis

Scanning Electron Microscope is a type of electron microscope that depicts the sample surface through the scan process by using a high-energy electrons beam in a raster scan pattern. Electron interaction with atoms of the sample helps in generating a signal that is most frequently used to study sample's surface topography, composition and other properties such as electrical conductivity. It is capable of generating high resolution images, which allow to examine the characteristics with a high magnification and detail. SEM has a large depth of field, which can focus on the more samples at a time and produce good shadow of three dimensional samples. SEM also produces high-resolution images, which means approaching shadows that can be tested with high magnification. Higher magnification, dark field, greater resolution, and composition & information of crystallography are the important features of SEM. Comparing the Figures 3.5 and 3.6, we can observe that the white particles appears on the Fig 3.5 are the Calcium Carbonate crystals formation.

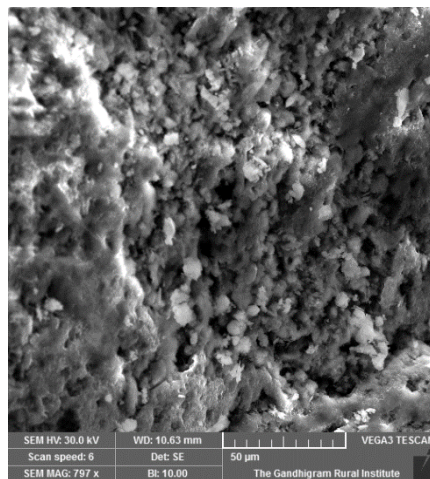


Fig. 3.5 10^7 Cell Bacterial Concrete

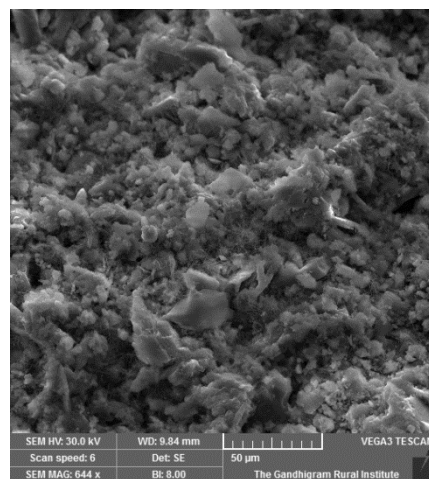


Fig.3.6 Conventional Concrete

3.7 Durability Studies

Durability of the concrete is defined as the capability of concrete to resist weathering action, chemical attack and abrasion while maintaining its desired engineering properties. Factors affecting durability of concrete are cement content, compaction, curing, cover, Permeability.

The following durability tests were studied:

- a) Water absorption
- b) Acid resistance

3.7.1 Water absorption

For water absorption test the cylinder size of 100mm dia and 50mm height was used. After Demolding the specimen are immersed in a water for 28 days. After 28 days of curing the specimen were taken out to measure saturated weight (w_2). Thus the specimen were dried in oven at a temperature of 105o C for 72 hours and taken it as an oven dried weight (w_1).

The water absorption was calculated as: $(w_2 - w_1) / w_1 \times 100$

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Table 3.3 Water Absorption Test Results

Specimen Code	Saturated weight (g)	Oven dried weight (g)	% of water absorption
Conventional	938	890	5.11
10 ⁵ Cells/ml	930	887	4.62
10 ⁷ Cells/ml	920	878	4.56
10 ⁹ Cells/ml	927	881	4.96

3.7.2 Acid Resistance

Acid resistance test was performed on Concrete cubes of size 50mm × 50mm × 50mm were cast and stored in a place at room temperature for 24 hours and then the specimens were demolded and kept for curing in water for 28 days and Specimen were taken out placed in room temperature and weight was taken as (w1) . After 28 days of curing, the specimens were taken out and allowed to dry for one day. Weights of the cubes were taken as (w2). Sulphuric acid solutions with 0.3 normality per litre were prepared in acid- resistant tanks. The 0.3 Normality H₂SO₄ water solution (8.24 mL/litre water). The percentage of weight loss were calculated. The acid resistance is calculated as

$$(w2-w1) / w1 \times 100$$

Table 3.4 Acid Resistance Test Results

Specimen Code	Before 28 days (g)	After 28 days (g)	% of weight loss
Conventional	325	319	1.84
10 ⁵ Cells/ml	318	314	1.25
10 ⁷ Cells/ml	327	321	1.83
10 ⁹ Cells/ml	308	304	1.30

IV. CONCLUSION

Based on the experimental results, the following conclusions are made.

1. The Bacillus subtilis bacteria plays a significant role in increasing compressive strength of concrete.
2. From the durability studies, the bacterial concrete results are almost same as that of the conventional concrete.
3. Bacterial concrete exhibited lower rate of water absorption than conventional concrete. This is due to the bacteria induced formation of Calcium Carbonate in the pores present in concrete, leading to a lesser voids and hence a lesser permeability.
4. From the UPV Test Results, it is found that the internal cracks are closed for all Bacterial Concrete, Especially for 10⁷ cells/ml concentration, the rate crack healing is more.
5. From the SEM Analysis, it is confirmed that the formation of calcium carbonate crystals on the concrete to seal the micropores.
6. The Optimum cell concentration was found – 10⁷ cells/ml
7. The study accomplishes that these of bacteria (*Bacillus Subtilis*) in concrete enhances its strength and durability hence using this type of bacteria for self-healing mechanism in concrete can produce cost effective strong or durable structures

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