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Experimental Study on Self- Healing Concrete Using Bacteria - Bacillus Subtilis

A PROJECT REPORT

submitted by

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The APJ Abdul Kalam Technological University

in partial fulfilment of the requirements for the award of the Degree

of

MASTER OF TECHNOLOGY

In

STRUCTURAL ENGINEERING AND CONSTRUCTION MANAGEMENT

(CIVIL ENGINEERING)

DEPARTMENT OF CIVIL ENGINEERING
INDIRA GANDHI INSTITUTE OF ENGINEERING &
TECHNOLOGY, KOTHAMANGALAM
APRIL 2026

DECLARATION

I undersigned hereby declare that the project report “Experimental study on Self - Healing Concrete using Bacteria – Bacillus Subtillis”, submitted for partial fulfilment of the requirements for the award degree of Master of Technology of the APJ Abdul Kalam Technological University, Kerala is a bonafide work done by me under supervision of Asst Prof. Geethika G Pillai. This submission represents my ideas in my own words and where ideas or words of others have been included, I have adequately and accurately cited and referenced the original sources. I also declare that I have adhered to ethics of academic honesty and integrity and have not misrepresented or fabricated any data or idea or fact or source in my submission. I understand that any violation of the above will be a cause for disciplinary action by the institute and/or the University and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been obtained. This report has not been previously formed the basis for the award of any degree, diploma or similar title of any other University.

Place: Kothamangalam

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DEPARTMENT OF CIVIL ENGINEERING

INDIRA GANDHI INSTITUTE OF ENGINEERING AND TECHNOLOGY, KOTHAMANGALAM

CERTIFICATE

This is to certify that the report entitled, “**EXPERIMENTAL STUDY ON SELF- HEALING CONCRETE USING BACTERIA – BACILLUS SUBTILIS**” submitted by **SREEJITH K BABU(IGW24CESC03)** to the APJ Abdul Kalam Technological University in partial fulfilment of the requirements for the award of the Degree of Master of Technology in Structural Engineering and Construction Management (Civil Engineering) is a bonafide record of the project work carried out by him under my guidance and supervision. This report in any form has not been submitted to any other University or Institute for any purpose.

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First, I would like to thank the almighty for the divine grace bestowed on me to complete this Project.

I Express my heartful thanks to Dr. S Senthilkumar, Principal, Indira Gandhi Institute of Engineering and Technology for granting me the permission to do the project and also I express my sincere gratitude to Asst Prof. Geethika G Pillai, Department of Civil Engineering, Indira Gandhi Institute of Engineering and Technology, Kothamangalam for her timely guidance and support for taking up this project work and Asst Prof. Geethika G Pillai, Head of Civil Engineering Department, Indira Gandhi Institute of Engineering and Technology, Kothamangalam for their cooperation and constant encouragement. The help and support rendered by all the staff, teachers and students of M.Tech section of Civil Engineering Department of Indira Gandhi Engineering and Technology was also valuable in making this report.

SREEJITH K BABU

ABSTRACT

The aim of this project is the development of a new type of concrete in which integrated bacteria promote self-healing of cracks. Concrete is the most popular construction material. But its low tensile strength makes it prone to cracking, which will decrease the service life of concrete structures. Now self healing of cracks has become a hot topic because it is more economical, convenient and smart, with a great potential in practical application. Concrete structures usually show self-healing capacity, i.e. the ability to heal or seal freshly formed micro-cracks. In this project a new type of self healing concrete in which bacteria mediate the production of minerals which rapidly seal freshly formed cracks, a process that concomitantly decreases concrete permeability, and thus better protects embedded steel reinforcement corrosion.

In this study spores of specific alkali-resistant bacteria related to the genus Bacillus were added to the concrete mixture as self-healing agent and the newly produced compound such as calcium carbonate based mineral precipitated that is Calcium Lactate is added. This paper focuses on the use of bacteria for healing cracks on concrete that can be identified by using environmental scanning electron microscope. It is expected that further development of this new type of self-healing concrete will result in a more durable and moreover sustainable concrete which will be particularly suited for application in wet environment where reinforcement corrosion tends to impede durability of traditional concrete constructions. The bacteria based concrete proposed here could substantially reduce maintenance, repair and premature structure degradation which not only saves money but also reduces atmospheric CO_2 emissions considerably as less cement is needed for this type of self-healing concrete.

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CHAPTER 1

INTRODUCTION

1.1 PROJECT OVERVIEW

Concrete structures usually show some self healing capacity, i.e. the ability to heal or seal freshly formed micro cracks. This property is mainly due to the presence of non-hydrated excess cement particles in the materials matrix, which undergo delayed or secondary hydration upon reaction with ingress water. In this project a new type of self healing concrete in which bacteria mediate the production of minerals which rapidly seal freshly formed cracks, a process that concomitantly decreases concrete permeability, and thus better protects embedded steel reinforcement from corrosion. Self Healing Concrete as a new method for crack control and enhanced service life in concrete structure. This concept is one of the maintenance-free methods which, apart from saving direct costs for maintenance and repair, reduce the indirect cost.

1.2 SELF HEALING CONCRETE

The mechanism of crack healing in bacterial concrete presumably occurs through metabolic conversion of calcium lactate to calcium carbonate what results in crack-sealing. It is expected that further development of this new type of self-healing concrete will result in a more durable and moreover sustainable concrete which will be particularly suited for applications in wet environments where reinforcement corrosion tends to impede durability of traditional concrete constructions.

Jonker and Schlangen (2009) studied that the principle mechanism of bacterial crack healing, which is the bacteria themselves act largely as a catalyst, and transform a precursor compound to a suitable filler material. However, when bacteria were directly added to the concrete mixture, their life time limited to a few months only. Because continuing cement hydration results in matrix pore diameter smaller than 1µm size which cause bacterial cell collapse. To protect the bacterial spores, a two component biochemical healing agent composed of bacterial spores and a suitable organic bio-cement precursor compound is used. The self-healing process in bacterial concrete is much more efficient due to the active metabolic conversion of calcium lactate by the present bacteria:

$$Ca(C_3H_5O_2) + 7O_2 \quad CaCO_3 + 5CO_2 + 5H_2O$$

This process does not only produce calcium carbonate directly but also indirectly via the reaction of on-site produced CO_2 with calcium hydroxide present on the crack surface. In the latter case, calcium hydroxide does not dissolve and diffuse away from the crack surface, but instead reacts directly on the spot with local bacterially produced CO_2 to additional calcium carbonate.

Self healing bacterial concrete can be used for such as tunnel-lining, structural basement walls, highway bridges, concrete floors and marine structures

1.3 SELF HEALING BACTERIA

The “Bacterial Concrete” can be made by embedding bacteria in the concrete that are able to constantly precipitate calcite. This phenomenon is called microbiologically induced calcite precipitation. Calcium carbonate precipitation, a widespread phenomenon among bacteria, has been investigated due to its wide range of scientific and technological implications. Calcite formation by Bacillus subtilis is a model laboratory bacterium, which can produce the calcite precipitates on suitable media supplemented with a calcium source. A common soil bacterium, Bacillus subtilis, was used to induce $CaCO_3$ precipitation. The basic principles for this application are that the microbial urease hydrolyzes urea to produce ammonia and carbon dioxide, and the ammonia released in surroundings subsequently increases pH, leading to accumulation of insoluble $CaCO_3$.

Bacillus subtilis is a gram positive bacteria It can be grown easily in labs in minimum cost. It is a non pathogenic bacteria, Ie it doesn’t harm humans, so safe for use.

1.4 OBJECTIVE AND SCOPE OF THIS STUDY

The objective of the present investigation is to obtain the performance of the concrete by the microbiologically induced special growth/filler. One such thought has lead to the development of a very special concrete known as Bacterial Concrete where bacteria is induced in the mortars and concrete to heal up the faults. Researchers with different bacteria's proposed different bacterial concrete's. Here an attempt was made by using the bacteria "Bacillus subtilis". This study showed a significant increase in the compressive strength was observed due to the addition of bacteria From Scanning Electron Micrography analysis, it is noted that pores were partially filled up by material growth with the addition of the bacteria.

1.5 ADVANTAGES OF SHC

- Incorporation of the agent in the concrete will be relatively cheap as well as easy when the aggregate is immobilized in porous light weight aggregate prior to addition to the concrete mixture.
- The self healing bacterial concrete helps in reduced maintenance and repair costs of steel reinforced concrete structures.
- Oxygen is an agent that can induce corrosion, as bacteria feeds on oxygen tendency for the corrosion of reinforcement can be reduced.
- Self healing bacteria can be used in places where humans find it difficult to reach for the maintenance of the structures. Hence it reduces risking of human life in dangerous areas and also increases the durability of the structure.
- Formation of crack will be healed in the initial stage itself thereby increasing the service life of the structure than expected life

CHAPTER 2

LITERATURE SURVEY

2.1. BACTERIA-BASED SELF-HEALING CONCRETE - H. M. Jonkers

In the present study the crack healing capacity of a specific bio-chemical additive, consisting of a mixture of viable but dormant bacteria and organic compounds packed in porous expanded clay particles, was investigated. The mechanism of crack healing in bacterial concrete presumably occurs through metabolic conversion of calcium lactate to calcium carbonate what results in crack-sealing. It is expected that further development of this new type of self-healing concrete will result in a more durable and moreover sustainable concrete which will be particularly suited for applications in wet environments where reinforcement corrosion tends to impede durability of traditional concrete constructions.

Main objective of this study was to establish whether bacteria immobilized in porous expanded clay particles prior to concrete mix addition can substantially increase bacterially-mediated self-healing in comparison to direct unprotected addition of bacteria to the concrete mixture as was done in a previous study. The results of this study appear promising as 100% healing (6 out of 6 tested specimens) of cracks induced in 2 months cured bacterial specimens occurred in contrast to 33% healing (2 out of 6 tested specimens) of control specimens. Tests showed furthermore that bacterial spore viability increased from 2 to more than 6 months when added immobilized (protected) inside porous expanded clay particles compared to direct (unprotected) addition to the concrete mixture.

2.2 APPLICATION OF BACTERIA AS SELF-HEALING AGENT FOR THE DEVELOPMENT OF SUSTAINABLE CONCRETE

HenkM.Jonkers,ArjanThijssen,GerardMuyzer,OguzhanCopuroglu,ErikSchlangen

In this study we investigated the potential of bacteria to act as self-healing agent in concrete,i.e.their ability to repair occurring cracks. A specic group of alkali-resistant spore-forming bacteria related to the genus Bacillus was selected for this purpose. Bac-teria lspores directly added to the cement paste mixture remainedviableforaperiodupto4months.A continuous decrease inporesize diameter during cement stone setting probably limited life span of spores as pore widths decreased below1m,the typical size of Bacillus spores. However, asbacterial cement stone specimens appeared to produce substantially more crack-plugging minerals than control specimens, the potential application of bacterials pores as self-healing agent appears promising.

The main objective of this study was to establish whether bacteria in corporate in the cement stone matrix could act as self-healing agent to catalyze the process of autonomous repair of freshly formed cracks.

In conclusion we can state that alkali-resistant spore-forming bacteria related to the genus Bacillus represent promising candidates for application as self-healing agent in concrete and probably other cement-based materials. We found evidence that cement stone incorporated bacterial spores are able to convert concomitantly in corporate calcium lactate to calcium carbonate-based minerals upon activation by crack ingress water. Our continuing research focuses on obtaining a substantially increased time-related functionality as well as on the quantication of the self-healing capacity and thus increased durability of bacteriabased self-healing concrete.

2.3 SELF HEALING CONCRETE A SUSTAINABLE FUTURE

Simon Dunn, BEng (hons), Cardiff University

The cement industry is a major global contributor to world CO2 emissions (8% in 2008). A major cause of this high percentage is the durability issues associated with concrete. In recent years a new breed on concrete that has the ability to heal cracks which are a major cause of these durability issue has been developed called Self-healing Concrete. This paper will introduce this new breed of concrete in its various forms, with particular attention paid to the form which incorporates shape memory polymers as the healing mechanism. The shape memory polymer-cementitious composite has been developed at Cardiff University and is the subject of a patent pending. The paper will focus on the experimental and numerical work undertaken to understand the material behaviour of shape memory polymers and how this can be applied to the cementitious composite. A numerical model has been developed and the successful comparison to experimental data will be presented.

The development of self-healing cementitious composites is a relatively new area of research which to this date has focused both on the natural ability of hydrates to heal cracks over time (autogenic) and artificial means of crack repair that are man-made inclusions (autonomic) (7). The motivation for such work is to increase the durability of concrete.

A series of experimental studies have been presented which highlight Aerovac Shrinktite PET as a suitable polymer for the proposed self healing concrete system. The PET generates a shrinkage stress of 32.5MPa which far surpasses the required 20MPa. The stress is also achieved at a suitable temperature of 90°C.

2.4 BIOENGINEERED CONCRETE - A SUSTAINABLE SELF-HEALING CONSTRUCTION MATERIAL.

M.V. Seshagiri Rao, V. Srinivasa Reddy, M. Hafsa, P. Veena and P. Anusha

In the present paper, an attempt is made to incorporate dormant but viable bacteria in the concrete matrix which will contribute to the strength and durability of the concrete. Water which enters the concrete will activate the dormant bacteria which in turn will give strength to the concrete through the process of metabolically mediated calcium carbonate precipitation. Concrete, due to its high internal pH, relative dryness and lack of nutrients needed for growth, is a rather hostile environment for common bacteria, but there are some extremophilic spore forming bacteria may be able to survive in this environment and increase the strength and durability of cement concrete. Overview of development of bioengineered concrete using bacterial strain Bacillus subtilis JC3 and its enhanced mechanical and durability characteristics will be briefly described in this paper.

An alkaliphilic aerobic microorganism bacillus subtilis JC3 is induced into cement mortar samples at various cell concentrations in suspension along with the mixing water. The greatest improvement in compressive strength occurs at cell concentrations of 10^5 cells/ml for all ages.

The study showed that a 25% increase in 28 day compressive strength of cement mortar was achieved. The strength improvement is due to growth of filler material within the pores of the cement–sand matrix as shown by the scanning electron microscopy. Scanning Electron Microscopy (SEM) also confirmed the role of microbiologically induced precipitation within the mortar matrix.

2.5 CRACK SELF-HEALING BEHAVIOR OF CEMENTITIOUS COMPOSITES INCORPORATING VARIOUS MINERAL ADMIXTURES.

Tae-Ho Ahn and Toshiharu Kishi

This study aims to develop and apply self-healing concrete as a new method for crack control and enhanced service life in concrete structure. This concept is one of the maintenance-free methods which, apart from saving direct costs for maintenance and repair, reduces the indirect costs – a saving generally welcomed by contractors. In this research, the self-healing phenomenon of autogenous healing concrete using geo-materials for practical industrial application was investigated. Moreover, a self-healing concrete was fabricated by ready-mixed car in a ready-mixed concrete factory, then used for the construction of artificial water-retaining structures and actual tunnel structures. The results show that the crack of concrete was significantly self-healed up to 28 days re-curing. Crack-width of 0.15mm was self-healed af-ter re-curing for 3 days and the crack width decreased from 0.22 mm to 0.16 mm after re-curing for 7 days. Furthermore, it was almost completely self-healed at 33 days. It was founded that this phenomenon occurred mainly due to the swell-ing effect, expansion effect and re-crystallization.In this research, it was found that the alkaline activa-tion of Geo-material A in the presence of calcium hy-droxide led to the formation of an amorphous calcium aluminosilicate between cracks, which had the same characteristics as a geopolymeric gel in a highly alkaline environment

In this study, the new method of self-healing design to repair cracks in cracked concrete was suggested, and the self-healing properties of cracked concrete using various mineral admixtures were investigated.

2.6 STUDIES ON PERMEABILITY OF SELF-HEALING BUILT-IN BACTERIA CONCRETE

Srinivasa Reddy V, Jyothi Kumar K S, Seshagiri Rao M V, Sasikala Ch

Permeability is the most crucial internal factor in concrete durability. The durability of a concrete is closely related to its permeability. The permeability dictates the rate at which aggressive agents can penetrate to attack the concrete and the steel reinforcement. Water can be harmful for concrete, because of its ability to leach calcium hydroxide from the cement paste, to carry harmful dissolved species such as chlorides or acids into the concrete, to form ice in large pores in the paste, and to cause leaching of compounds from the concrete. Water absorption, sorptivity and especially during early stages it is cause for the cement water permeability measurement are some methods to determine the water penetrability of concrete. A triaxial cell permeability apparatus and method for determining water permeability of concrete are presented in this paper.

Test results indicated that bacterial concrete is highly impermeable than normal concrete. Permeability measurement techniques and durability modeling are based on the Darcy equation for permeability based on measurement of flow rate, and the Valetta equation for permeability based on measurement of penetration depth and time. Bacteria built-in concrete works on the phenomenon of microbiologically induced calcite precipitation. regulates the speed of aggressive water penetration into the Calcite crystals formed, due to microbial activities of bacteria Bacillus subtilus JC3, seals the cracks and pores in concrete and enhances the strength and durability of concrete by making concrete impermeable to transport different fluids or gases, like water, chlorides, sulfates or oxygen.

2.7PERFORMANCE OF STANDARD GRADE BACTERIAL (BACILLUS SUBTILIS) CONCRETE

S.Sunil Pratap Reddy , M.V.Seshagiri Rao , P.Aparna and Ch. Sasikala

The objective of the present investigation is to obtain the performance of the concrete by the microbiologically induced special growth/filler. One such thought has lead to the development of a very special concrete known as Bacterial Concrete where bacteria is induced in the mortars and concrete to heal up the faults. Researchers with different bacteria's proposed different bacterial concrete's. Here an attempt was made by using the bacteria "Bacillus subtilis". Calcite formation by Bacillus subtilis is a model laboratory bacterium, which can produce calcite precipitates on suitable media supplemented with a calcium source. Cement mortar cubes with four different cell concentrations were cast and control specimen was also cast.

This study showed a significant increase in the compressive cells per strength was observed due to the addition of bacteria for a cell concentration of 10^5ml of mixing water. From Scanning Electron Micrography analysis, it is noted that pores were partially filled up by material growth with the addition of the bacteria. Reduction in pore due to such material growth will obviously increase the material strength. Concrete cubes with and without addition of bacteria were cast and it is observed that there is an improvement in the compressive strength for the cubes with the addition of bacteria. Concrete cylinders with and without addition of bacteria were cast and it is observed that there is an improvement in the Split tensile strength for the cylinders with the addition of bacteria. From the durability studies, the percentage weight loss and percentage strength loss SO revealed that Bacterial concrete has less weight and strength losses than the with 5% H_2SO_4conventional concrete and it also revealed that bacterial concrete is more durable in terms of "Acid Durability Factor" and "Acid Attack Factor" than conventional concrete.

2.8 POTENTIAL APPLICATION OF BACTERIA TO IMPROVE THE STRENGTH OF CEMENT CONCRETE.

C. C.Gavimath ,B.M. Mali ,V.R. Hooli ,J. D. Mallpur , A. B. Patil ,D. P. Gaddi, , C.R.Ternikar and B.E.Ravishankera

The objective of the present investigation is to study the potential application of bacterial species i.e.B.sphaericus to improve the strength of cement concrete. Here we have made an attempt to incorporate dormant but viable bacteria in the concrete matrix which will contribute to the strength of the concrete.Water which enters the concrete will activate the dormant bacteria which in turn will give strength to the concrete through the process of metabolically mediated calcium carbonate precipitation. Concrete, however, is due to its high internal pH, relative dryness and lack of nutrients needed for growth, a rather hostile environment for common bacteria, but there are some extremophilic spore forming bacteria may be able to survive in this artificial environment and increase the strength and durability of cement concrete. In this study we found that incorporation of spore forming bacteria of the speceies Bacillus will not negatively affect the compressive and split tensile strength of the cement concrete.

The main objective of this study was to investigate whether bacteria can potentially act as a self healing agent in concrete. The bacteria tested are known to be alkali resistant i.e. they grow in natural environments characterised by a reletively high pH (10-11).

2.9 SELF-HEALING IN CEMENTITIOUS MATERIALS—A REVIEW

Kim Van Tittelboom and Nele De Belie

Concrete is very sensitive to crack formation. As wide cracks endanger the durability, repair may be required. However, these repair works raise the life-cycle cost of concrete as they are labor intensive and because the structure becomes in disuse during repair. In 1994, C. Dry was the first who proposed the intentional introduction of self-healing properties in concrete. In the following years, several researchers started to investigate this topic. The goal of this review is to provide an in-depth comparison of the different self-healing approaches which are available today. Among these approaches, some are aimed at improving the natural mechanism of autogenous crack healing, while others are aimed at modifying concrete by embedding capsules with suitable healing agents so that cracks heal in a completely autonomous way after they appear. In this review,special attention is paid to the types of healing agents and capsules used. In addition, the various methodologies have been evaluated based on the trigger mechanism used and attention has been paid to the properties regained due to self-healing.

It should become clear from this review paper that self-healing concrete is a truly interdisciplinary research topic involving microbiology, chemistry, material science, civil engineering, etc. In order to develop a practically applicable self-healing approach cross-disciplinary cooperation and communication between researchers with different expertise will be of utmost importance.

2.10 BACTERIA-BASED SELF-HEALING CONCRETE – AN INTRODUCTION

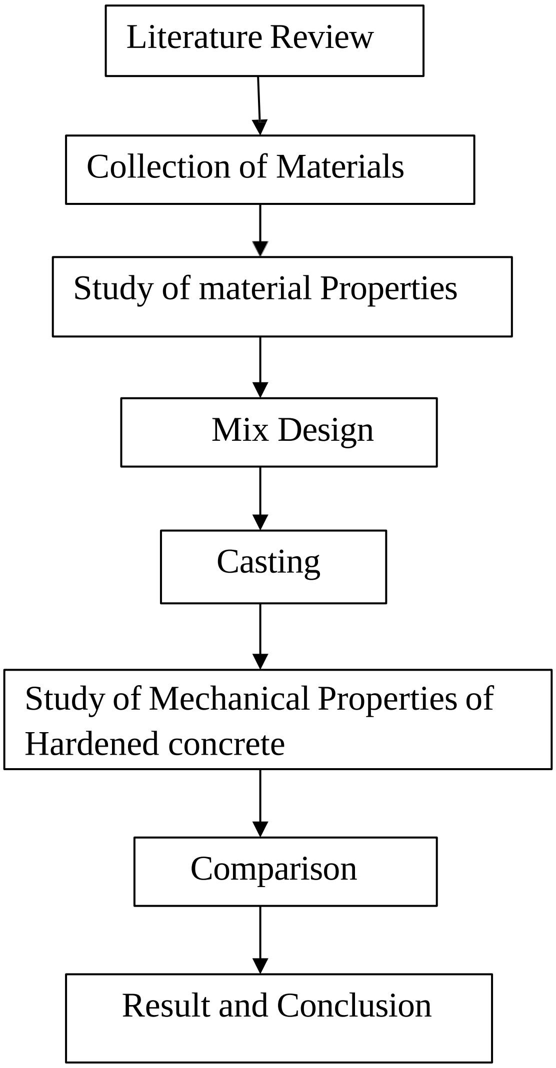
Renée M. Mors, Henk M. Jonkers

Crack formation in concrete is common, but a typical phenomenon related to durability. Percolation of cracks may lead to leakage problems or ingress of deleterious materials, causing deterioration of the concrete matrix or corrosion of embedded steel reinforcement. Durability can be enhanced by preventing further ingress of water and other substances. In recent years a bacteria-based self-healing concrete is being developed to extend the service life. A two component healing agent is added to the concrete mixture. The agent consists of bacteria and an organic mineral precursor compound. Whenever cracks occur and water is present the bacteria become active and convert the incorporated organic com-pounds into calcium carbonate, which precipitates and is able to seal and block cracks. This paper aims to review the development of bacteria-based self-healing concrete, introducing the proposed healing system.

To the concrete mixture a healing agent is added, consisting of two components immobilized in expanded clay particles. Due to bacterial activity a calcium carbonate layer is deposited on the crack surface, sealing and blocking entrance to deteriorating substances. Further research and development is needed in order to make the material ready for application in practice. The system currently available may limit the field of application. Addition of a substantial quantity of light weight aggregates not only affects material properties, it can also impose economic restraints. Since potential advantages are mainly anticipated in reduction of costs for maintenance and repair and service life extension of concrete structures, the self-healing material needs to be cost efficient and durable.

CHAPTER 3 MEHODOLOGY

3.1 PROGRAMME CHART



3.2 MATERIALS USED

The material that are used in the production of self Healing of Concrete using bacteria are

1. Cement
2. Fine aggregate
3. Coarse aggregate
4. Bacillus(Bacteria)
5. Water

3.2.1 CEMENT

Cement is a binding material in concrete which binds the other material to form a compact mass. Generally OPC is used for all engineering construction work. The specific gravity of all grades of OPC is 3.15. OPC is available in three grades. In this project work, 53 grades OPC cement conforming to IS: 12269 is used for experimental study. The typical content of cement is 350 – 450 KG/m^3 more than 500 Kg/m^3 cement can be dangerous and increase the shrinkage. Less than 350 Kg/m^3 may only be suitable with the inclusion of other finer filler, such as fly ash, pozzolanic, etc. The properties of cement have been determined by the standard tests conducted according to IS 403/1968. It conforms to IS specification and test result are given below.

- Standard consistency: 28.6 %
- Initial setting time: 260 minutes
- Final setting time: 435 minutes
- Compressive strength at 3 days: 22.08 N/mm^2
- Compressive strength at 7 days: 24.66 N/mm^2
- Compressive strength of 28 days: 35.64 N/mm^2

3.2.2 FINE AGGREGATE

Aggregates are inert granular materials such as sand, gravel, or crushed stone that, along with water and Portland cement, are an essential ingredient in concrete. Aggregates strongly influence concrete’s freshly mixed and hardened properties, mixture proportions, and economy, consequently, selection of aggregates is an important process. Although some variation in aggregate properties is expected, characteristics that are considered include:

- Grading
- Durability
- Particle shape and surface texture
- Abrasion and skid resistance
- Unit weights and voids
- Absorption and surface moisture

Locally available clean, well-graded, natural river sand having fineness modulus of 2.89 conforming to IS 383-1970 was used as fine aggregate.

3.2.3 COARSE AGGREGATES

Nominal size 20mm as per IS: 383-1970 Table. The maximum size of coarse aggregate is generally limited to 20mm. Coarse aggregate has been obtained by blending aggregates of nominal size 20mm, 12.5mm, and 6mm is desirable for structures having congested reinforcement Corresponds to recommended. Well graded cubical or rounded aggregates are desirable. Aggregate should be having uniform quality with respect to shape and grading. Grading may done as per IS 383/1970. The properties of the material are as follows.

- Specific Gravity:2.77%
- Flakiness Index: 12.50%
- Elongation Index: 24.5%

3.2.4 WATER

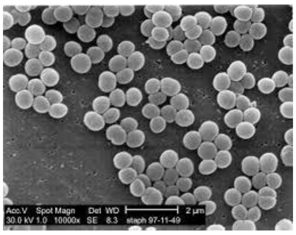
It is generally stated that the water fit for potable drinking and clean was used for both mixing and curing of concrete specimens.

3.2.5 BACILLUS

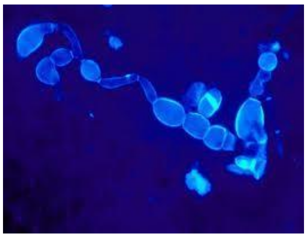
Bacillus subtilis is a gram positive bacteria It can be grown easily in labs in minimum cost. It is a non pathogenic bacteria, Ie it doesn’t harm humans, so safe for use.

Cement and water have a pH value of up to 13 when mixed together, usually a hostile environment for life, most organisms die in an environment with a pH value of 10 or above. In order to find the right microbes that thrive in alkaline environments can be found in natural environments, such as alkali lakes in Russia, carbonate-rich soils in desert areas of Spain and soda lakes in Egypt. Strains of endolithic bacteria of genus Bacillus were found to thrive in this high-alkaline environment. These bacteria were grown in a flask of water that would then be used as the part of the water mix for the concrete. Different types of bacteria were incorporated into a small block of concrete.

Each concrete block would be left for two months to set hard. Then the block would be pulverized and the remains tested to see whether the bacteria had survived. It was found that the only group of bacteria that were able to survive were the ones that produced spores comparable to plant seeds. They are namely bacillus pasturii, bacillus filla and bacillus cohnii.

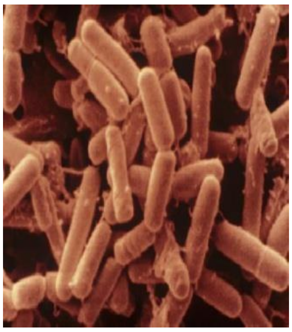


3.2.5(a) Bacillus cohnii



3.2.5(b)Bacillus filla

3.2.5(c)Bacillus parturii



3.2.5(d) Bacillus subtilis

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. They would become activated when the concrete starts to crack, food is available, and water seeps into the structure. This process lowers the pH of the highly alkaline concrete to values in the range (pH 10 to 11.5) where the bacterial spores become activated.

3.3 MATERIAL TEST

3.3.1 TEST ON CEMENT

3.3.1.1 FINENESS TEST OF CEMENT

1OO gram of cement is taken in a standard IS sieve no 90µ. The material is sieved continuously for minutes using sieve shaker. The residue left on the sieve is weighed

Table 3.3.1.1 Result of Fineness modulus of cement

SL.NO	OBSERVATION	TRIAL-1 (kg)	TRIAL-2 (kg)	TRIAL-3 (kg)
1.	Weight of sample taken	100	100	100
2.	Weight ofmaterial retained after sieving no 90µ	1.9	1.7	2.0
3.	% of residue left on the sieve no 90µ	1.7	1.7	2.0

$$\text{Percentage of residue left on sieve} = \frac{\text{weight retained}}{\text{Weight taken}} \times 100$$

$$= \frac{1.8}{100} \times 100$$

Fineness modulus of cement = 1.8

3.3.1.2 SPECIFIC GRAVITY OF CEMENT

The dry pycnometer is weighed as W_1 kg. The pycnometer is filled with distilled water and weighed as W_2 kg. TheWeight of pycnometer, with kerosene W_3 kg., pycnometer is dried and filled with cement and kerosene and weighed as W_4 kg. Weight of cement W_5.

Table 3.3.1.2 Result of Specific Gravity of Cement

SL.NO	**Description**	**Trail 1**	**Trail 2**	**Trail 3**
1.	Weight of empty Pycnometer (W_1)kg	25	25	25
2.	Weight of pycnometer + Water (W_2)kg	76	75	76
3.	Weight of pycnometer + Kerosene (W_3)kg	69	68	70
4.	Weight of pycnometer + Kerosene + Cement (W_4)kg	83	81.5	83
5.	Weight of Cement (W_5)kg	20	21	20
	Specific Gravity	3.33	3.01	2.86

$$\text{Specific gravity of Cement} = \frac{W5}{W5+(W3-W2)}$$

Specific gravity of Cement = 3.06

3.3.1.3 CONSISTENCY TEST

This method is used to determine the amount of water required to prepare hydraulic cement paste with normal consistency, as required for certain standard tests. The principle of the standard consistency of cement is that consistency at which the Vicat plunger penetrates to a point 5-7 mm from the bottom of Vicat mould.

Table 3.3.13 consistency of cement

Trial 1	Weight of cement (g)	% of water (ml)	Amount of water (ml)	Pointer reading from bottom
1	300	30	90	18
2	300	31	93	10
3	300	32	96	8
4	300	33	99	5

Consistency of cement = 33%

3.3.2 TEST FOR FINE AGGREGATE

3.3.2.1 FINENESS TEST OF FINE AGGREGATE

Sieve analysis help to determine the particle size distribution of the coarse and fine aggregates. This is done by sieving the aggregateas per IS: 2386 (part I) –1963. In this we use different sieves as standardized by the IS code and then pass aggregates through them and thus collect different sized particles left over different sieves

Table 3.3.2.1 Result of Fineness Modulus Fine aggregate

SL.NO	IS Sieves	Weight Retained	% Weight Retained	Cumulative % Weight Passing	Cumulative % Weight of Retained
1	4.75 mm	0	0	0	100
2	2.36 mm	0.0080	08.0	0.8	0.92
3	1.18 mm	0.210	0.210	21.029	71
4	600 µ	0.223	22.3	51.3	48.7
5	300 µ	0.120	12.0	63.3	36.7
6	150 µ	0.117	11.7	75.0	25
7	pan	0.035	3.5	78.5	21.5

$$\textbf{Fineness modulus} = \frac{\text{cumulative \% weight retained}}{100}$$

Fineness Modulus = 2.90

Sand Conforming Zone II

3.3.2.2 SPECIFIC GRAVITY OF FINE AGGREGATE

This test method covers the determination of bulk and apparentspecific gravity, 23/23c, and absorptionof fine aggregate. it determines (after 24 h in water) the bulk specific gravity and the apparent specific gravity.

Table 3.3.2.2 Specific Gravity Of Fine Aggregate

SL.NO	Description	Trail 1	Trail 2	Trail 3

1	Weight of pycnometer (W1)	0.62	0.61	0.62
2	Weight of pycnometer + sand (W2)	1.165	1.160	1.143
3	Weight of pycnometer + sand + water (W3)	1.84	1.78	1.70
4	Weight of pycnometer + water (W4)	1.510	1.410	1.39
	Specific gravity of fine aggregate	2.53	3.05	2.46

$$\text{Specific Gravity of Fine Aggregate} = \frac{W2-W1}{(W4-W1)-(W3-W2)}$$

Specific Gravity of Fine Aggregate = 2.70

3.3.2.3 MOISTURE CONTENT TEST FOR FINE AGGREGATE

Moisture is the property of the sand it is defined as the amount of water present in the moulding sand. Low moisture content in the sand does not develop strength properties. Highmoisture conten degreases permeability.

Table 3.3.2.3 Moisture Content Of Fine Aggregate

SL.NO	**Observation**	

		Trail (g)
1	Weight of sand	200
2	Weight of wet sand	202
3	% of water observed	1

Percentage of moisture content $= \frac{W2-W1}{W1} \times 100$

Moisture Content of Fine Aggregate = 1%

3.3.3 TEST FOR COARSE AGGREGATE

3.3.3.1 FINENESS MODULUD OF COARSE AGGREGATE

Sieve analysis help to determine the particle size distribution of the coarse and fine aggregates. This is done by sieving the aggregate as per IS: 2386(partI) –1963. In this, different sieves as standardized by the IS code and then pass aggregates through them and thus collect different sized particles left over different sieves.

Weight of sample taken = 1kg

Table 3.3.3.1 Fineness Modulus of Coarse Aggregate

SL.NO	IS Sieve No	Weight retained	% of weight retained	% of weight passing	Cumulative % weight retained
1	20.00mm	1.57	31.4	31.4	68.60
2	10.00mm	0.50	2.5	33.90	66.10

3	4.75mm	0.69	4.76	38.66	61.34
4	2.36mm	0.36	1.296	39.97	60.04
5	1.18mm	-	-	-	100
6	600µ	-	-	-	100
7	300µ	-	-	-	100
8	150µ	-	-	-	100

$$\text{Fineness modulus} \quad = \quad \frac{cumulative\,\%\,weight\,retained}{100}$$

Fineness Modulus of Coarse Aggregate = 7.16

3.3.3.2 SPECIFIC GRAVITY OF COARSE AGGREGATE

The coarse aggregate specific gravity test is used to calculate the specific gravity of coarse aggregate sample by determining the ratio of the weight of a given volume of aggregate to the weight of an equal volume of water.

Table 3.3.3.2 –Specific Gravity Of Coarse Aggregate

SL.NO	Observation	Trial 1	Trial 2	Trial 3
1	Weight of pycnometer (W1)	4.48	4.48	4.48
2	Weight of pycnometer + coarse aggregate (W2)	8.88	8.32	8.98

3	Weight of pycnometer + coarse aggregate + water (W3)	15.26	14.86	15.64
4	Weight of pycnometer + water (W4)	12.44	12.44	12.74
	Specific gravity	2.78	2.70	2.81

Specific gravity of coarse aggregate = $\frac{W2-W1}{(W4-W1)-W3-W2)}$

Specific Gravity of Coarse Aggregate = 2.8

3.3.3.3 MOISTURE CONTENT TEST FOR COARSE AGGREGATE

This test helps to determine the water absorption of coarse aggregate as per IS 2380 (PART III) –1963. For this test a sample not less than 2000g should be used.

Table 3.3.3.3 Moisture Content of Coarse Aggregate

SL.NO	Observation	Trial 1 (g)
1	Weight of sample (w1)	500
2	Eight of wet sand (w2)	502.5
3	% of water observation	0.5

Percentage of moisture content = $\frac{W2-W1}{W1}$ X 100

Moisture Content of Coarse Aggregate = 0.5%

3.3.4 TESTS ON CONCRETE

3.3.4.1 SLUMP TEST:

Slump test is the most commonly used method of measuring the consistency of concrete. It is not a suitable method for very wet or very dry concrete. It does not measure all factors contributing to workability, nor is it always the representative of the placibility of concrete. The apparatus used for conducting the slump test essentially consists of metallic mould in the form of a frustum of a cone having the internal dimensions as under:

Bottom diameter : 20 cm

Top diameter : 10 cm

Height : 30 cm

Table 3.3.4.1 –Slump Test Value

SL.NO	W/C Ratio	Value of slump	Nature of collapse
1	0.45	0	No slump
2	0.55	10	No slump
3	0.65	15	True slump
4	0.75	60	Shear slump

5	0.85	100	Collapse

The slump value = 10

CHAPTER 4

MIX DESIGN

4.1 GENERAL

The mix design is carried out in accordance with IS Proportioning –Guidelines code book.

4.2 SPECIFICATIONS:

a) Grade designation –M20

b) Type of cement –OPC 53 grade

c) Maximum nominal size of aggregate –20 mm

d) Minimum cement content –320 N/mm

e) Maximum water cement ratio –0.45

f) Workability –100 mm (slump)

g) Exposure condition –moderate

h) Degree of supervision -good

i) Type of aggregate –crushed angular aggregate

j) Specific gravity of cement –3.00

k) Specific gravity of coarse aggregate –2.80

l) Specific gravity of fine aggregate –2.70

m) Percentage of water absorbed by coarse aggregate –1%

n) Percentage of water absorbed by fine aggregate –1.5%

o) Grading of fine aggregate –Zone II

4.3 MIX DESIGN

4.3.1 Target Mean Strength

$$F_{ck}' = f_{ck} + 1.65s \qquad (4.1)$$

$$F_{ck} = f_{ck} + (1.65 \text{ x } 4)$$

$$= 26.60 \text{ N/mm}^2$$

4.3.2 Water –Cement Ratio

Maximum water cement ratio = 0.5

Adopt water content of 0.5

4.3.3 Selection Of Water And Sand Content

Content of sand =186 kg

Water content for 100 mm slump = 186 + ((6÷100) ×186) (4.2)

= 197.16 litres

4.3.4 Calculation of Cement Content

Water cement ratio = 0.5

$$\text{Cement} = \frac{197.16}{0.5}$$

$$= 394.32 \text{ kg/m}^3$$

4.3.5 Proportion Of Volume Of Coarse Aggregate And Fine Aggregate Content

From Table 3, volume of coarse aggregate corresponding to 20 mm size aggregate and fine aggregate for w/c ratio 0.5 = 0.62. Here, w/c ratio is 0.45. So increase 0.01. Volume of coarse aggregate corresponding to 20 mm size aggregate and fine aggregate for w/c ratio 0.5 = 0.62.

Volume of coarse aggregate content = 0.636

Volume of fine aggregate content = 1 -0.636

= 0.364

4.3.6 Calculations

a) Volume of concrete = 1 m³

b) Volume of cement

$$= \frac{Mass\ of\ cement}{\text{specific gravity of cement}} \text{ x } \frac{1}{1000} \qquad (4.3)$$

$$= \frac{394.32}{3.00} \text{ x } \frac{1}{1000} \quad = \quad 0.131 \text{ m}^3$$

c) Volume of water

$$= \frac{Mass\ of\ water}{\text{specific gravity of water}} \text{ x } \frac{1}{1000} \qquad (4.4)$$

$$= \frac{197.16}{1} \text{ x } \frac{1}{1000}$$

= 0.19716 m³

d) Volume of all in aggregate = 1 –(0.131+0.197) =0.672 m

e) Mass of coarse aggregate = (d) × Volume of CA × Specific gravity of CA × 1000 (4.5)

= 0.672 × 0.636 ×2.80 × 1000

= 1196.70 kg

f) Mass of fine aggregate = (d) × Volume of CA × Specific gravity of FA × 1000 (4.6)

= 0.672 × 0.364 × 2.70 × 1000

= 660.44 kg

The mix proportions are;

a) Cement = 394.32 kg/m³

b) Water = 197. 16

c) Fine Aggregate = 660.44 kg

d) Coarse Aggregate = 1196.70 kg

e) Water Cement ratio = 0.5

Cement: FA: CA = 1: 1.67: 3.03

Table 4.1 Mix ratio

Cement kg/m³	**Fine aggregate kg/m³**	**Coarse aggregate Kg/³**	**Water lit/m³**
394.32 1196.70	660.44	1196.70	197. l6
1	1.67	3.03	0.5

CHAPTER 5

EXPERIMENTAL INVESTIGATION

5.1 INTRODUCTION

The objective of the present investigation is to obtain the performance of the concrete by the microbiologically induced special growth and also find the compressive strength of concrete using bacteria and calcium lactate. One such thought has lead to the development of a very special concrete known as Bacterial Concrete where bacteria is induced in the mortars and concrete to heal up the faults. Various researchers proposed different bacterial concrete’s. Here an attempt was made by using the bacteria “Bacillus subtilis”. Calcite formation by Bacillus subtilis is a model laboratory bacterium, which can produce calcite precipitates on suitable media supplemented with a calcium source.

From Scanning Electron Micrography analysis, it is noted that pores were partially filled up by material growth with the addition of the bacteria. Reduction in pore due to such material growth will obviously increase the material strength.

Concrete cubes with and without addition of bacteria and calcium lactate were cast and it is observed that there is an improvement in the compressive strength for the cubes with the addition of bacteria.

Concrete cylinders cast with RCC by the size of 3mm with addition of bacteria, it is observed that there isn’t any improvement in heal the cracks by normal eye visualize. The other method is to cast the slab with RCC and the bacteria are added with slurry then the slab is placed and measured the crack width.

5.2 COLLECTION OF MATERIALS

The materials used, Bacteria (Bacillus subtilis), Nutrient Broth (culturing medium) and Calcium Lactate were collected from **BIOSYS**, **Trivandrum**.

5.2.1 BACILLUS SUBTILLIS

Bacillus subtilis a model laboratory bacterium is used. This bacterium is kept in a deep freezer, So that it will not die in the environment. The life up to 10 – 24 month.

5.2.1 Bacillus subtilis

5.2.2 CULTURE MEDIUM

A Growth medium or culture medium is a liquid or gel designed to support the growth of microorganism. There are two major types of growth media, which are nutrient broths and agar plates. Nutrient broth is liquid media and nutrient agar is solids media. Here nutrient broth is used as a culturing medium.

5.2.2 Medium: Nutrient broth

5.2.3 CALCIUM LACTATE

Calcium Lactate is one of the most naturally precipitated minerals on earth in the form of natural rocks and exists in environments such as marine water, fresh water, and soils. Addition of calcium lactate the compressive strength will be increase.

5.2.3 Calcium Lactate

5.3 CULTURE OF BACTERIA

The pure culture was isolated from **Mount Zion Medical College, Kerala** and is maintained constantly on nutrient broth slants. It forms irregular dry white colonies on nutrient broth. Whenever required a single colony of the culture is inoculated into nutrient broth of 25ml in 100ml conical flask and the growth condition are maintained at 37^{0}C temperature and placed in 125rpm orbital shaker. The medium composition required for growth of culture is

Peptone	: 5g/lt.
NaCl	: 5g/lt.
Yeast extract	: 3g/lt.

5.4 MAINTENANCE OF STOCK CULTURES

Stock cultures of Bacillus subtilis were maintained on nutrient broth. The culture was streaked on broth with an inoculating loop and the broths were incubated at 37^{0}C. After 2-3 days of growth, broth cultures were preserved under refrigeration (4^{0}C) until further use. Subculturing was carried out for every 90 days. Contamination from other bacteria was checked periodically by streaking on nutrient broth plates.

5.4 Cultured Bacteria

5.5 PREPARATION OF MATERIALS

All materials shall be brought to room temperature before commencing the results (as per IS: 516-1959). The cement samples, on arrival at the laboratory, shall be thoroughly mixed dry either by hand or in a suitable mixer in such a manner as to ensure the greatest possible blending and uniformity in the material, care is being taken to avoid the intrusion of foreign matter. The cement shall then be stored in a dry place, preferably in airtight metal containers. Samples of aggregates for each batch of concrete shall be of the desired grading and shall be in an air-dried condition. In general, the aggregate shall be separated into fine and coarse fractions, but where special grading are being investigated, both fine and coarse fractions shall be further separated into different sizes.

5.5.1 PROPORTIONING

The proportions of the materials, including water, in concrete mixes used for determining the suitability of the materials available, shall be similar in all respects to those to be employed in the work. Where the proportions of the ingredients of the concrete as used on the site are to be specified by volume, they shall be calculated from the proportions by weight used in the test cubes and the unit weights of the materials.

5.5.2 WEIGHING

The quantities of cement, each size of aggregate, foundry sand and water for each batch shall be determined by weight from the design.

5.5.3 HAND MIXING

The concrete batch shall be mixed on a watertight, non-absorbent platform with a shovel, trowel or similar suitable implement,

Using the following procedure:

a) The cement ant fine aggregate shall be mixed dry until the mixture is thoroughly blended and is uniform in color.

b) The coarse aggregate shall then be added and mixed with the cement ant fine aggregate until coarse aggregate is uniformly distributed throughout the batch, and

c) The water shall then be added and entire batch mixed until the concrete appears to be homogenous and has the desired consistency. If repeated mixing is necessary, because of the addition of water in increments while adjusting the consistency, the batch shall be discarded and a fresh batch made without consistency tests.

5.5.4 COMPACTION BY HAND

When compacting by hand, the standard tamping bar shall be used and the strokes of the bar shall be distributed in a uniform manner over the cross section of the mould. The number of strokes per layer required to produce specified conditions will vary according to the type of concrete. For cubical specimens, in no case shall the concrete be subject to less than 35 strokes per layer for 15 cm cubes or 25 strokes per layer for 15 cm cubes. The strokes shall penetrate into the underlying layer and the bottom layer shall be rooted throughout its depth. Where voids are left by tamping bar, the sides of the mould shall be tapped to close the voids.

5.5.5 CURING OF TEST SPECIMENS

The test specimen shall be stored on the site at a place free from vibration, under damp matting, sacks or other similar material for 24 hours + ½ hour from the time of adding the water to the other ingredients. After the period of 24 hours, they shall be marked for later identification, removed from the moulds and, unless required for testing within 24 hours, stored in clean water at a room temperature until they are transported to the testing laboratory. They shall be sent to the testing laboratory well packed in damp sand, damp socks, or other suitable material so as to arrive there in a damp condition not less than 24 hours before the time of the test. On arrival at the testing laboratory, the specimens shall be stored in water at a room temperature until the time of the test. Records of the daily maximum and minimum temperature shall be kept both during the period of the specimens remain on the site and in the laboratory.

CHAPTER 6

TEST ON CONCRETE

6.1 MICROSCOPIC TESTING

6.1.1 SCANNING ELECTRON MICROSCOPE

Change of crack width was measured by scanning electron microscope. A scanning electron microscope equipped with energy dispersive X-ray analysis (SEM- EDX) is an important supplement to the optical microscope when examining new, old and deteriorated concrete. SEM was used to document the role of bacteria in improving the durability aspects of concrete.

Specifications

SEMs are modeled after light microscopes. Unlike a light microscope or a TEM, the SEM does not require electrons to pass through a material. Hence, thin samples are not required and bulk investigations are made possible by 'scanning' the surface with a moving beam.

An SEM works as follows: at the top of the column, an electron source (usually thermally activated) emits electrons of a specific energy (usually specified as a voltage for the accelerating field or as electron-volt units). The electrons head down the column at a terrific speed, but they're still fairly spread out just after launch. The stream of electrons must pass through two condenser lenses and two apertures, which tighten the beam down to a few nanometers in width. This is the maximum resolution that an electron microscope can achieve due to imperfections in the magnetic condenser lenses. The final stage is the objective lens that scans the beam horizontally and vertically over the sample area. Depending on the results you want, different measurements then take place. Measuring the current that is absorbed for a specific location on the sample can relay simple 'visual' information.

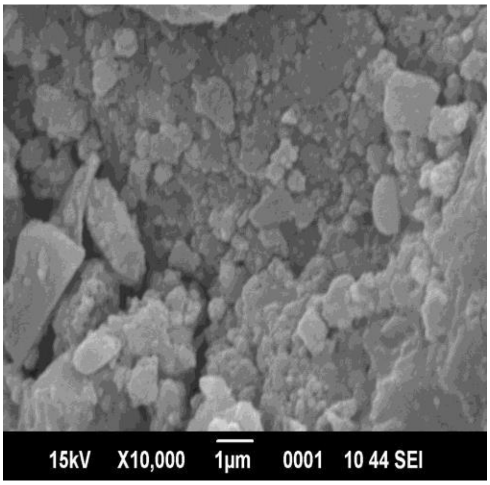
6.1.2 TEST PROCEDURE

Cement concrete specimens (5cm x 5cm x 0.5cm) prepared with a water- to-cement weight ratio of 0.5 and placed on a 7day curing. Bacillus Subtilis is added about 1ml in air voids after the curing. The formation of bacteria could be seen in Scanning Electron Microscopy.

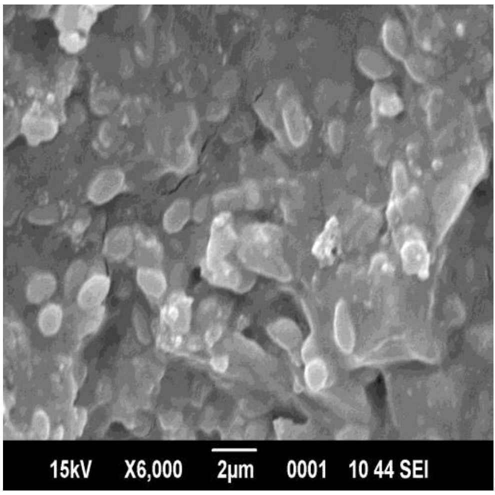
6.1.2 Specimen preparations for Microscopic Testing

The below figure shows the Scanning Electron Micrography analysis, it is noted that pores were partially filled up by material growth with the addition of the bacteria **.**Electron Images showed that the cracks due to the testing were of 1–10μm width. The cracks traversed the paste and followed the interfaces of larger aggregate particles. On self healing was seen on 300–1000 X magnification as partly closing of several cracks smaller than 5 μm.

For specimen 1



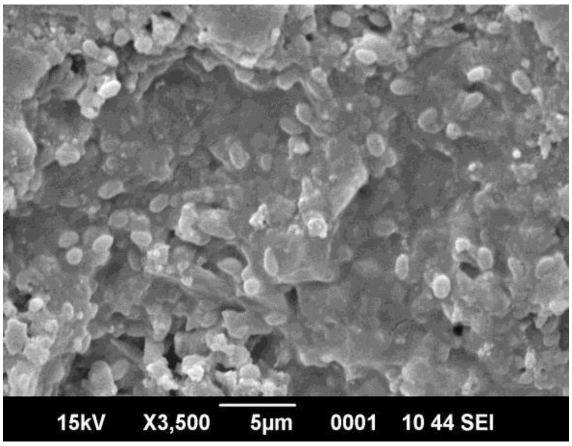
SEM.1 Magnified view of SEM micrograph of



SEM.2 Magnified view of SEM micrograph of

concrete without any bacteria

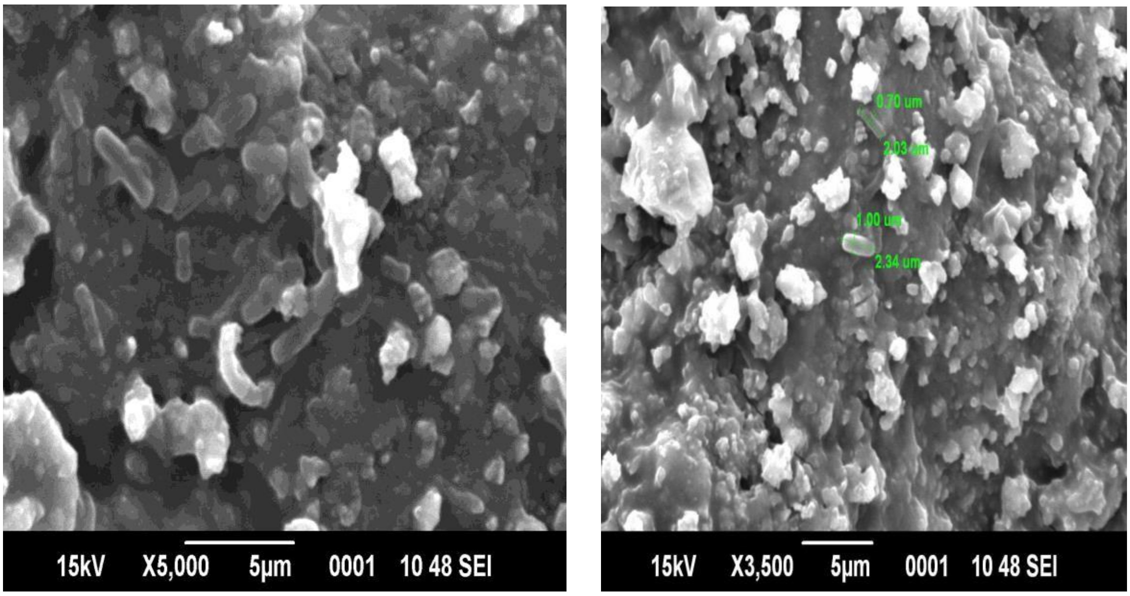
concrete with bacteria and shows cracks

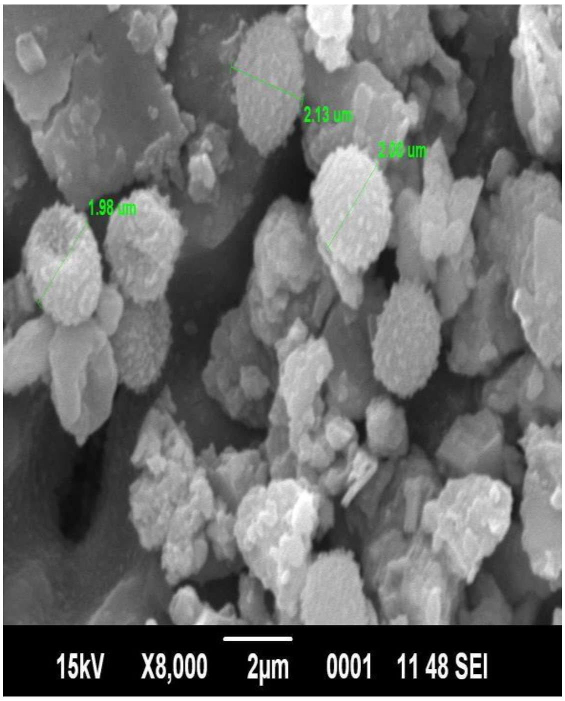


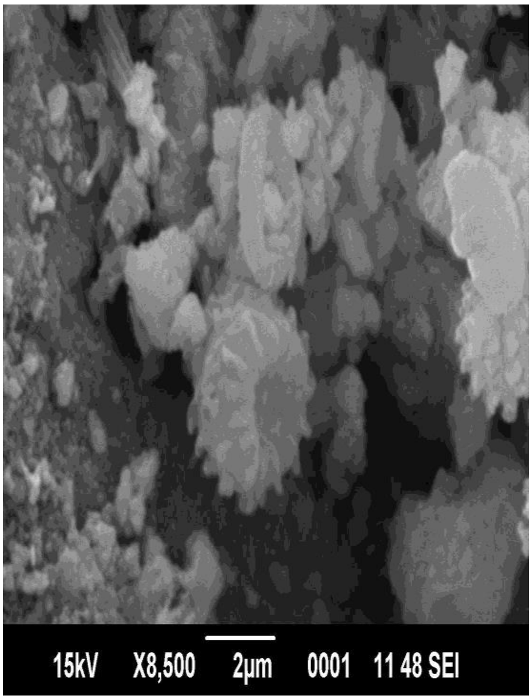
SEM.3 Magnified view of SEM micrograph of concrete

and shows completely healed cracks

Specimen 2 and 3 shows the growth of bacteria







6.2 COMPRESSIVE STRENGTH TEST

An experimental program was conducted on ordinary Portland cement concrete and bacterial concrete. The cubical moulds of size 150mm x150mm x 150mm were cleaned and checked against the joint movement. A coat of oil was applied on the inner surface of the moulds and kept ready for the concreting operation. Meanwhile the required quantities cement, fine aggregate and coarse aggregate (passing through IS sieve of 20mm size and retained on 4.75mm) for particular mix are weighed accurately for concreting.

Weighed quantity of fine aggregate, cement and coarse aggregate were mixed thoroughly. Added 10% of bacteria and calcium lactate water was added and mixing was continued for about 3 to 5 minutes to get a uniform mix. The wet concrete is now poured into the moulds and for every 2 to 3 layers and compacted manually. After concreting the operations, the upper surface is leveled and finished with a mason’s trowel.

The corresponding identification marks were labeled over the finishing surface and they were tested for 7 and 28 days strengths in a compressive strength machine. The specimens should be removed from the water just before testing and make it to dry.

Then the specimen is placed on the loading surface of the CTM and the load is applied till the specimen fails. The ultimate load at the time of failure is noted down. The test procedure were adopted as per ASTM standards. The load was applied at the rate of 140 Kg/cm^2/minute till the cube breaks.

Fig 6.2 Compression testing machine

6.2.1 TESTING RESULTS

Table 6.2.1 Compressive Strength Results for Conventional Concrete Cubes in 7 days

Specimen	Load (KN)	Compression Strength (N/mm^2)	Average (N/mm^2)
1	394.2	17.52	
2	391.4	17.39	
3	393.2	17.47	

4	391.5	17.40	17.46
5	392.6	17.44	
6	392.4	17.44	
7	393.1	17.47	
8	393.4	17.48	
9	393.8	17.50	
10	393.5	17.48	

Table 6.2.1 Compressive Strength Results for Conventional Concrete Cubes in 28 days

Specimen	**Load (KN)**	**Compression Strength (N/mm^2)**	**Average (N/mm^2)**
1	611.2	27.16	27.17
2	610.6	27.13	
3	611	27.15	
4	611.7	27.18	
5	612.5	27.22	
6	612	27.20	
7	611.5	27.17	
8	610.9	27.15	
9	612.6	27.22	
10	611.4	27.17	

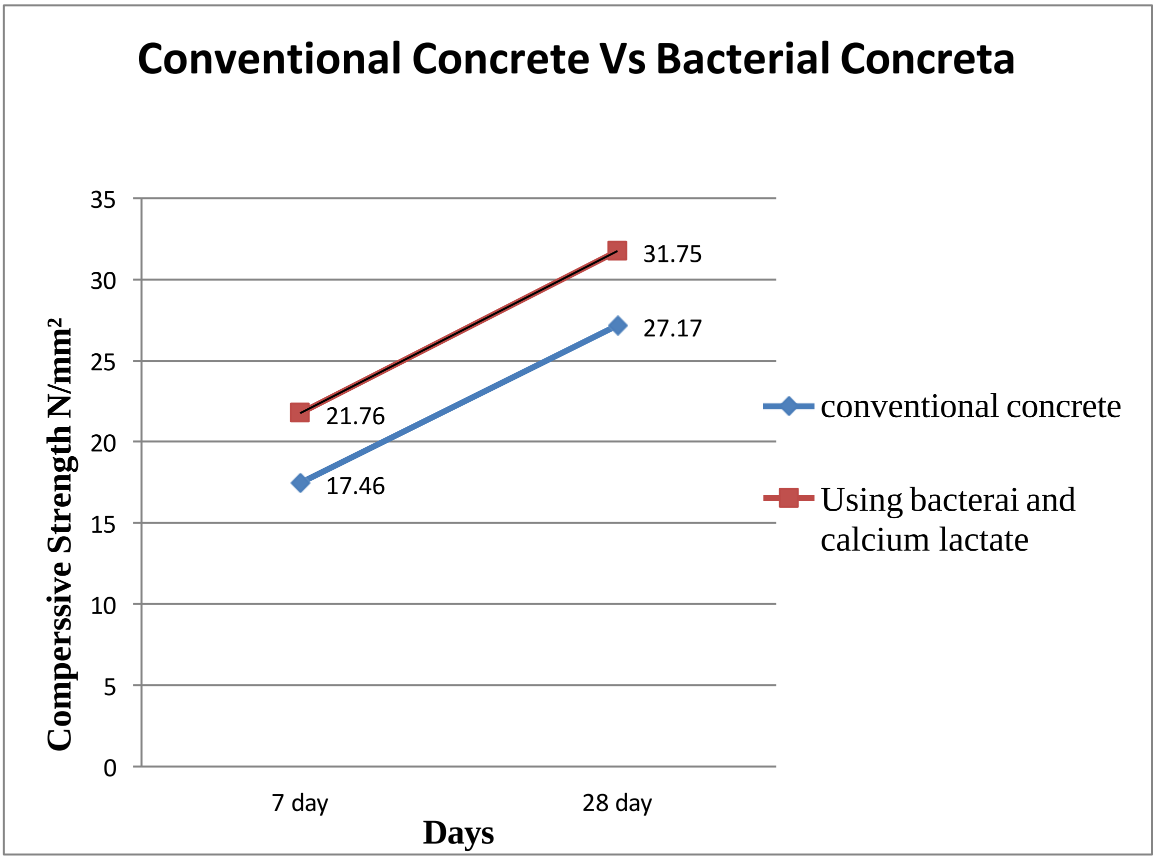
Table 6.2.1 Compressive Strength Results for adding 10% of bacteria and calcium lactate in 7 days

Specimen	Load (KN)	Compression Strength (N/mm^2)	Average (N/mm^2)
1	489.2	21.74	21.76
2	489.5	21.75	
3	489.4	21.75	
4	490.2	21.78	
5	489.8	21.76	
6	490.4	21.79	
7	488.8	21.72	
8	489.4	21.75	
9	490	21.77	
10	490.5	21.80	

Table 6.2.1 Compressive Strength Results for adding 10% of bacteria and calcium lactate in 28 days

Specimen	Load (KN)	Compression Strength (N/mm^2)	Average (N/mm^2)
1	714.5	31.75	
2	714.1	31.73	
3	714.3	31.74	
4	714	31.73	

5	714.8	31.76	31.75
6	715	31.77	
7	715.4	31.79	
8	713.8	31.72	
9	715.5	31.80	
10	714.6	31.76	



6.3 CONCRETE REPAIR WITH BACTERIA

6.3.1 TEST ON CYLINDER

Specimen preparation

The specimen is prepared with designing a mix of size 150 mm diameter and 300 mm height with RCC size of 3mm. The concrete is filled with three layers and compacted well and it is vibrated using table vibrator. The specimen is subjected to curing for 28 days. After the curing period the specimen is taken out from the curing tank and wipes it clean. The dimensions of the specimens and the weight of the specimens were noted down with accuracy.

The compression testing machine is used for the test. The cylinder specimen is placed horizontally between the loading surfaces and applied load continuously up to the specimen occurred cracks. Then the bacteria would be added in the cracks for measured the healing crack width. After 7 days it is observed that there isn't any improvement in heal the cracks by normal eye visualize.

Fig 6.3.1

Appling Load

Fig 6.3.1 Appling Bacteria

6.3.2 TEST ON SLAB

Specimen preparation

The specimen RCC slab of size 11.5cm x 7.5 cm x 2.5cm were reinforced with a mesh of 3mm thick. The concrete is filled and compacted well. The specimen is subjected to curing for 7days. After the curing period the specimen is taken out from the curing tank and minor load is applied for crack formation, the specimen is placed on slurry with and without bacteria for 7 days.

The figure shows, without bacteria the specimen was not change for heal the crack.

After 7 days it was observed that, the formation of bacteria.

Before adding Bacteria

Fig 6.3.2

Fig 6.3.2 After adding Bacteria for 7 days

CHAPTER 7

CONCLUSION

- From this research it became clear that self healing is possible, It would be cleared in microscopy analysis. Crack repair with a biological treatment in which a bacillus subtilis culture is most effective.
- The addition of bacillus subtilis and calcium lactate is used to increased the compressive strength of concrete were compared with conventional concrete.
- The use of this biological treatment is highly desirable because the mineral precipitation induced as a result of microbial activities is pollution-free and natural.
- Biological approach for healing and self healing of cracks in concrete and consolidation of building materials can be possible by adopting this green technology, which makes the structures durable and environment friendly.
- This bacterial healing can be used for repair concrete structure by doing deeper study on bigger specimen in future.

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