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Study of Behavior of Bacterial Concrete

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ABSTRACT :- Concrete structures often suffer from cracking that leads to much earlier deterioration than designed service life. Repairs can be particularly time consuming and expensive because it is often very difficult to gain access to the structure to make repairs, especially if they are underground. In particular, the utilization of self-healing technologies has high potential as a new repair method for cracked concrete. Self-healing is a natural process of crack repair that can occur in concrete in the presence of moisture. Self-healing character of concrete can be accelerating using different materials like mineral admixture, bacteria and fibers. Mineral admixtures have been deployed as an approach for self-healing of concrete cracks by reducing the water permeability after concrete damage. Mineral admixture (Expansive agents and geo-materials) swell in the presence of water and fills the cracks. Fibers in concrete recover the mechanical properties of concrete as a result of self-healing of concrete and helps to controlled tight crack width. Bacteria additive self-healing approach utilizes bacteria that induce precipitation of calcium carbonate as a result of carbonate generation by bacteria metabolism in a high calcium environment. The precipitation of calcium carbonate fills the larger cracks. Self-healing concrete has significant implications in extending service life of building by reducing its repairing and repairing costs. Thus, self-healing concrete could be a major enabling technology towards sustainable civil infrastructure.

KEYWORDS: Bacteria, Concrete, Fibers, Mineral Admixture, Self-Healing

I. INTRODUCTION

1.1 General

Concrete is a vital building material that is an absolutely essential component of public infrastructure and most buildings. Concrete is a construction material composed of cement (commonly Portland cement) as well as other cementitious materials such as fly ash and slag cement, aggregate (generally a coarse aggregate such as gravel limestone or granite, plus a fine aggregate such as sand), water, and chemical admixtures. The word concrete comes from the Latin word "concretus", which means "hardened" or "hard". Concrete solidifies and hardens after mixing with water due to a chemical process known as hydration. The water reacts with the cement, which bonds the other components together, eventually creating a stone-like material. . Cement is the dry powder when mixed with other additives and water makes concrete. Over the past decade, new types of concrete and cement have been formulated that do everything from bend, to grow plants, and let light through. Some of the new types of concrete that have evolved with the passage of time, have unique advantages are presented below.

1.2 Bendable Concrete

This concrete was developed in 2005 by the researchers at the University of Michigan USA. This new type of concrete is 500 times more resistant to cracking and 40 percent lighter in weight as compared to the traditional concrete. The materials in this concrete are itself designed for maximum flexibility. Traditional concrete presents many problems: failure under severe loading, lack of durability and sustainability, and the resulting expenses of repair. The bendable or ductile, concrete is made mainly of the same ingredients as in regular concrete with no coarse aggregate. It looks exactly like regular concrete, but under excessive strain, the Engineered cement composites (ECC) concrete having network of fibers veining the cement is allowed to slide within the cement, thus avoiding the inflexibility that causes brittleness and breakage. The Engineered Cement Composites technology i.e. the bendable concrete has been already used on projects in Japan, Korea, Switzerland and Australia

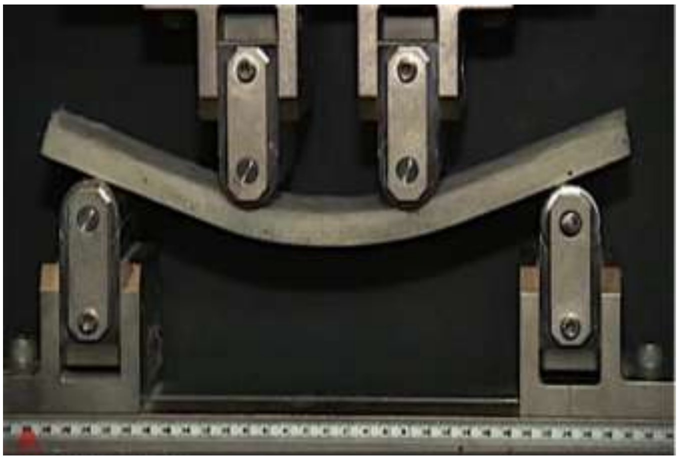


Fig.1 Bendable concrete

1.3 Pervious concrete

Pervious concrete is some time determined by designers and architects when porosity is obliged to permit some air development or to facilitate the waste and stream of water through structures. Pervious concrete is alluded to as "no fines" concrete on the grounds that it is fabricated by forgetting the sand or "fine total". A pervious solid blend contains almost no sand (fines), making a generous void substance. Utilizing adequate glue to coat and tie the total particles together makes an arrangement of very porous, interconnected voids that depletes rapidly. Ordinarily, somewhere around 15% and 25% voids are accomplished in the solidified cement, and stream rates for water through pervious solid are normally around 480 in./hr (0.34 cm/s, which is 5 gal/ft^2/ min or 200 L/m^2/min), despite the fact that they can be much higher.

Fig.2 Pervious concrete

1.4 Light Transmitting Concrete

One such new construction material is light transmitting concrete. In 2001 Aron Losonczi, a Hungarian Architect developed a special concrete that allowed light to pass through it by using 4to 5% optical fibres. Light transmitting concrete is a special type of concrete that allows light to pass through it. Strength of this concrete is about same as regular concrete and strength does not reduce much. It can continue to transmit light through walls up to twenty meters thick, as the fibre works without any loss in light up to twenty meters.

Fig.3 Light transmitting Concrete

1.5 Self-Healing Bacterial Concrete

Microbiologists at Delft University of Technology (TU Delft) in Netherlands embedded calcite-precipitating bacteria into a concrete mixture to give it self-healing properties under the right conditions. This new type of concrete has the ability to repair itself in order to prevent cracks and pot holes from forming. The self-repairing bio concrete uses a "healing agent" that becomes active when water gets into cracks on its surface. A reaction between water and Bacillus bacteria causes limestone to form and close up the cracks. In theory, using this type of bacteria within commercial concrete mixtures would create substantial savings and lead to more durable concrete structures as the crack would be self-healed by the concrete itself. Self -healing concrete would be ideal for constructing containers for storing hazardous waste as it is difficult to carry out human repairs in such containers. The current cost of constructing this concrete is very high making other potential applications, such as constructing residential buildings, offices, etc. are not yet commercially viable. Autogenously crack-healing capacity of concrete has been recognized in several recent studies. Mainly micro cracks with widths typically in the range of 0.05 to 0.1 mm have been observed to become completely sealed particularly under repetitive dry/wet cycles. The mechanism of this autogenously healing is chiefly due to secondary hydration of non- or partially reacted cement particles present in the concrete matrix. Due to capillary forces water is repeatedly drawn into micro cracks under changing wet and dry cycles, resulting in expansion of hydrated cement particles due to the formation of calcium silicate hydrates and calcium hydroxide. These reaction products are able to completely seal cracks provided that crack widths are small.

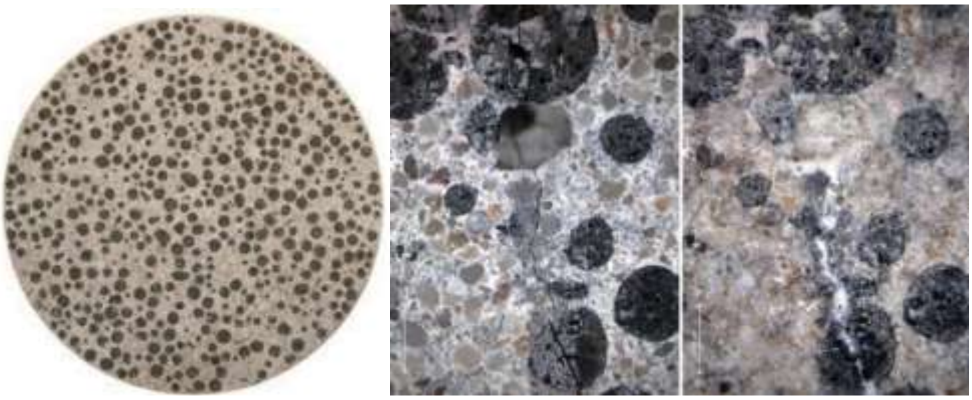


Fig.4 Bacterial concrete

Larger sized cracks can only be partially filled due to the limited amount of non-reacted cement particles present, thus resulting in only a thin layer of hydration products on the crack surface. With respect to crack-sealing capacity, a process homologous to secondary hydration of cement particles is the process of carbonation. This reaction is also expansive as ingress atmospheric carbon dioxide (CO2) reacts with calcium hydroxide particles present in the concrete matrix to various calcium carbonate minerals. From the perspective of durability, rapid sealing of particularly freshly formed surface cracks is important as this hampers the ingress of water and other aggressive chemicals into the concrete matrix.

Although bacteria, and particularly acid-producing bacteria, have been traditionally considered as harmful organisms for concrete, recent research has shown that specific species such as ureolytic and other bacteria can actually be useful as a tool to repair cracks or clean the surface of concrete. In the latter studies bacteria were externally and manually applied on the concrete surface, while for autogenously repair an intrinsic healing agent is needed. Species from Bacillus group appear promising intrinsic agents as their spores, specialized thick-walled dormant cells, have been shown to be viable for over 200 years under dry conditions. Such bacteria would comprise one of the two components needed for an autogenously healing system. For crack repair filler material is needed, and bacteria can act as catalyst for the metabolic conversion of a suitable organic or inorganic component, the second component, to produce this. The nature of metabolically produced filler materials could be bio minerals such as calcite (calcium carbonate) or apatite (calcium phosphate). These minerals are relatively dense and can block cracks, and thus hamper ingress of water efficiently. The development of a self-healing mechanism in concrete that is based on a potentially cheaper and more sustainable material then cement could thus be beneficial for both economy and environment.

1.6 Use of Self-Healing Bacterial Concrete:

Concrete will continue to be the most important building material for infrastructure but most concrete structures are prone to cracking. Tiny cracks on the surface of the concrete make the whole structure vulnerable because water seeps in to degrade the concrete and corrode the steel reinforcement, greatly reducing the lifespan of a structure. Concrete can withstand compressive forces very well but not tensile forces. When it is subjected to tension it starts to crack, which is why it is reinforced with steel to withstand the tensile forces. Structures built in a high water environment, such as underground basements and marine structures, are particularly vulnerable to corrosion of steel reinforcement. Motorway bridges are also vulnerable because salts used to de-ice the roads penetrate into the cracks in the structures and can accelerate the corrosion of steel reinforcement. In many civil engineering structures tensile forces can lead to cracks and these can occur relatively soon after the structure is built. Repair of conventional concrete structures usually involves applying a concrete mortar which is bonded to the damaged surface. Sometimes, the mortar needs to be keyed into the existing structure with metal pins to ensure that it does not fall away. Repairs can be particularly time consuming and expensive because it is often very difficult to gain access to the structure to make repairs, especially if they are underground or at a great height.

1.7 Advantages

1. The self-healing bacterial concrete helps in reduced maintenance and repair costs of steel reinforced concrete structures.
2. Oxygen is an agent that can induce corrosion, as bacteria feeds on oxygen tendency for the corrosion of reinforcement can be reduced.
3. 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.
4. Formation of crack will be healed in the initial stage itself thereby increasing the service life of the structure than expected life.

1.8 Disadvantages

1. If the volume of self-healing agents (bacteria) mixed becomes greater than 20% the strength of the concrete is reduced.
2. Preparation of self-healing concrete needs the requirement of bacteria. Hence preparation of Self-healing concrete costs more than conventional concrete.

1.9 Applications

1 .Self-healing bacterial concrete can be used for sectors such as tunnel-lining structure basement wall, Highway Bridge, concrete floors and marine structures.

1.10 Objective of the Study:

The main objectives of the study are to study the following properties.

- Evaluation of compressive strength of controlled concrete and bacterial concrete mixes of grade M20.

- Check the behavior of concrete while adding different percentage of bacteria

- To check the time at what percentage of bacteria crack fill at minimum time.

II. LITERATURE REVIEW

1. Henk.M.Jonkers and Erik Schlangen have published a paper on Development of a bacteria-based self-healing concrete. In this paper Bacillus cohnii, Bacillus halodurans and Bacillus pseudofirmus species were obtained from the German Collection of Microorganisms and Cell cultures. The bacteria cultures were cleaned from medium residues by centrifugation, washing and resuspension of the cell pellet in tap water. The cement samples were made incorporating the suspension and are tested. It was found that addition of healing agents such as bacteria lead to a 10% loss in the compressive strength. But such a loss in strength may be acceptable when this is compensated by self-healing capacity. They have used both bacteria and mineral precursor compounds mixed with the paste and thus therefore formed as an integral material.

2. Z.P.Bhathena and Namrata Gadkar have published a paper about on Bacterial concrete, a novel approach for increasing its durability. In this paper a total of six samples were collected from different sites such as mangrove area. From these samples the calcite precipitating organisms which precipitate calcium carbonate by means of ureolysis were screened. The screened urease producing isolates were checked for the ability to grow at varying pH. A total of 10 OTU (Operational Taxonomical Units) were obtained from 6 different samples after an incubation period of 7 days. Out of 10 isolates 8 isolates showed urease activity indicated by change in color of media around the colony. Out of 8 isolates only 3 isolates showed growth at all temperatures. The ability of the isolates to initiate calcium carbonate precipitation was assessed by in-vitro assay. Compressive strength of organisms within the cement matrix was analysed as per IS 4031:1988 taken after 3 and 7 days of curing in water. It was observed that their value was higher than the required valueof OPC.

3. Chintalapudi Karthik and Rama Mohan Rao have published a paper on Properties of self-healing concrete. In this paper Bacillus subtilisaureolytic bacteria which is aerobic is used. By converting ammonium and carbonate Bacillus subtilis precipitates $CaCO_3$ in high alkaline environment. The formation of precipitated calcium carbonate was viewed using Scanning Electronic Microscope. The process resulted in a bio-based crack sealing technique in concrete. The biological treatment of the cement composites resulted in crack sealing, decrease of water permeability and the advantages of incorporating bio-based cement composites initially reduce the maintenance costs, repair costs and hence results in increase of durability of the structures.

4. B.Naveen and S.Sivakamasundari have published a paper on Study on the effect of calcite-precipitating bacteria on self-healing mechanism of concrete. In this paper crack repair was enhanced through a biological treatment in which a B.sphaericus culture incorporated in a gel matrix and a calcium source is provided. They have used silica gel to protect the bacteria against the pH in concrete which was found to be effective as $CaCO_3$ crystals precipitated inside the matrix. Crack sealing resulted in permeability of water. Precipitation of the crystals enhanced the durability of the material. Efficiency of the biological treatment was assessed by means of Ultrasonic pulse velocity and visual measurements. The use of these technique was found to be highly desirable, pollution free and natural.

5. L.Soundariet have published a paper on Experimental study on strengthening of concrete by using bacterial mineral precipitation. In this paper initially nutrient broth and other chemicals were mixed with required water and boiled by autoclaving process. The boiled water should be of reddish color to which required bacterial cell is transferred and the liquid media is covered by aluminum foil and shaked periodically until it turns to light yellow color which shows the presence of bacillus subtilis. Concrete specimens are made by mixing in using electrically operated mixer by adding coarse aggregate, fine aggregate, cement and required amount of bacterial water. For M25 grade concrete, with the addition of bacteria the percentage of improvement in the compressive strength is in the order of 12.32% to 30.05% at different ages, the percentage of improvement in the split tensile strength is in the order of 13.80% to 18.45% at different ages, the reddish color to which required bacterial cell is transferred and the liquid media is covered by aluminium foil and shaked periodically until it turns to light yellow color which shows the presence of bacillus subtilis. Concrete specimens are made by mixing in using electrically operated mixer by adding coarse aggregate, fine aggregate, cement and required amount of bacterial water. For M25 grade concrete, with the addition of bacteria the percentage of improvement in the compressive strength is in the order of 12.32% to 30.05% at different ages, the percentage of improvement in the split tensile strength is in the order of 13.80% to 18.45% at different ages, the percentage of improvement in the flexural tensile strength is in the order of 13.19% to 15.56% at different ages.

6. Vijeth N Kashyap and Radhakrishna have published a paper on Study on effect of Bacteria on Cement composites. In this paper two different types of bacteria named Bacillus sphaericus and Sporosarcinapastuerii was obtained from Microbial type culture collection and gene bank, Chandigarh in a freeze dried condition. Bacteria was cultured in solid media and then transferred to nutrient brothfor about 48 hours. 5cm3 cubes were casted by mixing grown bacterial cultures of different concentration with cement paste and mortar. The cubes were cured under tap water at room temperature and tested at 7 and 28 days. The strength gain was about 39.8% and 33.07% in case of paste and 50% and 28.2% in mortar for sphaericus and Sporosarcinapastuerii respectively compared that of conventional mix. The SEM and XRD analysis showed the presence of calcite inside cement composite specimens which are produced microbially. The microbes enhance the strength and durability of cement composites.

7. Sakina Najmuddin Saifeet al1 published a paper on Critical appraisal on Bacterial Concrete. In this paper they discussed about the different types of bacteria and their applications. The bacterial concrete is very much useful in increasing the durability of cemetous materials, repair of limestone monuments, sealing of concrete cracks to highly durable cracks etc. It also useful for construction of low cost durable roads, high strength buildings with more bearing capacity, erosion prevention of loose sands and low cost durable houses. They have also briefed about the working principle of bacterial concrete as a repair material. It was also observed in the study that the metabolic activities in the microorganisms taking place inside the concrete results into increasing the overall performance of concrete including its compressive strength. This study also explains the chemical process to remediate cracks.

8. Meera C M and Dr. Subha have published a paper on Strength And Durability assessment Of Bacteria Based Self-Healing Concrete. In this paper they have discussed about the effect of Bacillus subtilis JC3 on the strength and durability of concrete. They used cubes of sizes 150mm x 150mm x 150mm and cylinders with a diameter of 100mm and a height of 200mm with and without addition of micro organisms, of M20 grade concrete. For strength assessments, cubes were tested for different bacterial concentrations at 7 days and 28 days and cylinders were tested for split tensile strength at 28 days. It was observed that the compressive strength of concrete showed significant increase by 42% for cell concentration of 105 of mixing water. And also, with the addition of bacteria there is a significant increase in the tensile strength by 63% for a bacteria concentration of 105cells/ml at 28 days. For durability assessment, acid durability test, chloride test and water absorption test were done. From the results it could be inferred that the addition of bacteria prevents the loss in weight during acid exposure to a certain limit, proving the bacterial concrete to have higher Acid Attack Factor. The Water Absorption Test, showed a lesser increase in weight of bacteria concrete sample than control, from which it could be reckoned that the concrete will become less porous due to the formation of Calcium Carbonate, due to which it resulted in lesser water absorption rate. Chloride test results showed that the addition of bacteria decreases weight loss, due to Chloride exposure and enhances the Compressive Strength.

9. Ravindranatha, N. Kannan, Likhit M have published a paper on Self-Healing Material Bacterial Concrete. In this paper a comparison study was made with concrete cubes and beams subjected to compressive and flexural strength tests with and without the bacterium Bacillus pasteurii. The concrete cubes and beams were prepared by adding calculated quantity of bacterial solution and they were tested for 7 and 28 day compressive and flexural strengths. It was found that there was high increase in strength and healing of cracks subjected to loading on the concrete specimens. The microbe proved to be efficient in enhancing the properties of the concrete by achieving a very high initial strength increase. The calcium carbonate produced by the bacteria has filled some percentage of void volume thereby making the texture more compact and resistive to seepage.

10. A.T.Manikandan1, A.Padmavathi have published a paper on An Experimental Investigation on Improvement of Concrete Serviceability by using Bacterial Mineral Precipitation. In this paper ,the bacteria Bacillussubtilis strain 121 was from Microbial Type Culture Collection and Gene Bank, Chandigarh. Samples were prepared in sets of three for a water cement ratio of 0.5 by mass for conventional concrete and a water cement ratio of 0.25 and bacterial culture of 0.25 for bacterial concrete by mass. The cubes were tested by Non-Destructive Testing and HEICO compression testing machine on the 3rd, 7th and 28th days after casting. There was an improvement in compressive strength by B. subtilis strain 121 due to deposition of Calcite (CaCO3) in cement-sand matrix of microbial concrete which remediate the pore structure within the mortar. The temperature sustainability test of B. subtilis in bacterial concrete was carried out at various temperatures and found that the B. subtilis was found to be alive at –30 C low temperatures to 700 C high temperatures. There is increase in compressive strength of the bacterial concrete with B. subtilis bacteria with microbial calcite precipitation in the crack sample was examined in SEM .The sample showed the presence of calcite crystals grown all over the surface of the crack and also the presence of B. subtilis bacteria is the evidence, that suggests microbial remediation properties of bacterial concrete.

11. Jagadeesha Kumar B G, R Prabhakara and Pushpa published a paper on Effect of Bacterial Calcite Precipitation on Compressive Strength of Mortar Cubes. This paper describes about the experimental investigations carried out on mortar cubes which were subjected to bacterial precipitation by different bacterial strains and influence of bacterial calcite precipitation on the compressive strength of mortar cube on 7, 14 and 28 days of bacterial treatment. Three bacterial strains Bacillus flexus, isolated from concrete environment, Bacillus pasturii and Bacillus sphaericus were used. The cubes were immersed in bacterial and culture medium for above mentioned days with control cubes immersed in water and was tested for compressive strength. The result indicated that there was an improvement in the compressive strength in the early strength of cubes which were reduced with time. Among the three strains of bacteria, Cubes treated with Bacillus flexus, which is not reported as bacteria for calcite precipitation has shown maximum compressive strength than the other two bacterial strains and control cubes. It was studied that the increase in compressive strengths is mainly due to consolidation of the pores inside the cement mortar cubes with micro biologically induced Calcium Carbonate precipitation. The urease activity was determined for all the bacteria in Urease media by measuring the amount of ammonia released from urea according to the phenol-hypochlorite assay method. All the three strains of bacteria were tested for urease activity. The change of the color of the media from yellow to pink indicated that it is urease positive. All the three strains were urease positive. X-ray diffraction analysis was also carried out to determine chemical composition of the precipitation that occurred due to bacterial mineralization.

12. RA.B.Depaaand T. Felix Kala have published a paper on Experimental Investigation of Self Healing Behavior of Concrete using Silica Fume and GGBFS as Mineral Admixtures. In this paper cubes have been prepared by adding silica fume in percentage of 2.5%, 5%,7.5%, 10%, 12.5% as a binder in addition to adding cement to concrete and also by replacing 35% and 55% of cement with GGBFS.A conventional mixture without any admixture is cast for comparing the strength and durability properties of silica fume and GGBFS concretes. The specimens are first tested for compressive strength at 28 days, and then 70% and 90% of the compressive load is applied to another set of specimens to generate microcracks for studying the durability properties of the specimens. The preloaded concrete specimens are tested for compressive strength at 7 and 28 days and sorptivity index tests after 28 days. The concrete mix containing cement replaced with 35% GGBFS has given maximum compressive strength value. Further when silica fume is added as mineral admixture, the mix has given maximum strength at 12.5% addition of silica fume.

13. Chithra P Bai and Shibi Varghese have published a paper on an experimental investigation on the strength properties of fly ash based Bacterial concrete. In this paper, The bacteria Bacillus Subtilis was used for study with different cell concentrations of 103, 105 and 107 cells/ml for preparing the bacterial concrete. Cement was partially replaced by 10%, 20% and 30% of fly ash by weight for making the bacterial concrete. Concrete of grade M30 was prepared and tests such as Compressive strength, Split tensile strength, Flexural strength and Ultrasonic Pulse Velocity were conducted after 28 and 56 days of water curing. For fly ash concrete, maximum compressive strength, split tensile strength, flexural Strength and Ultrasonic Pulse Velocity values were obtained for 10% fly ash replacement. For bacterial concrete maximum compressive strength, split tensile strength, flexural strength, and UPV values were obtained for the bacteria cell concentration of 105cells/ml. The improvement in the strength properties of fly ash concrete is due to the precipitation of calcium carbonate (CaCO3) in the micro environment by the bacteria Bacillus Subtilis.

14. V Srinivasa Reddy, M V SeshagiriRaoand S Sushma have published a paper on Feasibility Study on Bacterial Concrete as an innovative self-crack healing system. This paper describes about the effect of bacterial cell concentration of Bacillus subtilis JC3, on the strength, by determining the compressive strength of standard cement mortar cubes of different grades, incorporated with various bacterial cell concentrations. This shows that the Improvement in compressive strength reaches a maximum at about 105/ml cell concentration. The cost of using microbial concrete compared to conventional concrete which is critical in determining the economic feasibility of the technology, is also studied. The cost analysis showed an increase in cost of 2.3 to 3.9 times between microbial concrete and conventional concrete with decrease of grade. And nutrients such as inexpensive, high protein- containing industrial wastes such as corn steep liquor (CSL) or lactose mother liquor (LML) effluent from starch industry can also be used, so that overall process cost reduces dramatically. Precipitation of these crystals inside the gel matrix also enhances the durability of concrete significantly. Furthermore, this analysis has shown an increase in the cost of production and a significant decrease in carbon footprint compared to conventional concrete.

15. N. Ganesh Babu and Dr. S. Siddiraju have published a paper onan experimental study on strength and fracture properties of self-healing concrete. In this paper they have made an attempt is made to arrest the cracks in concrete using bacteria and calcium lactate. The percentages of bacteria selected for the study are 3.5% and 5% by weight of cement. In addition, calcium lactate was used at 5% and 10% replacement of cement by weight. Bacteria produce calcium carbonate crystals which blocks the micro cracks and pores in the concrete after reacting with calcium lactate. Bacillus pasteurii is used for different bacterial concentrations for M40 grade of concrete. Various tests such as compressive strength, elastic modulus and fracture of concrete were analyzed. The cubes of dimensions of 100x100x100 mm were used for compressive strength test. It was observed that compressive strength for controlled concrete using calcium lactate, at 7 days and 28 days were 19.8MPa and 40.53MPa respectively. With the addition of calcium lactate, there is considerable decrease in compressive strength. Compressive strength of concrete with 5% bacteria was found to be 49.5Mpa at 28 days, which is more than controlled concrete. With the addition of calcium lactate at 10% (optimum percentage) and bacteria to concrete, there is considerable increase in compressive strength. Hence calcium lactate along with 3.5% and 5% bacteria can be used as an effective self-healing agent.

16. MohitGoyal and P. Krishna Chaitanya published a paper on Behavior of Bacterial Concrete as Self-Healing Material. In this paper they have carried out laboratory investigations to compare the different parameters of bacterial concrete with ordinary concrete and concrete, in which 70% cement was partially replaced with 30% of Fly Ash and 30% of GGBS. In this paper, Bacillus pasteurii, is used to prepare M25 concrete. Various tests such as slump flow test, compressive strength, flexural strength and split tensile strength were conducted for different specimens of, bacterial concentrations of 40ml, 50ml and 60 ml for each specimen. In order to identify atomic and molecular structure and to check the presence of formation of calcium carbonate X- Ray diffraction test was conducted. There was significant improvement of compressive strength by 30% in concrete mix with bacteria and more than 15% in fly ash and 20% in GGBS. It was observed that bacterial concrete achieves maximum split tensile strength and flexural strength when 40 ml and 50 ml bacterial solution was used but loses this trend after 14 days with 60ml bacterial solution when flexural strength test was performed. Also, 50ml bacterial solution proved to be effective in increasing the split tensile strength, compressive strength and flexural strength of the specimen as compared to 40ml and 60 ml bacterial solution. Also, from the XRD analysis, it is proven that the presence on bacteria is contributing to CaCO3 production, which has reduced the percentage of air voids, thus, increasing the strength of the structure considerably.

III. MATERIALS AND METHODOLGY

The Bacterial concrete used in the test program consisted of cementing materials, mineral aggregates, bacteria with the following specifications:

- Ordinary Portland Cement (53 Grade)
- Graded fine aggregates.
- Graded coarse aggregates.
- Water.
- Bacteria – Bacillus Subtilis

3.1.1Ordinary Portland Cement

Ordinary Portland cement is one of the most widely used types of Portland cement where there is no exposure to sulphates in the soil or groundwater. OPC is a grey colored powder. It is capable of bonding mineral fragments into a compact whole when mixed with water and this hydration process results in a progressive stiffening, hardening and strength development.

The cement is a binding material. It is conforming to IS456-2000-53 grade. It consists of grinding the raw materials, mixing them intimately in certain proportion depending upon their purity and composition and burning them in a kiln at a temperature of about 1300 – 1500 degree centigrade at which temperature, the material Cinter and partially fuses to form modular chapped clinker. The clinker is cooled and ground to a fine powder with addition of 2 to 3% of gypsum the product formed by using this procedure Portland cement. Of all the materials that influence the behavior of concrete, cement is the most important constituent, because it is 11 used to bind sand and aggregate and it resists atmospheric action. Portland cement is a general term used to describe hydraulic cement.

Table 1. Physical Properties of Cement.

S. No	**Property of Cement**	**Values**
1	Specific gravity	3.10
2	Fineness modulus	7.4
3	Initial setting time	34 min
4	Final setting time	448 min
5	Consistency	28%

Fig.5 Cement

3.1.2 Fine Aggregates

The materials smaller than 4.75 mm size is called fine aggregates.

The code to be referred to understand the specification for fine aggregates is: IS 383:1970.

The criteria to classify fine aggregates are:

- If they are Natural/ Man-made.
- According to their size.
- According to the IS specification

Fine aggregate may be described more clearly according to their availability as:

• Natural Sand– it is the aggregate resulting from the natural disintegration of rock and which has been deposited by streams or glacial agencies

• Crushed Stone Sand– it is the fine aggregate produced by crushing hard stone.

Crushed Gravel Sand– it is the fine aggregate produced by crushing natural gravel.

According to size the fine aggregate may be described as coarse sand, medium sand and fine sand.IS specifications classify the fine aggregate into four types according to its grading as fine aggregate of grading Zone-1 to grading Zone-4. The four grading zones become progressively finer from grading Zone-1 to grading Zone-4. 90% to 100% of the fine aggregate passes 4.75 mm IS sieve and 0 to 15% passes 150 micron IS sieve depending upon its grading zone.

In this project Natural sand is used of following properties

Table 2. Physical Properties of Fine Aggregate.

Properties	Natural sand
Maximum aggregate size (mm)	2.36
Bulk specific gravity	2.56
Absorption capacity (%)	1.21
Unit weight(kg/m3)	1500
Fineness modulus	2.73

Fig.6 Fine aggregate

3.1.3 Coarse Aggregates:

Locally available well graded granite aggregates of normal size greater than 4.75 mm and less than 16mm. The code to be referred to understand the specification of the coarse aggregates from natural sources is: IS 383:1970.

Coarse aggregate may be further classified as:

- Uncrushed Stone– it results from natural disintegration of rock.
- Crushed Stone– it results from crushing of gravel or hard stone.
- Partially Crushed Stone– it is a product of the blending of the above two aggregate.

In this project Crushed stone used as coarse aggregate of following properties

Table 3. Physical Properties of Coarse Aggregate.

Properties	Crushed stone
Maximum aggregate size (mm)	16
Bulk Specific gravity	2.71
Absorption capacity (%)	0.45
Unit weight (kg/m3)	1556
Fineness modulus	6.74

Fig.7 Coarse aggregate

3.1.4 Water

Potable water has been used for casting concrete specimens. The water is free from oils, acids, and alkalis and has a water-soluble Chloride content of 140 mg/lit. As per IS 456 – 2000, the permissible limit for chloride is 500 mg/lit for reinforced concrete; hence the amount of chloride present is very less than the permissible limit.Ph is an important criterion, if the pH value of water is lying between 6 to 8, then this water is free from organic matter. This water can be adopted for construction purposes.

Fig. 8 Water

3.1.5 Bacteria- (Bacillus Subtilis)

3.1.5.1 Description and Significance

Originally named Vibrio subtilis in 1835, this organism was renamed Bacillus subtilis in 1872. Other names for this bacterium also include Bacillus uniflagellatus, Bacillus globigii, and Bacillus natto. Bacillus subtilis bacteria were one of the first bacteria to be studied. These bacteria are a good model for cellular development and differentiation (Entrez Genome Project). Bacillus subtilis cells are rod-shaped, Gram-positive bacteria that are naturally found in soil and vegetation. Bacillus subtilis grow in the mesophilic temperature range. The optimal temperature is 25-35 degrees Celsius (Entrez Genome Project). Stress and starvation are common in this environment; therefore, Bacillus subtilis has evolved a set of strategies that allow survival under these harsh conditions. One strategy, for example, is the formation of stress-resistant endospores.

3.1.5.2 Cell Structure and Metabolism

Bacillus subtilis are rod-shaped bacteria that are Gram-positive (Perez 2000). The cell wall is a rigid structure outside the cell. It is composed of peptidoglycan, which is a polymer of sugars and amino acids. The peptidoglycan that is found in bacteria is known as murein. Other constituents that extend from the murein are teichoic acids, lipoteichoic acids, and proteins. The cell wall forms the barrier between the environment and the bacterial cell. It is also responsible for maintaining the shape of the cell and withstanding the cell's high internal turgor pressure (Schaechter 2006). The formation of the endospore occurs in several stages, denoted 0 through VI. Sporulation occurs in the following fashion. First the nucleoid lengthens, becoming an axial filament. Then, the cell forms a polar septum, one fourth of the cell length from one end, and begins to divide. The smaller product of this division is called the forespore and the larger product is called the mother cell (Perez 2000). The mother cell is responsible for nourishing the newly formed spore. When the septum forms, 30% of the chromosome is already on the forespore side (Schaechter 2006). The remaining 70% of the chromosome enters the forespore in a fashion similar to DNA transfer during conjugation; it is pumped by a protein called SpoIIIE. The mother cell then engulfs the forespore by acting like a phagocyte. This causes the forespore to have two cytoplasmic membranes with a thick murein layer, namely the cortex, between them. A protein spore coat and an exosporium, a membranous layer, form outside of the forespore membranes. At this time, the forespore undergoes internal changes. Lastly, the forespore leaves the mother cell upon lysis of the mother cell (Perez 2000). A mature endospore has no metabolic activity; it is inert. The interior of the endospore, the core, is very dry and resistant to moisture (Schaechter 2006).

3.1.5.3 Ecology

The main habitat of endospore forming Bacillus organisms isthe soil. Likewise Bacillus subtilis is most commonly found in soil environments and on plant undergrowth. These mesophilic microbes have historically been considered strict aerobes.. Consider how this organism functions in s competitive microbial community: when carbon-, nitrogen and phosphorus-nutrient levels fall below the bacterium's optimal threshold, it produces spores. Scientists have demonstrated that Bacillus subtilis concurrently produces antibiotics and spores. Antibiotic production increases Bacillus Subtilis's chance at survival as the organism produces spores and a toxin that might kill surrounding gram positive microbes that compete for the same nutrients. Bacillus subtilis supports plant growth. As a member of Bacillus, this bacterium often plays a role in replenishing soil nutrients by supplying the terrestrial carbon cycle and the nitrogen cycle. Bacillus subtilis bacteria form rough biofilms, which are dense organism communities, at the air and water interface. Bacillus subtilis biofilms are beneficial. They allow for the control of plant pathogen infections. Bacillus subtilis biofilm communities form a mutualistic interaction with plant rhizome systems. The plant benefits because Bacillus subtilis provides preemptive colonization. Preemptive colonization prevents other pathogens from infecting the plant because Bacillus subtilis has the advantage of being at the site first. The biofilm communities form a mutualistic interaction with plant rhizome systems. Bacillus subtilis biofilms found in the rhizosphere of plants promote growth and serve as a bio controller. In this sense, Bacillus subtilis biofilm communities form a mutualistic interaction with plant rhizome systems. The plant benefits because Bacillus subtilis provides preemptive colonization. Bacillus subtilis benefits by deriving nutrients and surface area for biofilm formation from the plant's root structure. Bacillus subtilis strains can act as bio fungicides for benefiting agricultural crops and antibacterial agents. Bacillus subtilis also reduces mild steel corrosion (Morikawa 2006). Bacillus subtilis bacteria are non-pathogenic.

Fig.9 Bacillus subtilis

3.2 Preparation of Bacterial Concrete

Bacterial concrete can be prepared in two ways

- By direct application

- By encapsulation in light weight concrete

By the method of direct application bacterial spores and calcium lactate are added directly while making the concrete and mixed .Here when the crack occurs in the concrete bacterial spores broke and bacteria comes to life comes to life and feed on the calcium lactate and limestone is produced which fill the cracks.

By encapsulation method the bacteria and its food, calcium lactate, are placed inside treated clay pellets and concrete is made. About 6% of the clay pellets are added for making bacterial concrete. When concrete structures are made with bacterial concrete, when the crack occurs in the structure and clay pellets are broken and bacterial treatment occurs and hence the concrete healed. Minor cracks about 0.5mm width can be treated by using bacterial concrete.

Among these two methods Direct Method is used in the preparation of Bacterial concrete.

3.3 Test For Compressive Strength Of Bacterial concrete

Compression test is the important test conducted on hardened concrete because most of the desired characteristics of concrete are qualitatively related to compressive strength. The main objective of the test is control of quality and to check that the concrete at site has developed required strength. It gives us idea about correction to be made in further mixes. Cubes of standard sizes 100x100x100mm as per I.S. 516 are cast. Three cubes each of 7 days, 14 days& 28 days test are cast. The surface of the moulds are covered with oil in order to avoid the development of bond between the mould and concrete and also on the contact surface at the bottom of mould and the base plate so that water does not escape during filling. Cube specimen is filled soon after mixing. Cube is filled in three layers and each layer is well compacted. Compaction is done by hand or by vibration. After compaction, the top surface of the concrete is properly finished with the help of trowel. The cube is stored undisturbed for 24 hours at 50% humidity and then striped and immersed in water for curing. These cubes are then tested at the age of 7 days, 14 days& 28 days. After curing, these cubes were tested on Compression Testing machine at 7 and 28 days. The failure load was recorded. In each category three cubes were tested and their average value is reported.

Compressive Strength (MPa) = Failure Load/Cross Sectional Area

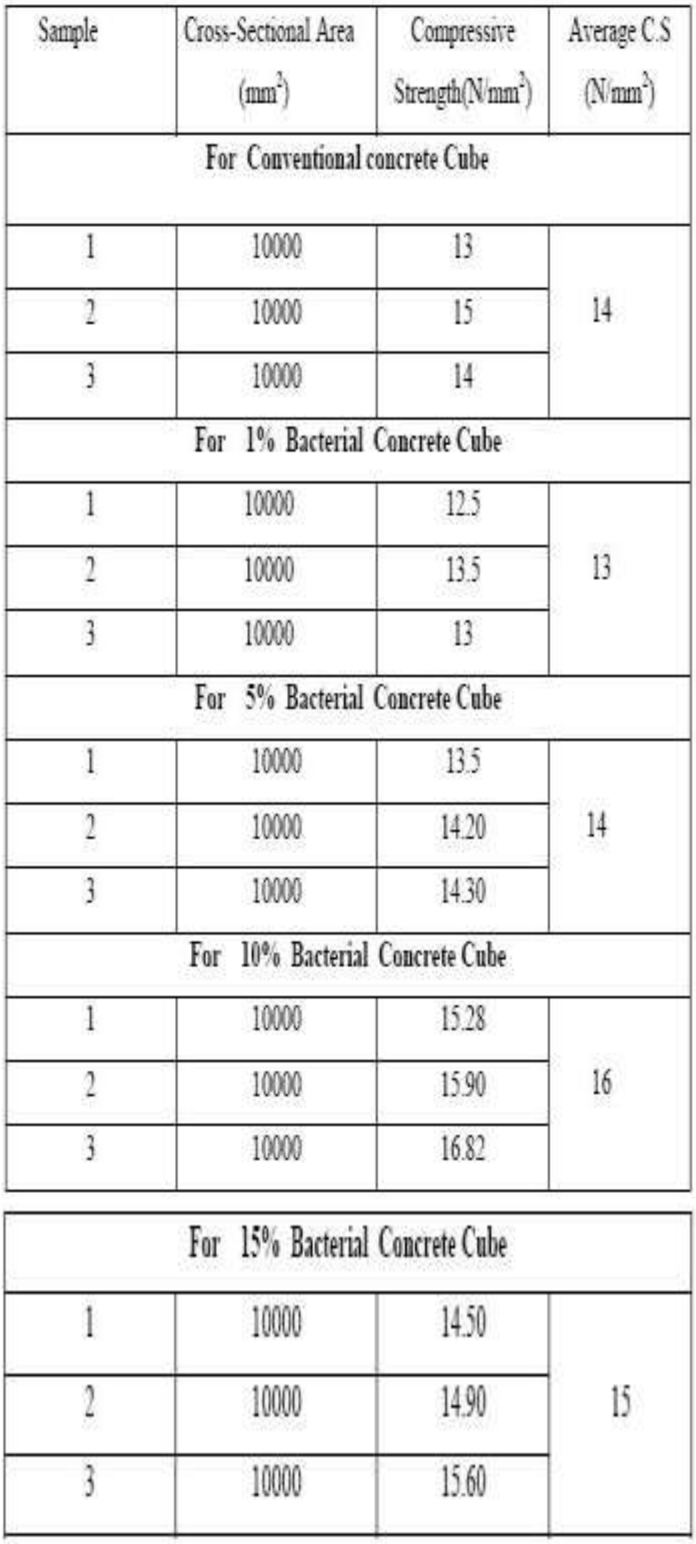
Fig.10 Experimental Setup for Compressive Strength Test

IV. RESULT & ANALYSIS

4.1 Compressive strength by varying percentage of Bacteria.

4.1.1 Compressive strength Result after 7 Days curing

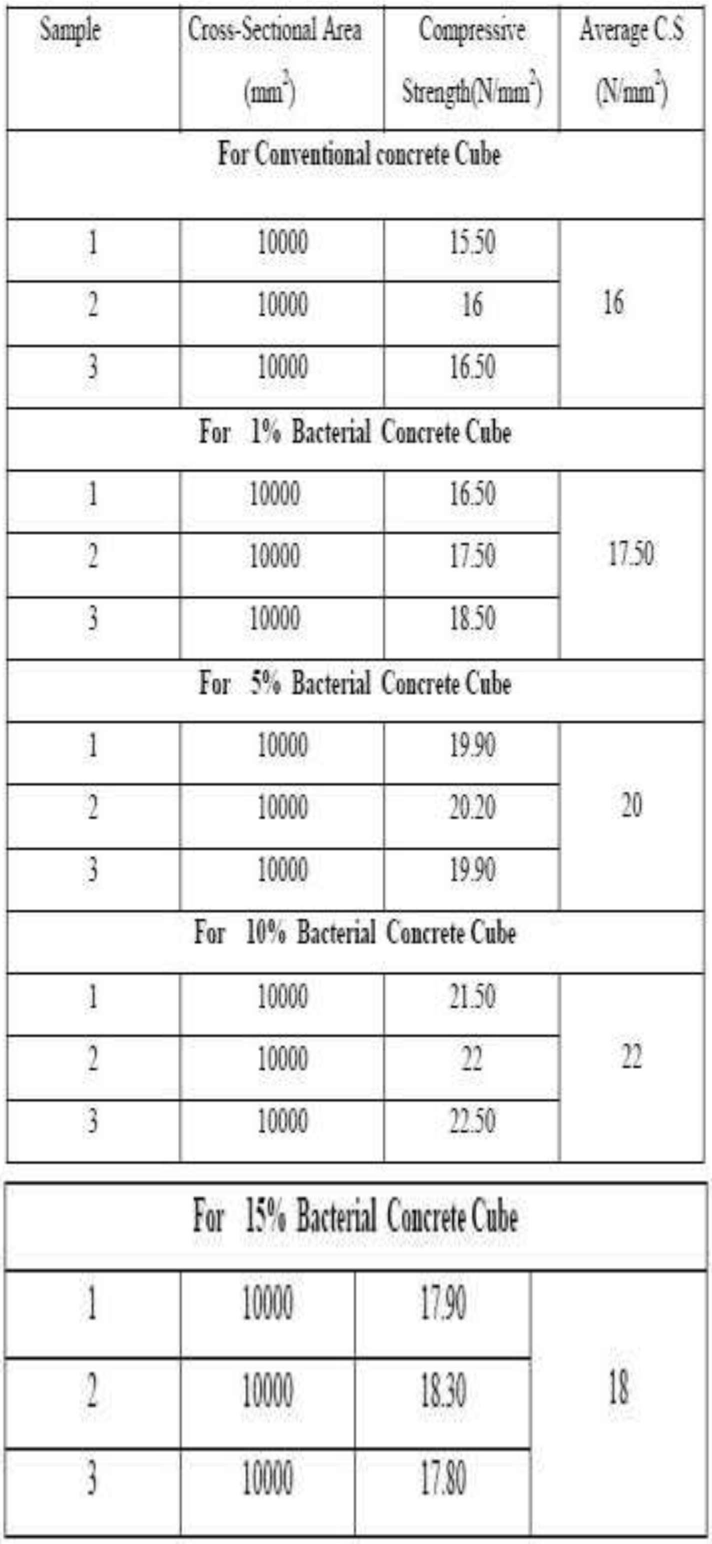
Table 4- Compressive strength Result after 7 Days curing



Sample	Cross-Sectional Area (mm^2)	Compressive Strength(N/mm^2)	Average C.S (N/mm^2)
For Conventional concrete Cube			
1	10000	13	14
2	10000	15	
3	10000	14	
For 1% Bacterial Concrete Cube			
1	10000	12.5	13
2	10000	13.5	
3	10000	13	
For 5% Bacterial Concrete Cube			
1	10000	13.5	14
2	10000	14.20	
3	10000	14.30	
For 10% Bacterial Concrete Cube			
1	10000	15.28	16
2	10000	15.90	
3	10000	16.82	
For 15% Bacterial Concrete Cube			
1	10000	14.50	15
2	10000	14.90	
3	10000	15.60	

4.1.2 Compressive strength Result after 14 Days curing

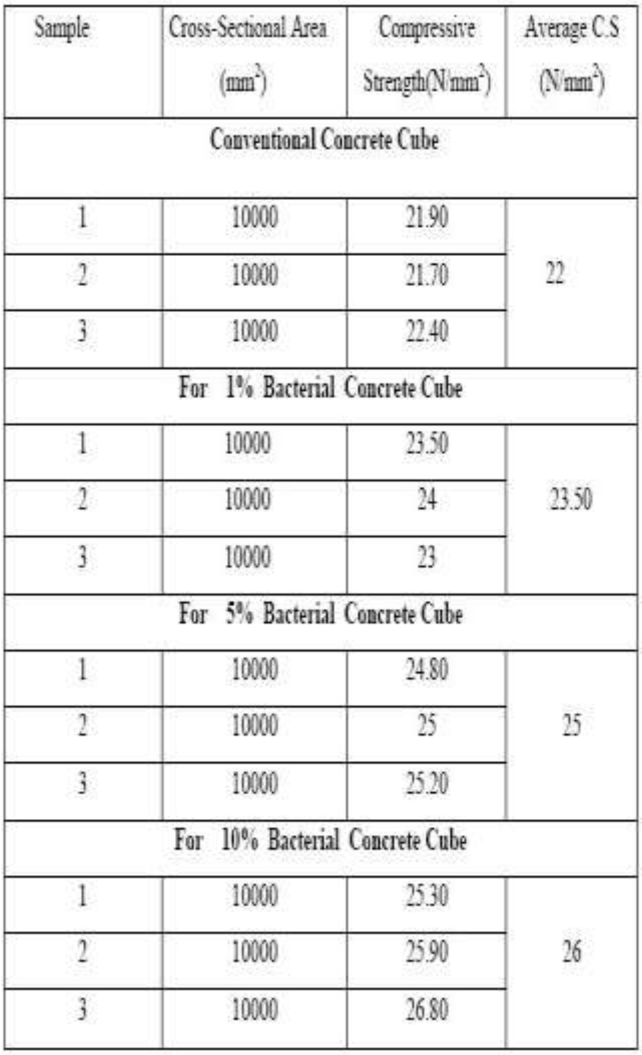
Table 5- Compressive strength Result after 14 Days curing

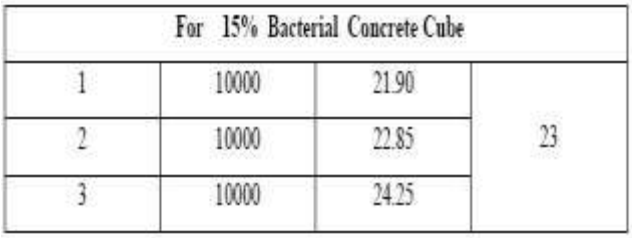


Sample	Cross-Sectional Area (mm^2)	Compressive Strength(N/mm^2)	Average C.S (N/mm^2)
For Conventional concrete Cube			
1	10000	15.50	16
2	10000	16	
3	10000	16.50	
For 1% Bacterial Concrete Cube			
1	10000	16.50	17.50
2	10000	17.50	
3	10000	18.50	
For 5% Bacterial Concrete Cube			
1	10000	19.90	20
2	10000	20.20	
3	10000	19.90	
For 10% Bacterial Concrete Cube			
1	10000	21.50	22
2	10000	22	
3	10000	22.50	
For 15% Bacterial Concrete Cube			
1	10000	17.90	18
2	10000	18.30	
3	10000	17.80	

4.1.3 Compressive strength Result after 28 Days curing

Table 6- Compressive strength Result after 28 Days curing

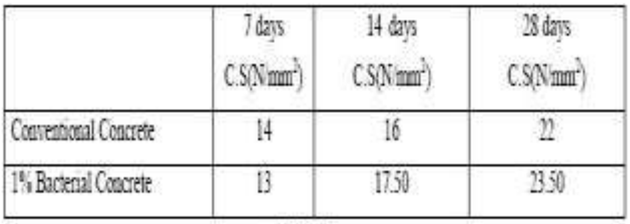




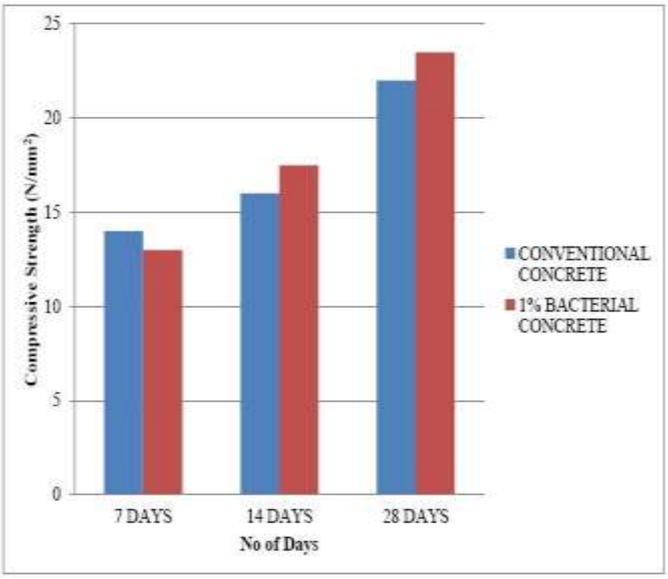
Sample	Cross-Sectional Area (mm^2)	Compressive Strength(N/mm^2)	Average C.S (N/mm^2)
Conventional Concrete Cube			
1	10000	21.90	22
2	10000	21.70	
3	10000	22.40	
For 1% Bacterial Concrete Cube			
1	10000	23.50	23.50
2	10000	24	
3	10000	23	
For 5% Bacterial Concrete Cube			
1	10000	24.80	25
2	10000	25	
3	10000	25.20	
For 10% Bacterial Concrete Cube			
1	10000	25.30	26
2	10000	25.90	
3	10000	26.80	
For 15% Bacterial Concrete Cube			
1	10000	21.90	23
2	10000	22.85	
3	10000	24.25	

4.2 Comparative study of 1% bacterial concrete with conventional concrete.

Table 7



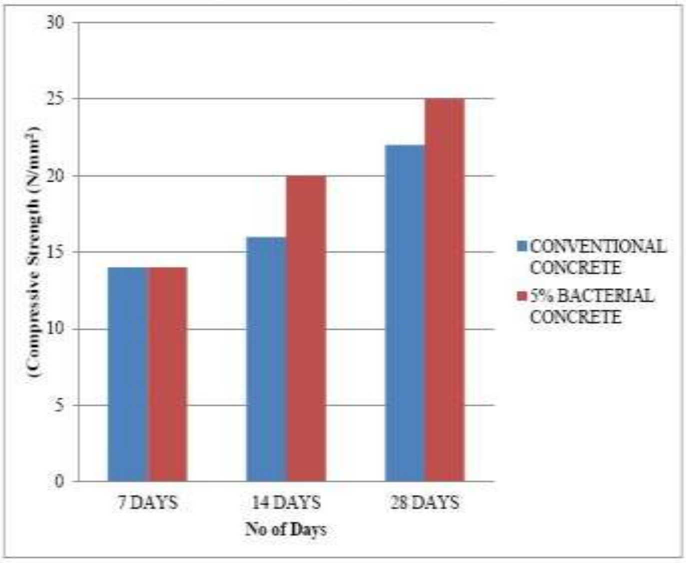
	7 days C.S(N/mm^2)	14 days C.S(N/mm^2)	28 days C.S(N/mm^2)
Conventional Concrete	14	16	22
1% Bacterial Concrete	13	17.50	23.50



4.3 Comparative study of 5% bacterial concrete with conventional concrete.

Table 8

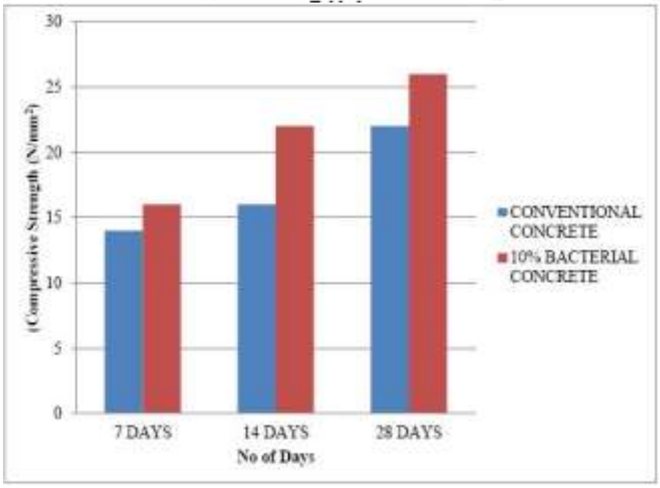
	7 days C.S(N/mm²)	14 days C.S(N/mm²)	28 days C.S(N/mm²)
Conventional Concrete	14	16	22
5%Bacterial Concrete	14	20	25



4.4 Comparative Study of 10% Bacterial Concrete with Conventional Concrete

Table 9

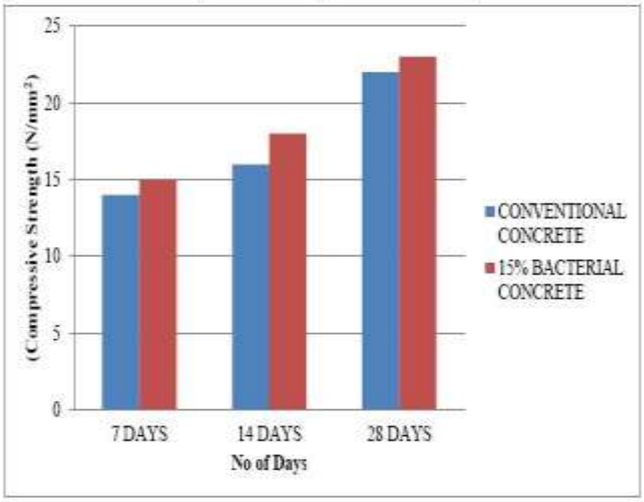
	7 days C.S(N/mm2)	14 days C.S(N/mm2)	28th days C.S(N/mm2)
Conventional concrete	14	16	22
10%Bacterial Concrete	16	22	26



4.5 Comparative Study of 15% Bacterial Concrete with Conventional Concrete

Table 10

	7 days C.S(N/mm^2)	14 days C.S(N/mm^2)	28 days C.S(N/mm^2)
Conventional Concrete	14	16	22
15%Bacterial Concrete	15	18	23



4.6 Response of Bacteria on crack filling

1) When 10% Bacteria added in the concrete the crack filling capacity of Bacteria is good.
2) Bacteria can easily heal crack size upto 1mm.
3) For larger Crack healing capacity of bacteria is not so good.
4) When 10% bacteria is added in the concrete the crack fill in minimum day comparative to other percentage of bacteria.
5) At 10% bacteria healing is good but when 15% Bacteria is added healing properties is increases but Compressive Strength decreases.

V. CONCLUSION

Based on the present experimental investigation the following conclusion is drawn.
1) The compressive strength is 26 MPa that is maximum when the addition of bacillus subtilis bacteria is 10 %.

2) The M20 grade bacterial concrete having higher compressive strength then the normal M25 grade concrete.

3) The self-healing property is successfully achieved in bacterial concrete.

4) Bacterial concrete technology has proved to be better than many conventional technologies, because of its eco-friendly nature and very convient for usage.

5) This innovative concrete technology will soon proved the basis for an alternative and high quality structures that will be cost effective and environmentally safe.

6) Self-healing concrete is crack resistant which protects the concrete and reinforcement from cracks and from corrosion.

7) When 10% Bacteria added in the concrete the crack filling capacity of Bacteria is good.

8) Bacteria can easily heal crack size upto 1 mm.

9) At 10% bacteria healing is good but when 15% Bacteria is added healing properties is increases but Compressive Strength decreases.

10) There is increase of Compressive Strength of 15% in Compare to Conventional When we added 10% of bacteria.

5.2 Further Scope of study

1) To study the durability of concrete under various weathering conditions.
2) To check the performance of bacillus subtilis by durability test.
3) To verify the performance of bacillus subtilis with 1mm and 2mm crack width and 15mm, 20mm, 25mm, and 30mm crack depth.
4) More work should be done on the retention of nutrients and metabolic products in the building materials detail microbial ecology studies are also needed in order to ascertain the effects of introduction of new bacteria into natural microbial communities.
5) Fatigue studies on bacteria induced concrete are essential to use it in rigid pavement constructions.

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