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AN EXPERIMENTAL INVESTIGATION ON MECHANICAL PROPERTIES OF BACTERIAL CONCRETE

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ABSTRACT
Concrete is the only construction material which satisfies the properties of strength and durability. Concrete, which is brittle, by the nature has a tendency of developing cracks with the passage of time. The development of cracks induces problems on the reinforcement with the intrusion of salts, chlorides and water through these cracks. So, in order to counteract this problem, the concept of Bacterial Concrete can be used by which concrete heals itself, the micro cracks developed at the early stage. This type of concrete can also be called as a Self-Healing Concrete. In this project work, Bacteria is prepared using Bacillus Subtillus, the culture which is laboratory developed in the institution using the raw bacteria. 2.5%, 5% and 7.5% of water is replaced with the developed bacteria and added to the cement concrete. The plugging of artificially cracked cement concrete using Bacillus Subtillus bacteria combined with sand as a filling material in artificially made cuts in cement mortar which was cured in urea and $CaCl_2$ medium. The effect on the mechanical properties of the cement concrete cubes due to the mixing of bacteria is also discussed. Laboratory tests viz., Compressive Strength Test and Split Tensile Test are carried out and the results are compared. It was found that use of bacteria improves the mechanical properties (stiffness and compressive) strength of concrete.

Investigations have shown that the bacteria Bacillus pasturii can be used for improving the resistance of concrete to alkali or sulphate attack, drying shrinkage etc., which will increase the strength and durability of concrete. However, not much investigation is reported in India for producing bacterial concrete using Bacillus subtilis. Keeping this in view, the present experimental investigations are taken up to study the strength characteristics in ordinary grade concrete and standard grade of concrete with and without addition of bacteria Bacillus subtilis

Key words: Bacterial concrete, Bacillus subtillus bacteria, Self-Healing concrete, Compressive strength, Split tensile strength.

I. INTRODUCTION

Concrete is a vital building material that is an absolutely essential component of public infrastructure and most buildings. It is most effective when reinforced by steel rebar, mainly because its tensile strength without reinforcement is considerably low relative to its compressive strength. It is also a very brittle material with low tolerance for strain, so it is commonly expected to crack with time. These cracks, while not compromising structural integrity immediately, do expose the steel reinforcement to the elements, leading to corrosion which heightens maintenance costs and compromises structural integrity over long periods of time. That being said, concrete is a high maintenance material. It cracks and suffers serious wear and tear over the decades of its expected term of service. It is not flexible and cannot handle significant amounts of strain. Self- healing concrete in general seeks to rectify these flaws in order to extend the service life of any given concrete structure.

There is a material in the realm of self-healing concrete in development, now, that can solve many of the problems commonly associated with standard concrete. This material is bacterial self- healing concrete, Self-healing concrete consists of a mix with bacteria incorporated into the concrete and calcium factate food to support those bacteria when they become active. The bacteria, feeding on the provided food source, heal the damage done and can also reduce the amount of damage sustained by the concrete structure in place.

Concrete is used in structures to resist the compression stresses and reinforcements are used to resist the tensile stresses in concrete. Concrete does not require much water to achieve maximum strength. But a wide majority of concrete used in residential work has too much water added to the concrete on the job site. This water is added to make the concrete easier to install. This excess water also greatly reduces the strength of the concrete. Shrinkage is a main cause of cracking. As concrete hardens and dries it shrinks. This is due to the evaporation of excess mixing water. The wetter or soupier the concrete mix, the greater the shrinkage will be. This Crack formation in concrete is a phenomenon that can hardly be complete avoided due to for example shrinkage reactions of setting concrete and tensile stresses occurring in set structures.

While larger cracks can potentially hamper a structures' integrity and therefore require repair actions, smaller cracks typically with a crack width smaller than 0.2 mm are generally considered unproblematic. Although such micro cracks do not affect strength properties of structures they do on the other hand contribute to material porosity and permeability. Ingress of aggressive chemicals such as chlorides, sulfates and acids may result on the longer term in concrete matrix degradation and premature corrosion of the embedded steel reinforcement and thus hamper the structures' durability on the long term. In several studies indications have been found that concrete structures have a certain capacity for autonomous healing of such micro cracks.

The actual capacity of micro crack healing appears primarily related to the composition of the concrete mixtures. Particularly mixtures based on a high binder content show remarkable crack-healing properties . what is due to delayed (secondary) hydration of matrix embedded non hydrated cement and binder particles upon reaction with crack ingress water. Autogenous self-healing of cracks in traditional but also high-binder content mixtures appear limited to cracks with a width smaller than 0.2 mm .This somewhat limited effectiveness appears largely due to the restricted expansive potential of the small non-hydrated cement particles lying exposed at the crack surface. Another limitation to application of highbinder content mixtures solely for the purpose of increasing self-healing capacities are current policies which advocate sparse use of cement in concrete for sustainability reasons as current cement production contributes about 7% to global anthropogenic CO2 emissions.

For latter reasons, alternative and more sustainable self-healing mechanisms are therefore wanted. One possible mechanism is currently being investigated and developed in several laboratories, i.e. a technique based on the application of mineral producing bacteria. E.g. efficient sealing of surface cracks by mineral precipitation was observed when bacteria based mixtures were sprayed or applied onto damaged surfaces or manually inserted into cracks. As in those studies bacteria were manually and externally applied to existing structures, this mode of repair cannot be categorized as truly self-healing. In several follow up studies therefore, the possibility to use viable bacteria as a sustainable and concrete-embedded self-healing agent was explored. In one study spores of specific alkali-resistant bacteria related to the genus Bacillus were added to the concrete mixture as self-healing agent.

Definition: The "Bacterial Concrete" is a concrete which can be made by embedding bacteria in the concrete that are able to constantly precipitate calcite. This phenomenon is called microbiologically induced calcite precipitation. It has been shown that under favorable conditions for instance Bacillus Pasteruii, a common soil bacterium, can continuously precipitate a new highly impermeable calcite layer over the surface of an already existing concrete layer. The favorable conditions do not directly exist in a concrete but have to be created.

These spores germinated after activation by crack ingress water and produced copious amounts of crack filling calcium carbonates based minerals through conversion of precursor organic compounds which were also purposely added to the concrete mixture. However, in that study it was found that the bacteria-based self-healing potential was limited to relatively young (7-days cured) concrete only, as viability and related activity of bacterial spores directly (unprotected)embedded in the concrete matrix was restricted to about two months. The present study builds further on results reported in latter research paper. Here, bacterial spores and organic mineral precursor compounds are packed in porous expanded clay particles prior to addition to the concrete mixture. It is hypothesized that protection of bacterial spores within porous light weight aggregates extends there viability period and thus concrete self-healing functionality when embedded in the material matrix.

1.2Cracks in concrete

In concrete cracks are most common due to its low tensile strength. High tensile stresses impose deformations due to temperature gradients, reinforcement corrosion, silica reaction, differential settlements and sulphate attack. If the treatment to cracks was not instant and accurate, cracks tend to enlarge rapidly and need costly repairs. Micro- cracks developed in concrete allow liquids and gases through them which eventually lead to damage not only concrete but also the reinforcement gets corroded. Therefore, micro-cracks may lead to structural failure due to failure of both concrete and reinforcement. To sustain and self-strengthening of concrete in harsh environments like sea floors, off shores, highways, sewage pipes, bridges, tunnels and structures for liquid, solid waste carrying toxic and radioactive waste bacteria (bacillus pasteurii) is added. There are many techniques available for the treatment of cracks.

Besides, by these techniques there are disadvantageous like different thermal expansion coefficient, environment hazard and health hazard. There is a necessity to develop a new biological technique which is both environmental and health friendly. Therefore, bacterially produced Calcite precipitation (CaCO3) is a biological technique called bio- mineralization is used as self-healing concrete. This technique is also used to increase the stiffness of the cracked concrete specimen. Microbial Calcite Precipitation (MICP) technique lead to develop the research in its ability to heal the cracks in concrete, restoration of historical monuments, sand consolidation and other such applications. Use of these MICP techniques and Bio mineralogy lead to invention of new material called Bacterial Concrete.

1.3 Bacterial concrete

The concept of bacterial concrete was first introduced by V. Ramakrishnan. A novel technique is adopted in remediating cracks and fissures in concrete by utilizing microbiologically induced calcite ($CaCO_3$) precipitation.

Microbiologically induced calcite precipitation (MICP) is a technique that comes under a broader category of science called biomineralization. Bacillus subtilis, a common soil bacterium can induce the precipitation of calcite. As a microbial sealant, $CaCO_3$ exhibited its positive potential in selectively consolidating simulated fractures and surface fissures in granites and in the consolidation of sand.

Microbiologically induced calcite precipitation is highly desirable because the calcite precipitation induced as a result of microbial activities, is pollution free and natural. The technique can be used to improve the compressive strength and stiffness of cracked concrete specimens.

The bacterial concrete makes use of calcite precipitation by bacteria. The phenomenon is called microbiologically induced calcite precipitation (MICP). The pioneering work on repairing concrete with MICP is reported by the research group of Ramakrishnan V and others at the South Dakota School of Mines & Technology, USA. The MICP is a technique that comes under a broader category of science called biomineralization. It is a process by which living organisms or bacteria form inorganic solids. Bacillus subtilis JC3, a common soil bacterium, can induce the precipitation of calcite. Under favorable conditions Bacillus subtilis JC3, when used in concrete, can continuously precipitate a new highly impermeable calcite layer over the surface of the already existing concrete layer.

Need For Bacterial Concrete:

The ongoing research in the field of concrete technology has led to the development of special concrete considering the speed of construction, the strength of concrete, the durability of concrete and the environmental friendliness with industrial material like fly ash, blast furnace slag, silica fume, metakaolin etc. The process can occur inside or outside the microbial cell or even some distance away within the concrete of a bacterial activity is simply trigger a change in solution Chemistry that leads to over saturation and mineral precipitation.

1.3.1 Advantages and disadvantages of Bacterial Concrete: Advantages:

- Self-repairing of cracks without any external aide.
- Significant increase in compressive strength and flexural strength when compared to normal concrete.
- Resistance towards freeze-thaw attacks.
- Reduction in permeability of concrete.
- Reduces the corrosion of steel due to the cracks formation and improves the durability of steel reinforced concrete.
- Bacillus bacteria are harmless to human life and hence it can be used effectively.

Disadvantages:

- Cost of bacterial concrete is double than conventional concrete.
- Growth of bacteria is not good in any atmosphere and media.
- The clay pellets holding the self-healing agent comprise 20% of the volume of the concrete. This may become a shear zone or fault zone in the concrete.
- Design of mix concrete with bacteria here is not available any IS code or other code.
- Investigation of calcite precipitate is costly.

1.4 APPLICATIONS OF BACTERIA IN CONCRETE

Microbial concrete as an alternative surface treatment for concrete an important measure to protect concrete against damage is diminishing the uptake of water [10]. Many of the physical and chemical deterioration mechanisms of concrete are related to m aggressive substances present in aqueous solution. Surface treatments play an important role in limiting the infiltration of water. Broad arrays of organic and inorganic products are available in the market for the protection of concrete surfaces, such as a variety of coatings, water repellents

and pore blockers. But these means of protection beside their favorable influences even show disadvantageous aspects such as: Degradation over time, need for constant maintenance, Different thermal expansion coefficient of the treated layers, Use of certain solvents contributes to environmental pollution as well. Microbial concrete as concrete crack remediation/healing When cracks appear in the concrete, the possibility for corrosion of the embedded steel arises which could eventually ruin the integrity of the structure. Without immediate attention, the cracks can expand and cause extensive damage. Current forms of concrete crack remediation are structural epoxy, resins, epoxy mortar, and other synthetic filler agents. These synthetic solutions often need to be applied more than once as the cracks expand. Clearly there is a need for an effective, long-term, environmentally safe method to repair cracks in concrete

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structures. Several research groups have investigated the possibility of bio-mineralization as an effective method to remediate cracks and fissures in concrete structures. Cracks filled with a mixture of Bacteria subtilis and sand showed a significant increase in compressive strength and stiffness, compared to cracks without cells. Microscopy confirmed the presence of calcite crystals and cells near the surface of the cracks.

Table .1: Microbial Concrete applications

Applications	Types of bacteria
Microbial concrete as crack healer	Bacillus pasteurii, Bacillus subtilis , Deleya halophila, Halomonas eurihalina, Myxococcus Xanthus, Bacillus megaterium
Microbial concrete as surface treatment	Bacillus subtilis , Bacillus sphaericus
Microbial concrete as water purifier	Bacillus subtilis, Bacillus sphaericus,Thiobacillus

Table.2: Overview of various Construction Materials made using MICP

Application	Microorganism	Metabolism	Nutrients	Reference
Biological mortar	Bacillus cereus	oxidative deamination of amino acids	Growth media (peptone, extract yeast, KNO3, NaCl) + CaCl2.2H2O, Actical, Natamycine	(Muynck et al., 2010)
Crack in concrete remediatio	Bacillus subtilis	Hydrolysis of urea	Nutrient broth, urea, CaCl2.2H2O, NH4Cl, NaHCO3	(Santhosh et al., 2001)
Crack in concrete remediation	Bacillus sphaericus	Hydrolysis of urea	Extract yeast, urea,	(Belie, 2010)

Table 3: Microorganism used for Calcium Carbonate Precipitation in Concrete

Type of microorganism	System	Crystal type	Reference
Photosynthetic organism : Synechococcus GL24	Meromictic lake	Calcite (CaCO3)	(Douglas and Beveridge, 1998)
Photosynthetic organism : Chlorella	Lucerne Lake	Calcite (CaCO3)	(Dittrich, 2004)
Sulfate reducing bacteria: Isolate SRB LVform6	Anoxic hypersaline lagoon	Dolomite (Ca(Mg) CO3)	-
Nitrogen cycle Bacillus subtilis	Urea degradation in synthetic medium	Calcite (CaCO3)	(Mc Connaughey, 2000)
Nitrogen cycle Bacillus cereus	Ammonification and nitrate reduction	Calcite (CaCO3)	(Castanier et al., 1999)

1.5 Objective and scope of study

Cracks widths in concrete structure should be limited, mainly for durability reasons. If cracks widths are too large the cracks need to be repaired or extra reinforcement is needed in the design. If a method could be developed to automatically repair cracks in concrete this would save an enormous amount of money, both on the costs of injection fluids for cracks and also on the extra steel that is put in structures only to limit crack widths. For structural reasons this extra steel has no meaning. A reliable self-healing method for concrete would lead to a new way of designing durable concrete structures which is beneficial for national and global economy.

The main of objective of the study is to find out the mechanical properties of bacterial concrete mix by adding different proportion of fly ash or cement, water and aggregates with suitable percentage of bacteria. The test results are compared with that of the curing period of cubes and different proportions adding. Also observe the cracks developed in the cubes during the hardening process and self-healing of concrete.

II. LITERATURE REVIEW

1. Pappupreethi K, RajishaVelluva Ammakunnoth,2017 Concrete is the foremost building material broadly used in building construction, but cracks in concrete are inevitable and are one of the inherent weakness of concrete. The major downside of concrete is its low tensile strength due to which micro crack occurs when the load applied is more than its limit and this paves way for the seepage of water and other salts. This initiates corrosion and makes the whole structure vulnerable and leads to the failure of structure. To remediate this type of failure due to cracks and fissures, an approach of using bio mineralization in concrete has evolved in recent years. In this method, of enhancing the performance of concrete, the calcite precipitating spore forming bacteria is introduced into concrete. When water enters through the cracks, it reacts with bacteria and forms precipitates of calcium carbonate, as a by-product, which fills the cracks and makes crack free concrete. This type of concrete prepared with bacteria is called as bacterial concrete. Thus, this paper is an attempt to define bacterial concrete, types and classification of micro-organisms, working of bio concrete as a repair material, advantages and disadvantages of bacterial concrete and applications by literature review are discussed.

2. Abhishek Thakur, Akshay Phogat, Khushpreet,2016 The concrete structures have various durability issues due to the different physiological conditions and it results to irretrievable damage to the structure and eventually reduction in the strength of concrete structure. The main reason behind the downgrading of the durability and mechanical aspects of concrete is the pore structure of

concrete. In the recent years MICCP (microbiologically induced calcium carbonate precipitation) by the bacteria considered as an environment friendly method to enhance the properties of concrete, also for the repair of concrete structure and to consolidate different construction materials. This paper presents a review of different researches in the recent years on the use of bacterial concrete/bio-concrete for the enhancement in the durability, mechanical and permeation aspects of concrete. It contains studies on different bacteria's, their isolation process, different approaches for addition of bacteria in concrete, their effects on compressive strength and water absorption properties of concrete and also the SEM and XRD analysis of concrete containing bacteria.

3. Abhishek Pandit, Sahila Shaikh, Pranjali Mangalwedhekar, Sakshi Jagtap, Swapnil Gorade,2018
Concrete is a brittle material and it crack under sustained loading and aggressive environment which effect on durability. Micro cracks formation in concrete allows water, chemicals and gases to enter and degrade the concrete as well as corrode the reinforcement. Repairing of cracks require regular maintenance and sometimes special treatments which are expensive hence a novel technique come into lime light which is addition of calcite mineral precipitating bacteria for plugging of pores and cracks in concrete. This mechanism also called self-healing mechanism to repair the crack by producing calcium carbonate crystals which seal the micro cracks in concrete. Hence this paper presents a detail overview on bacterial concrete including types of bacteria, methodologies, advantages, disadvantages etc.

III. MATERIALS

3.0 General

In the present investigation, locally available materials have been used as ingredients for the preparation of concrete specimens. The concrete mixes are designed for strengths 20N/mm2.

3.1 Material selection

The results of various physical tests are reported in methodology for ordinary Portland cement of grade 53 is used in the preparation of all the specimens. The fact that this cement confirms it is free from lumps. The locally available river sand belonging to zone II of IS:383-1963 has been used as the fine aggregate. For coarse aggregate 10 mm and downsized granite metal of angular shape is utilized. Ordinary portable tap water is used in the preparation of the concrete. The culturing bacteria solution is used in the preparation of bacterial concrete.

3.2 Ingredients of concrete

Concrete is used extensively as a construction material because of its versatility. It is good in compression, but weak in tension. This drawback can be overcome by providing steel in tension zone. This technique called "REINFORCED CEMENT CONCRETE", improves the load carrying capacity of concrete members. At the same time durability of concrete is also important. Durability is mainly affected due to cracks developed by creep and shrinkage. This can be avoided by using certain chemical admixtures. But once a crack develops in the member there are no barriers to stop the propagation of such cracks. In RCC it leads the corrosion of the reinforcement slowly and finally it results in the failure of the structure. So, this problem overcome by the using of bacterial solution in concrete.

3.2.1 Cement

Cements may be defined as adhesive substances capable of uniting fragments or masses of solid mater to a compact whole. Portland cement was invented in 1824 by an English mason, Joseph Aspin, who named his product Portland cement because it produced a concrete that was of the same colour as natural stone on the Isle of Portland in the English Channel.

Raw materials for manufacturing cement consist of basically calcareous and siliceous (generally argillaceous) material. The mixture is heated to a high temperature within a rotating kiln to produce a complex group of chemicals, collectively called cement clinker. Cement is distinct from the ancient cement. It is termed hydraulic cement for its ability to set and harden under water. Briefly, the chemicals present in clinker are nominally the four major potential compounds and several minor compounds. The four major potential compounds are normally termed as Tricalcium silicate (3CaO.SiO2), declaim silicate (2CaO.SiO2), tricalcium aluminates (3CaO.Al2O3) and tetra calcium alumino ferrite (4CaO. Al2O3.Fe2O3).

FIG .1 CEMENT

- **FINENESS**

Fineness or particle size of cement affects the rate of hydration; gain of strength and also on the rate of evolution of heat. Finer cement gets strength faster because it offers a larger surface area for hydration. Maximum number of particles in a sample of cement should have a size less than about 100 microns. Smallest particle may have size of about 1.5 microns. If the cement particles are coarser, hydration starts on the surface of the particles. So, the coarser particles possibly will not be entirely hydrated. This causes low strength and low durability. For a fast development of strength, a high fineness is required.

- **COMPRESSIVE STRENGTH**

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One of the most essential characteristics of hardened cement is its compressive strength. That is why the strength of cement is always tested in a laboratory before it is utilized in field work. Because of the challenges of excessive shrinkage and subsequent cracking of neat cement, strength tests are not performed on fresh cement paste. Cement strength is determined indirectly by the proportions of cement-sand mortar. The cement's strength is tested over a variety of time periods:

- 1 day (for high early strength cement).
- 3 days, 7 days, 28 days and 90 days (for monitoring strength progress)

In most codes, 28-day strength is used as a control basis. The w/c ratio, cement-fine aggregate ratio, curing circumstances, specimen shape and size, fine aggregate type and grading, loading conditions, and age all influence cement strength.

- **SETTING TIME**

The setting time of cement has been divided into two categories: initial setting time and final setting time. It's difficult to establish a clear line between these two seemingly unrelated divisions. The first setting time is defined as the period of time between when water is added to the cement and when the paste begins to lose its flexibility. The final setting time is the time between when water is introduced to the cement and when the paste has entirely lost its flexibility and is solid enough to withstand a specific amount of pressure. For mixing, transporting, installing, compacting, and finishing cement paste, mortar, or concrete, a particular amount of setting time is required. The fineness of the cement, the w/c ratio, the chemical content (particularly gypsum concentration), and the admixtures all affect the setting time of the cement. Setting tests are used to determine how a cement paste will set.

- **SOUNDNESS**

The ability to resist volume growth is defined as soundness. It is critical that the cement does not undergo any substantial volume changes after setting. When cement is utilized that is not sound, it will have a significant impact on the structure's durability. Excess lime, magnesia, or sulphates in the cement cause it to be unsound. Free lime (CaO) and magnesia (MgO) react slowly with water and expand significantly in volume, resulting in cracking, deformation, and crumbling. As a result, the amount of magnesia allowed in cement is limited to 6%. If the amount of gypsum added exceeds 3-5 percent, it may combine with C3A, but the surplus gypsum will remain free in the cement. This extra gypsum causes the cement paste to expand
unnecessarily, causing the set to be disrupted.

3.2.3 AGGREGATES

Aggregates are inert or chemically inactive elements that give concrete its bulk proportion. Cement is used to hold the aggregates together. Fine and coarse aggregates are the two types of aggregates. Fine aggregate is defined as material that passes through BIS test sieve no. 480. Finely crushed stone can be utilized as fine aggregate if natural river sand is not economically available. Coarse aggregate is the material that is retained on the BIS test sieve no. 480.Type of work describes the maximum size of coarse aggregate. The maximum size of coarse aggregate for thin slabs and walls should be one-third the thickness of the concrete section. The aggregates used in cement concrete work should be firm, long-lasting, and free of contaminants. The aggregates should be free of clay lumps, organic and vegetable debris, fine dust, and other contaminants. The presence of all of this debris limits aggregate bonding and so diminishes concrete strength.

FIG .2 COARSE AGGREGATES

Fine aggregate

Aggregates are inert or chemically inactive elements that give concrete its bulk proportion. Cement is used to hold the aggregates together. Fine and coarse aggregates are the two types of aggregates. Fine aggregate is defined as material that passes through BIS test sieve no. 480. Finely crushed stone can be utilized as fine aggregate if natural river sand is not economically available. Coarse aggregate is the material that is retained on the BIS test sieve no. 480.Type of work describes the maximum size of coarse aggregate. The maximum size of coarse aggregate for thin slabs and walls should be one-third the thickness of the concrete section. The aggregates used in cement concrete work should be firm, long-lasting, and free of contaminants. The aggregates should be free of clay lumps, organic and vegetable debris, fine dust, and other contaminants. The presence of all of this debris limits aggregate bonding and so diminishes concrete strength.

3.2.4 Bacteria

Bacillus Subtilis:

Bacillus Subtilis is bacteria with species B. subtilis, having domain name Bacteria which is a Gram positive bacterium generally found in the soil. It is found in the roots of plants and gastrointestinal tract of ruminants and humans. The use of bacteria in concrete technology has been made with only those organisms that has been extracted from the roots of plants. It is the bacterial champions which shows the self-healing characteristics when is mixed in the concrete.

Bacillus Pasteurii:

Bacillus Pasteuri were also known as Sporosarcina pasteurii. This is a bacteria having species of Sporosarcina pasteurii, with geneus Sporosarcina. These bacteria are a gram positive bacterium. These bacteria have a characteristic of more calcite precipitation. This bacterium also shows the spreading characteristics against the crack healing mechanism with auto heal process.

Bacillus Sephaericus:

Bacillus Sephaericus was also known as Lysinibacillus Sphaericus. Bacillus Sephaericus is a gram positive bacteria with strict aerobic bacterium features. Generally, the shape of this bacteria is rod in shape and found in the soil. These bacteria can be extract from the larva of mosquito but the strain obtained from the larva of mosquito can only be used for human drug research for medicine. In concrete technology, for crack healing the bacteria must be obtained from the soil.

Bacillus Pseudofirmus:

Bacillus Pseudofirmus is a gram positive bacterium having the features of alkaliphilic and alkalitolerant an aerobic. The strain of these bacteria shows the selfhealing characteristics in the concrete. It also maintains the PH value in the concrete.

Bacillus Licheniformis:

Bacillus Licheniformis is a gram positive bacteria, generally shows mesophilic in nature. Normally these bacteria can be obtaining from the soil. But also these bacteria are available in the feathers of birds and ducks. It also shows the characteristics of self-healing, when is mixed in the concrete.

Transfer of bacteria

After sufficient growth of bacteria in laboratory same is transfer to cracked mortar cubes by mixing with sand and required amount of cell concentration of bacteria.

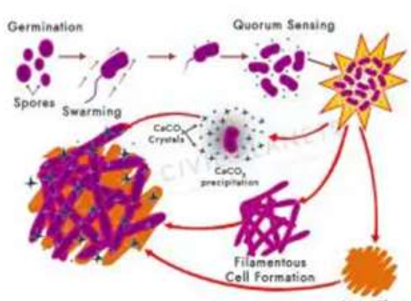


Fig 3. Process of fixing crack in concrete

3.2.5 Water

The requirement of water used for mixing and curing shall be taken as per IS code provisions. However, use of sea water is prohibited.

3.0 Water cement ratio

Experience has shown that for a satisfactory for bacterial concrete it should contain a mortar volume of above 20% consisting of particles between 5mm to 10mm.The strength of bacterial concrete achieved will be maximum when it is cast without any segregation at the maximum water cement ratio. It is found that bacterial concrete cast under good control will achieve its maximum strength at water cement ratio around 0.5to 0.55.

Water Permeability

Water permeability, or how easily water can invade the material, of concrete is dependent on the porosity and on the connectivity of the pores. The more open the pore structures are, the more vulnerable the concrete is to matrix degradation. Low permeability is desirable in order to limit the entrance of harmful chemicals into the concrete, allowing it to last longer.

ER DIAGRAM

Fig .4 flow chat of ER diagram

IV. METHODOLOGY

4.0 Bacteria

Bacteria are microscopic organisms, single-celled prokaryotic creatures. Bacteria come in different shapes and the sizes. Bacteria are ubiquitous in every habitat on Earth, growing in soil, acidic hot springs, radioactive waste, water, and deep in the Earth's crust, as well as in organic matter and the live bodies of plants and animals. There are typically 40 million bacterial cells in a gram of soil and a million bacterial cells in a millilitre of fresh water; in all, there are approximately five nonillion (5×1030) bacteria on Earth (Whitman et al. 1998, Vol.95) forming much of the world's biomass.

Bacteria were first observed by Antoine van Leeuwenhoek in 1676, using a single-lens microscope of his own design. He called them "animalcules" and published his observations in a series of letters to the Royal Society. The name bacterium was introduced much later, by Christian Gottfried Ehrenberg in 1838. Louis Pasteur demonstrated in 1859 that the fermentation process is caused by the growth of microorganisms. Along with his contemporary, Robert Koch, Pasteur was an early advocate of the germ theory of disease.

4.1 Bacillus subtilis

Researchers with different bacteria proposed different bacterial concretes. The various bacteria used in the concrete are Bacillus pasteurii, Bacillus sphaericus, E. coli etc. In the present study an attempt was made by using the bacteria Bacillus subtilis strain no. JC3. The main advantage of embedding bacteria in the concrete is that it can constantly precipitate calcite. This phenomenon is called microbiologically induced calcite precipitation (MICP). Calcium carbonate precipitation, a widespread phenomenon among bacteria, has been investigated due to its wide range of scientific and technological implications. Bacillus subtilis is a laboratory cultured soil bacterium and its effect on the strength and durability is studied here.

4.2 Methodology of the project

The present work is divided into three phases, they are
Phase I – Developing Culture of bacteria
Phase II – Casting the Cubes & Cylinders using Bacterial Concrete
Phase III – Conducting tests in Laboratory, i.e., Compressive Strength Test of Concrete Cube & Split Tensile Strength Test and compared with the normal Concrete.

V. RESULTS AND DISCUSSIONS

Compressive strength test:

The Compressive Strength test is carried out for all the cubes which are casted and cured for the age of 7, 14 and 28 days. The Compressive Strengths of all the cubes are tabulated as follows:

S. NO.	e of concretecube	Compressive strength in N/mm²		
		7 days	14 days	28 days
1.	NCB	17.88	21.66	23.67
2.	B2.5	19.66	23.11	26.77
3.	B5.0	16.55	20.66	22.87
4.	B7.5	16.33	19.88	22.33

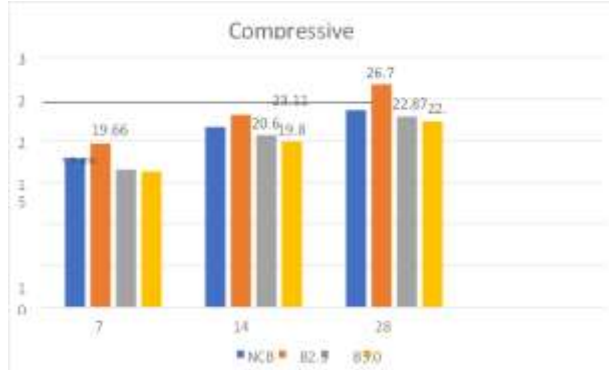
Table .4 shows the results of the compressive strength test of concrete cubes

- NCB: Normal concrete blocks
- B2.5: 2.5% bacterial concrete blocks
- B5.0: 5.0% bacterial concrete blocks
- B7.5: 7.5% bacterial concrete blocks

Compressive strength for cube= compressive load/cube area N/mm2 .

It is observed that a 2.5% replacement of bacterial solution with water in the concrete production has got better results when compared to the normal concrete. However, it depends on the type of cracks developed in the cube. These results tell that at a very small percentage of bacteria, cracks are healed and if the bacteria are added more, no appreciable strength is identified.

Plot the graph between normal concrete and bacterial concrete.



Graph .1 shows the compressive strengths of normal concrete and bacterial concrete

Split tensile strength test:

The Split Tensile Strength test is carried out for all the cylinders which are casted and cured for the age of 7 and 28 days. The Compressive Strengths of all the cylinders are tabulated as follows:

S.NO	Type of concrete cube	Split tensile strength in N/mm²	
		7 days	28 days
1.	NCB	1.41	2.06
2.	B2.5	1.83	2.12
3.	B5.0	1.98	1.98
4.	B7.5	1.55	1.83

Table 5. shows the results of the split tensile strengths of cylinders

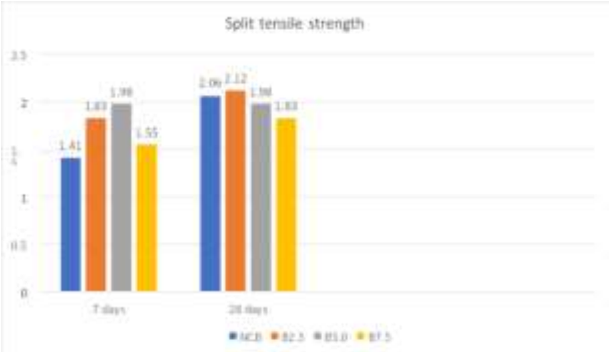
- NCB: Normal concrete blocks
- B2.5: 2.5% bacterial concrete blocks
- B5.0: 5.0% bacterial concrete blocks
- B7.5: 7.5% bacterial concrete blocks

Split tensile strength for cylinder=2P/πDL

From the above observations, the same B2.5% bacterial concrete is giving the better results when compared to the B5.0 & B7.5 Bacterial Concrete.

From both the Tests, one can suggest that 2.5% of bacteria is enough to get the desired strength for concrete which indirectly tells us that the micro cracks are healed by itself. However, further the work can be extended for better results so that the materials can be used economically.

Plot the graph between normal concrete and bacterial concrete



Graph .2: show the tensile strength of normal concrete and bacterial concrete

VI. CONCLUSION

The outcome of this study shows that crack healing of bacterial concrete based on expanded porous clay particles loaded with bacteria and calcium lactate, i.e., an organic bio-mineral precursor compound, is much more efficient than of concrete of the same composition however with empty expanded clay particles. The reason for this can be explained by the strictly chemical processes in the control and additional biological processes in the bacterial concrete. Non-hydrated cement particles exposed at the crack surface of concrete will undergo secondary hydration and in addition in control specimens carbon dioxide present in the bulk water will react with present calcium hydroxide particles to produce calcium carbonate-based mineral precipitates.

Latter mineral precipitates will particularly form near the crack rim due to the relatively high solubility of calcium hydroxide. Here it is hypothesized that calcium hydroxide particles present at the surface of the crack interior will first scavenge all available carbon dioxide from crack ingress water, where after remaining calcium hydroxide will dissolve and diffuse out of the crack into the bulk water. Once in the bulk water it will react with carbon dioxide present in close approximation to the crack rim resulting in the chemical production and precipitation of larger quantities of much lower soluble calcium carbonate.

The following conclusions are observed this project work:

1. With a very small number of raw bacteria, culture of bacteria can be developed which can be used for the concrete production that requires a skilled worker at site.
2. At 2.5% of bacteria the results are appreciable, further the work can be extended for 0.5%, 1.0%, 1.5% & 2.0% of bacteria.
3. The durability characteristics can be studied further using the percentage of bacteria used.

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