IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

EXPERIMENTAL STUDY ON SELF HEALING CONCRETE

1SURAJ BHAN SINGH SIKARWAR, 2Mr. Rameezut Tauheed

ABSTRACT

Cracking of concrete is a common phenomenon without immediate and proper treatment, cracks in concrete structures tends to expand further and eventually require costly repairs. Even though it is possible to reduce the extent of cracking by available modern technology, remediation of cracks in concrete has been the subject of research for many years. Cracks and fissures are a common problem in building structures, pavements, and historic monuments.

We have introduced a novel technique in fitting cracks with environmentally friendly biological process that is a continuous self-remediating process. In this study bacillus substile that is abundant in soil has been used to induced CaCo3. It is therefore vital to understand the fundamentals of microbial participation in crack remediation. Cracks in concrete form an open pathway to reinforcement can lead to durability problems like corrosion of the steel rebar's. furthermore, cracks can cause leakage in case of liquid retaining structures, due to alkali, sulphate, and drying shrinkage to overcome this problem, a variant of smart concrete is rapidly developing, which is known as "self-healing concrete". The self-healing concrete is one that senses its crack formation and react to cure itself without human intervention. The impact of Eco-friendly micro-organism has been made use of the self-healing process in the current project.

The cement industry is a major global contributor to world CO2 emissions (7% in 2019). A major cause of this high percentage is the durability issues associated with concrete, in recent years a new breed on concrete that can heal cracks which are a major cause of these durability. This will introduce this new breed of concrete in its various forms, with particular attention paid to the form which incorporates use of microbes as the healing agents.

In recent years a bacteria-based self-healing concrete is being developed to extend the service life. A two-component healing agent is added to the concrete mixture. The agent consists of bacteria and mineral precursor compound. Whenever cracks occurs and water is present the bacteria become active and convert the incorporated organic compounds into the mineral calcium precipitates and can seal and block cracks, allowing autonomous healing. This paper aims to

review the development of bacteria-based self-healing concrete, introducing the proposed healing system. Different stages in the developing are discussed, and some recommendation for further research.

Cement mortar durability is the function of its internal pore structure and distribution, porosity, and its permeation properties. Research has shown that some specific bacterial species isolated from soil can tolerate harsh and challenging alkaline environment and can be used in remediating cracks in cement mortar structures. This state-of-the-art microbial based crack healing mechanism is one such phenomenon on which studies were carried out to investigate the role of calcite mineral precipitation in improvement of durability in bacteria integrated cement mortar. The primary goal of this study is to explore the potential of biomineralization microbial calcium carbonate deposition in cement mortar, to develop sustainable construction materials. The idea has led to the conception of energy efficient and sustainable construction material called ‘Bacterial Cement mortar’. This paper primarily focuses on the studies related to the characterization of bacteria produced calcium carbonate crystals using various nano characterization techniques such as Scanning Electron Microscope (SEM), X-ray diffraction (XRD), and Thermo gravimetric analysis (TGA) to validate that cracks/pore were sealed up by calcite crystals grown due to complex metabolic mechanism of nitrogen cycle by *Bacillus subtilis* JC3.

In concrete, cracking is a common phenomenon developed due to relatively low tensile strength. High tensile strength may be developed in concrete due to external loads, imposed deformations, plastic shrinkage, plastic settlement and expensive reaction. Proper and immediate treatment should be done to prevent expansion of cracks which may eventually be of higher cost. For crack repair, a variety of traditional repair system are available which possess several disadvantages aspect such as different thermal expansion coefficient, environmental and hazards of health. Bacterially induced calcium carbonate precipitation has been proposed as an alternative and environmentally friendly crack repair technique. It is found that microbial mineral precipitation as a result from metabolic activities of favorable bacteria in concrete improved the overall behavior of concrete. It is expected that further development of this technique will result in a more durable, sustainable, and crack free concrete that can be used efficiently for construction in wet atmosphere where corrosion of reinforcement affects the durability, permeability, and strength of concrete.

CHAPTER - 1

INTRODUCTION

1.1 Definition: Self-healing concrete

The Self-healing Concrete is one that senses its crack formation and reacts to cure itself without human intervention. Self-healing concrete is a product that will biologically produce limestone to heal cracks that appear on the surface of concrete structures. Specially selected types of the bacteria Bacillus subtilis, is added to the ingredients of the concrete when it is being mixed. These self-healing agents can lie dormant within the concrete for up to 200 years.

1.2 Bacterial concrete

The "Bacterial Concrete" can be made by embedding bacteria in the concrete that are able to constantly precipitate calcite. Bacillus subtilis is a 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. A Main part of the research will focus on this topic. Tests are conducted to study the mechanical properties of the above concrete with various percentages of Bacteria. The tests carried out are Compressive strength test, Split Tensile strength test.

1.3 Mechanism

Some possible mechanisms for Self-healing are:
1. Formation of material like calcite.
2. Blocking of the path by sedimentation of particles.
3. Continued hydration of cement particles.
4. Swelling of the surrounding cement matrix

1.4 Objects of biological approach

To develop methods to enhance durability of concrete by adding bacteria. To regain the maximum strength of concrete after cracking rectification. To develop methods of concrete after cracking rectification.

1.5 Bio-mineralization

Natural processes such as weathering, faults, land subsidence, earthquakes and human activities create fractures and fissures in concrete structures and historical stone monuments. These fractures and fissures are detrimental since they can reduce the service life of the structure. In the case of 20 monuments and buildings of historic importance, these cracks tend to disfigure and destroy the structure. Use of bacterial concrete for remediating these structures will reduce the crack width and increase the strength of the structure. Therefore, a novel technique for remediating damaged structural formations has been developed by employing a selective microbial plugging process, in which microbial metabolic activities promote calcium carbonate (calcite) precipitation. The technique is called "Microbiologically Enhanced Crack Remediation (MECR). This technique comes under a broader category of science called "Biomineralization". It is a process by which living organism form inorganic solids. Bacterial deposition of a layer of calcite on the surface of the specimens resulted in a decrease of capillary water uptake and permeability towards gas. This bacterial treatment resulted in a limited change of the chromatic aspect of mortar and concrete surface. The type of bacterial culture and medium composition had a profound impact on CaCo3 crystal morphology.

Microbial mineral precipitation resulting from metabolic activities of some specific microorganisms in concrete to improve the overall behavior of concrete has become a considerable area of research. These bacteria can influence the precipitation of calcium carbonate by the process of Ammonification (Ammo acid degradation). Precipitation of calcium carbonate crystals occur by heterogeneous nucleation on bacterial cell walls once supersaturation is achieved.

The application of concrete is rapidly increasing worldwide and therefore the development of bacterial mediated concrete is urgently needed for environmental reasons. As presently, about 8% of atmospheric carbon dioxide emission is due to cement production, mechanisms that would contribute to longer service life of concrete structures would make the material not only more durable but also self-repair, i.e., the autonomous healing of cracks in concrete. The potential of bacteria to act as self-healing agent in concrete has proven to be a promising future. This field appears to be more beneficial as bacterial concrete appears to produce more substantially more crack plugging minerals than control specimens (without bacteria). A promising sustainable repair methodology is currently being investigated and developed in several laboratories, i.e., a technique based on the application of mineral producing bacteria. The application for ecological engineering purposes is becoming increasingly popular as is reflected by recent studies where bacteria were applied for removal of chemicals from wastewater streams, for bioremediation of contaminated soils and removal of greenhouse gases from landfills.

The applicability of specifically mineral producing bacteria for sand consolidation and limestone monument repair and filling of pores and cracks in concrete have been recently investigated. In all these studies so far, bacteria were externally applied on cracked concrete structures or test specimens, i.e., as surface treatment or repair system.

An integrated healing agent would save manual inspection and repair and moreover increase structure durability. Addition of such an agent to the concrete mixture would thus save both money and the environment as less maintenance and use of environmentally friendly repair material is needed. Microbial carbonate precipitation (bio deposition) decreases the permeation properties of concrete. Hence, a deposition of a layer of calcium carbonate on the surface of concrete resulted in a decrease of water absorption and porosity. Bacteria-based self-healing concrete is produced by incorporating spores of bacteria of a special kind (*Bacillus subtilis*JC3), in the concrete matrix at the stage of preparation of the concrete by mixing the spore suspension in concrete mixing water. When crack is formed water enters the crack subsequently the homogeneously distributed bacterial spore in hardened concrete matrix gets activated and germinate to become metabolically active vegetative cells that can convert the organic nutrient compounds into insoluble inorganic calcium carbonate-based minerals.

Bio-mineralization is also defined as a biologically induced precipitation in which an organism creates a local micro-environment with conditions that allow optimal extracellular chemical precipitation of mineral phases. Numerous diverse microbial species participate in the precipitation of mineral carbonates in various natural environments including soils, geological formations, freshwater bio films, oceans, and saline lakes. The precise role of the microbes in the carbonate precipitation process is still not clear. Almost all bacteria are capable of calcium carbonate precipitation. A novel technique for the remediation of damaged structural formations has been developed by employing a selective microbial plugging process, in which metabolic activities promote precipitation of calcium carbonate in the form of calcite. Biomineralization of calcium carbonate is one of the strategies to remediate cracks in building materials. In nature, microorganisms can induce calcite mineral precipitation through nitrogen cycle by ammonification of amino acids/ nitrate reduction/ hydrolysis of urea. The binding strength of the precipitated crystals is highly dependent on the rate of carbonate formation and under suitable conditions it is possible to control the reaction to generate hard binding calcite cement (or bio-cement).

1.6 Chemistry of bio-classification by *BACILLUS SUBTILIS* JC3

Bacterial calcium carbonate precipitation results from both passive and active nucleation. Passive carbonate nucleation occurs from metabolically driven changes in the bulk fluid environment surrounding the bacterial cells. This increases the mineral saturation and induces nucleation. In the Ammo acid degradation driven system, this occurs from an increase in pH due to ammonification. Active carbonate nucleation occurs when the bacterial cell surface is utilized as the nucleation site. The cell clusters exhibit a net electronegative charge which favors the adsorption of Ca2+ ions. The Ca2+ ions attract CO3 2- and HCO3- ions, which will eventually form calcium carbonate precipitates. Although it is known that there are many different types of bacteria capable of calcium carbonate precipitation, it has been hypothesized that there are specific attributes of certain bacteria that promote and affect CaCO3 precipitation more than others. It has already been noted that cell walls have an inherent electronegative charge that affect the binding of certain ions, but the extracellular polymeric substance associated with bio films may also be involved. Bio film cells are contained in the extracellular polymeric substance matrix and may exhibit an overall negative charge. This negative charge is important in trapping metal ions. Strain *Bacillus subtilis* JC3, selected for the present study, was distinguished as aerobic alkaliphilic spore-forming soil bacteria. The medium used to grow *Bacillus subtilis*JC3 was based on peptone, NaCl, yeast extract. The pure culture was isolated from the soil sample of JNTU.

Microbiologically induced calcium carbonate precipitation occurs via more complicated processes than chemically induced precipitation. In nutrients medium, it is possible that individual microorganisms produce ammonia because of amino acids degradation to create an alkaline micro-environment around the cell. The high pH of these localized areas, without an initial increase in pH in the entire medium, commences the growth of CaCO3 crystals around the cell. Specific proteins present in biological extracellular polymeric substances cause the formation of different calcium carbonate polymorphs. Some bacteria and fungi can induce precipitation of calcium carbonate extracellularly through several processes that include photosynthesis, ammonification, denitrification, sulfate reduction and anaerobic sulphide oxidation. Although all the Bacillus strains were capable of depositing calcium carbonate, differences occurred in the amount of precipitated calcium carbonate on agar plate colonies. Oxidative deamination of amino acids by *Bacillus subtilis*JC3 is temperature dependent and that the highest calcite precipitation rates occurred near the point of critical saturation. *B. Subtilis*JC3 member of the genus Bacillus is Gram-positive, rod-shaped, endospore forming bacteria commonly found in soil; precipitate calcium carbonate (CaCO3) in its micro-environment by the ammonification of amino acids into ammonium (NH4+) and carbonate (CO3) ^2- ions.

Microbiologically induced (also called ‘‘bacteriogenic’’) calcite carbonate precipitation by Ammonification (Ammo acid degradation) comprises of series of complex biochemical reactions. Amino acids released during proteolysis (the process of enzymatic breakdown of proteins by the microorganisms with the help of proteolysis enzymes) undergo deamination in which nitrogen containing amino (NH2-) group is removed. Thus, process of deamination which leads to the production of ammonia is termed as "ammonification".

The process of ammonification is mediated by *Bacillus subtilis*JC3. Ammonification usually occurs under aerobic conditions (known as oxidative de amination) with the liberation of ammonia (NH3) or ammonium ions (NH4) when dissolved in water. The biochemical reactions of ammonification in peptone-based medium is represented as follows

Ca2+ + *B.subtilis*Cell → *B.subtilis*Cell- Ca2+CH3CH(NH2)COOH (Peptone) + ½O2 ---------> C2H2 + H2CO3 + NH3
H2CO3 ----------> H+ + HCO3-
NH3 + H2O --------> NH4+ + OH- (pH increase)
HCO3- + H+ + OH- ---------->CO3^2- + H2O
B.subtilis Cell- Ca2+ + CO3^2- → *B.subtilis* Cell- CaCO3

Upon examination, bacterial cells were shown encased in calcite crystals, which indicated that the bacteria acted as a nucleation site for the mineralization process, an example of active nucleation.

1.7 Application of bacteria in concrete

1.7.1 Microbial concrete as an alternative surface treatment for concrete

An important measure to protect concrete against damage is diminishing the uptake of water. many of the physical and chemical deterioration mechanisms of concrete are related to 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.

1.7.2 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 structures. Several research groups have investigated the possibility of biomineralization as an effective method to remediate cracks and fissures in concrete structures. Cracks filled with a mixture of *B. 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.

CHAPTER - 2

LITERATURE REVIEW

• V. Ramakrishnan, R.K.Panchalan, and S.S.Bang has published a paper on Bacterial Concrete – A Concrete for the Future which says a common soil bacterium was used to induce calcite precipitation. This technique is highly desirable because the mineral precipitation induced because of microbial activities, is pollution free and natural. The effectiveness of this technique was evaluated by comparing the compressive strength and stiffness of cracked specimens remediated with bacteria and those of the control specimens (without bacteria). Experimental investigation was also conducted to determine the strength regaining capacity (modulus of rupture) of cracked beams remediated with different concentrations of bacteria. This paper also presents the results of a durability study on cement mortar beams treated with bacteria, exposed to alkaline, sulfate and freeze-thaw environments. Different concentrations of bacteria were used for the investigation. It was found that the use of bacteria improved the stiffness, compressive strength, modulus of rupture and durability of concrete. Scanning electron microscope (SEM) was used to document the role of microbiologically induced mineral precipitation in improving the strength and durability aspects of concrete.

• C. C. Gavimath, B. M. Mali, V. R. Hooli, J. D. Mallpur , A. B. Patil , D.P.Gaddi, C.R.Ternikar has published a paper on potential application of bacteria to improve the strength of cement concret in which the potential application of bacterial species i.e. B.sphaericus to improve the strength of cement concrete is studied. Here they have made an attempt to incorporate dormant but viable bacteria in the concrete matrix which will contribute to the strength of the concrete. Water which enters the concrete will activate the dormant bacteria which in turn will give strength to the concrete through the process of metabolically mediated calcium carbonate precipitation. Concrete, however, is due to its high internal pH, relative dryness and lack of nutrients needed for growth, a rather hostile environment for common bacteria, but there are some extremophilic spore forming bacteria may be able to survive in this artificial environment and increase the strength and durability of cement concrete. In this study they found that incorporation of spore forming bacteria of the species Bacillus will not negatively affect the compressive and split tensile strength of the cement concrete.

• Surendran and S. John Vennison has published a Journal on Occurrence and Distribution of Mosquitocidal Bacillus sphaericus in Soil which says Bacillus sphaericus is one of the effective biolarvicides to control Culex species and the monitoring of larval susceptibility is essential to avoid resistance development. Mosquito larvicidal activity of B. sphaericus was assessed by isolating them from ecologically different soil habitats in and around Devakottai of Tamil Nadu inSouth India. The isolated organisms were
confirmed as Bacillus sphaericus based on biochemical characterization and microscopic observations.

• Thirumalaichettiar has published a paper on bacterial concrete says a novel technique in remediating cracks and fissures in concrete by utilizing microbiologically induced calcite ($CaCo_3$) precipitation is discussed. Microbiologically induced calcite precipitation (MICP) is a technique that comes under a broader category of science called biomineralization. It is a process by which living organisms form inorganic solids. Bacillus Pasteruii, a common soil bacterium can induce the precipitation of calcite.

• Ellie Zolfagharifard(2012) has published a article on Biological concrete could usher in a new era of self-healing civil structures says its Far better would be to use a material that heals itself just as a crack begins to appear. Existing research has focused on the use of synthetic materials that can seal up cracks as they develop. But the work by Delft and Ghent universities is unique in that they plan to use living bacteria to achieve what they hope will be better results. At Delft University, DrHenk Jonkers has developed a biological concrete that uses specially selected bacteria of the genus Bacillus, alongside a combination of calcium lactate, nitrogen and phosphorus, to create a healing agent within the concrete. If untouched, these agents can remain dormant in the concrete for centuries. But if water begins to seep into the cracks, the Emerging Trends in Engineering Research 19 ISBN 978-93-82338-32-1| © 2012 Bonfring spores of the bacteria start to generate and feed on the calcium lactate. This consumes oxygen, which in turn converts the calcium lactate into limestone that solidifies and seals the surface. The removal of oxygen also improves the durability of the steel reinforcement.

• Dr. Nele De Belie, Ghent University, Belgium has published a paper on Healing and Self-Healing of Concrete has shown during their presentation how repair and consolidation of mineral phases of building materials and the healing and self-healing of concrete with the help of bacteria is possible. Micro-organisms play a crucial role in pedogenesis, transformation of minerals and exchange of elements in structures. This also includes transformation of hard rocks to soft soil, which supports plant growth and is a positive process in nature. However, when this rock is used as a building block or a constituent of concrete, this biodegradation process is far from positive. The building materials may be protected by traditional systems such as coatings and hydrophobic sealers or with organic dispersions. In the bacterial treatment, the solution medium used was of equimolar concentration of urea (20g/l) and CaCl2 or Ca(NO3)2 for 3 days and thereafter dried for 3 days at 28oC. The bacteria used were B. Sphaericus(BS). But to protect these bacteria from the strong alkaline environment in concrete, they were immobilized in Silica Sol-gel. The treatments were applied by placing the samples on plastic rods in the treatment solution, where the liquid level was 10 mm above their lower side. Remediation of cracks could be possible by formation of biocers.

• KanthaD.Arunachalam , K.S. Sathyanarayanan , B.S. Darshan, R.Balaji Raja has published a article on Biosealant properties of Bacillus sphaericus in which they say Bacillus spharecius was yet another partially characterized species with similar entity, having the capability of precipitating calcium carbonate. Earlier researchers have shown very less implementation of the 8 organism in remediation aspect. Bacillus spharecius was sub cultured and temperature, pH were optimized at 7.4 and 37°C. Growth curve for Bacillus spharecius showed that the log phase was between 4-11 hours and after 21 hours the bacterial growth was inhibited. EDTA titration was performed to find out the amount of CaCO3 precipitate and it was highest at pH 8. The broth culture was subjected to Atomic Force Microscope studies. The analysis confirmed the presence of calcite in both the bacterial solution and dry scrapes. Optimum nickel ion concentration for calcium carbonate precipitation was found to be 80μm. The cubes were treated for 5 days in laboratory scale and to pilot scale in the second phase for 25 days. At the end of the study, the potential of Bacillus spharecius in Bio-concrete was well established.

• P S Tan, M Q Zhang, D Bhattacharyya has published a article on Processing and Performance of Self-Healing Materials says Two self-healing methods were implemented into composite

materials with self healing capabilities, using hollow glass fibres (HGF) and microencapsulated epoxy resin with mercaptan as the hardener. For the HGF approach, two perpendicular layers of HGF were put into an E-glass/epoxy composite, and were filled with coloured epoxy resin and hardener. The HGF samples had a novel ball indentation test method done on them. The samples were analysed using micro-CT scanning, confocal microscopy and penetrant dye. Micro-CT and confocal microscopy produced limited success, but their viability was established. Penetrant dye images showed resin obstructing flow of dye through damage regions, suggesting infiltration of resin into cracks. Three-point bend tests showed that overall performance could be affected by the flaws arising from embedding HGF in the material. For the microcapsule approach, samples were prepared for novel double-torsion tests used to generate large cracks. The samples were compared with pure resin samples by analysing them using photo elastic imaging and scanning electron microscope (SEM) on crack surfaces. Further double-torsion testing showed that healing recovered approximately 24% of material strength. Self-healing materials are materials designed to recover strength from low-level damage done to the material over the course of its service lifetime. The self-healing
technique is particularly useful when applied to composite materials, since composites have low damage detectability and is susceptible to sudden and brittle failure. This study is aimed at two self-healing methods that had been implemented into composite materials with self-healing capabilities, that is: (1) using embedded hollow glass fibres (HGF) storing epoxy resin and hardener, and (2) using microencapsulated epoxy resin with 2- methylimidazole/CuBr2 as the hardener. Current methods of evaluating the performance of self-healing polymer composites involve inducing some form of damage into the material.

• SakinaNajmuddinSaifeeet .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 Cementous 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. Bacterial Concrete:

• Meera C M and Dr. Subha V2, 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 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 microorganisms, 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, 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.

• Ravindranatha, N. Kannan, Likhit M. L3, 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.

• A.T.Manikandan1, A.Padmavathi4, have published a paper on An Experimental Investigation on Improvement of Concrete Serviceability by using Bacterial Mineral Precipitation. In this paper, the bacteria *Bacillus subtilis* 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 daysafter casting. There was an improvement in compressive strength by B. subtilis strain 121 due to deposition of Calcite ($CaCO_3$) 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.

• Jagadeesha Kumar B G, R Prabhakara and Pushpa H5, 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 Pappupreethi K, RajishaVelluvaAmmakunnoth and P. Magudeaswaran 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 phenolhypochlorit eassay 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.

• RA. B. Depaaand T. Felix Kala6, 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 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.

• Chithra P Bai and Shibi Varghese7, 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.

• V Srinivasa Reddy, M V SeshagiriRaoand S Sushma8, 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.

• MohitGoyal and P. Krishna Chaitanya9 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 Bacterial Concrete: A Review parameter 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. 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 $CaCO_3$ production, which has reduced the percentage of air voids, thus, increasing the strength of the structure considerably.

• N. Ganesh Babu and Dr. S. Siddiraju10,has published a paper on an experimental study on strength and fracture properties of self-healing concrete. In this paper they have tried 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 pasteuriiis 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 19.8 MPa and 40.53 MPa 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 49.5 Mpa 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.

CHAPTER - 3

MATERIALS REQUIRED FOR EXPERIMENTAL WORK

3.1 Materials required for experimental study

The ordinary concrete used in the test program consisted of cementing materials, mineral aggregates and corrosion inhibitor with the following specifications:

- Ordinary Portland Cement
- Flyash
- Graded fine aggregates.
- Graded coarse aggregates.
- Water
- Chemical admixture.
- Bacteria – Bacillus Substills
- Calcium lactate
- Urea Cacl2

a. **Ordinary Portland Cement**

OPC 53 Grade at is produced Conformed to the Indian Standards Specifications as per IS: 12269-1987. The cement that is prepared by grinding Portland Cement Clinker and suitable proportions of Gypsum is called as Ordinary Portland cement. Small additions of performance improvers such as Fly ash, Blast furnace slag etc. are permitted.

53 grade Ordinary Portland Cement is high strength OPC and provides numerous advantages wherever concrete for special high strength applications is required. The rate of development of strength is faster than 43 grade OPC.

53 Grade OPC is different from Rapid Hardening Portland Cement IS: 8041and their purposes of usage are different.

The Cement mortar that is prepared in 1: 3 proportions using standard sand (as per IS:650) and tested at standard laboratory conditions and gains the compressive strength of not less than 53 MPa after 28 days, then the Cement is said to be 53 Grade Ordinary Portland Cement.

b. Flyash:

Fly ash is a byproduct from burning pulverized coal in electric power generating plants. During combustion, mineral impurities in the coal (clay, feldspar, quartz, and shale) fuse in suspension and float out of the combustion chamber with the exhaust gases. As the fused material rises, it cools and solidifies into spherical glassy particles called fly ash. Fly ash is collected from the exhaust gases by electrostatic precipitators or bag filters. The fine powder does resemble Portland cement but it is chemically different. Fly ash chemically reacts with the byproduct calcium hydroxide released by the chemical reaction between cement and water to form additional cementitious products that improve many desirable properties of concrete. All fly ashes exhibit cementitious properties to varying degrees depending on the chemical and physical properties of both the fly ash and cement. Compared to cement and water, the chemical reaction between fly ash and calcium hydroxide typically is slower resulting in delayed hardening of the concrete. Delayed concrete hardening coupled with the variability of fly ash properties can create significant challenges for the concrete producer and finisher when placing steel-troweled floors.

c. Graded Fine Aggregates

The materials smaller than 4.75 mm size is called fine aggregates. Natural sand is generally used as fine aggregate. In this experimental work replacement of river sand by quarry waste (fineness modulus of crushed sand equal to 3.2) conforming to grading Zone III of IS – 383 – 1970 was used as fine aggregates.

d. Graded Coarse Aggregate

Locally available well graded granite aggregates of normal size greater than 4.75 mm and less than 16mm having fineness modulus of 2.72 was used as coarse aggregates.

e. Water

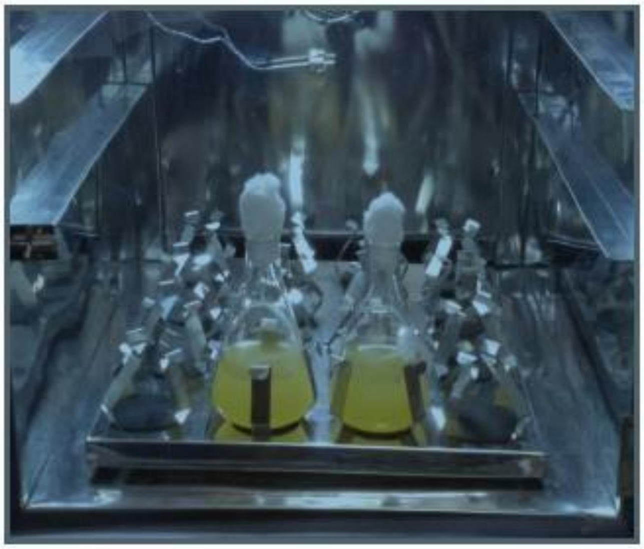
Potable water has been used for casting concrete specimens. The water is free from oils, acids, and alkalis and has a water-soluble Chloride content of 140 mg/lit. As per IS 456 – 2000, the permissible limit for chloride is 500 mg/lit for reinforced concrete; hence the amount of chloride present is very less than the permissible limit.

f. Chemical admixture

Chemical admixtures are the ingredients in concrete other than portland cement, water, and aggregate that are added to the mix immediately before or during mixing. Producers use admixtures primarily to reduce the cost of concrete construction; to modify the properties of hardened concrete; to ensure the quality of concrete during mixing, transporting, placing, and curing; and to overcome certain emergencies during concrete operations.

g. Bacteria

Bacillus substilis is an obligate aerobe bacterium used as a larvicide for mosquito control. It forms spherical endospores. Bacillus substilis is a gram-positive bacterium, with rod shaped cells that form chains-Medium-sized, smooth colonies with an entire margin. and Rod-shaped cells. Gram-variable, large, spore-forming rods with a diameter < 0.9 µm. Catalase -positive. Lecithinase-negative. Does not attack sugars. Grow thing range of Temperature: 37oc Optimum Temperature- 35-37^oC



3.2. Tests on Material

3.2.1. Specific Gravity and Water Absorption

Specific Gravity helps in measuring the quality of aggregate used. It is defined as the ratio of mass of any substance to the mass of equivalent volume of water. Aggregates having lower specific gravity are considered as weak than the aggregates having higher specific gravity. If the water absorption value of aggregates is high, then they are weak and porous. It is determined as per IS: 2386 (Part III) –1963.

In case of coarse aggregates, the specific gravity is obtained by using wire basket. About 2kg of coarse aggregates are tested. The aggregates are kept in the wire basket and submerged in water. Air entrapped on the surface of aggregate shall be expelled by gentle disturbance or by rapid clockwise and anti-clockwise movement of wire basket. The basket and aggregate remain submerged in water for 24 hrs. Then the aggregates are surface dried and weighed. After that the aggregates are oven dried.

Specific gravity = W4 W3−(W1−W2)

Apparent Specific gravity = W4 W4−(W1−W2)

Water absorption = W3−W4 W4 × 100

Where,

W1 = weight of wire basket containing sample and filled with distilled water, gm

W2 = weight of wire basket filled with distilled water only, gm

W3 = weight of saturated and surface-dry aggregate, gm

W4 = weight of oven-dry aggregate, gm

In case of fine aggregate pycnometer is used for determination specific gravity as per IS: 2386 (Part III) –1963. Sample of weight 500gm is taken for test. Saturated surface dry aggregates are used for the testing. These aggregates are then deposited in pycnometer and distilled water is filled to the top so that water in the hole is flat and its weight is taken. Weight of pycnometer is taken when it is filled with water. Then fine aggregate is oven dried.

Specific gravity = W4 W1−(W2−W3)

Apparent specific gravity = W4 W4−(W2−W3)

Water absorption = (W1−W4) W4 × 100

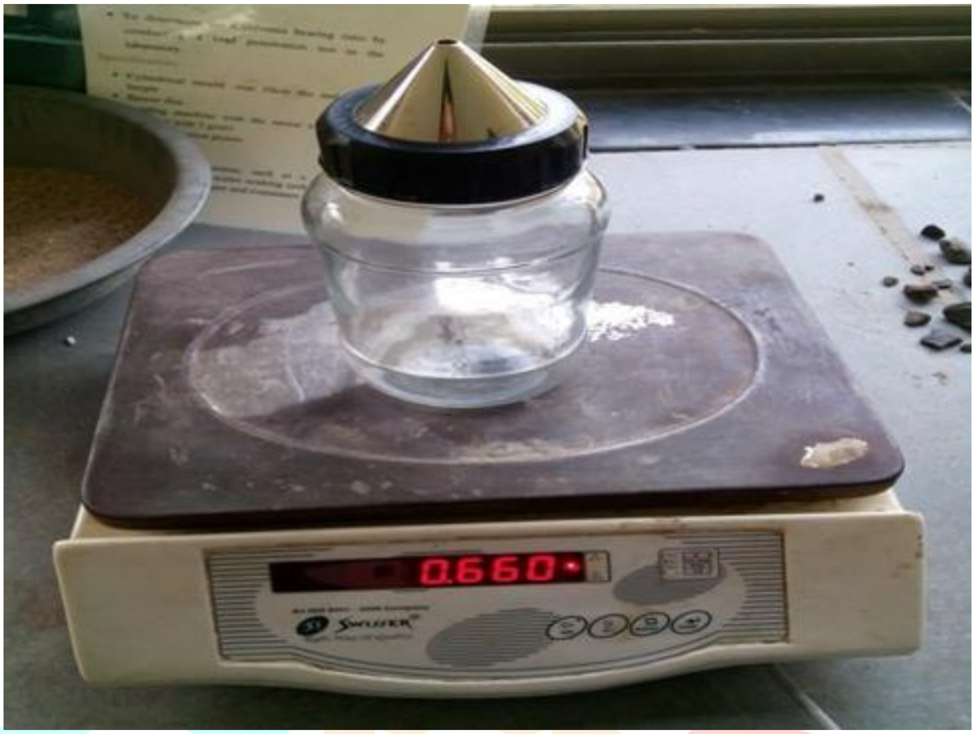
Where,

W1 = weight of saturated and surface-dry fine aggregate, gm

W2 = weight of pycnometer containing fine aggregate and filled with distilled water, gm

W3 = weight of pycnometer filled with distilled water, gm

W4 = weight of oven-dried fine aggregate, gm

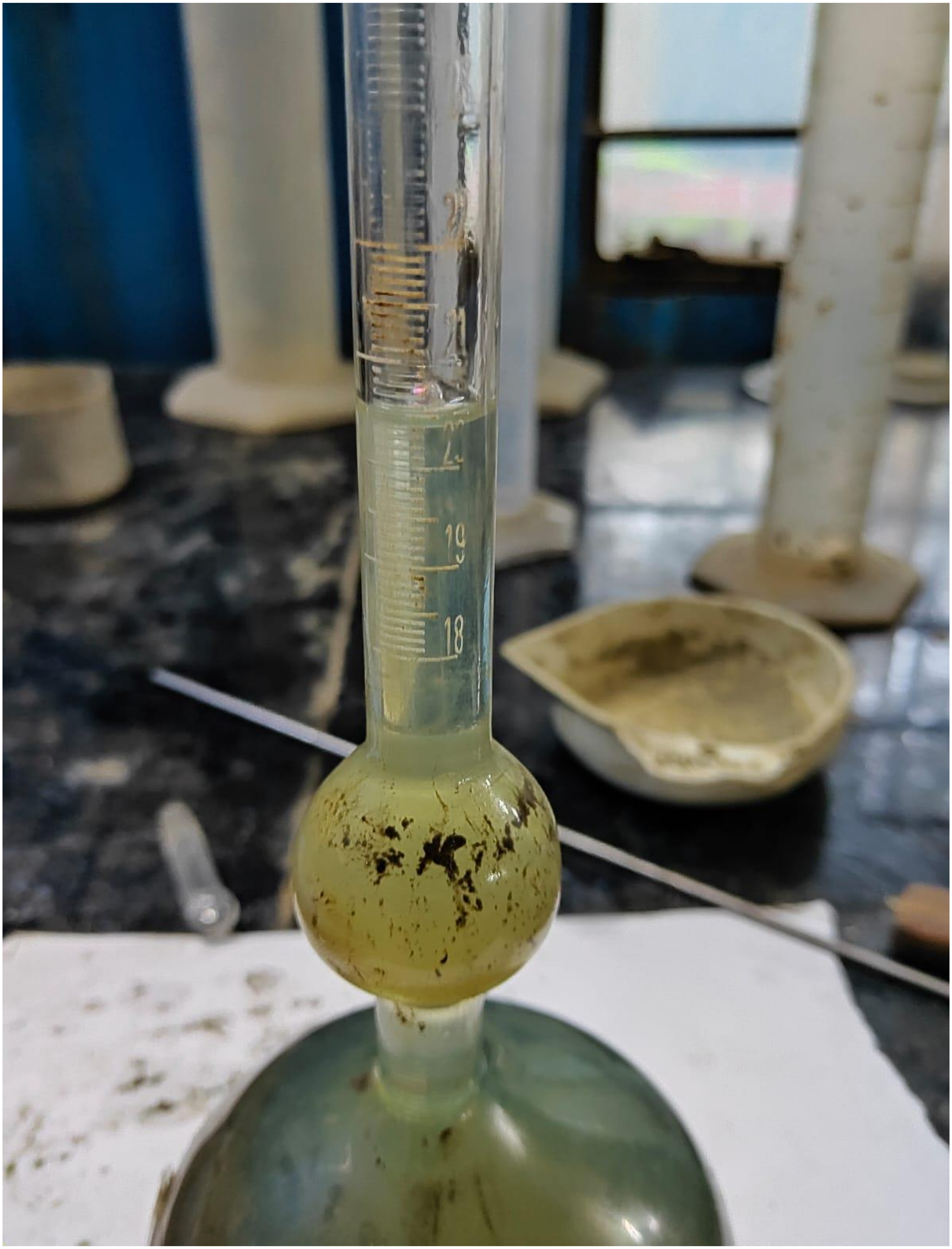


Specific gravity of cement

In case of cementitious material specific gravity is obtained by using Le-Ch atelier flask. Kerosene oil or Naphtha is filled in the flask in between 0- and 1-ml. Specific gravity of cementitious material is determined as per IS: 4031 (part XI)- 1988.

Le-Ch atelier Flask Initial reading is noted down. Using funnel cementitious material is filled in the flask of about 60 gm.

The final reading is taken. Specific gravity is given by, G = Mass of cement, gm Displaced volume, cm 3



3.2.2. Aggregate Crushing Test

Aggregate crushing test is carried out to determine the strength of aggregate. It is determined as per the IS: 2386 (Part IV) -1963. Surface dry aggregate is used which passes through 12.5 mm IS sieve and retain on IS sieve 10 mm is filled in three equal layers in a mould of cylindrical shape, each layer being ramped 25 times by the tamper. The plunger is placed on the top of specimen and a load of 40 tones is applied at certain rate by the compression machine. The crushed aggregates are sieved through 2.36 mm IS sieve. Strong aggregate give low aggregate crushing value.

Aggregate crushing value = W2 W1 × 100 percent (3.8)

Where W1 = weight of surface dry aggregate

W2 = weight of crushed aggregate passing 2.36 mm IS sieve.

3.2.3. Aggregate Impact Test

This test carried out to determine the toughness or resistance of aggregate to fracture under repeated impacts. It is determined as per IS: 2386 (Part IV) -1963.

Impact Testing Machine The aggregates which passes 12.5mm sieve and retain on 10mm sieve is filled in a mould of inner diameter 10.2cm and depth 5cm in three layers and giving each layer 25 blows. The hammer of weight 13.5-14 kg is lifted to a ht. of 380mm above the top surface of mould in which aggregates are placed and allowed to drop on the specimen. The aggregates are subjected to 15 blows with 1 sec interval. The crushed aggregates are sieved through 2.36mm.

Impact value = W2 W1 × 100 percent

Where W1 = weight of surface dry aggregate

W2 = weight of crushed aggregate passing 2.36 mm sieve.

3.2.4. Aggregate Abrasion Test

This test is carried out to determine the hardness of aggregates. The test is carried out as per IS: 2386 (Part IV) -1963. Los Angeles abrasion testing machine is used for the testing which is a hollow steel cylinder closed at both ends and having internal diameter of 700mm and length of 500mm. A steel shelf is radially projected 88mm for the full length of cylinder. Specified weight of aggregate depending upon the gradation is placed in the machine. The machine rotates at a speed of 33rpm for specified number of rotations as per grading. Then the aggregates are taken and sieved through 1.7mm sieve.

Los Angeles Abrasion Testing Machine Abrasion value = W2 W1 × 100 (3.10)

Where W1 = weight of surface dry aggregate

W2 = weight of crushed aggregate passing 1.7 mm sieve.

3.2.5. Consistency of Cementitious Material

Consistency is the percentage of water required for cement paste at which viscosity of the paste becomes such that the plunger in a Vicat's apparatus penetrates a depth of 5 to 7mm, measured 21 from the bottom of Vicat mould. Consistency of cementitious material is determined as per IS: 4031 (Part IV) – 1988. In this test measured quantity of cementitious material is mixed with measured quantity of potable or distilled water, care should be taken such that the gauging time should not be less than 3 minutes and not more than 5 minutes. The gauging time is the time of mixing water to dry cementitious material up to the commencing of filling the mould. The Vicat mould is kept on non-porous plate. Mould is filled with cement paste and leveled using trowel.

Vicat's Apparatus Mould is slightly shaken to expel air. Plunger is attached to the apparatus and allowed to rest on the surface of the test mould. Then the plunger is quickly released to sink into the mould. This procedure is repeated until plunger penetrates 5 to 7 mm from the bottom by adjusting the quantity of water added.

Consistency = A B × 100 = P

Where A = quantity of water added

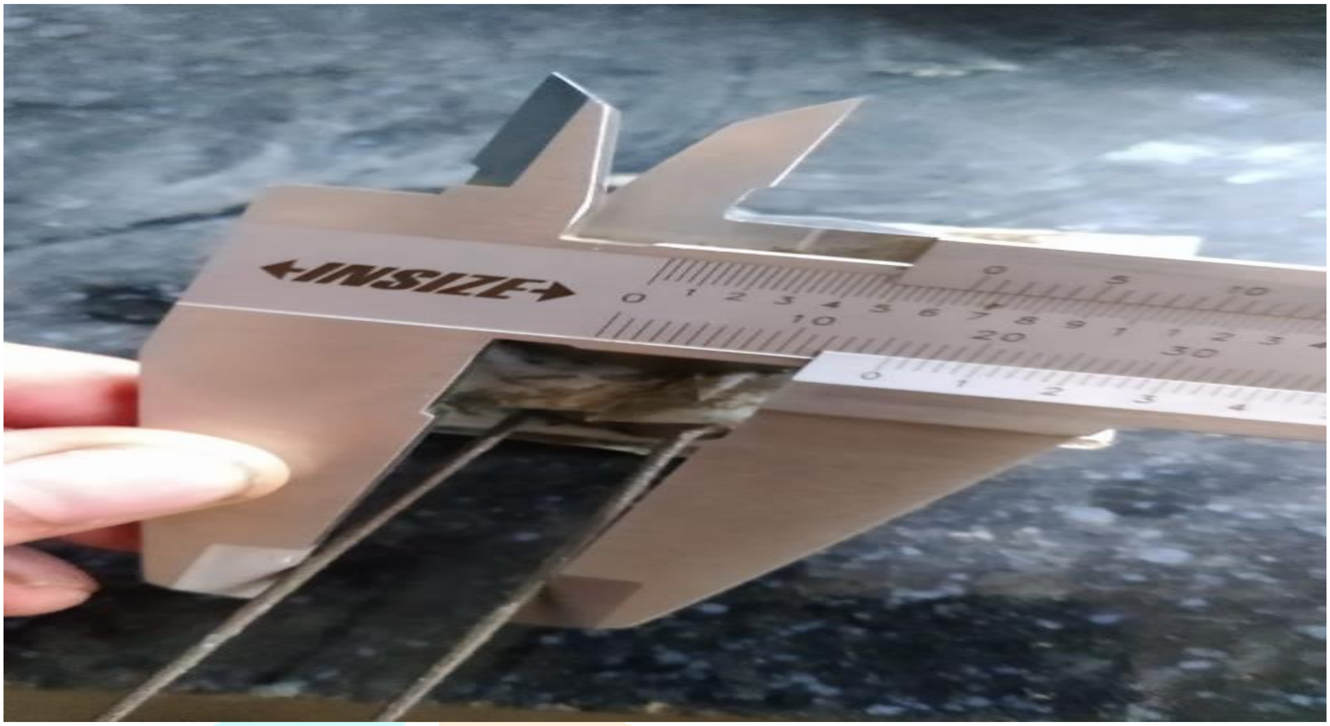
B = quantity of cementitious material used

3.2.6. Soundness

Test is carried out to detect the presence of uncombined lime in cement. It is the property by virtue of which the cement does not undergo any appreciable expansion (or change in volume) after it has set, thus eliminating any chances of disrupting the mortar or concrete. The apparatus used for soundness test is Le-chatelier apparatus. Soundness test is carried out as per IS: 4031 (Part III) - 1988. The mould and glass sheets are lightly oiled and cement paste formed by adding cement with 0.78 times the water required to form paste of standard consistency is placed in the Le chatelier's mould by placing a glass sheet below and holding the two edges together.

Le-chatelier Apparatus

The Le-chatelier mould is covered with other glass sheet and a weight is placed over the whole assembly. Immediately submerge the whole assembly in water for 24 hours. The distance between the two indicators is measured. Again, immerse the sample in water and boil for 3 hours and distance between both indicators are noted. The difference of both the reading indicates the expansion of cement.



3.2.7. Initial and Final Setting Time

Initial setting time is the time period that elapses from the time when water is added to the cementitious material and the needle for initial setting time ceases to penetrate 5 to 7 mm from bottom of the Vicat's mould.

Vicat's Apparatus Final setting time is the time period that elapses from the moment water is added to the cementitious material and the needle for final setting time with annular collar at the tip of needle just makes an impression on the paste. Initial and final setting time of cementitious material is determined as per IS: 4031(PART V) – 1988. For this test measured quantity of cementitious material is taken and mixed with 0.85times the water required to form standard consistency paste. Gauging time is maintained. Needle is used for initial setting time and for final setting time needle with annular attachment is used.

3.2.8. Fineness

The fineness of cement is a measure of cement particle size and is denoted as terms of the specific surface area of cement. The Fineness Test of Cement is done by sieving cement sample through standard IS sieve. The weight of cement particle whose size is greater than 90 microns is determined and the percentage of retained cement particle are calculated. This is known as the Fineness of cement.

Equipment's required to check fineness of cement

- 90µm IS Sieve,
- Weight Balance having capacity 10 mg to 100 g,
- Nylon or pure bristle brush

Fineness Test of Cement Procedure

1. Collect a sample of cement and rub with your hands. The Fineness test sample should be free of lumps.
2. Take 100 gm of cement sample and note its weight as W1.
3. Drop 100 gm of cement in 90 µm sieve and close it with the lid.
4. Now, shake the sieve with your hands by agitating the sieve in planetary and linear movements for 15 minutes.
5. After that take weight the retained cement on the 90 µm sieve as W2. To calculate fineness of cement formula is given below

$$\text{Fineness} = (W2/W1) * 100$$

- Then, calculate the percentage of Weight of cement–retained on Sieve.
- Repeat this procedure with three different samples of cement and average the values for accurate results.

3.2.9. Flakiness and Elongation Index

The flakiness and elongation index are determined as per IS: 2386 (Part IV) -1963. The flakiness index of an aggregate is the percentage by weight of particles in it whose least dimension (thickness) is less than three-fifths of their mean dimension. The test is not applicable to sizes smaller than 6.3 mm. The thickness gauge is used for flakiness of aggregate.

The measured quantity of material is sieved through the sieve size mentioned in the metal gauge and collected separately as per range. Then the fraction of material is gauged through thickness in metal gauge. The total mass of each size fraction of the sample also shall be determined. The mass of material passing the respective gauge to the total mass of aggregate retained on 6.3mm sieve gives the flakiness index of aggregate which is expressed in percentage. Elongation index of an aggregate is the percentage by weight of particles whose greatest dimension (length) is greater than one and four-fifths times their mean dimension. Normally, the properties of interest to the engineer are sufficiently covered by the flakiness or angularity tests. The elongation test is not applicable to sizes smaller than 6.3 mm. The fraction of material is gauged through length in metal gauge. The total weight of material retained in every range to the total weight of material retained.

3.2.10. Sieve Analysis of Aggregates

This method is adopted to determine the particle size distribution of fine and coarse aggregate. It is carried out as per IS: 2386 (Part I) – 1963. Set of sieves are used for analysis of both fine and coarse aggregates which are arranged in descending order. Measured quantity of air dry 26 aggregates are used. Aggregates are passed through the set of sieves and material retained on each sieve is weighed. The result is calculated as cumulative percentage by weight of the total sample passing each of the sieves, to the nearest whole number. The result is represented graphically.

3.3 Mix Proportioning

The quality of concrete mainly depends upon the proportioning of its constituent's materials. The mix proportioning mainly influences the permeability of concrete and cause cracks. Design mix is more appropriate to know the exact behavior of cracks rather than nominal mix. In this experiment the concrete used is 25 MPa having water to cement ratio of 0.42.

3.4 Mix Design

The aim of studying the various properties of materials of concrete, plastic concrete and hardened concrete is to design a concrete mix for strength. Design of concrete mix needs complete knowledge of the various properties of the constituent material, the implications in place of change on the conditions at site, the impact of the properties of plastic concrete on the hardened concrete and the complicated interrelationship between the variables. Mix design can be defined as the process of selecting suitable ingredients of concrete and determining their relative proportions with the object of producing concrete of certain minimum strength and durability as economically as possible. The mix design procedure is explained in the following section.

3.5 Indian Standard Mix Design Stipulations

a. Concrete grade : M25
b. Exposure : Moderate
c. Quality control : Fair
d. Size of aggregate : 20 mm
e. Degree of workability : Very good
f. Cement used : OPC 53 grade cement
g. Sand grading zone : II
h. Minimum Cementitious content : 300 Kg/cum, as per IS-456:2000, Clause No.: 8.2.5,
i. Maximum Cement (OPC) content : 450 Kg/cum (As per IS: 456 :2000, Clause no.8.2.4
ratio : 0.50 (As per IS-456:2000, Clause No.: 8.2.5, Table – 5
k. Workability (Slump) : 75-150mm
l. Degree of supervision : Very good
m. Type of coarse aggregate : Single Sized Crushed Angular Aggregate of Nominal Size 20mm (As per IS 383: 2016)
n. Type of fine aggregate : River sand conforming IS 383:2016
o. Chemical admixture : Superplasticizer conforming to IS :9103

3.6 Test data for raw material

1	Cement used	:-	ULTRATECH OPC 53
2	Specific Gravity of Cement	:-	3.15
3	Source of Admixture Used	:-	CHRYSO OPTIMA S857
4	Specific Gravity of Admixture	:-	1.12

5 Specific Gravity of Aggregate

a) Coarse Aggregate

i) 20mm Agg. :- 2.614

ii) 10mm Agg. :- 2.603

b) Fine Aggregate :- 2.588

6 Water Absorption of Aggregate %

a) Coarse Aggregate

i) 20mm Agg. :- 0.56

ii) 10mm Agg. :- 0.84

b) Fine Aggregate :- 1.32

7 Free (Surface) Moisture

a) Coarse Aggregate

i) 20mm Agg. :- Nil

ii) 10mm Agg. :- Nil

b) Fine Aggregate :- Nil

8 Combined EI + FI of Aggregate :- 18.40%

9 Aggregate Impact Value :- 16.81%

10. Sieve analysis

1) Coarse Aggregate:-

IS Sieve Sizes (mm)	Coarse Aggregate Fraction		Percentage of Different Fractions			Limits As per IS : 383 (Table -7)
	20 mm	10 mm	20 mm	10 mm	Combined	
			0	50		
40	100	100	50	50	100.0	100
20	92.42	100	46.21	50.00	96.21	90-100
10	5.52	92.44	2.76	46.22	48.98	25-55
4.75	0.92	5.43	0.46	2.72	3.18	0-10

2) Fine Aggregate: - Conforming to Grading Zone II of Table 9 of IS 383

Table 3.1: Mix design summary

Material	Weight(kg)	Volume(m3)
Cement	255	0.081
Fly ash	85	0.039
Coarse Aggregate (20MM)	570	0.218
Coarse Aggregate (10MM)	569	0.218
Fine Aggregate	778	0.300
Water	142	0.142
Admixture	2.04	0.002
Total	2401	1.000

CHAPTER - 4

PREPARATION OF BACTERIA

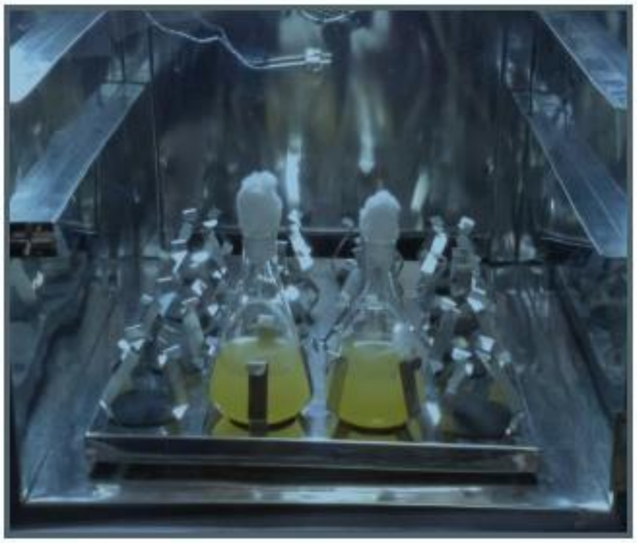
4.1 Mixing of Bacteria

Luria Berta-powder form (6.75gms) +500ml of distilled water peptone(3gms)+yeast extract(1.5gms)+Beef extract(1.5gms) +sodium chloride (3gms/100ml) +1Loop of Bacteria (gel medium) = Incubator 37oC

4.2 Preparation of Nutrient Agar

Bacteriological media came a wide range of types. Nutrient Agar is a complex medium.Nutrient Agar contains beef extract (0.3%), peptone (0.5%), and Agar (1.5%) in water. Beef extract is prepared as dehydrated form of autolyzed beef and is supplied in the form of paste. Peptone is casein (milk protein) that has been digested with the enzyme pepsin. Peptone is dehydrated and supplied as a powder. peptone and Beef extract contains a mixture of amino acids and peptides. Beef extract also contains water soluble digest products of all other macromolecules (nucleic acids, fats, polysaccharides) as well as vitamins trace minerals. Agar is purified from red algae in which it is an accessory polysaccharide (polyelectronic acid) of their cell walls. Agar is added to microbiological media only as a solidification agent. Agar for most purposes has no nutrient value. Agar is an excellent solidification agent because it dissolves at near boiling point solidifier at 45ºC. Thus, one can prepare molten (liquid) agar at 45ºC, mix cells with it, then allow it to solidify thereby trapping living cells. Below 45ºC agar is a solid and remains so as the temperature is raised melting only when greater than 95oC is obtained.


B.O.D.INCUBATOR
B. O. D. INCUBATOR
SCIENTIFIC



In this method Bacteria are added during casting of concrete. The amount of Bacteria added inthe range of 10ml & 15 ml/m3 of concrete. Concrete could soon be healing its own hairline cracking. Holes and pores of wet concrete are healed. Combined calcium with oxygen and carbon di oxide to form calcite is essential for healing tiny cracks which arrest the seepage of water. Figure 4.4.1: View on Growthing of Bacteria

The technique of using soil bacterium is highly desirable because the mineral precipitation induced because of microbial activities, is pollution free and natural. Bacillus spharecius was yet another partially characterized species, having the capability of precipitating calcium carbonate. Its Far better would be to use bacillus sphaericus as a material that heals itself just as the cell divines and produces a visible mass. The colony isolated from other colonies; isolated colonies are assumed to be pure culture.

4.3 Culturing and Isolation

Microorganism must have a constant nutrient supply if they are to survive. Media may be liquid (broth) or solid (agar). Any desired nutrients may be in corporate into the broth (or) agarto grow bacteria. Organism grown in broth cultures causes turbidity, (or) cloudiness, in the broth. On agar, masses of cells known as colonies, appear after a period of incusation certain separated on agar so that as the cell divines and produces a visible mass. The colony isolated from other colonies; isolated colonies are assumed to be pure culture. A. Gandhimathi, N.

Vigneswari, S.M. Janani, D. Ramya, D. Suji and T. Meenambal 22 ISBN 978-93-82338-32-1| © 2012 Bonfring

4.4 Ability of Bacterial Concrete to Repair the Cracks

Both attentions will be given on closure of cracks (blocking the path for ingress of water and ions)and on regaining mechanical properties. Cracks in concrete specimen subjected to various loading situations will be investigated before and after the healing. For this impregnation techniques and SEM will be applied. (Scanning electron microscope). On the other hand, the micro-organisms such as bacteria, cyono bacteria, algae, lichens, yeasts, fungi and mosses etc. Which are omnipresent and omnipotent are responsible for metabolism action that results in a microbial deposition of a protective $CaCO_3$ layer. Also, this process results in re-establishment of the cohesion b\n particles of mineral building materials and protects against further decay of stone material. To prove the positive effects of microbial $CaCO_3$ precipitation. The increase in porosity in concrete leads to increase in capillary water uptake, increase in gas permeability along with higher carbonation rate, high chloride migration and freeze-thaw damage.

4.5 Processing of Bacteria

Concrete could soon be healing its own hairline cracking. Holes and pores of wet concrete are healed. Combined calcium with oxygen and carbon di oxide to form calcite is essential for healing tiny cracks which arrest the seepage of water

CHAPTER – 5

EXPERIMENTAL STUDY

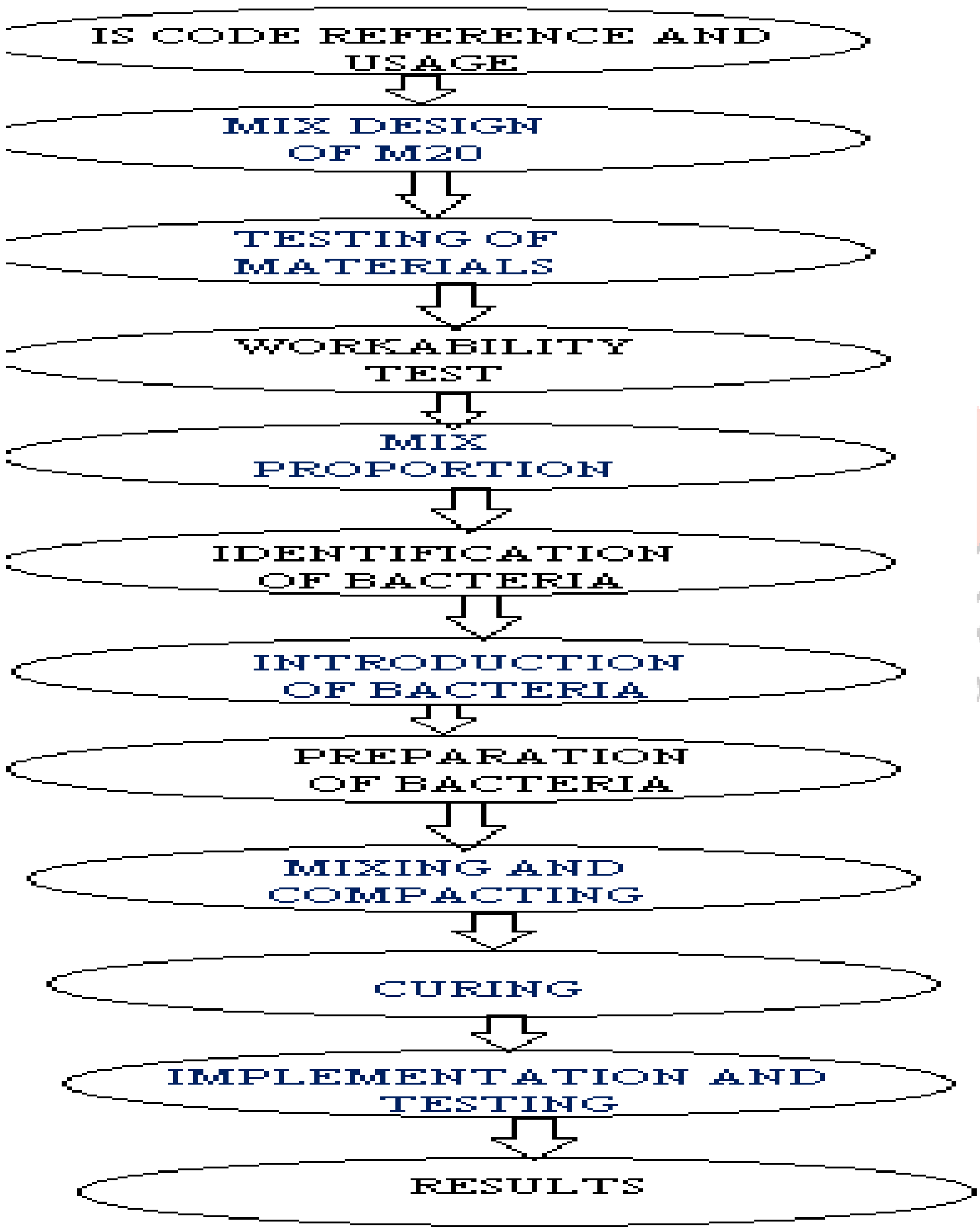
5.1 Process of manufacture of concrete

Production of quality concrete requires meticulous care exercised at every stage of manufacture of concrete. If meticulous care is not exercised, and good rules are not observed, the resultant concrete is going to be of bad concrete. Therefore, it is necessary for us to know what the good rules are to be followed in each stage of manufacture of concrete for producing good quality concrete. The various stages of manufacture of concrete are:

1. Batching
2. Mixing
3. Placing
4. Compacting
5. Curing

5.1.1 Weigh Batching

Weigh batching is the correct method of measuring the materials. For important concrete, invariably, weigh batching system should be adopted. Use of weight system in batching, facilitates accuracy , flexibility and simplicity. Different types of weigh batchers are available, the particular type to be used, depends upon the nature of job. When weigh batching is adopted, the measurement of water must be done accurately using measuring jars.



5.1.2 Electrical portable Mixer

The **concrete mixer** It is a machine used for the manufacture of mortar and concrete, after mixing different components such as aggregates of different sizes, water, and cement, basically. It is a machinery specially designed for the field of **construction**. It is made up of a body and a cylindrical container that rotates with great force transmitted by an electric motor.

The **electric concrete mixers** They have the controls in the form of a button or push button. It is necessary to take care of its installation to avoid further damage or injury, thus avoiding accidental activation of the start-up switches and easy operation of the stop buttons. The push buttons should not be next to the engine, but preferably on the outside, in an easily accessible place, away from the transmission belt from the engine to the cylinder. It will only be possible to place the start-up switch next to the transmission belt if it is fully protected.

5.1.3 Placing

It is not enough that a concrete mix correctly designed, batched, mixed, it is of utmost importance that the concrete must be placed in systematic manner to yield optimum results. The precautions to be taken and methods adopted while placing concrete in the moulds.

5.1.4. Hand Compaction

Hand compaction of concrete is adopted in case of small concrete works. Sometimes, this method is also applied in such situation, where a large quantity of reinforcement is used, which cannot be normally compacted by mechanical means. Hand compaction consists of rodding, ramming, or tamping. When hand compaction is adopted, the consistency of concrete is maintained at a high level. Tamping is one of the usual methods adopted in compacting roof or floor slab or road pavements where the thickness of concrete is comparatively less and thesurface to be finished smooth and level.

5.1.5 Curing

Concrete derives its strength by the hydration of cement particles. The hydration of cement is nota momentary action but a process continuing for long time. Curing can also be described as keeping the concrete moist and warm enough so that the hydration of cement can continue. More elaborately, it can be described as the process of maintaining a satisfactory moisture content and a favorable temperature in concrete during the period immediately following placement, so that the hydration of cement may continue until the desired properties are developed to a sufficient degree to meet the requirement of service. The casted cubes and cylinders are immersed in water tanks for 3 days, 7days, 14 days and 28 days.

5.1.6 Workability of Concrete

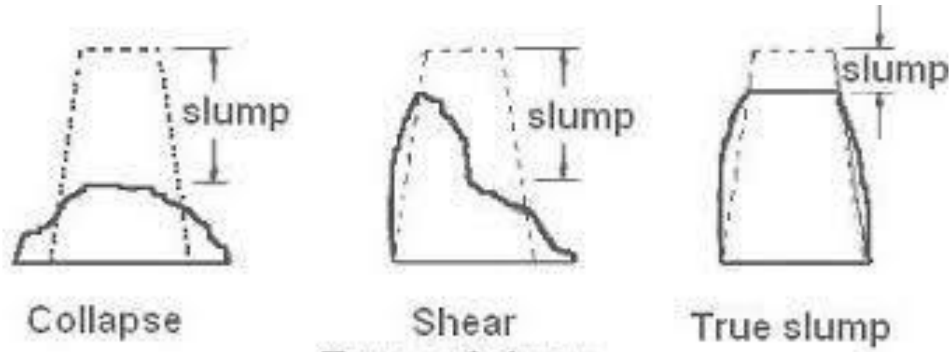
Workability is the amount of useful internal work required to produce full compaction of concrete. It depends on,

1. Types of aggregate
2. Grading of coarse and fine aggregate
3. Quantity of cement paste
4. Consistency of the cement paste

5.1.7 Slump Test

Slump test is the most used method of measuring consistency of concrete which can be employed either in laboratory or at site of work. It is not a suitable method for very wet or very dry concrete. It is used conveniently as a control test and gives an indication of the uniformity of concrete from batch to batch. The deformation shows the characteristics of concrete with respect for segregation The thickness of the metallic sheet for the mould should not be thinner than 1.6mm. for tamping the concrete, a steel tamping rod 16mm dia, 0.6 meter along with bullet end is used. The mould is then filled in four layers, each approximately 1/3rdof the mould (As per IS 1199). Each layer is tamped 25 times by the tamping rod taking care to distribute the strokes evenly over the cross section. After the top layer has been rodded, the concrete is struck off level with a trowel and tamping rod. The mould is removed from the concrete immediately by rising it slowly and carefully in a vertical direction. This allows the concrete to subside. This subside is referred as slump of concrete.

The value of slump = 90 mm



Types of slump

5.2 Mixing, Compaction and Curing

Good concrete can be obtained only through and uniform mixing, better through and uniform mixing, better through compaction and adequate curing. In the laboratory, the concrete was mixed by electrical portable mixer. All the constituent materials were weighed, and dry mixing was carried out for about 5 minutes and then water was added. The mixing was continued till concrete of uniform consistency was obtained / the specimens were compacted using tamping rod in 3 layers (each layer 35 blows). After 24hours, the specimens were remolded and kept immersed curing tank containing potable water tillthe required curing period is over. The mix proportions are given in table. For control specimen the w/c ratio is 0.42. The same amount of water is used for all other specimens.

CHAPTER – 6

RESULT AND CONCLUSION

6.1 Result and conclusion

Concrete plays a major role in the construction industry. For a durable structure, good quality concrete must be used. A Self-Healing Concrete for the Future which says a common soil bacterium was used to induce calcite precipitation which is highly desirable because the mineral precipitation induced because of microbial activities is pollution free and natural. The workability test of the bacterial concrete resulted in 90mm of slump value.

We have found out that the compressive strength of the bacterial concrete with 5% bacteria +0.005 mol/lit. Calcium lactate+ Urea CaCl2 is maximum in comparison of other compositions

Bacteria is added with the following:

1. Urea CaCl2
2. Buffer -solution (phosphate buffer)

Bacteria will not survive in water. So, it cannot be mixed with water, and it was found out in the Research when the bacteria mixed with Buffer - solution give better results. Even it will not change the pH value when added with acid (or) alkali is added to it. The bacteria will be mixed in different ratios in the specimen concretes for testing and Research. The cost of bacterial concrete when compared to conventional concrete is more or less the same which will not require any rehabilitation work which is costlier for rectification of crack after 15 years, but this self-healing concrete will help in regaining of strength and healing of cracks automatically without any human intervention

6.2 Compressive Strength Test

The compressive strength had considerable improvement with concrete specimens containing bacteria and calcium lactate shown in detail given below. The highest increment of compressive strength for both bacteria is with calcium lactate of 0.005 mol/l concentration.The increment of concrete specimen strength with Ent.f and Ent.f with calcium lactate of 0.001 mol/l, 0.005 mol/l and 0.01 mol/l concentration compared to control are 6.11%, 6.9%, 18.9% and 8.3% respectively. Whereas, the increment of strength for concrete specimens containing B.sp and B.sp with calcium lactate of 0.001 mol/l, 0.005 mol/l and 0.01 mol/l concentrations compared to control are 2.7%, 6.9%, 10% and 5% respectively.

Irwan et al., ha started those materials added into concrete which does not participate in hydration process with the binder could attribute to decrease in compressive strength. Bacteria added into concrete does not directly involved in the hydration process itself butused the by-product of the reaction to produce calcium carbonate. The slight reduction of compressive strength with higher concentration of calcium lactate shows that over production of calcium carbonate would affect the compressive strength. Similar result is reported by Faiz and Steve, which stated that minimal amount of calcium carbonate was found most effective in increment of strength. Researchers have studied that certain concentration of bacteria increases compressive strength compared to control.

However, the concentration of bacteria depends on the bacteria itself. As every bacterium used are of different origins. Thus, may have different reactions. In Xu *et al*. and Abo-El-Enein studies, calcium source were added into bio concrete. After which compressive strength were tested and compared. It was found that different calcium source precipitates different amount of calcium carbonate. Different calcium source influences the rate of bacteria precipitation and amount.

The precipitation of calcium carbonate that fills the pore within the concrete matrix is the factor for increment of compressive strength. Addition of *Ent.f* in concrete has considerable impact on the compressive strength compared to *B.sp*. The obvious difference for both bacteria is with 0.005 mol/l concentration of calcium lactate. *Ent.f* has shown a tremendous increase of compressive strength compared to *B.sp*. This is due to *Ent.f* reaction to the addition of calcium source. The addition of calcium source allows the bacteria to increase precipitation which benefited the concrete. Calcium lactate with concentration of 0.01 mol/l has caused an over production of calcium carbonate which cause the strength to reduce slightly. This is similar for both bacteria. The increment of strength with addition of bacteria are due to deposition of calcite facilitated by calcium nutrient.

Table 6.1

Type of concrete	Compressive strength of concrete after 7 days		
	Sample 1	**Sample 2**	**Sample 3**
Conventional	**22.7**	**23.0**	**23.5**
5% *Bacillus sp* (*B.sp*)	**24.0**	**24.5**	**24.8**
5% *B.sp*+ 0.005 CL mol/l	**25.7**	**26.3**	**26.5**
5% *B.sp*+ 0.005 CL mol/l+ Urea CaCl2	**28**	**28.5**	**29.4**

Table 6.2

Type of concrete	**Compressive strength of concrete after 14days**		
	Sample 1	**Sample 2**	**Sample 3**
Conventional	**28.3**	29.1	**29.5**
5% *Bacillus sp* (*B.sp*)	**29.1**	**29.9**	**30.3**
5% *B.sp*+ 0.005 CL mol/l	**31.0**	**30.8**	**31.9**
5% *B.sp*+ 0.005 CL mol/l + Urea CaCl2	**32.5**	**32.0**	**33.3**

Table 6.3

Type of concrete	Compressive strength of concrete after 28 days		
	Sample 1	**Sample 2**	**Sample 3**
Conventional	**31.7**	**32.5**	**32.9**

5% *Bacillus sp* (*B.sp*)	**33.2**	**34.5**	**34.9**
5% *B.sp*+ 0.005 CL mol/l	**34.5**	**35.8**	**37.0**
5% *B.sp*+ 0.005 CL mol/l + Urea CaCl2	**35.4**	**36.5**	**37.5**

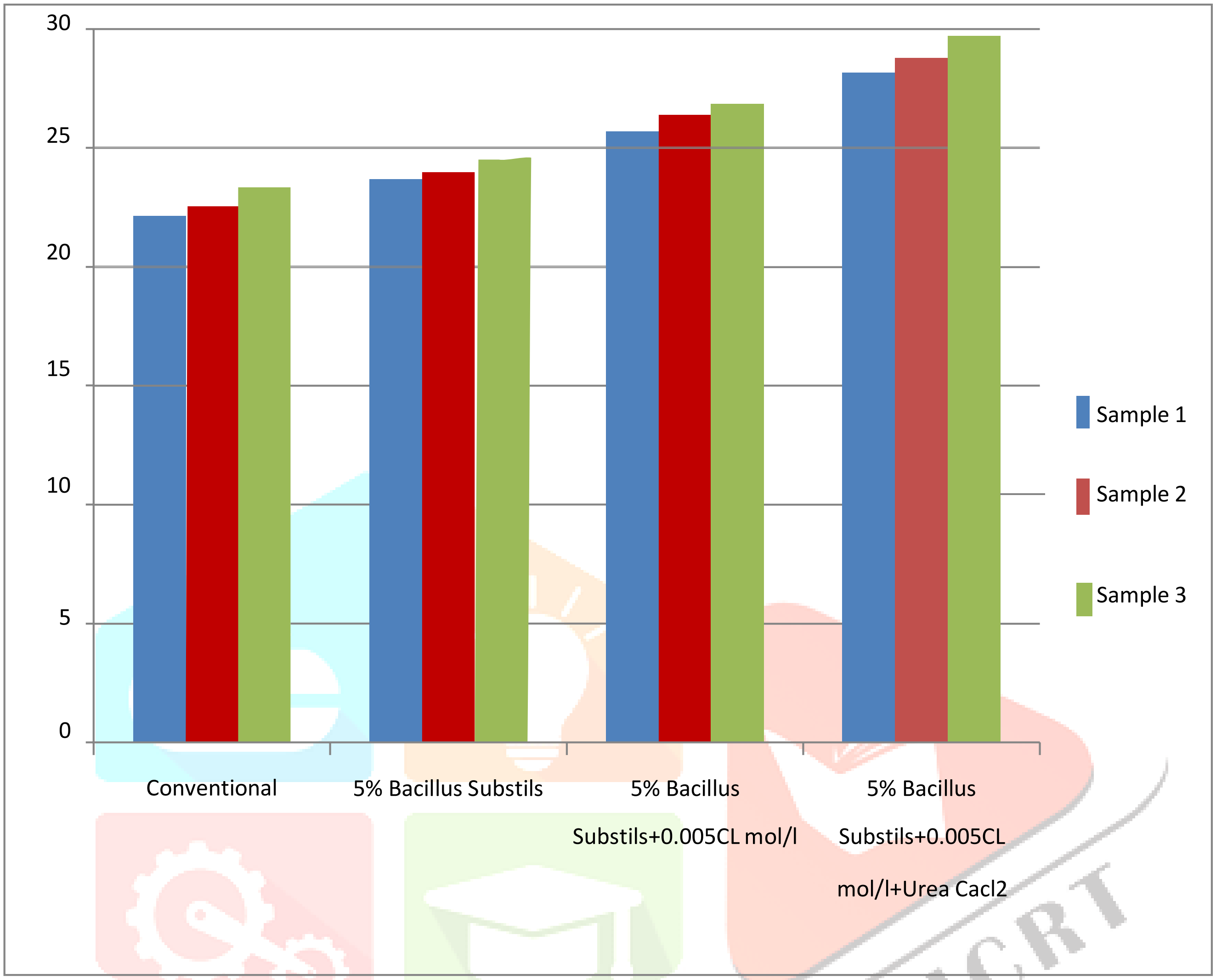


Figure 6.1(Compressive Strength After 7 Days of Curing)

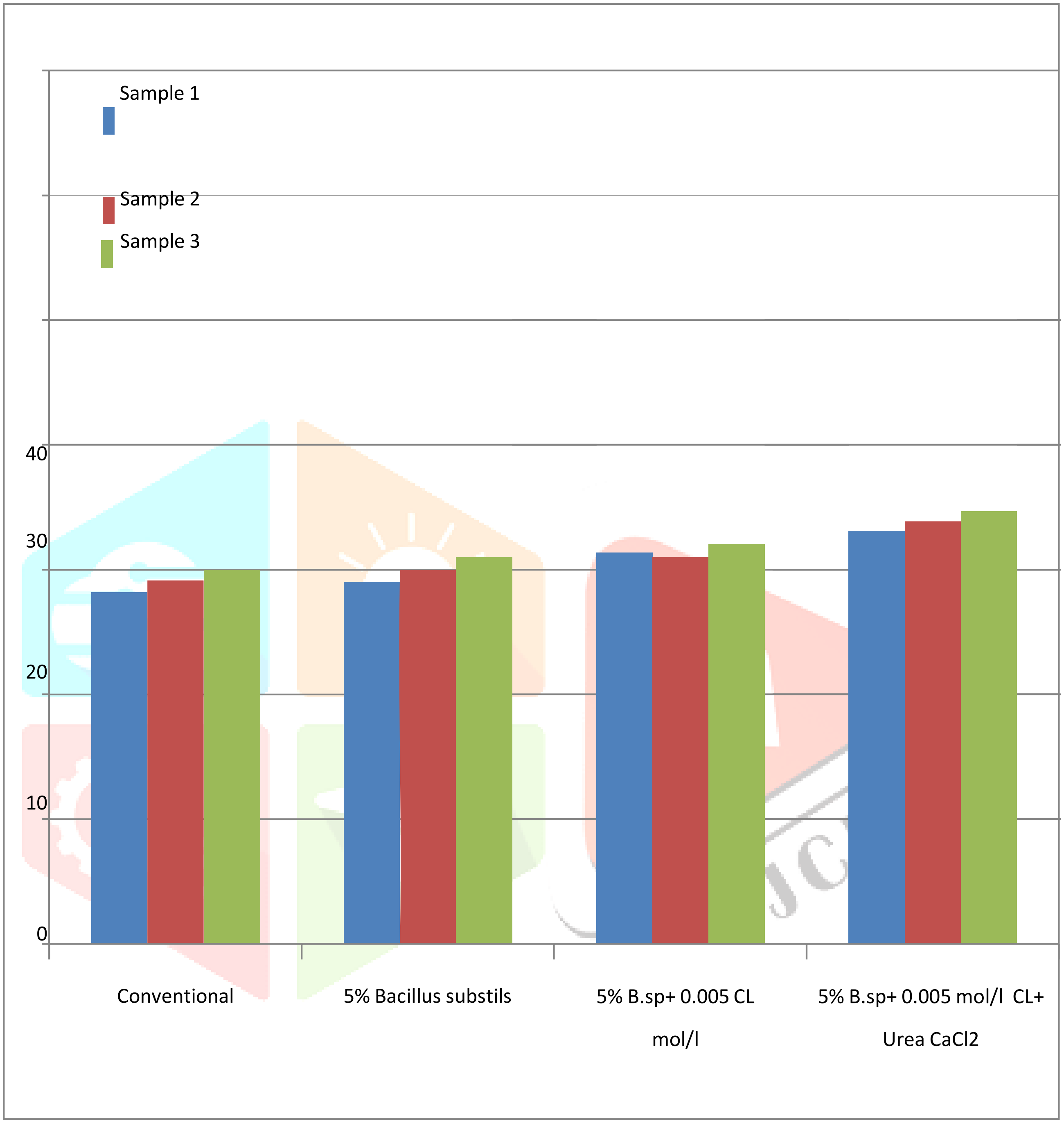


Figure 6.2(Compressive Strength After 14 Days of Curing)

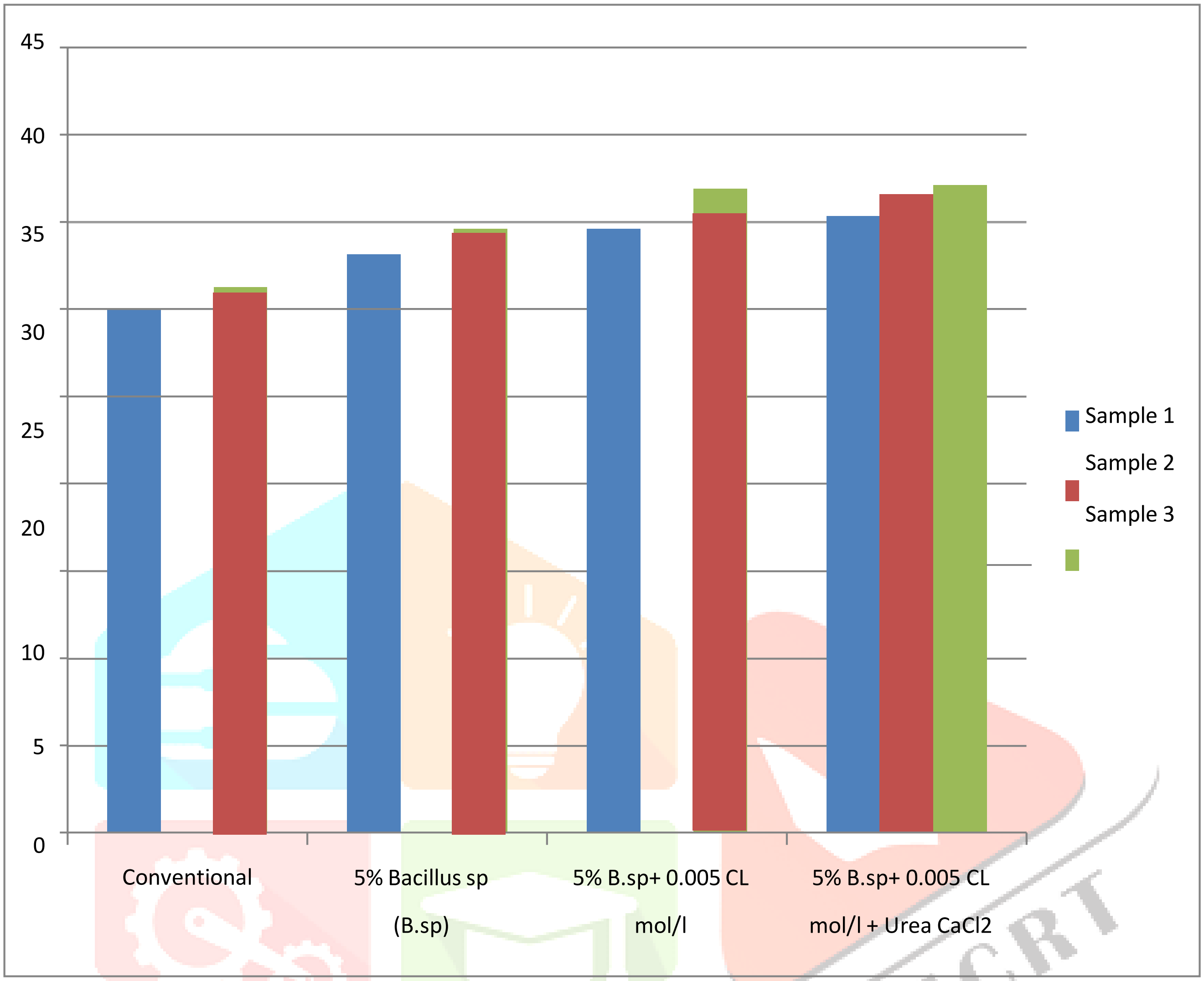


Figure 6.3 Compressive Strength After 28 Days of Curing

6.3 Test on bacteria

Healing agent(i.e, bacteria + calcium lactate) isapplied on the cracked surface

Day 1 healing Agent Applied

After 10 days Gentle curing results in filling up the crack

20th day photo- healing of small portion of crack completely

Another experiment was conducted in which 2ml of bacteria was mixed with 2mg of calcium lactate. The mixture was shaked in test tube and placed in lab for 24hrs and then sealed for next 24 hours. This result inhardened mass in tube which confirm formation of calcium carbonate in tube.

REFERENCES

[1] Sakina Najmuddin Saifee, Divya Maheshbhai Lad, Jayesh Rameshbhai Juremalani. Critical appraisal on Bacterial Concrete, *IJRDO-Journal of Mechanical And Civil Engineering*, ISSN: 2456-1479, Volume-1, Issue-3, March 2015, PP 10-14

[2] Meera C.M, Dr. Subha V. Strength, and Durability assessment Of Bacteria Based Self-Healing Concrete *IOSR Journal of Mechanical and Civil Engineering*, e-ISSN: 2278-1684, PP 01-07

[3] Ravindranatha, N. Kannan, Likhit M. L. Self-healing material bacterial concrete, *International Journal of Research in Engineering and Technology*, Volume: 03, Special Issue: 03, May-2014, NCRIET-2014, PP656-659

[4] A.T. Manikandan, A. Padmavathi. An Experimental Investigation on improvement of Concrete Serviceability by using Bacterial Mineral Precipitation Volume II, Issue III, March 2015 IJRSI

[5] Jagadeesha Kumar B G, R Prabhakara, Pushpa H. Effect of Bacterial Calcite Precipitation On Compressive Strength Of Mortar Cube, International Journal of Engineering and Advanced Technology (IJEAT), ISSN: 2249 – 8958, Volume-2, Issue-3, February 2013, PP 486-491

[6] RA. B. Depaa and T. Felix Kala Experimental Investigation of Self-Healing Behavior of concrete usingSilica Fume and GGBFS as Mineral Admixtures Indian Journal of Science and Technology, Vol 8(36), DOI:0.17485/ijst/2015/v8i36/87644, December 2015

[7] Chithra P, BaiShibi Varghese. An experimental investigation on the strength properties of fly ash based bacterial concrete International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN:2349-2763 Issue 08, Volume 3 (August 2016)

[8] V Srinivasa Reddy, M V Seshagiri Rao, S Sushma. Feasibility Study on Bacterial Concrete as an innovative self-crack healing system. International Journal of Modern Trends in Engineering 67 and Research, e-ISSNNo.:2349-9745, Volume 2, Issue 7, [July-2015] Special Issue of ICRTET'2015, Date: 2-4 July 2015, PP642-647.

[9] Ashish Babarao Gawande, Yash Suneel Khandekar and Ojas Pravin Rahate, Applicability of Concrete Treated with Self-Healing Bacterial Agents. International Journal of Civil Engineering and Technology,7(5), 2016, pp.275–283.

[10] Abhishek Thakur, Akshay Phogat and Khushpreet Singh, Bacterial Concrete and Effect of Different Bacteria on the Strength and Water Absorption Characteristics of Concrete: A Review. International Journal of Civil Engineering and Technology, 7(5), 2016, pp.43–56.

[11] Mohit Goyal, P. Krishna Chaitanya. Behavior of Bacterial Concrete as Self-Healing Material, International Journal of Emerging Technology and Advanced Engineering, ISSN 2250-2459, Volume 5, Issue 1, January 2015,PP 100-103

[12] N. Ganesh Babu. An experimental study on strength and fracture properties of self-healing concrete, International Journal of Civil Engineering and Technology (IJCIET), Volume 7, Issue 3, 1 May–June 2016, PP. 398–406

[13] Kim Van Tittelboom, ... Nele De Belie, Self-healing concrete with encapsulated polyurethane, in Eco-Efficient Repair and Rehabilitation of Concrete Infrastructures, 2018

[14] Xu Huang, Sakdirat Kaewunruen, Self-healing concrete, in New Materials in Civil Engineering, 2020

[15] H.M. Jonkers, ... V. Wiktor, Biotech solutions for concrete repair with enhanced durability, in Biopolymers and Biotech Admixtures for Eco-Efficient Construction Materials, 2016

[16] Nele De Belie, ... Kevin Paine, Bacteria-based concrete, in Eco-Efficient Repair and Rehabilitation of Concrete Infrastructures, 2018