

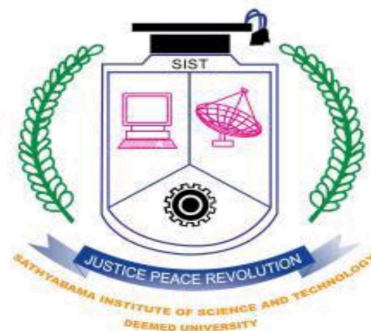
INVESTIGATE THE BEHAVIOUR OF SELF HEALING CONCRETE FOR SUSTAINABILITY DEVELOPMENT

Submitted in partial fulfilment of the requirements for the award of
Bachelor of Engineering degree in
Civil Engineering

by

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**DEPARTMENT OF CIVIL ENGINEERING
SCHOOL OF BUILDING AND ENVIRONMENT**

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

Accredited with Grade “A++” by NAAC

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APRIL – 2024



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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of Om Chavan.CH (Register No: 40200017), Sheik Abdullah .M (Register No: 40200707) who carried out the project entitled **"INVESTIGATE THE BEHAVIOUR OF SELF HEALING CONCRETE FOR SUSTAINABILITY DEVELOPMENT"** under my supervision from June 2023 to April 2024.

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DECLARATION

We Om Chavan.CH (Register No: 40200017), Sheik Abdullah .M (Register No: 40200707), here by declare that the Project Report entitled "Investigate the behaviour of self-healing concrete for sustainability development" done by us under the guidance of Dr. P. Eshanthini is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering degree in Civil Engineering.

1. 

2. 

DATE: 5/4/2024.

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ABSTRACT

The use of self-healing concrete is an effective strategy to deal with damage to concrete, thereby increasing its durability and reducing maintenance costs. This study investigates the use of *Bacillus subtilis* as a self-healing agent in concrete. *Bacillus subtilis*, a soil bacterium, begins producing calcium carbonate (CaCO_3) through microbially induced carbonate precipitation (MICP) when exposed to calcium ions and urea found in fractured rock. This microbial process effectively seals cracks and prevents the entry of water and harmful chemicals, prolonging the life and healing of concrete. The report provides an in-depth look at the self-healing process, methods for evaluating its results, and the environmental and economic benefits associated with integrating the process into the construction industry.

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LIST OF SYMBOLS & ABBREVIATIONS

SYMBOLS

Kg

MPa

%

AHF

Mm

M²

N

ABBREVIATIONS

Kilograms

Mega pascals

Percentage

Areca husk fibre

Milli metre

Metre square

Newton

CHAPTER - 1

INTRODUCTION

GENERAL

1.1 ARECA FIBRE

Areca nut, also known as betel nut, is a fruit grown in tropical and subtropical regions of Asia, including countries like India, Indonesia, and Malaysia. It is commonly chewed alone or with other ingredients like betel leaf, lime, and tobacco. The discarded shells have various potential uses, such as composting, animal feed, or in the production of biodegradable products. However, recent studies have shown that fibers extracted from these shells can be a valuable source of natural fibers. Areca fiber is gaining attention among natural fiber reinforcing materials due to its affordability, abundance, and high lignocellulosic content, making it a potentially valuable resource. The areca nut palm is considered a potential perennial crop because of its adaptability to tropical climates. Its botanical name is *Areca Catechu* Linnaeus, and it belongs to the *Aceraceae* (*Palmae*) family and *Arctoidea* subfamily. Therefore, a comprehensive study of the physical, chemical, and mechanical characteristics of areca husk fiber is necessary for its use as a structural material. Areca nut fibers or particles are commonly incorporated into composites as a A phase that is stronger and more complex than the continuous matrix phase and serves as the main component of the charge. The tensile strength of areca fiber varies from 147 to 322 MPa; this is higher than other fibers such as coconut fiber (95-230 MPa) and palm fiber (80-248 MPa). Areca fibers, extracted from beetle nut husks, can be used as reinforcing fibers in fiber-reinforced cement composites.

1.2 BACILLUS SUBTILIS

Bacillus subtilis, commonly known as *Bacillus subtilis* is a Gram-positive bacterium found in soil and in the digestive tract of humans and animals. because of him versatile metabolic abilities, resilience, and capacity to produce endospores—dormant, tough structures that allow it to survive harsh conditions like high temperatures, desiccation, and exposure to chemicals.

An intriguing characteristic of *Bacillus subtilis* is its capability to form robust biofilms. These biofilms are complex communities of bacteria that adhere to surfaces and are surrounded by an extracellular matrix (EPS). *B. subtilis* biofilms are not only structurally strong but also have potential applications in various industries and biotechnology. In agriculture, for example, *B. subtilis* can enhance plant growth and protect crops from pathogens. Moreover, researchers are exploring its potential role in bioremediation.

1.3 CALCIUM LACTATE

Calcium lactate is a compound with the chemical formula $\text{Ca}(\text{C}_3\text{H}_5\text{O}_3)_2$. free crystalline salt, soluble in water and alcohol. This compound is a common food additive used for its calcium content and as a firming agent. It is also used in the medical field as a source of calcium, particularly for individuals who cannot get enough calcium from their diets.

One of the interesting properties of calcium lactate is its ability to form complexes with other substances, which can affect its solubility and bioavailability. In the food industry, calcium lactate is often used to fortify products with calcium without significantly affecting the taste or texture. It is commonly found in dairy products, beverages, and baked goods.

Calcium lactate is also It is used to create self-healing concrete, a new material that can heal cracks on its own. In this application, calcium lactate is mixed with bacteria such as *Bacillus subtilis*. When the rock breaks and water gets in, the bacteria open up and the bacteria heal the rock by producing calcite to fill the cracks.

CHAPTER – 2

LITERATURE REVIEW

2.1 GENERAL

The following major research project has been taken from international journals as reference to concepts for the project.

2.2 REVIEW of LITERATURES

Wan-En et al., (2022) In recent decades, the urgency of sustainable development has grown due to the impacts global warming. The cement sector is the second largest emitter of carbon dioxide (CO₂), accounting for 7% of the global total (International Energy Agency, 2018). Ordinary Portland MAAs (OPC) are a widely used material in construction and are a significant greenhouse gas emitter, emitting approximately 0.83 kg of carbon dioxide per kilogram of OPC (Adesina, 2021). This emission is mainly associated with the combustion of fuel during the calcination of limestone in cement kilns. City forecasts show that demand for cement will increase in the coming years, underscoring the need to take steps to reduce cement's environmental footprint. Geopolymers are another material that provides a solution to the carbon footprint of OPC. Geopolymer production involves the use of waste, low energy consumption, low CO₂ emissions and reduced dependence on natural resources. More importantly, geopolymer production does not require heating, saving time and energy. Geopolymers are derived from pozzolanic materials containing silica and aluminum oxide, which dissolve and polymerize in alkaline conditions to form a three-dimensional aluminosilicate network (Davidovits, 1994). The network strengthens over time through environmental hardening. Geopolymers have high overall strength, low shrinkage, and excellent thermal and chemical resistance (Luukkonen et al., 2018), making them promising environmental solutions for OPC.

Ross.J.H. et al., (2022), Alkali-activated materials (AAM), or geopolymers, are a sustainable alternative to Portland cement (OPC), reducing carbon emissions by up to 80% compared to OPC. Geopolymers are made by mixing an alkaline activator (such as alkali metal hydroxide or silicate) with aluminosilicate materials (such as fly

ash, blast furnace slag, silica powder, or metakaolin). This results in the formation of an amorphous aluminosilicate reaction. A strong and dense network creates a material whose matrix permeability proves to be lower, higher at the beginning and stronger at the end. Self-healing of cement materials refers to their ability to repair damage. This ability can be divided into two main elements: independence and self-healing. Self-healing occurs when bacteria or polymers promote healing. Self-healing occurs without external influences. Containing high levels of silicon and aluminum, this adhesive is activated in molecular chains and networks using alkaline solutions. This process forms the basis of gypsum concrete, also known as inorganic polymer cement or alkali-activated cement. Commonly used materials include metakaolin (MK), fly ash (FA), red mud, rice husk ash (RHA), silica fly ash (SFA), granulated blast furnace slag (GGBS), and palm oil ash (POFA). Cementitious materials (SCM).

Amran .M et al., (2021), Geopolymer concrete is a new and environmentally friendly engineering material considered as an alternative to Ordinary Portland Cement (OPC), traditionally used in many construction projects such as transportation, construction, construction and marine use. Geopolymers are one of the alkali-activated materials that provide a solution to the large CO₂ emissions associated with OPC production. Gypsum concrete is a form of geopolymer known for its durability and solves problems associated with concrete construction. Geopolymer adhesives are generally derived from natural or commercial products and are minimally processed. Silicone- and aluminum-rich binders are opened into molecular chains and networks using alkaline solutions, which form the basis of gypsum concrete or inorganic polymer cement or alkali-activated cement. Commonly used materials include metakaolin (MK), fly ash (FA), red mud, rice husk ash (RHA), silica fly ash (SFA), ground granular blast furnace slag (GGBS), and palm oil ash (POFA). additional cementitious materials (SCM). Once considered waste, the use of these SCMs has significant environmental benefits, including reducing resource extraction. Alkaline activated materials such as gypsum concrete are known to be more durable than OPC concrete. This change in the use of SCM not only helps reduce industrial waste, but also increases energy gain, making gypsum concrete a good choice for rapid construction. Gypsum concrete has a high tensile strength, is less brittle than OPC, and can withstand greater movement, indicating its superiority over conventional concrete.

Paris.J.M et al., (2016), As awareness grows regarding the sustainable use of natural resources and the negative consequences of improper waste disposal, there is increasing interest in the beneficial utilization of municipal and industrial byproducts (Meyer, 2009). One common suggestion is to incorporate these discarded materials into construction products for buildings, roads, and other infrastructure. Apart from decreasing the amount of waste sent to landfills, this approach also minimizes the need for extracting natural resources, thereby reducing the construction industry's environmental footprint and impact on the natural environment.

Salmabanu Luhar et al., and Suthar Gourav, (2015 Concrete is prone to cracking when exposed to water, CO₂, and chemicals, which can reduce its It's about endurance, strength and motivation. Repairing these cracks requires expensive maintenance and special repairs. To solve this problem, a self-healing method was introduced, in which bacteria produce calcium carbonate crystals that clog microcracks and pores in the stone. *Bacillus pasturianum*, *Bacillus subtilis* and *Bacillus* spp. bacteria like. *sphaericus* is known for its ability to survive in an alkaline environment and is used in experiments by many scientists. These organisms improve concrete properties such as tensile strength, water permeability, durability and compressive strength. The research used the difference model between different types of bacteria mixed into concrete and found that the mixture mixed with bacteria improved the self-healing properties of the stones. Continuous improvement of this self-healing property should lead to a durable and robust product, particularly suitable for applications in wet areas where corrosion of steel bars can affect the durability of concrete structures. Develop a self-healing method to address the expensive maintenance and special operations required to repair cracks in stone. This process involves bacteria that produce calcium carbonate, which effectively seals cracks and pores in the rock. Bacteria such as *Bacillus pasturianii*, *Bacillus subtilis* and *Bacillus sphaeroides* are known for their ability to survive in alkaline environments. Repairing these cracks requires expensive maintenance and special repairs. To solve this problem, a self-healing method was introduced, in which bacteria produce calcium carbonate crystals that clog microcracks and pores in the stone. *Bacillus pasturianum*, *Bacillus subtilis* and *Bacillus* spp. bacteria like. *sphaericus* is known for its ability to survive in an alkaline environment and is used in experiments by many scientists

Muhammad Arshad AZA, (2014), Recent investigations have explored the carbon dioxide (CO₂) emissions of geopolymers (GPLs) sourced from industrial waste, revealing that GPLs have the potential to emit five times less CO₂ than ordinary Portland cement (OPC). Previous studies have also demonstrated that GPLs exhibit superior mechanical properties compared to OPC. Additionally, GPLs have been successfully used to resist chemical and acidic reactions, and their reduced permeability makes them resistant to water penetration and corrosive actions. These favorable characteristics have garnered attention for the use of GPL Mortar as an alternative to pure OPC mortar. Additionally, GPL's friendly environment makes it the first choice to support sustainable development. Using waste from the base product in GPL production solves problems related to recycling and waste disposal.

Wiktor, V. and Jonkers, H.M, (2011) Cracks commonly form in concrete structures, which can increase permeability and reduce durability by allowing aggressive substances to penetrate, especially in moist environments. To enhance the self-healing ability For concrete, special hardening agents can be added to the concrete matrix. This study aims to evaluate the explosive development of two self-healing biochemical elements embedded in expanded clay, which replaces some mixed rocks and serves as a reservoir for the maintenance manager. When the materials are broken, water entering the crack releases bacterial spores and biochemical substances including calcium lactate from the granules. Bacteria then repair the calcium carbonate formation, closing the gap in the body. Test results showed that the infected concrete was able to repair cracks up to 0.46 mm wide, while the control sample was only able to repair cracks of 0.18 mm after soaking for 100 days. Oxygen measurements confirmed metabolic disturbances during treatment because oxygen was consumed in diseased samples but not in control samples. This new biochemical self-healing agent has the ability to increase the durability of concrete buildings, especially in humid environments. Oxygen measurements analyzed metabolic activity during treatment, as indicated by oxygen consumption in diseased samples but not in control samples. The new biochemical self-healing agent will increase the durability of buildings, especially in humid environments. Oxygen measurements confirmed metabolic disturbances during treatment because oxygen was consumed in diseased samples but not in control samples. This new biochemical self-healing agent. self-healing biochemical elements embedded in expanded clay,

which replaces some mixed rocks and serves as a reservoir for the maintenance manager.

Abubakar Magaji et al., (2019), In recent years, there has been increasing interest in increasing the strength, toughness and durability of cement concrete. One area of growth is the self-healing of concrete, especially since concrete tends to crack and deteriorate quickly. Crack formation is a natural phenomenon in stone and causes it to deteriorate over time.

Amirreza Talaiekhazan, et al., (2014) Self-healing concrete is increasingly used as a solution to increase the durability of concrete. Although there are some literature reviews on this topic, comprehensive reviews of all aspects of self-healing are lacking. This article provides a comprehensive review of the natural, chemical and biological processes involved in the self-healing of biomaterials, with a particular focus on biology. It provides new insights into solving the problem of unexpected explosions in rocks, making it useful for biotechnologists and bioprocess engineers to find new insights into self-healing research.

Abo-El-Enein et al., (2013), Cracking is a common Problems that allow water and chemicals to penetrate concrete buildings, reducing their durability and strength, and affecting steel reinforcement when exposed to environmental factors. These cracks can be expensive to repair and may require special repairs. To solve this problem, researchers introduced the process of self-healing. In this process, *Bacillus pasturianus*, *Bacillus subtilis* and *Bacillus* spp. Bacteria such as are used. *Sphaericus* is known to survive in alkaline areas, producing calcium carbonate products that clog microcracks and pores. Different strains require certain growth, and mathematical models have been developed to study the stress response behavior of strains to increase the overall strength of concrete. You seem to be interested in the strength, durability and durability of cement-based structures, especially the self-healing process of concrete. If you have specific questions or want to learn more about this topic, please feel free to ask! *Bacillus sphaericus* is known for its ability to survive in an alkaline environment and is used in experiments by many scientists. The growth of different strains, in order to obtain the best results, mathematical models have been introduced to study the stress of strains that can increase the strength of concrete. , CO₂ and other chemicals. Repairing these cracks requires expensive maintenance

and special repairs. To solve this problem, the stone is treated with a self-healing process that heals cracks by forming calcium carbonate crystals to block the cracks and pores.

Jonkers, H., (2011) Crack formation is a problem that affects the stability of many concrete structures. While large cracks can compromise structural integrity, even small-sized cracks can cause long-term problems by increasing matrix permeability. This allows water and chemicals to penetrate, causing premature deterioration of the matrix and corrosion of the embedded steel bars. Maintenance and repair of concrete structures is often costly and sometimes impossible. Therefore, using self-cleaning machines can reduce maintenance costs and increase product durability. At TU Delft's Delft Materials Centre, researchers are investigating the effectiveness of various self-healing materials to create a new generation of self-healing systems. This study focuses on the blast remediation potential of certain biochemical products. The additive contains a mixture of living but immobile organisms and organic compounds contained in porous expanded clay particles. Microscopic technique combined with permeability testing showed complete healing of cracks in infected concrete, whereas only partial healing was observed in control concrete. It is believed that the healing of cracks in concrete occurs by closing the cracks by converting calcium lactate into calcium carbonate. This process, mediated by biochemicals, effectively seals small cracks (0.15 mm wide).

Jonkers H.M et al., (2008), The increasing use of concrete worldwide shows that there is an urgent need for effective solutions due to environmental concerns. Currently, approximately 7% of all anthropogenic atmospheric CO₂ emissions come from cement production. Increasing the durability of concrete buildings not only extends their lifespan but also supports sustainability. One of the methods that has received more attention is the self-healing ability of concrete, particularly the self-healing of cracks. This study investigated bacteria that can act as self-healing agents in concrete, focusing on their ability to repair cracks. For this purpose, a special group of alkali-converting bacteria belonging to the genus *Bacillus* was selected. Bacterial spores added directly to the grout mixture can work for up to 4 months. However, as the pore diameter decreases during cement concrete, the length of the spores will be limited, which will reduce the pore size to less than 1 μm (the size of *Bacillus* spores). Despite this limitation, the cement samples tested contained more fracture-inhibiting

minerals than the control samples. This demonstrates the potential of bacterial spores as a self-healing agent for concrete.

Van Brugel K, (2007), Stone is a material that breaks under tensile or shear stress, causing the permeability of embedded steel bars and accelerating the deterioration of the product by exposure to ambient air. The stone industry also faces the problem of sustainable development because stone production uses too much energy and emits too much carbon dioxide. These problems are further compounded by the premature collapse of concrete structures, which requires additional material for reconstruction. To solve these problems, the strength of concrete must be increased. A promising approach is the incorporation of nature-inspired self-healing techniques into cement and concrete products. This article explores the concept of self-healing that occurs due to the heterogeneity of rock. It also introduces various experimentally proven biomimetic technologies that enable concrete materials and materials to heal themselves. These include many methods and show promise in improving the self-healing abilities of design models. Finally, the report states that if the cracks that are not caused by the brittleness of the concrete are closed, repaired or repaired, the concrete will have sufficient height for a long working life, thus increasing its durability and stability.

Li V. C and Yang E, (2007), Self-healing in concrete has been recognized for many years. Observations of old stone structure have revealed The cracks are covered with white crystalline material. Indicating that concrete can naturally seal cracks with chemical products, potentially aided by rainwater and airborne carbon dioxide. Researchers studying Water flows hydraulically through broken rocks gradients have also A gradual decrease in permeability was noted over time; This shows that fractured rock can self-organize and reduce water flow.

The main mechanism behind this self-sealing process is the formation of calcium carbonate, which is formed as a result of the reaction of hydrated cement and carbon dioxide dissolved in water. Therefore, the phenomenon of concrete self-sealing under certain conditions is well documented. This self-sufficiency is essential to maintaining water quality and extending the life of the building

Dick J.W. et al., (2006), To develop a process for calcite recovery from degraded limestone, researchers tested the ability of five different strains of *Bacillus sphaericus* and one strain of *B. bradys* to break down calcium carbonate from uric acid. Although all species can precipitate calcium carbonate, there are differences in the amount of calcium carbonate precipitated across agar plate colonies. Seven important aspects have not yet been examined: calcite deposition on limestone cubes, pH increase, degradability of urea, production of extracellular polymers (EPS), biofilm formation, gamma potential, and deposition of dense crystal layers. Bacteria that achieve the optimum CaCO_3 layer thickness on limestone are selected based on their ability to reduce water absorption of the treated limestone. However, not all of these species are effective in remediating degraded Ewell limestone. The best calcite precipitating bacteria exhibited high urea analysis activity, calcite deposition on limestone cubes, and very poor ability.

Reinhardt H. W. V et al., (2003), Self-healing of concrete and concrete is a good result. This is also called autologous treatment. Many publications demonstrate the high level of knowledge of Edvardsen Meissner (and Riphæan), who studied the individual capacity of concrete from various aspects. However, the relationship between self-healing and temperature has received little attention. This is surprising because water transport and filtration processes are often accompanied by temperature changes. The research started with Solar Water Storage Design and Construction. Water is heated by solar collectors and pumped into underground storage containers. The maximum temperature of the water is 95°C , and the stored energy must be stored for use in the cold season of the year. The question arises regarding the self-healing of concrete at temperatures between 20 and 80°C . This article presents some theoretical considerations as well as experimental models and research results. It concerns only one type of high-performance computing (HPC). A detailed description and summary of the tests, as well as a combination of other studies, can be found in Joss and Reinhardt. The maximum temperature of the water is 95°C , and the stored energy must be stored for use in the cold season of the year. The question arises regarding the self-healing of concrete at temperatures between, The research started with Solar Water Storage Design and Construction. Water is heated by solar collectors and pumped into underground storage containers.

Neville A., (2002). Autogenous Healing Concrete Miracle. Concrete International, Infrastructures encompass a wide range of materials, with This article focuses on civil engineering, specifically concrete and asphalt. Public demand for these infrastructures is high; It requires high service, efficiency, durability and minimum ecological impact. The emergence of self-healing materials offers solutions to these problems. This article provides an overview of recent advances in self-healing research in cement and asphalt concrete. Various projects at Delft University are investigating self-healing techniques. The first discussion is rock bacteria, which involves the incorporation of bacteria into the rock. These bacteria cause calcite to form in the cracks, making the stones waterproof and lasting longer. The second project focuses on hybrid fiber cement products that enable cracks to be repaired when they occur. The final project described in this article addresses the problem of loosening of porous asphalt concrete and explores ways to repair this damage, such as inserting microcapsules or steel fibers. State-of-the-art results from each project show that self-healing is no miracle; Data can be produced for this. This article provides an overview of recent advances in self-healing research in cement and asphalt concrete. Various projects at Delft University are investigating self-healing techniques. The first discussion is rock bacteria, which involves the incorporation of bacteria into the rock.

Bang S et al., (2001), Use foam to immobilize all cells of *B. pasturianum*. Immobilized cells were found to have calcite precipitation and ammonia production as free cells. Scanning electron micrographs identified cells embedded in calcite crystals throughout the PU matrix. Calcite in PU has little effect on the elastic modulus and tensile strength of the polymer, but it increases the compressive strength of concrete, and its cracks can be repaired by PU brain. These observations led us to believe that calcite may be deposited in a precipitated form rather than as a matrix-bound material.

Mihashi H et al., (2000), In Europe, approximately 50% of the annual construction budget is allocated to the repair and maintenance of existing structures. This situation shows the importance of self-healing in concrete and explosive materials. In this study, encapsulated healing agents were embedded in the mortar matrix to provide self-healing products. When the material breaks, the capsule ruptures, releasing the drug and healing the fracture. As a result of computerized tomography and visual examination of the cracks, it was determined that the cracks were filled with a good material. Research shows that more than 50% of original strength and hardness can be restored through self-treatment. Additionally, due to the processing of cracks, water permeability can be reduced by 10² to 10⁴ times. This feature has the ability to partially restore the building after its destruction. This situation shows the importance of self-healing in concrete and explosive materials. In this study, encapsulated healing agents were embedded in the mortar matrix to provide self-healing products. When the material breaks, the capsule ruptures, releasing the drug and healing the fracture.

Rivadeneyra M. A et al., (1996) The study examined carbonate precipitation by 20 strains of the moderately halophilic species *Halo monas eurihalina* in both solid and liquid media, considering the influence of salinity and temperature on the quantity and type of crystals formed. Some strains of *H. euryhalina* were found to produce crystals under all tested conditions. The precipitated mineral phases included magnesium calcite, aragonite, and monohydrocalcite, with proportions varying based on factors such as the growth medium and its salinity. Scanning electron microscopy and X-ray dispersive energy microanalysis were used to analyze the crystal formation process, revealing a sequential biolith formation process. Initially, chains or filaments of bacteria were observed, followed by the formation of discs, and finally, the production of spherical forms approximately 50 µm in diameter. The study proposes a mechanism for carbonate crystal formation by *H. eurihalina*.

CHAPTER - 3

AIM & SCOPE

3.1 OBJECTIVES OF THE STUDY

- ✓ Testing of properties of crushed aggregates.
- ✓ To determine the compressive strength and tensile strength of ordinary and self-healing concrete.
- ✓ Compare the strength of ordinary and self-healing concrete.

3.2 AIM OF THE STUDY

The goal of self-healing research is to create smart concrete that can self-heal as a way to control cracking and extend the service life of concrete structures. The concept of self-healing is a method of self-healing that does not necessarily save on the direct costs of maintenance and repair, but also reduces indirect costs and is generally welcomed by contractors. 1 A self-healing machine can be built without humans. Interruption. When cracks occur, there will be no need to reduce the frequency of inspection and maintenance.

3.3 SCOPE OF THE PROJECT

Autogenous healing in cementitious materials plays a crucial role in the self-closure of cracks, significantly influencing the physical and mechanical performance of composites. This phenomenon is a key reason for the extended lifespan of ancient structures and buildings. The French Academy of Science first observed autogenous self-healing in cement-based composites in 1836 when cracks in structures like pipes and water-retaining structures spontaneously healed. This discovery has sparked considerable interest and research in construction materials and civil engineering.

CHAPTER – 4

METHODOLOGY

4.1 METHOD OF INVESTIGATION

The methodology of the experimental study is shown in the below Figure.

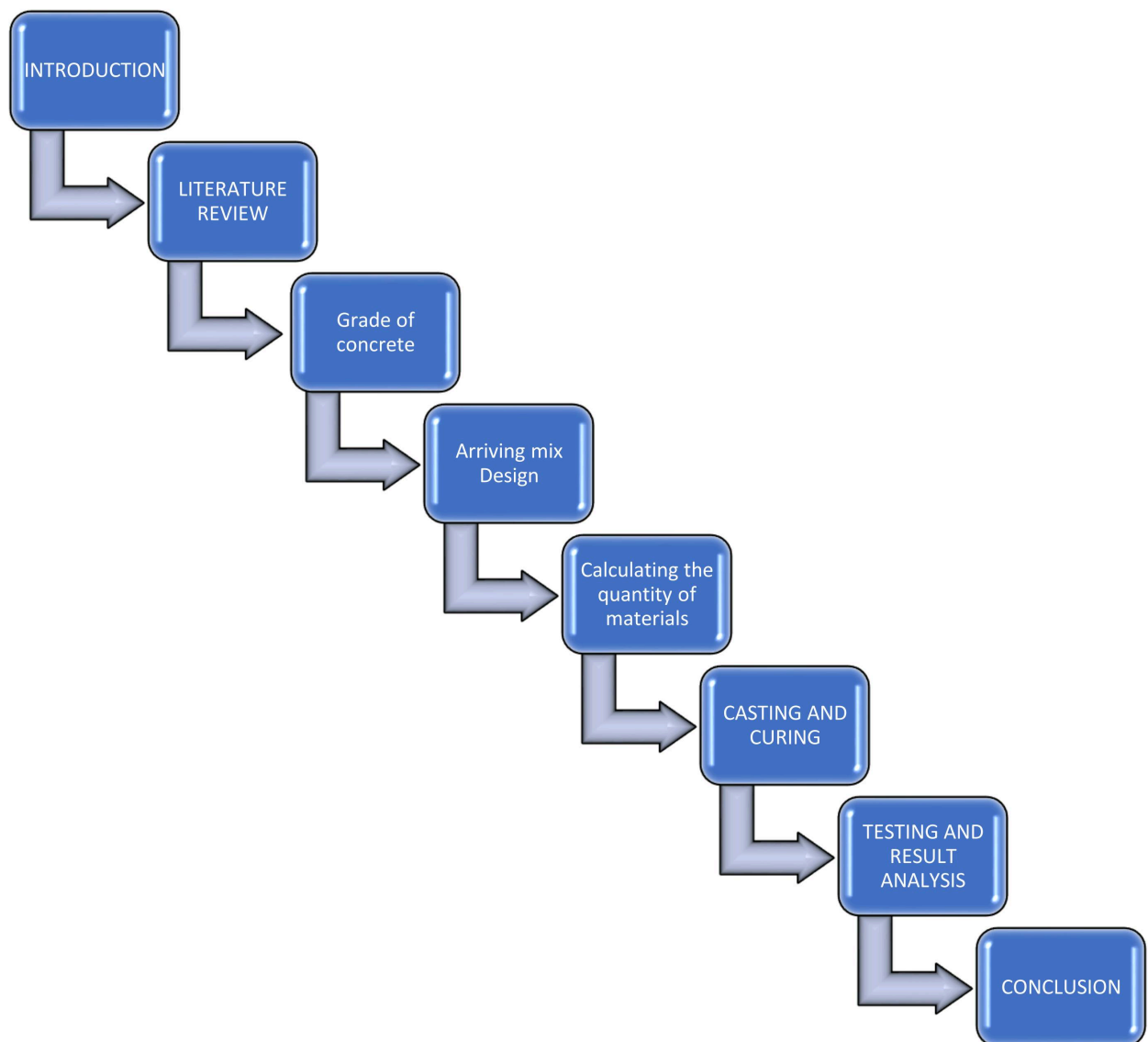


Fig: 4.1: Methodology of the Work

4.2 MATERIALS COLLECTED

The raw materials used in this experiment were sourced locally and included ordinary Silicate cement is used as the agent, water sand and coarse aggregate are used as fine aggregate. *Bacillus subtilis* is also used. In research, taps are used for mixing and stabilization, However, a significant drawback is their inherent variability, which can result in poor bonding with matrix resins. This can lead to reduced flexibility in the resulting composite materials.

4.2.1 *Areca fibre*

Areca fiber is primarily obtained from the fruit, frond, and stalk leaf of the areca palm. In the face of a global challenge to find innovative ways to manage solid waste, especially non-biodegradable polymers, traditional waste separation methods are often costly and environmentally harmful. Natural fibers like areca are readily available, biodegradable, and offer high tensile strength, making them ideal substitutes for conventional fibers. However, a significant drawback is their inherent variability, which can result in poor bonding with matrix resins, leading to reduced flexibility in the resulting composite materials.



Fig: 4.2: Areca Fibre

4.2.1.1 *Advantages of Areca Fibre*

Improved mechanical properties: Areca fibers can enhance the compressive strength, flexural strength, and toughness of concrete, due to their high aspect ratio, high tensile strength, and good bonding with the matrix.

Reduced environmental impact: Areca fibers are renewable, biodegradable, and locally available in many tropical regions, which can reduce the carbon footprint and transportation costs of concrete production.

Improved workability: Areca fibers can improve the workability and cohesiveness of fresh concrete, due to their ability to absorb water and act as a lubricant.

Reduced cost: Areca fibers are cost-effective compared to alternative fibers like steel and carbon fibers, potentially lowering the overall cost of concrete production. They are readily accessible in the market.

4.2.1.2 Disadvantages of Areca Fibre

- Limited Availability.
- Processing Challenges.
- Seasonal Dependency.

4.2.1.3 Applications of Areca Fibre

Construction of Eco-Friendly Structures: AFRC, with the addition of Areca fibers, contributes to a more sustainable and eco-friendly construction material. Areca fibers are renewable and biodegradable, making them a greener alternative.

Enhanced Flexural and Tensile Strength in Structures: Adding Areca fibers to concrete can boost its flexural and tensile strength, which is especially advantageous in situations requiring crack resistance and increased ductility. This enhancement is valuable in various applications, including beams, pavements, and precast elements.

Reduced Shrinkage and Cracking: Areca fibers can help reduce the shrinkage and cracking tendencies of concrete. This is especially advantageous in structures where minimizing cracking is critical for durability and long-term performance.

Improved Impact Resistance: Incorporating Areca fibers into concrete can improve its impact resistance, which is particularly advantageous in scenarios like pavements that endure dynamic loads from vehicles.

4.2.2 *Bacillus Subtilis*

Bacillus subtilis is a well-studied bacterium that serves as a model organism for Gram-positive bacteria. It is rod-shaped and produces endospores, enabling survival in harsh environmental conditions like heat and desiccation. In soil, its natural habitat, *B. subtilis* regularly encounters fluctuating environmental factors, including varying oxygen levels. Oxygen is crucial as an electron acceptor in aerobic respiration. The ability of *B. subtilis* to adapt to such changing conditions underscores its significance as a model organism for understanding bacterial responses to environmental stresses.



Fig: 4.3: *Bacillus Subtilis*

4.2.2.1 Advantages of *Bacillus Subtilis*

Enhanced Strength: Bacterial concrete is purported to exhibit greater tensile and compressive strength than traditional concrete.

Reduced Permeability: Introducing *Bacillus subtilis* into concrete results in the formation of mineral compounds that can effectively mend cracks. This self-healing mechanism reduces the permeability of corrosive agents into the concrete, thereby enhancing its longevity.

Eco-Friendly: Employing bacterial self-healing methods reduces the necessity for extra cement, a significant source of carbon dioxide emissions. Encouraging self-healing not only prolongs the lifespan of concrete structures but also minimizes their environmental footprint.

Cost Savings: Self-healing concrete can lower maintenance costs for reinforced concrete structures. Cracks are naturally repaired, reducing the need for frequent repairs and replacements.

4.2.2.2 Disadvantages of Bacillus Subtilis

Lack of Design Guidelines: At present, the IS Codes do not provide specific design specifications for creating self-healing concrete with *Bacillus subtilis*. The absence of clear guidelines can pose challenges for the implementation and standardization of this technology.

Higher Initial Cost: The initial expense of bacterial concrete exceeds that of traditional concrete. Integrating *Bacillus subtilis* and ensuring its effective activation and distribution can elevate the overall construction costs.

Vulnerability to Harsh Conditions: Blending bacteria with cement mortar can subject them to harsh environments, such as elevated pH levels, which can result in cellular harm and mortality. Nonetheless, encapsulating the bacteria within a protective layer can alleviate these issues by creating a physical shield between the bacteria and the cement mortar.

Maintenance and Monitoring: Maintaining self-healing concrete with *Bacillus subtilis* entails continuous monitoring and upkeep. Sustaining the viability and activity of the bacteria over time is crucial for ensuring successful self-repair. Regular inspections and interventions may be required.

4.2.3 Fine Aggregate

River sand is a naturally occurring sand typically collected from riverbanks, and it is the most prevalent sand variety used in construction. Characterized by its small particle size and soft texture, river sand is favoured for projects requiring a smooth finish, such as plastering and RCC projects. Its whitish-grey coloration makes it distinctive, and its fine, smooth texture enables strong binding with cement, aggregates, and water for concrete construction. Its natural sourcing also contributes to its cost-effectiveness compared to other sand types..



Fig: 4.4: Sand

4.2.4 Water

Water plays a crucial role in papercrete. Because it often reacts chemically with cement. It is important to prepare the mortar, mix the cement stone and be careful when using it. The quality and quantity of water affects the strength of mortar and cement concrete. Therefore, the water used for mixing and curing must be clean and free of alkalis, acids, oil, salt, noise, organic matter that can damage brick, stone, stone or metal, and toxic substances that can harm plant growth. Most drinking water considered suitable for mixing has a pH value of not less than 6.

4.2.5 Cement

The investigation utilized Ordinary Portland Cement of 53 Grade from the Ultra Tech Company, which was locally available. Special care was taken to procure the cement from a single batch, ensuring it was stored in airtight containers to prevent exposure to atmospheric conditions. The cement was subjected to testing for physical requirements as per IS: 169-1989 and for chemical requirements as per IS: 4032-1988.



Fig: 4.5: Cement

4.2.6 Coarse Aggregate

The study utilized crushed aggregates smaller than 12.5 mm is obtained from local crushing plant. Only the part of the aggregate that passes through the 12.5 mm sieve and remains on the 10 mm sieve is selected. These aggregates are tested for physical strength as well as integrity, smoothness, specific magnetism and density as follows. guidelines outlined in IS: 2386-1963.

4.3 TEST ON CEMENT

Material inspection is a critical aspect of civil engineering, as the longevity of a structure relies on the quality of materials employed. The following tests are essential for evaluating the quality of cement.

1. Fineness Consistency
2. Initial and Final Setting Time
3. Soundness
4. Specific gravity
5. Compressive strength
6. Compatibility test with Areca fibre.

Table 4.1: Properties of Cement

Properties	values	Requirements as per I.S. codes
Specific gravity	3.12	IS 2720 part 3 (3.15 is generally assumed)
Normal consistency	29%	S 4031-part 4
Initial setting time	65 min	Not less than 30 minutes as per IS 4031 Part 5
Final setting time	275 min	Not more than 600 minutes as per IS 4031-Part 5
fineness	330kg/m	Not>10% as per IS 4031- part 1
soundness	2.5mm	Not>10mm as per IS 4031-part 3
Bulk density	830-1650 kg/m	

4.3.1 Consistency of Cement

The purpose of this test is to determine the amount of water required to obtain a consistent cement pattern that will allow the Vicat piston to penetrate the Vicat mold to a depth of 5 to 7 months. The procedure for determining the amount of water required to produce cement of a certain consistency is as follows:

1. Make sure Vicat tool is at beginner level. If you are using a unit with a buffer make sure the travel is at maximum and firm.
2. Inject the required oil into the empty half, tighten the top, and then actuate the piston several times for proper operation.
3. Install the plunger used to measure the corresponding standard on the moving rod and operate it frequently.
4. Take 400 grams of cement in the pot and add measured water to the beaker.
5. Mix the water and cement into a paste and start the standing time while adding the water to the cement.
6. Place the Vicat mold on a non-porous plate and fill it with cement slurry. 7. After filling the mold, gently shake it to remove bubbles and smooth the surface of the paste with the top of the mold.
8. Slowly lower the plunger until it touches the cement slurry surface and release it quickly. If you are using the VEKA machine with a bad machine, place the filled mold and the non-absorbent plate on the base of the device. Lift the buffer piston so that it contacts the moving arm on the top cover.
9. Remove the pin holding the removable rod and quickly release it, allowing the plunger to engage the paste. This step should be done immediately after filling the mold.

Table 4.2: Consistency Values of Cement

S.No	Percentage of Water	Height of Plunger
1.	25%	35mm
2.	26%	32mm
3.	27%	30mm
4.	28%	25mm
5.	29%	22mm
6.	30%	7mm

4.4 MIX DESIGN

Mix design is the method of choosing appropriate concrete ingredients and establishing their relative ratios to create concrete that meets specific strength and durability requirements, all while being cost-effective.

4.4.1 Mix Proportion

Grade designation: M30

- Cement Type: 43-grade Ordinary Portland Cement (OPC)
- Fine Aggregate: zone-2
- Water-cement ratio: 0.45 (adjust as per the specific water-cement ratio requirements)
- Areca Fibers: 0.02 to 0.05 parts (2% to 5% by volume of total mix)
- Bacterial solution: 5%,10%,15% in total mix
- Calcium lactate (0.2% in total mix) Minimum cement content: 320 kg/m³ (IS-456, table-3)
- Maximum aggregate size: 20mm. Exposure condition: severe (as per IS:456, table-3) Workability in terms of slump – 100mm (IS-456-CI.7.1)
- Cement content maximum - 450kg/m³ (As per IS-456, Clause 8.2.4.2)

4.4.2 Steps Involved in Mix Design

- Establishing the target strength
- Choosing the water-to-cement ratio
- Choosing of water content

- Calculation of content of cement
- Calculation of fine aggregate content
- Calculation of water content
- Calculation of the mix proportion

Target Strength

$$f'_{ck} = f_{ck} + 1.65 s / f_{ck} + x, \text{ whichever is higher value}$$

where,

f'_{ck} ,represents the target average compressive strength at 28 days.

f_{ck} = characteristics compressive strength at 28 days, and

s = standard deviation.

x = factor based on grade of concrete as per table-1

$s = 5.0 \text{ N/mm}^2$ (IS-10262:2019, Table-2)

$x = 6.5 \text{ N/mm}^2$ (IS-10262:2019, Table-1)

$$f'_{ck} = 30 + 1.65 \times 5 = 38.25 \text{ N/mm}^2$$

$$f'_{ck} = 30 + 6.5 = 36.5 \text{ N/mm}^2, \text{ hence, } F'_{ck} = 38.25 \text{ N/mm}^2$$

Water – Cement Ratio

Exposure – Severe

IS-456-2000,

Table-3&5,

Water cement ratio – 0.45

Water content

IS-10262, Table- 4

20mm aggregate – 186kg (for 50mm slump)

5mm- add 3% (IS-10262-Cl.5.3)

for 125mm, $186 + 9\% \text{ of } 186 = 203 \text{ lit}$

Water content = 203lit

Calculation of cement content

$$\text{water cement ratio} = \text{water content} / \text{cement content}$$

$$\text{cement content} = \text{water content} / \text{water cement ratio}$$

$$= 203 / 0.45 = 452 \text{ kg} / \text{m}^3 > 320 \text{ kg/m}^3$$

$$\text{Amount of cement} = 452 \text{ KG/M}^3$$

Aggregate Proportion Between C.A & F.A

IS- 10262, Table-5, Cl.5.5.1

zone – 2 – 0.62 [w/c ratio – 0.5]

every 0.05 decrease, increase 0.01 [w/c ratio – 0.45]

$$0.45 - 0.4 = -0.05$$

$$0.62 + 0.01 = 0.63$$

$$\text{Volume of Fine Aggregate} = 1 - 0.567 = 0.433 \text{ m}^3$$

$$\text{Volume of Coarse Aggregate} = 0.567 \text{ m}^3$$

Mix Calculation

$$\text{Volume of concrete} = 1 \text{ m}^3$$

$$\text{volume of cement} = (\text{mass} / \text{s.g}) \times (1/1000)$$

$$= 452 / (3.15 \times 1000)$$

$$= 0.145 \text{ m}^3$$

$$\text{Volume of Water (c)} = (\text{Mass/Sp.gravity}) \times (1/1000)$$

$$= 203 / (1 \times 1000)$$

$$\text{Volume of water} = 0.203 \text{ m}^3$$

Volume Of All In Aggregates

$$\begin{aligned}1 - (b + c) &= 1 - (0.145 + 0.203) \\&= 0.652 \text{ Volume of Cement} \\&= 0.145 \text{ m}^3\end{aligned}$$

Mass of Coarse Aggregate

$$\begin{aligned}&= (\text{Vol. of all in Aggregate}) \times (\text{Vol. of C.A}) \times (\text{Sp. Gravity of C.A}) \times (1000) \\&= 0.652 \times 0.567 \times 2.8 \times 1000 \\&= 1036 \text{ kg}\end{aligned}$$

Mass of coarse aggregate = 1036kg

Mass of Fine Aggregate

$$\begin{aligned}&= (\text{Vol. of all in Aggregate}) \times (\text{Vol of F. A}) \times (\text{Gravity of F.A}) \\&\quad \times (1000) \\&= 0.652 \times 0.433 \times 2.7 \times 1000 = 762.2\end{aligned}$$

Mass of fine aggregate = 762.25k

Summary

Cement	= 452 kg/ m ³
Water	= 203 kg/ m ³
Fine Aggregate	= 762.25 kg/ m ³
Coarse Aggregate	= 1036 kg/ m ³
Water Cement Ratio	= 0.45

PROPORTION -1:1.7:2.3

Therefore, the mix proportions for casting = 1:1.7:2.3

4.4.3 Factors to be Considered for Mix Design

- The grade designation specifies the required characteristic strength of concrete.
- The type of cement affects the rate at which flexural strength develops in concrete.
- The maximum nominal size of aggregates used in concrete should be as large as possible within the limits set by IS 456:2000.
- Cement content should be controlled to prevent shrinkage, cracking, and creep.
- The workability of concrete for proper placement and compaction depends on factors such as the size and shape of the section, quantity and spacing of reinforcement.

Table 4.3: Proportions of Mix Design

Cement	Fine Aggregate	Coarse Aggregate	Water
1	1.7	2.3	0.45

Table 4.4: Materials for standard mix

S. No	Materials	Quantity
1	Cement	452kg
2	Fine aggregate	762.25kg
3	Coarse aggregate	1036kg
4	Water	5000 ml

Table 4.5: Percentage of Materials

Description	Cement%	Coarse Aggregate %	Fine aggregate %	Calcium Lactate %	Areca fibre%	Bacterial %
Conventional Concrete	100	100	100	0.5	0	0
Specimen-1	99	75	100	0.5	1	5
Specimen-2	98	75	100	0.5	2	10
Specimen-3	97	75	100	0.5	3	15

Table 4.6: Number of Test Specimens

Description	Cubes	Cylinders
Conventional Concrete	3	3
Specimen-1	6	6
Specimen-2	6	6
Specimen-3	6	6

4.5 PROCEDURE FOR PREPARATION OF SPECIMENS

- **Prepare Tools and Materials:** Gather all necessary items, including a block Mold, cement, sand, and water.
- **Mix the Ingredients:** Combine the materials in the correct proportions (1:1.7:3) along with water.
- **Cast the Cubes:** Remove and clean the cube molds, ensuring all bolts are tightly secured. Fill the molds with concrete in three layers, compacting each layer with vibration.
- **Hand Compaction and Casting:** After casting the cubes, fill the cube molds with concrete samples, compacting each layer with vibration. Cast the cubes as quickly as possible.
- **Curing:** Place the casted cubes in a shed without vibrations, maintaining a temperature between 22°C to 33°C. The same procedure applies to cylinders.



Fig: 4.6: Casting of Concrete

4.5.1 Preparation of Specimen by Replacing 1% of Areca Fibre In Concrete and 5% Bacterial Solution and 0.5% Calcium Lactate

- In 5% solution
- Step 1- Cement + coarse aggregate + fine aggregate + water+ areca fibre
- Step 2- Calcium lactate + bacterial solution
- Total specimens -12



Fig: 4.7: Concrete Specimens

Table 4.7: Quantities With 5% Bacteria

S.No	Materials	Quantity
1.	cement	27kg
2.	Fine aggregates	44.5kg
3.	Coarse aggregates	61kg
4.	Water	12ltrs
5.	Arica fibre	51.4g
6.	Bacterial solution	5%(578ml)
7.	Calcium lactate	128g

4.5.2 Preparation of Specimen by Replacing 2% of Areca Fibre In Concrete and 10% Bacterial Solution and 0.5% Calcium Lactate

- In 10% solution
- Step 1- Cement + coarse aggregate + fine aggregate + water+ areca fibre
- Step 2- Calcium lactate + bacterial solution
- Total specimens -12

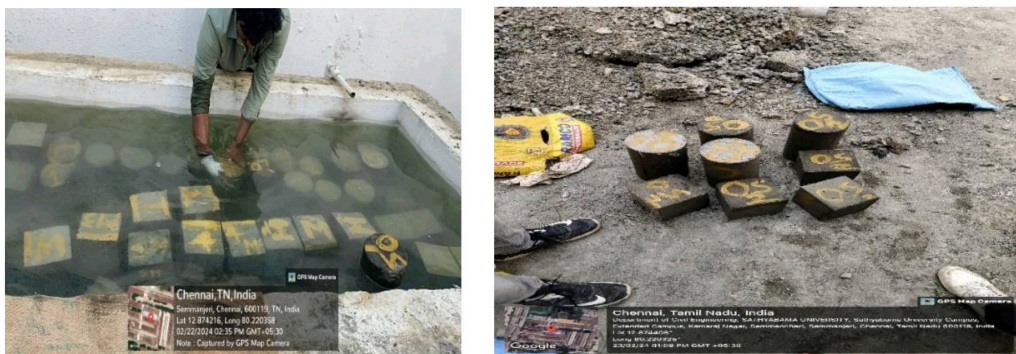


Fig: 4.8: Curing of Concrete

Table 4.8: Quantities With 10% Bacteria

S.No	Materials	Quantity
1.	cement	27kg
2.	Fine aggregates	44.5kg
3.	Coarse aggregates	61kg
4.	Water	12ltrs
5.	Arice fibre	51.4g
6.	Bacterial solution	10%(770ml)
7.	Calcium lactate	128g

4.5.3 Preparation of Specimen by Replacing 3% of Areca Fibre In Concrete and 15% Bacterial Solution and 0.5% Calcium Lactate

- In 15% solution
- Step 1- Cement + coarse aggregate + fine aggregate + water+ areca fibre
- Step 2- Calcium lactate + bacterial solution
- Total specimens -12

Table 4.9: Quantities With 15% Bacteria

S.No	Materials	Quantity
1.	cement	27kg
2.	Fine aggregates	44.5kg
3.	Coarse aggregates	61kg
4.	Water	12ltrs
5.	Arice fibre	51.4g
6.	Bacterial solution	15%(1070ml)
7.	Calcium lactate	128g

4.6 TESTING OF SPECIMENS

Testing methods used in the study

1. Compressive strength
2. Split tensile strength

Concrete testing is crucial for ensuring and regulating Cement stone engineering quality. It includes testing of raw materials, new concrete and hardened concrete, which is an important part of any quality control. These tests help improve the efficiency of the product and ensure better performance in terms of strength and durability. Tests should be simple, practical and effective. The main purpose of testing hardened concrete is to ensure that the concrete used in the field reaches the required strength.

4.6.1 Slump Test

1.Preparation:

Ensure that all necessary equipment is ready, including the slump cone, base plate, tamping rod, scoop, and a ruler.

2.Setup:

Position the slump cone on a smooth, flat surface, and moisten the interior surfaces of the cone.

3.Mixing and Sample Collection:

Conduct the mixing of AFRC according to the established mix design.

Collect a representative sample from the batch for the slump test.

4.Filling the Slump Cone:

Fill the slump cone in three equal layers, compacting each layer with 25 strokes of a tamping rod.

5.Striking Off Excess Concrete:

Strike off the excess concrete using a trowel or Use a straight edge to ensure that the surface is flush with the top of the slump cone.

6. Lifting the Cone:

Carefully lift the slump cone vertically, ensuring that it is done smoothly and without any lateral movement.

Allow the concrete to subside freely.

7. Measurement of Slump:

Slump is determined by measuring the difference in height between the initial height of the cone and the height of the concrete. Use a caliper to measure the drop to the nearest 5mm.

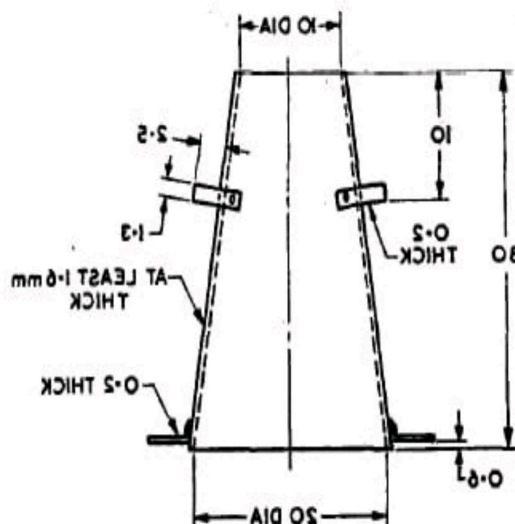


Fig: 4.9: Slump Cone

CHAPTER - 5

RESULTS AND DISCUSSION

5.1 COMPRESSIVE STRENGTH OF SPECIMEN

Purpose The Compression Test for a concrete block with rubber tyre is like checking how strong the block is when you apply the load. It helps us understand how much force it can take before it breaks. **Procedure**

- Take the concrete block that you want to test.
- Place the block on a compression testing machine that can push on it with a lot of force.
- The machine slowly applies pressure to the block.
- keep increasing the pressure until the block can't handle it anymore, and it starts to crack or break.
- The machine measures how much pressure was needed to make the block break. This pressure is a way of telling us how strong the block is. This test helps in finding out if the concrete block with rubber tyre is strong enough for to bear the load.
- Note down the values of the reading after founding the cracks on the specimen.
- Then remove the specimen and clean the machine.

$$\text{Compressive strength (N/mm}^2\text{)} = \text{Maximum load / Area of Cross Section} = P/A$$

Where,

F_{ck} = Compressive strength (N/mm²)

P = Ultimate load (N) or Breaking Load

A = Loaded area (150 mm X 150 mm) = 22500 mm²

Compressive strength refers to the ability of the material or structure to maintain the material in place without cracking or warping. Concrete blocks were cured for 7, 14 and 28 days, respectively. Each set of cubes was tested for compressive strength.

Apparatus required: The sand used in the test must meet the standards outlined in IS: 650-1966. Additionally, equipment such as a vibration machine, poking rod, 70.6 mm cube mold conforming to IS: 10080-1982, balance, gauging trowel, stopwatch, graduated glass cylinders, etc., will be required.



Fig: 5.1: Compressive Strength Test

Procedure

Position the cube at the centre of the lower platen of the compression testing machine so Loads are applied to the outside of the cube during casting, not to the top and bottom. Carefully align the axis of the model with the thrust center of the spherical seat. Do not use filler between the sample surface and the test steel plate. Loads were applied slowly and continuously at a rate of approximately 140 kg/cm²/min until the specimen failed under increasing loads and could support no more. Record the maximum load applied to the structure.

Table 5.1: Compressive Strength of Concrete

S.No	Specimen Composition	Compressive Strength At 7 Days (N/mm ²)	Compressive Strength At 14 Days (N/mm ²)	Compressive Strength At 28 Days (N/mm ²)
1.	CLC0	31.1	31.41	32.77
2.	CLC1	32.77	33.22	35.33
3.	CLC2	28.44	31.13	33.15
4.	CLC3	26.55	28.21	29.14

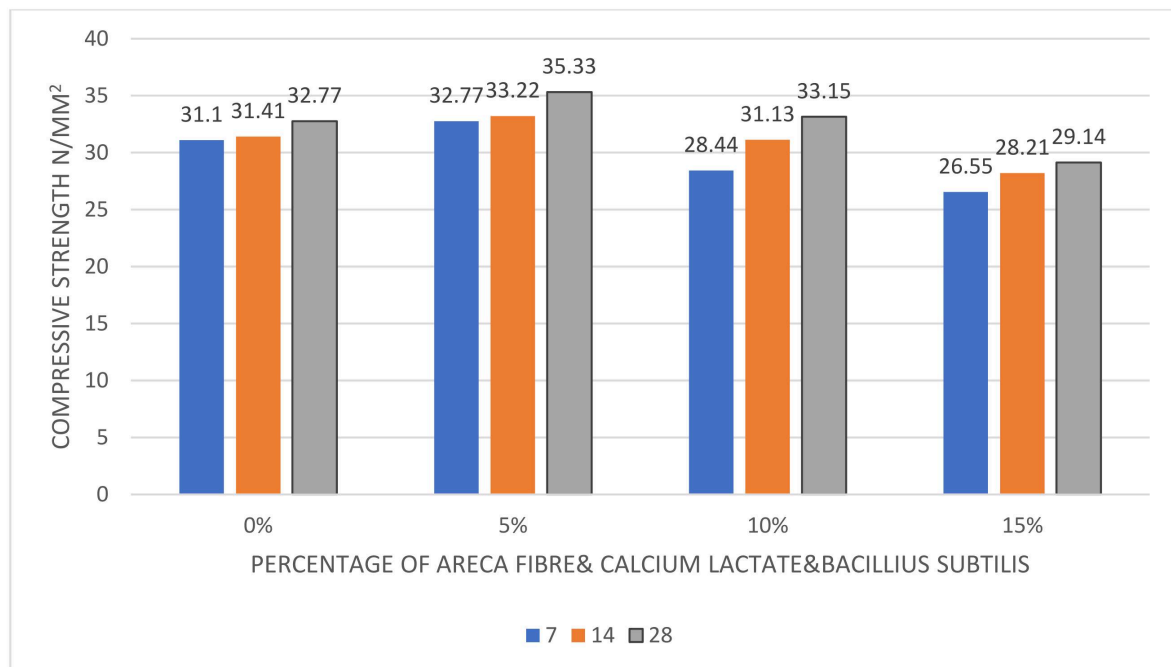


Fig: 5.2: Bar Graph Showing Compressive Test Value

5.2 SPLIT TENSILE STRENGTH

This property of concrete pertains to its tensile strength, which is determined by conducting a split tensile test on cylindrical concrete specimens. Tensile strength in concrete specimens It is defined as the stress resulting from the application of a compressive load to a sample.

Apparatus required: Testing Machine - The testing machine should be of reliable type, capable of testing well and handling the load at the specified rate. The permissible error must not exceed $\pm 2\%$ of the maximum load. Cylinder - Cylinder mold shall be 150 mm in diameter and 300 mm in height as per IS: 10086-1982

Other equipment needed includes weights and a weighing device, tools and containers for mixing, and a tamper with a square cross-section.



Fig: 5.3: Tensile Strength Test

Table 5.3: Tensile Strength of Cylinders

S.No	Specimen Composition	Compressive Strength At 7 Days (N/mm ²)	Compressive Strength At 14 Days (N/mm ²)	Compressive Strength At 28 Days (N/mm ²)
1.	CLC0	3.18	3.25	3.54
2.	CLC1	3.53	3.58	3.61
3.	CLC2	2.54	2.58	2.62
4.	CLC3	2.40	2.47	2.51

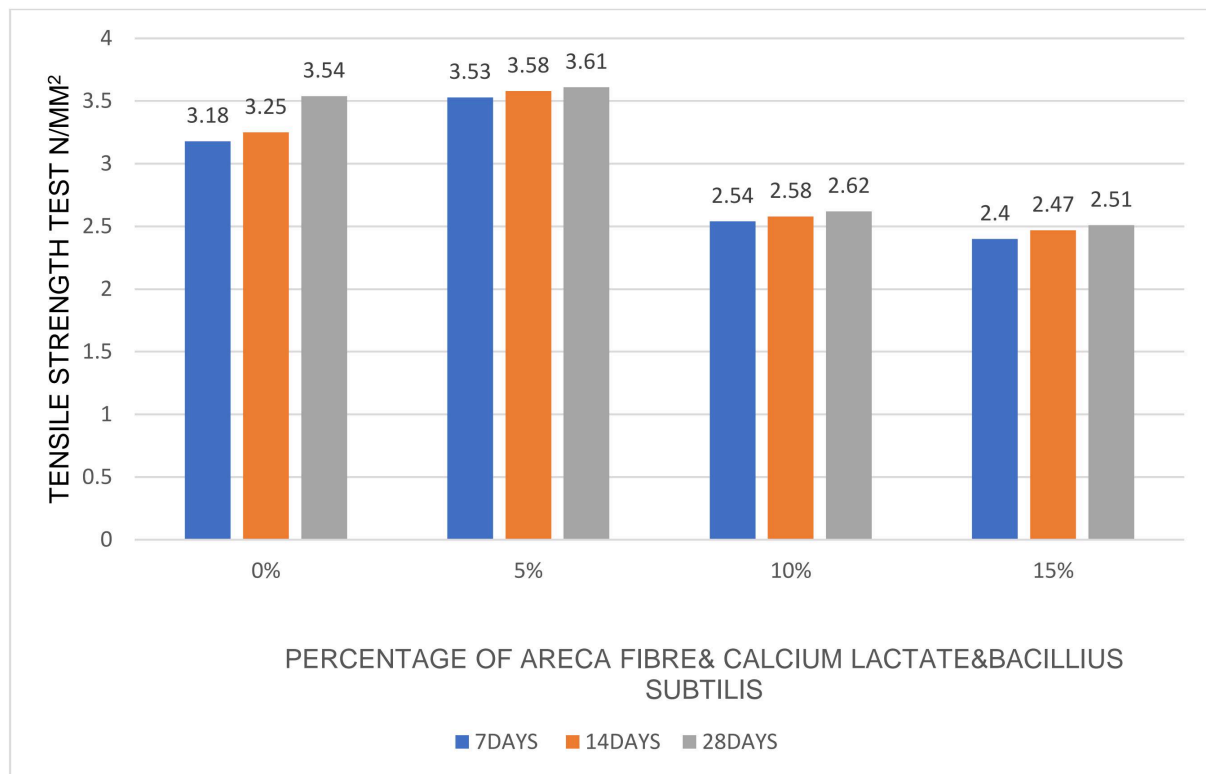


Fig: 5.4: Bar Chat Showing Tensile Strength Value

5.3 XRD ANALYSIS

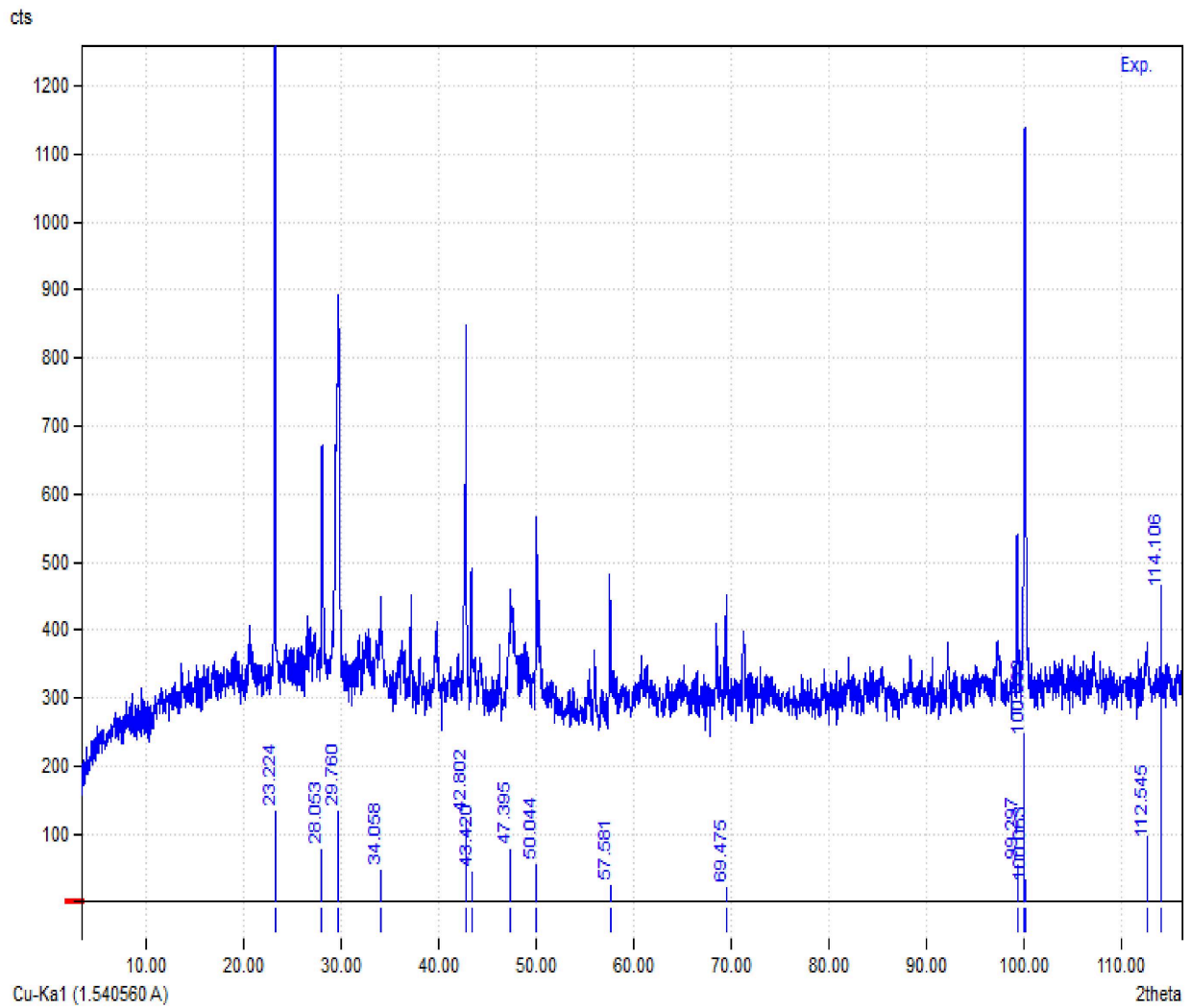


FIG 5.5 X – Beam Diffraction (XRD) Analysis of Crushed Concrete Powder

5.4 SEM ANALYSIS

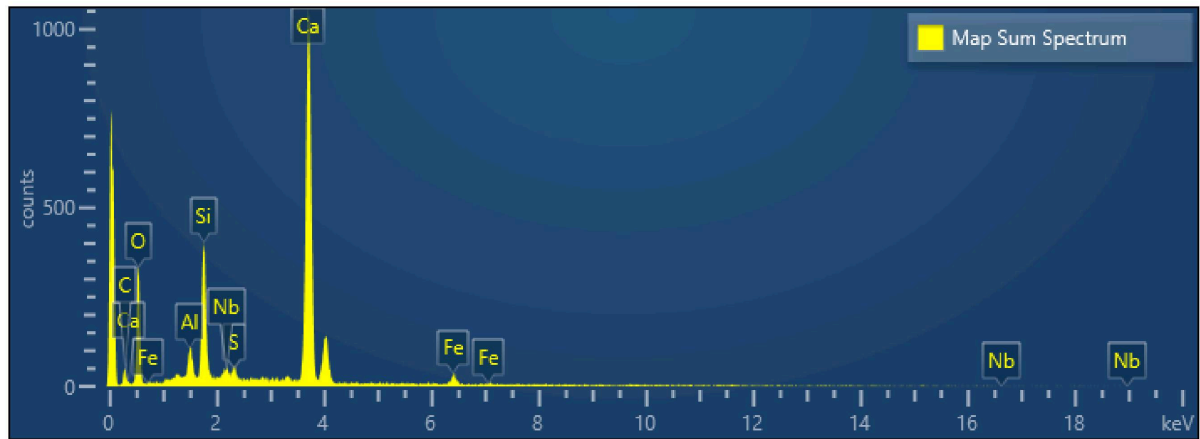


FIG 5.6 Intensity Map

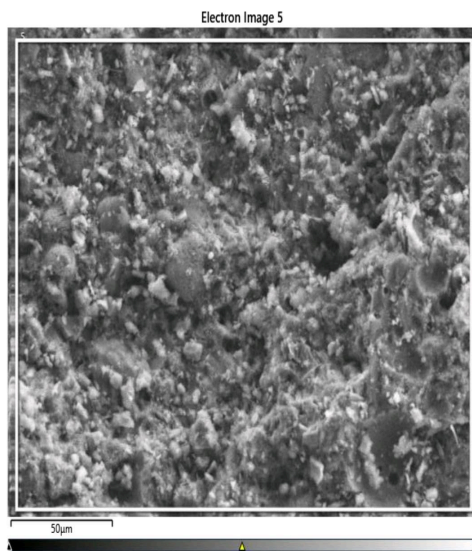


FIG 5.7 electron image

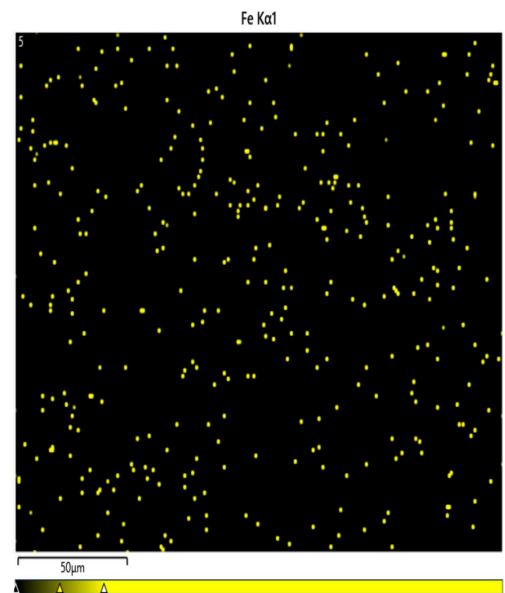


FIG 5.8 Presence of ferrous

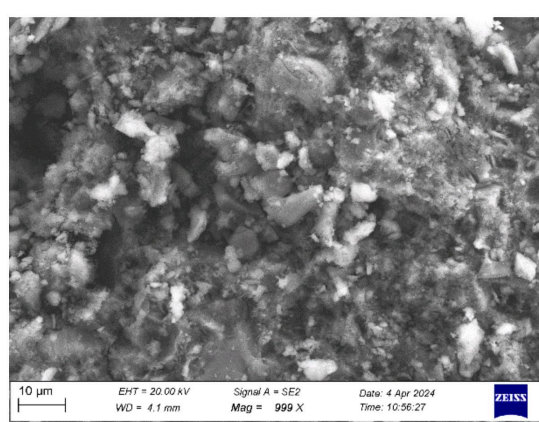
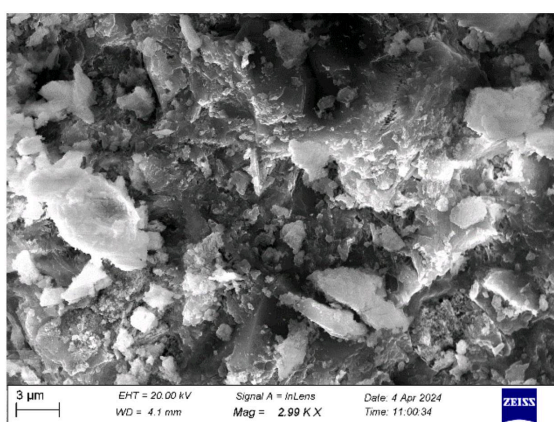
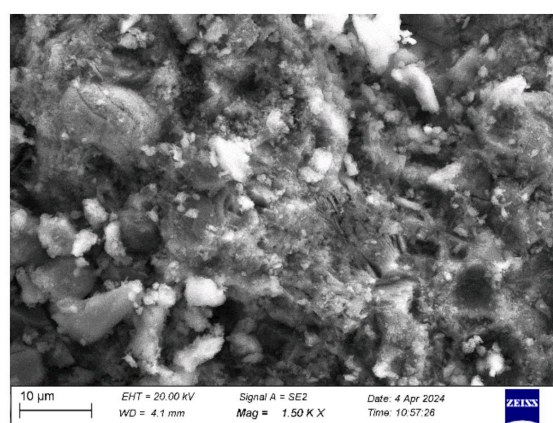
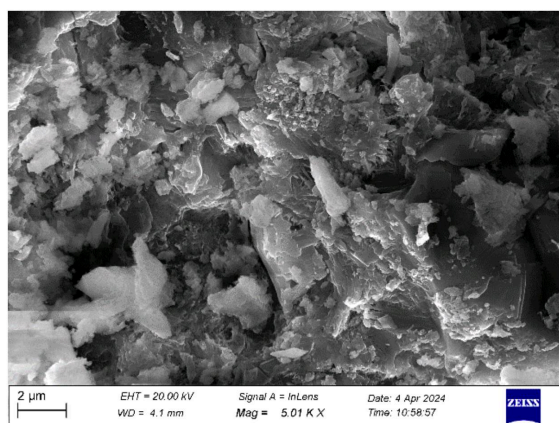
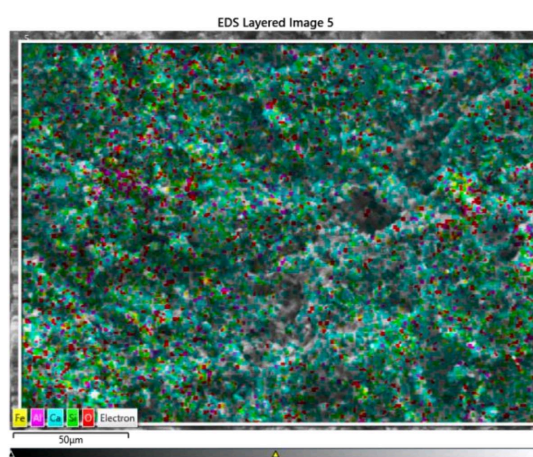
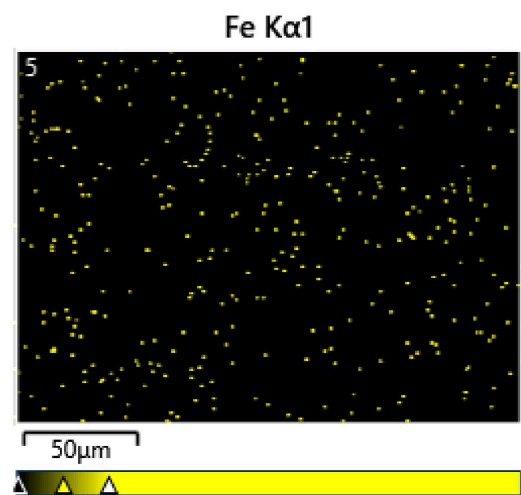
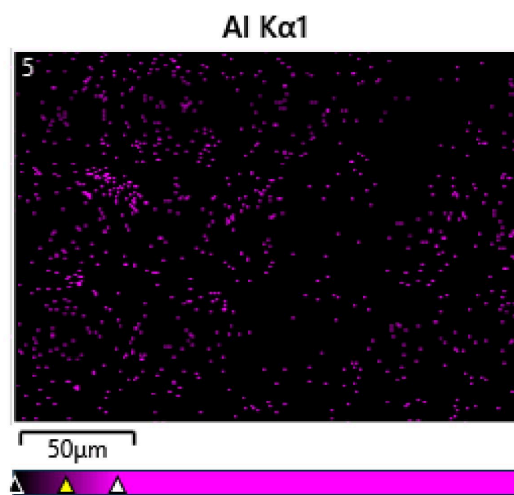


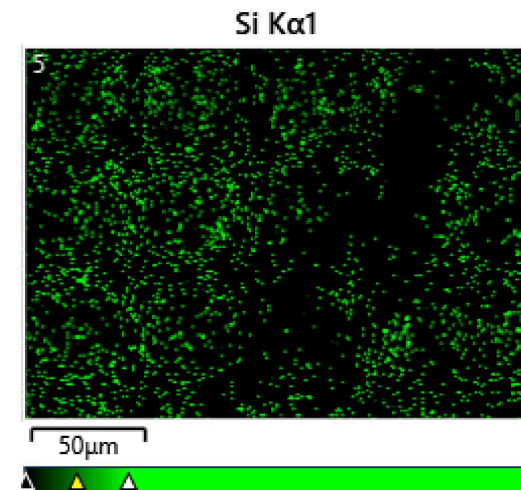
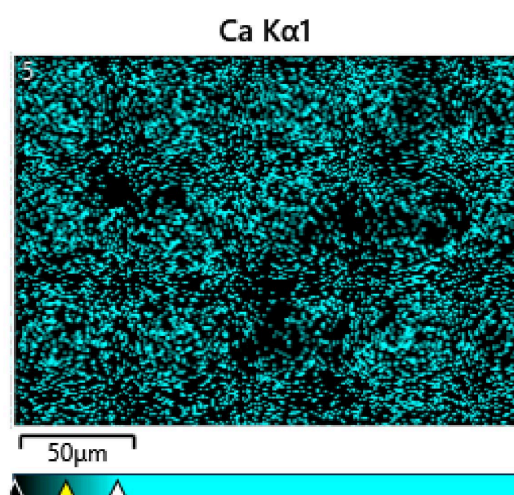
FIG 5.9 electron image



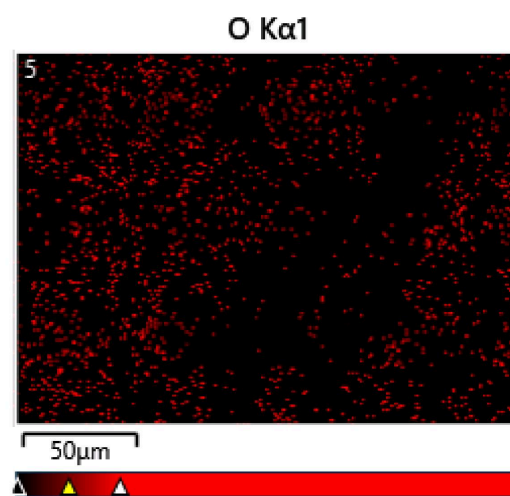
5.10 energy dispersive spectroscopy



5.11 Presence of aluminium & ferrous



5.12 Presence of calcium & silicon



5.13 Presence of oxygen

CHAPTER – 6

SUMMARY AND CONCLUSIONS

SUMMARY

The study "Exploring the Characteristics of Self-Healing Concrete for Sustainable Growth" delves into the advancement of self-healing concrete, which possesses the capability and prolong the durability of structures. Apart from enhancing longevity, this concrete variant offers sustainability advantages like decreased maintenance expenses, lower carbon footprints, and reduced repair costs. The research underscores the considerable potential of self-healing concrete in fostering sustainable development within the construction sector.

CONCLUSIONS

This research uses *Bacillus subtilis* as bacteria to create self-healing stones. The experimental study focused on grade M30 concrete in which 2% of the areca fiber in the cement was replaced. In addition, 0.5% calcium lactate and 5%, 10% and 15% antibiotics were added to the culture. The results obtained are as follows. Adding 5% *Bacillus subtilis*, 0.5% calcium lactate and 2% areca nut fiber can increase the compressive strength of concrete.

- The compressive strength of the concrete with 10% addition of *Bacillus subtilis* and 0.5%, 2% areca fibre is decreased in the compressive strength of the concrete.
- The increment in the compressive strength of 28 days of concrete.
- During the self-healing process when the cracks in the bio-concrete comes in contact of moisture and air, the bacteria feeds on the calcium lactate, joining the calcium with carbonate to form limestone, and hence fixing the cracks.

REFERENCES

1. Abo-El-Enein, Ali, Fatma Talkhan, Abdel-Gawwad, "Application of microbial biocementation to improve the physico-mechanica properties of cement mortar", Housing and Building National Research Center, 2013.
2. Abubakar Magaji, Mathias Yakubu and Yakubu Mamman Wakawa, "A Review Paper on Self-Healing Concrete", The International Journal of Engineering and Science (IJES), 2019, Volume-8, Issue -5, PP: 47-54.
3. Amirreza Talaiekhazan, Ali Keyvanfar, Ramin Andalib and Rosli Mohamad Zin, "A Review of Self-healing Concrete Research Development", Journal of Environmental Treatment Techniques, 2014, Volume -2, Issue- 1, PP: 1-20.
4. Arnold, D, "Ingenia - Self-Healing Concrete", Ingenia.Ogr.Uk Physical chemistry of self-organization and self-healing in metals, Phys. Chem. Chem, 2016, 11 :9530–9536.
5. Bang S. S., Galinat J. K., Ramakrishnan V, "Calcite precipitation induced by poly urethane immobilized *Bacillus pasteurii*, Enzyme and Microbial Technology" 2001, 28: 404–409.
6. Dick J.W. Windt, Graef B., Saveyn H. Meeren.P, De Belie N., W. Verstraete, "Biodeposition of a calcium carbonate layer on degraded limestone by *Bacillus* species", Biodegradation , 2006, 17 (4), PP:357–367.
7. Homma D., Mihashi H., Nishiwaki T, "Selfhealing capability of fibre reinforced cementitious composites", J Adv Conc Technol, 2009 , 7, PP:217–28.
8. IS 456:2000 - Code of practice for plain and reinforced concrete.
9. IS 10262 Part :2019 - Code of practice for concrete structures for storage of liquids
10. Jonkers H.M., Thijssen. A. Copuroglu O., Schlangen E, "Application of bacteria as self-healing agent for the development of sustainable concrete", Proceedings

of the 1st International Conference on Bio Geo Civil Engineering, Delft, The Netherlands, 2008, PP: 23–25.

11. Jonkers, H., “Bacteria-based self-healing concrete”, HERON, 2011, 56 (1), PP: 1-12.
12. Kusuma K., Amit Kumar Rai, Prashant Kumar, Harini K. and Harshita M.N, “SELF-HEALING COCRETE”, International Research Journal of Engineering and Technology, 2018, Volume- 05, Issue- 05.
13. Li, & E. Yang, “Self-healing materials –An alternative approach to 20 centuries of materials science”, Springer, the Netherlands, 2007, PP: 161–194.
14. Mihashi H., Kaneko Y., Nishiwaki T., Otsuka K, “Fundamental study on development of intelligent concrete characterized by self-healing capability”, 2000.
15. Neville A, “Autogenous Healing Concrete Miracle. Concrete International”, 2002, 24(11), PP: 76-82.
16. Rivadeneyra M. A., Ramos-Cormenzana A., Delgado G. Delgado R, “Process of carbonate precipitation by *Deleyahalophila*”, Current Microbiology, 1996, 32, PP: 308-313.
17. Salmabanu Luhar and Suthar Gourav, “A Review Paper on Self-Healing Concrete”, Journal of Civil Engineering Research, 2015, 5(3), PP: 53-58 .
18. Van der Zwaag S, “Self-Healing Materials—an Alternative Approach to 20 Centuries of Materials Science”, Springer, Dordrecht, The Netherlands, 2007.
19. Wiktor, V. and Jonkers, H.M, “Quantification of crack-healing in novel bacteria based self healing concrete”, Cement and Concrete Composites, 2011, 33, PP: 763- 770.



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