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A LITERATURE BASED STUDY ON BACTERIAL CONCRETE AND IT'S APPLICATIONS IN THE MODERN DAY.

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Abstract : Concrete is a composite material, which is mainly mixture of cement, sand, stone chips (coarse aggregate) and water. Though concrete is a brittle material, cracks are common facts in concrete. The factors affecting the development of cracks in concrete, are, Water-Cement Ratio, Tension in concrete, Freeze-Thaw Action, Shrinkage etc. Bacterial concrete is an, eco-friendly, innovative type of concrete that incorporates bacteria to enhance its durability and self-healing capabilities and fill up the cracks thus maintaining the structural integrity of concrete structure.
This paper mainly includes a study on Bacterial Concrete based on various research works going across the world and its application in modern days.

***Index Terms* – Self Healing Concrete, Eco-friendly, Crack, Void.**

I. INTRODUCTION

Concrete is a construction material composed of cement (commonly Portland cement) as well as other cementitious materials such as fly ash and slag cement, aggregate (generally a coarse aggregate such as gravel limestone or granite, plus a fine aggregate such as sand), water, and chemical admixtures. Cracks are a common phenomenon which are found in concrete for various reasons like Water-Cement Ratio, Tension in concrete, Freeze-Thaw Action, Shrinkage etc. These cracks are harmful for concrete structure as it reduces the strength of concrete and increases the water seepage in concrete. For repair of such concrete cracks, there are various types of methods like Epoxy Injection, Grouting and Sealing, Grouting, Stitching, Drilling and Plugging, etc. These methods are cost effective and need skilled labours. These methods also have environmental issues.

Bacterial Concrete is a new technique of modern era used for repairing crack. In this method, selected types of bacteria genus, called Bacillus are used as a crack filling agent. Apart from Bacillus, a calcium-based nutrient (calcium lactate), nitrogen, and phosphorus are added to the concrete and are encased in clay pellets in the ratio 1:19 of bacteria to calcium source [6]. These range in size from 0.1 mm to 0.5 mm. Bacillus is a spore-forming, meaning it forms specialized, thick cell walls that protect it. This allows the bacteria to lie dormant within the concrete for up to 200 years [6, 7]. Although most organisms cannot survive in conditions where pH ≤ 10, the bacteria are alkaliphilic, allowing them to survive in the very alkaline (~pH 13) conditions of the concrete [8]. Once a crack forms in the concrete, the clay pellets around the crack are broken, allowing the bacteria to metabolize the nutrient and perform their regular metabolic functions. When water enters through the cracks of concrete, the bacteria becomes active, and they took the nutrients which are soluble, and produce Calcium Carbonate, which is insoluble in water. This Calcium Carbonate gets stored, solidifies and fills the concrete cracks. This method is environment friendly as well as cheap also. These bacteria can remain active up to 200 years. Bacterial Concrete are also commonly known as "Self-Healing Concrete" as the cracks in concrete gets heal autogenously or autonomously due to presence of bacteria thus Bacterial concrete has the ability to fill cracks which develop in its structure without human intervention.

II. LITERATURE REVIEW:

Bacterial Concrete is one of the newest types of concrete whose research works are going across the world currently. The application of these type of concrete is increasing day by day because of its application and eco-friendly approach. Some of the studies are discussed below:

Sudip Chandra et. al. (2023) in his research paper gave a detail information about the type of bacteria used in bacterial concrete and its methodologies. Author mentioned that the micro bacteria fills the cracks in the concrete (up to 0.5mm) by producing calcium carbonate (CaCo3). These bacteria also improve the compressive strength as well as the overall strength on concrete after 28 days.

K. Mounika et. al. (2018) conducted an experiment to investigate the properties of bacterial concrete for constructional purposes. The compressive strength was found to be increase with bacterial addition and this increase is mainly due to deposition of microbial induced calcium carbonate precipitation on the microorganism cell surfaces and within the pores of the mortar. The percentage increase in compressive strength of 45ml and 60ml bacterial concrete using B. Subtilis for 7 days is higher than conventional concrete.

Deepak Pandurangan et. al. (2021) in his research paper gave a detail information about a significant improvement in the consistency of bacterial concrete as compared to traditional concrete, and that calcium carbonate precipitation is visible after 3-4 weeks in small scale splits. Author concluded that the concrete self-healing technology is one of the possible solutions for eliminating carbon dioxide emissions from cement production while also avoiding unnecessary concrete structure repair and maintenance.

Yasmeena Javeed et. al. (2024) in her research paper gave a detail information about how to fix the issues by self-healing techniques have been developed, including biomineralization-based-self healing, where bacteria are employed to initiate microbially induced calcium precipitate (MICP), promoting the healing of cracks. Author concluded a concise classification that outlines potential strategies, for developing the self-healing concrete. Author also encapsulated that the bacteria can enhance crack repair capability up to 1mm, offering a realistic, long-term self-healing solution.

S. S. Lucas et. al. (2018) did an experiment by immobilizing the bacteria in expanded clay and added to concrete by aggregate replacement. In this study, it was confirmed that the replacement of aggregates with expanded clay impregnated with bacteria could effectively contribute to strength recovery in concrete. Author concluded that it will not be enough to repair major cracks formed internally over a long period of use, so strategies need to be developed to achieve an efficient level of self-healing. This need lead to a new concept – self-healing. The biological approach is a suitable alternative to achieve healing in concrete. In this work, bacteria were immobilized in expanded clay and added to concrete by aggregate replacement.

Er. Sumit Sharma et.al (2021) in his research paper gave a details information about how bacterial concrete work by using of bacteria moisture, minerals, admixtures, bacteria, fiber. Author also discussed about how bacterial concrete can reduce building repair cost and increase the service life of building. Author concluded that bacteria can easily heal crack up to 1mm size.

Abhishek Thakur et. al. (2016) in his research paper gave a detail information about the concrete structures have various durability issues due to the different physiological conditions and it results to irretrievable damage the durability and mechanical aspects of concrete is the pore structure of concrete. In the recent years MICCP by the bacteria considered as an environment friendly method. The cost of the bacterial concrete, according to the opinions of other researchers can increase up to 30% than the conventional concrete, depending upon the type and concentration of bacteria. But the maintenance cost can be reduced by the use of bacterial concrete. This method is easy and convenient in the whole process of cementation.

Palanisamy M et. al. (2017) in his research paper gave a detail information about the performance of concrete, the calcite precipitating spore forming bacteria is introduced into concrete. When water enters through the cracks, it reacts with bacteria and forms precipitates of calcium carbonate, as a by-product, which fills the cracks and makes crack free concrete. This type of concrete prepared with bacteria is called as bacterial concrete. Thus, this paper is an attempt to define bacterial concrete, types and classification of microorganisms, working of bio concrete as a repair material, advantages and disadvantages of bacterial concrete. Bacterial concrete prepared with admixtures like silica fume, fly ash etc, also gives better strength and durability. Due to the introduction of bacteria into concrete there has been increase in the compressive and flexural strength with decrease in permeability, water absorption and corrosion of reinforcement when compared to conventional concrete. Thus, bacterial concrete can play a major role in modern construction, which requires precise technologies for producing high quality structures that will be cost effective and environmentally safe.

Gaikwad N et. al. (2021) in his research paper gave a detail information of Bacterial Concrete in which bacteria producing calcium carbonate crystals blocks cracks and pores in concrete. Author has suggested bacterial induced calcium carbon precipitate as an alternative and eco-friendly crack repair technique. Various types of bacillus bacteria can be used to produce self-healing concrete. Since water and cement mixture have a high pH, so a bacterium which can adapt such high alkaline environment should be added. When cracks occur, and water percolates these bacteria starts microbial activity which produces insoluble CaCo3 and heals crack. Addition of bacteria into a concrete makes it beneficial. From the study, author concluded that bacterial concrete increases approximately at least 10% of compressive strength and reduces water permeability up to 0.45%.

III. Healing Capacity:

[13] The healing capacity of conventional (normal) concrete is very limited and comparatively insignificant. Normal concrete structures are designed to allow cracks up to 0.2 mm wide to form, since these cracks will not compromise the strength of the construction. Bacterial concrete undergoes a much more efficient healing process than conventional concrete. The bacteria encased in the clay pellets only require exposure to air to activate them, which happens when the concrete around the pellet cracks, causing the pellet to break [7]. This allows the calcium lactate (the precursor material) to react with the bacteria, which then reacts to produce a highly impermeable calcite layer (Eqn. 1).

$$Ca(C_3H_5O_2)_2 + 7O_2 \rightarrow CaCO_3 + 5CO_2 + 5H_2O$$

$CaCO_3$ is produced from the metabolic reactions of the bacteria and the reaction between the non-hydrated cement particles and CO_2 from the bacteria's metabolic reaction. In terms of molar quantity, reactions of the bacteria themselves produce one mole of $CaCO_3$. Once the five moles of CO_2 from these metabolic reactions react with the portlandite, five additional moles of $CaCO_3$ are produced, resulting in a net total of six moles of $CaCO_3$ [7]. This makes the crack filling process extremely efficient. The healing process of bacterial concrete is much more effective than the autogenous healing that regular concrete undergoes [7]. This ability to self-heal means running costs are lower, which compensates for the higher initial price. This implies that for many applications with a high repair frequency and cost, bacterial concrete presents itself as a viable investment. Over time, as the technology evolves, the initial cost penalty would be expected to decline and the repair efficacy increase, improving the economic equation further.

IV. FAVOURABLE ENVIRONMENTAL CONDITIONS FOR BACTERIAL ACTIVITY IN CONCRETE:

For effective bacterial activity in concrete, certain environmental conditions must be met. The bacteria used are typically alkaliphilic and thrive in a high pH environment (around 8 to 11), which matches the alkaline nature of concrete. Moisture is essential, as it activates dormant bacterial spores and supports metabolic processes. Temperature also plays a key role, with optimal bacterial activity occurring between 25°C to 40°C. Additionally, the presence of nutrients like calcium lactate or urea is necessary to enable bacteria to produce calcium carbonate ($CaCO_3$), which fills and seals cracks. These conditions collectively ensure efficient self-healing and durability of bacterial concrete. Details are tabulated below:

Parameter	Ideal Range	Importance
pH	8.0–11.0	Bacteria must survive in alkaline concrete (normal pH ~12-13)
Temperature	25–40°C	Warmer temperatures speed up bacterial metabolism and $CaCO_3$ production
Moisture	Medium to High	Required to activate bacterial spores and transport nutrients
Nutrient Source	Urea, calcium lactate, yeast extract	Needed for bacterial metabolism and $CaCO_3$ formation
Oxygen Supply	Aerobic or anaerobic depending on species	Some bacteria require oxygen; others can work anaerobically in buried structures

Table:1 Favorable condition for Bacteria

V. COMMON TYPE OF BACTERIA USED IN CONCRETE

Bacterial concrete relies on calcite-precipitating bacteria that can survive within the highly alkaline environment of concrete and heal cracks by producing calcium carbonate ($CaCO_3$). These bacteria are typically alkaliphilic (thriving in high pH environments) and are capable of microbially induced calcium carbonate precipitation (MICP).

- Bacillus Subtilis.
- Bacillus Sphaericus.
- Sporosarcina pasteurii
- Bacillus Megaterium.
- Bacillus Pseudofirmus.

VI. CONCLUSION

Self-healing concrete can be a great concrete sealant. It improves durability of concrete, life of the structure. It reduces need of regular maintenance and inspection. It produces calcium carbonate which blocks and seals the crack which reduces water permeability. It increases compressive strength tensile strength and decreases water absorption and acid attacks. Through this paper we conclude that, the bacteria present in self-healing concrete (Bacterial Concrete), can seal the micro cracks (up to 0.5mm), by producing Calcium Carbonate and through this process it improves the strength of concrete also. Micro Bacteria fill the concrete voids by producing Calcium Carbonate (CaCo3), which decreases the water permeability and seepage in concrete and for this compressive strength also improves. Not only compressive strength, it improves overall strength of concrete in 28 days. Maintenance cost of the concrete will be less compared to the conventional concrete, but the manufacturing cost of the concrete is high. As per future perspective, we need to focus on more research and more study on this topic, so that we can develop a proper code or a proper guideline on the Bacterial Concrete. Also, we have to think about large scale production of the bacterial spore, that can help us in large production of this concrete which will eventually also reduce some cost of the concrete. After resolving these kinds of problems, the bacterial concrete will play a major role in future construction which will create a new direction in concrete technology, future construction and sustainable development as the use of self-healing concrete improves structural performance, reduces environmental impact, and cuts long-term costs. Moreover, it is valuable in infrastructure and water-related projects where durability and reliability are essential. As this technology becomes more affordable and standardized, its use will continue to expand across both public and private sectors in construction.

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