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Literature Review on Self-Healing Concrete by Using Bacteria

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Abstract: The purpose of this literature paper is to determine the use of bacteria is one of the most rising as well as bright approaches. The primary component of a concrete construction is cement. In concrete structure crack development is a typical phenomenon, it reduces durability & strength. Also analyse the impact of oxygen and water on the crack portion. In this study use of bacteria because the bacteria are having repair ability. This paper focuses on the mechanical properties of Bacillus family self-healing concrete. The mix proportion of material are taken while performing on bacterial based concrete. In the process of research and development of self-healing concrete, it is observed that there are main component of healing agent is bacteria which can produce or make the Calcite as a by-product of their activity. When these bacteria are incorporated into concrete, they can fill the cracks and voids with calcite, reducing permeability. Also improve concrete's mechanical properties and Enhance durability and resistances to degradation. In this study there are some kind of test and bacteria were used for performance in concrete mixture and to highlight the crack process also to point on the crack width how bacterial as well as bacteria concrete can heal the crack in minimum time period of crack developed on it. Current study used the bacteria in capsules formed to prevent the bacteria in other chemical reaction used capsule they can work on projection membrane of bacteria.
Keywords: Self-healing, Crack closing, Bacteria, Strength, Durability etc.

I. INTRODUCTION

Microbial technology-based self-healing concrete has become a viable option for improving the workability and sustainability of concrete structures throughout the past 20 years. Since the introduction of Portland cement in the early 19th century, concrete has been the most widely used construction material globally. Concrete is a construction material because it is inexpensive and has several desirable features such as workability, great compressive strength, and durability. Concrete's durability is threatened by a variety of chemical, mechanical, and biological phenomena [1]. Crack opening and expansion have a significant impact on the characteristics of concrete. In 2019, the British government pledged to spending 500.000 million pounds between 2020 and 2021 to restore the country's infrastructure, which is primarily composed of concrete [2]. In the Bhaskar work et al. [3]. The amount of cement produced increases with the demand for concrete, and this process emits a large amount of carbon dioxide (CO_2) into the environment. This specific CO_2 emission accounts for approximately 8% of all CO_2 emissions induced by human activities [3]. One method for achieving such capacity recovery is to improve the material's ability to mend its own cracks as they occur. The healing ability of micro-cracks, cracks and discontinuous cracks in the concrete without any external influence is called self-healing [4].
Non-reacted stone and calcium-based nutrients undergo a biological reaction with the aid of bacteria like as bacillus to heal the cracks appeared in the structure. The cracks in the structure can be healed by the bacteria. Formation of Calcium Carbonate ($CaCO_3$) as Calcium ion present in concrete reacts with CO_2 with the exposure of oxygen and water, this results in the formation of Calcium Carbonate layer which further heal the cracks [5][Assessing the potential application]. To extend the useful life of structures and reduce the high maintenance costs [6]. Adonay et al. [7] state that 20% of these repairs exhibit flaws after five years, and the majority are only functional for ten to fifteen years [7]. Microcapsules [8], Vascular technologies, Bacteria used in the cementitious composites should be able to survive in a high alkali environment [9] [Wei Zhang et al 2020]. The bacterial germs have likewise been enclosed in this consideration. Making use of porous materials (like expanded clays) [10]. Consider factors like as load-bearing capacity, surface crack pattern, crack propagation between layers, and healing effectiveness. The beams' maximum crack width surpassed 0.3 mm. According to a recent study, bacteria-based self-healing concrete has an 85% higher environmental effect per cubic meter than ordinary concrete because bacteria require nutrients and calcium precursors [11]. [Shan He, Masi Nuri et al., 2024]. To explore a variety of papers, they describe the bacterial concrete mixture was prepared by replacing 20% of the coarse aggregate by volume with bacteria-encapsulated.

The main cause of structural failure is the creation of microcracks in concrete as its ability to withstand rivet stresses declines [12].Alkali-resistant bacteria spores packed in porous solid or gel microcapsules were directly injected into concrete to mend fissures [13]. The study indicated that the fracture openings were < 300 µm, and the healing duration was 42 days. Concrete has an innate healing potential, known as autogenous healing [14] [M. Roig-Flores, S. Moscato et al., 2015]. According to the materials used for the concrete's self-healing, self-healing in this context is divided into two categories: autonomous or independent healing [15, 16]. In concrete, autonomous self-healing outperforms autogenous self-healing due to its greater healing capabilities. Specifically, autonomous self-healing can repair fissures that are more than twice the breadth of those fixed by autogenous self-healing [17].

After studying so many papers it concluded, that how well bacterial concrete can repair itself and withstand pressure also, many research work aimed to analyze the self-healing capabilities and compressive strength of bacterial concrete. It also compares different ways of adding bacteria to concrete to see which method works best [18][Sachindra Pratap et al., 2023]. Such result show that the different cracking methods, were as the manual crack injection, grouting, and sealing. The primary process of bacterial self-healing in concrete is accomplished through calcium carbonate ($CaCO_3$) precipitation, which fills the cracks and promotes their recovery. Moreover, this $CaCO_3$ precipitation has the potential to permeate internal voids within undamaged concrete, thereby enhancing its density and overall strength. However, this might not always hold true due to various influencing factors pertaining to the bacteria and the mixture, which can impact this process and, consequently, the concrete's strength [16] bacterial concentration [19] [Zaerkabeh et al., 2024], bacteria carriers [20][Huynh et al., 2017], concrete mix sign and additives [21] [Mirshahmohammad et al., 2022; Justo-Reinoso et al., 2022]. For the same regard [22]. After 100 days, it was shown that Bacillus alkalinitrilicus type could seal a 0.4 mm crack, whereas autogenous self-healing caused 0.18 mm-wide cracks in the bacterial-free control concrete specimen to repair. [23] [Jianyun el at., 2014]. A crack width of 0.79 mm was fully healed using *B. cohnii*, species [24]. The current literature also contains information on other bacterial species that are utilized. Each bacterium was isolated from the others using the streak plate technique. [25], [26], [27]. Recent research has solved this issue by developing self-healing concrete that can recover its own durability [28]. Overloading, structural ageing, forced deformations, shrinkage from drying, volume changes caused by temperature stresses, differential settlement, freezing and thawing processes, geological variables, climate changes, and human involvement all contribute to crack formation [29]. [Sankara et al., 2024]. Cracks are divided as structural and non-structural cracks [30].[B. A. Mir et al., 2023]. Cracks on structural elements such as beams, columns, and slabs are caused by flexure, shear, torsion, tension, bond, slide, corrosion, and shrinkage. Cracks can occur in vertical, horizontal, or diagonal directions [31].

II. ADOPTED METHODOLOGY

Precipitation of various calcium carbonate by bacteria is considered a general phenomenon if the improper growth of crack in structures [32]. The most studied species for the method is MICP i.e. (microbially induced calcium carbonate precipitation) is Sporosarcina pasteurii also, the Bacteria were used is the Bacillus family fungi, [33]. In experimental studies focused on concrete self-healing, bacteria are often embedded within carriers to maintain their vitality within the concrete matrix. These carriers serve as shelters, shielding the bacteria from the concrete's alkaline environment and moisture fluctuations. Various materials have been tested as encapsulation agents, including [34]: ceremsite, silica [35], hydrogels [36], and expanded clay particles [37]. The use of bacillus bacteria they can increase the strength as well as the age, life of the structure. To address varying types of damage, further research is necessary to explore and identify effective autonomous self-healing strategies [38] [Yasmina et al., 2024].

III. TEST SPECIMENS AND TESTING PROCEDURE

Researchers studied, the phenomenon about the sample and cubes were used, firstly the blocks without bacteria and the second one is the block with bacteria. Taking the cube of (150x150x150mm) add-mixture of cement, sand and aggregate ratio is grade M25. Mix properly and second sample of cube with bacteria added in capsules forms. There are 5-8 blocks are moulded at a time of casting it depends on capacity of work type. After the concrete block were made then the various test are performed on the bocks i.e. Compressive test, Slump test, Split tensile strength test, tensile strength test. Also read different literature paper they explain about the cracking process that is the minimum crack can heal is 0.3µm some cubes were pre cracked and were used to Use water permeability and fracture closure to assess self-healing capacity. The self-healing properties of bacterial concrete were investigated using a controlled cracking and healing protocol. The methodology involved: 1. Preparation of cubic specimens with induced cracks. 2. Monitoring of crack healing progression over time. 3. Evaluation of healing effectiveness and crack width decrease. 4. Quantification of healing efficiency through image analysis and microscopy.

5. Statistical analysis of healing time and crack size. 6. Examination of the impacts of environmental factors, nutrient availability, and bacterial strain [38]. The crack healing process were start in minimum 3 week of crack developed, they take 21-24 days for complete the healing process.

Author	Bacteria	Test	Result/findings
1. Manpreet Bagga. et, al.	Bacillus cohnii, Bacillus subtilis, Bacillus Sphaericus, Bacillus mucilaginous, Sporosarcina ureae.	Microbially induced calcium carbonate precipitation.	Overall, the aim of these models was to give directions for the manufacturing of self-healing materials with embedded capuseles containing the healing agents,but they give little or no consideration cement chemistry or the biological components.
2. Hesam Doostkami. et, al.	Bacillus Subtilis, II) SerpoBiotec Solution	1)Slump Test, 2)Water permeability test, 3)Compessive test	The slump for different mixes containing bacteria liquid solution were 7.5 and 2cm, resp. less their respective reference mixes, which measured 20 & 8cm.
3. Adonnay Pinto. et, al.	Yeast extract 0.75%	1) Flow test, 2)Vicat Apparatus test,	Combonation of XRD techniques, it was possible to determine the chemical composition arising during the hydration process.The add. of Lactate caused notable changes in the reaction of the aluminate.
4. Linzhen Tan. et, al.	Bacillus Cohnii	1)Hydration kinetics, 2)crack Creation, 3)Healing regimes,	Compared with calcium nitrate basd specimenise calcium acetrate based speciemen shown greatest healing performance.
5. Jae-InLee, Se-jin Choi	Cementitious material capsules.	1)Chloride-ion permeability test, 2)Spiliting test, 3)silicon Sheet attachment test, 4)Clamp fastening test, 5)Measurement of water passing through the crack.	The 56-D Compressive recovery rate of the control sample was approximately 110%, an no increase in the recovery rate was observed after 28 days.
6. Krishna kumar Maurya. et, al.	Bacillius cohnii bacteria, Bacillius subtills bacteria	1)EMI technique, 2)CVC sensor preparation	The EMI technique strongly refelected the crack healing by the bacteria over a time. The developed concept can be implemented for the damage and crack healing performance assessment of real-life concrete infrastructure.
7. Muhammad Basit Ehsan Khan. et, al.	Sporosarcina pasteurii, bacillius Subtills	X-ray diffraction (XRD) analysis and scanning electron microscopy (SEM). XL Scanning Electron Microscope.	In this study the specimens are taken is to be specimens containing only nutrients (NU), and bacteria-based mortar specimens with Group 2 EPAs, i.e. specimens containing both bacterial spores and nutrients (BA).

IV. RESEARCH GAP

Concrete is a fundamental construction material, is prone to cracking and degradation, leading to structural damage and costly repairs. Conventional repair techniques are frequently labor-intensive and impermanent. Recently, self-healing concrete using bacteria has emerged solution.

1) Optimal bacterial strain selection for self-healing efficiency.
2) Understanding the role of bacteria in improving concrete's tensile strength.
3) Effects of self-healing on concrete's stiffness and ductility.
4) Effects of bacterial activity on concrete's microstructure and durability.
5) Development of predictive models for self-healing concrete's mechanical behaviour.
6) Optimization of Bacterial Strains: Limited understanding of the most effective bacterial strains and their optimal concentrations.
7) Mechanical Properties: Insufficient data on self-healing concrete's mechanical properties, such as tensile strength and durability.
8) Environmental Factors: Lack of understanding of how environmental conditions like, humidity, pH. Impact self-healing efficiency.
9) Standardization and Regulation: Absence of standardized testing protocols and regulatory frameworks.

V. CONCLUSION

The concept we've developed can be used to evaluate how well real-life concrete structures can heal cracks and damages. This is important for making sure these structures last longer and stay safeAutogenous healing is the term for concrete's inherent capacity to mend itself. However, this process has limitations: - It only works for small cracks. It's affected by the surrounding environment (temperature, humidity, etc.) Benefits of self-healing concrete is Improved durability, Increased lifespan, Reduced maintenance costs, Enhanced sustainability. Water helps concrete heal faster But, sealing cracks completely is still the best way to prevent water leaks. Compared to other conditions, water immersion showed higher healing rates. Self-healing concrete using bacteria has the potential to revolutionize the construction industry, providing a sustainable and resilient solution for infrastructure development.

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