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A review paper on performance evaluation of bacteria induced concrete for rigid pavements

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Abstract

Concrete is a foundational material renowned for its performance across a spectrum of applications in construction and infrastructure. it is indispensable in meeting the diverse demands of modern engineering and architecture, from towering skyscrapers to intricate bridges, from residential homes to transportation networks, concrete's performance capabilities have shaped the built environment in profound ways. But conventional concrete is susceptibility to cracking, especially under tensile stresses. This can compromise the structural integrity of concrete elements and lead to durability issues and reduced service life. Rigid pavements are vulnerable to cracking due to temperature changes, shrinkage, and severe loads. Cracks have the potential to undermine the pavement's structural integrity, hastening deterioration and raising maintenance requirements. Review paper describes the method that is used in showing the performance Evaluation of concrete Through the process of carbonate ion formation, a microorganism secretes calcium precipitate externally, forming $CaCo_3$. This fills in the holes in the concrete texture, increasing its compactness. Conversely because of the expansion of the filler fabric inside the concrete mixer's pores, this improves the strength of the concrete. In the laboratory tests has been carried out to study the impact of introducing bacteria on concrete. here compressive strength, flexure strength, split tensile strength and durability test on Bacteria induced Concrete is studied and SEM and XRD analysis is also carried about to the study the microstructure of Bacteria induced concrete.

Keywords: Bacterial Concrete; *Bacillus subtilis*; JC-3; Performance Evaluation

1. Introduction

Concrete is the most commonly used construction material in the world due to its high compressive strength, ease of shaping, significant durability, and comparatively low cost. Concrete's brittle nature makes it vulnerable to the development and coalescence of microcracks, which reduces strength. This is one of the concrete's negative characteristics. Due to its cracking susceptibility, concrete can deteriorate when exposed to toxic chemicals and water, which can lead to corrosion of the steel reinforcement caused by chemical attack. This deterioration hampers the concrete structural integrity and durability necessitating intensive maintenance.

Concrete that exhibits self-healing capability allows for the sealing of existing cracks to stop them from spreading further. The use of structural concrete that is more durable and requires less maintenance during construction is highly appealing to the civil engineering community. One practical option for preventing the spread of cracks is bio concrete. The precipitated minerals in the calcite phase of concrete are robust, stable, and most importantly compatible with cementitious ingredients thanks to microbial activity.

In order to increase the durability of concrete, the biomineralization process also known as microbially induced calcium carbonate precipitation has been thoroughly explored. Because bacteria belonging to the genus Bacillus subtilis

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frequently develop spores with specialised cells capable of withstanding strong mechanical forces and hostile environments, these bacteria are typically used as healing agents for fracture repair.

2. Critical review on performance of bacteria induced concrete

Given are some of the most important reviews of the literature on bacteria induced concrete that have been published on national and international magazines. This all critiques enhances the normal and bacterial behaviour of bacteria induced concrete.

The addition of Bacillus subtilis JC-3 to modern concrete can boost its energy and overall durability. It discloses the presence of a metabolic activity known as bio-calcification. This process, in which the presence of a carbonate ion generates CaCo3, fills up the spaces in the concrete texture and increases its compactness, is how the microorganism externally secretes calcium precipitate. As a result of the filler fabric expanding inside the concrete mixer's pores, this in turn strengthens the concrete. A comparative analysis was conducted between concrete cubes and beams that underwent tests for compressive, tensile, and flexural strength, both with and without the bacteria. When tested using 14-day-old bacterial concrete at the 7, 14, and 28-day marks, the compressive strength was 16.09%, 17.5%, and 19.51% higher than that of conventional concrete. When tested using 14-day-old bacterial concrete at the 7, 14, and 28-day marks, the split tensile strength was 14%, 16.5%, and 17.8% higher than that of conventional concrete. Additionally, the flexural strength of 14-day-old concrete at days 7, 14, and 28 rose to 9.95%, 12.3%, and 14.24% higher than that of standard concrete. The outcomes of the experiment demonstrate that the bacterial precipitation procedure has improved the concrete's overall strength and durability. [1]

To develop a new technique that precipitates calcium carbonate under microbial influence in order to produce self-healing concrete based on bacteria. A collection of bacteria that generate spores and are associated with the genus Bacillus subtilis JC-3 were chosen to be cultivated in an enhanced pH solution. A 3-point bending test was performed to create cracks on the bottom of the beam that were 0.3 mm wide. The bacteria's metabolic activity caused the microcracks to spontaneously mend after 28 days of cure using calcium carbonate precipitation fills. In addition, the sealed beam that underwent repeated bending had flexural strength that was almost 14% higher than its residual flexural strength. Remedial of the matrix cracks and fiber-matrix interface bond repair allowed the beam flexural strength to recover. [2]

The effect of bacteria on the characteristics of concrete prepared using rice husk ash (RHA). Control concrete was created with a 28-d strength of 32.8 MPa specifically for this purpose. RHA was used to partially replace cement in the control concrete at weights of 0%, 5%, 10%, 15%, and 20%. Then, when creating concrete, Bacillus aerius (105 cells/mL) was added to water. According to the findings, adding bacteria to RHA-concrete increased its compressive strength across all age ranges. However, the best results were obtained with 10% RHA, as the 28-d compressive strength was 36.1 MPa and 40.0 MPa when bacteria were present. At all ages, the addition of bacteria to RHA concrete decreased its water absorption, porosity, and permeability because of calcite precipitation, which enhances these characteristics. The concrete became denser when ettringite, calcium silicate hydrate (CSH), and calcite formed in the pores, as shown by SEM and XRD studies. According to the investigation's findings, using bacteria and RHA improves concrete's durability. [3]

The durability of concrete is decreased by repetitive stresses on the pavement causing fissures that allow toxic substances to seep in. Therefore, by employing bacteria as a healing agent and recycled brick aggregate (RBA) as an immobiliser for bacterial spores, this research offers an environmentally responsible way to give concrete the potential to mend itself. This investigation used calcium lactate as the calcium supply and Bacillus subtilis JC-3 as the microorganisms. A control mix (mix 1), 30%, 50%, and 70% RBA were present in mixes 2, 3, and 4, respectively, on the specimens. In mixes 2, 3, and 4, the same 106 cells/ml of bacterial spores were maintained. The results indicated that as the percentage of RBA in the mix increased, there was a modest drop in both compressive and flexural strength. Additionally, self-healing tests were performed, and the results demonstrated that samples containing 50% RBA and bacterial spores could heal up to 0.92 mm with a 69% strength recovery when cracked after 7 days and 0.68 mm with a 57% strength recovery when cracked after 28 days. Furthermore, the calcite precipitation was also verified by XRD and SEM examination. [4]

A very recent self-healing technique involves using bacterial material that has been engineered to precipitate calcite in concrete mixtures to repair or fill concrete cracks. The purpose of this study is to review the techniques for this type of precipitation and provide a thorough examination of the calcium carbonate precipitation process, the physical, mechanical, and durability properties, and the microstructure performance of concrete. The current study demonstrates that a number of parameters, including the application process and the maintenance of bacterial cells, are crucial to the process of bio-mineralization. Moreover, it has been found that the amount of urea in concrete mixes directly correlates with the environmental effect of bacterial material. [5]

The effect of the bacteria Bacillus Subtilis JC-3 (B. Subtilis) on the strength characteristics of 100% recycled concrete aggregate (RCA), which replaces cement with silica fume (SF). With two distinct cement contents (400 and 450 kg/m3) in each, two groups of mixes (A for w/c=0.3 and B for w/c=0.35) were prepared. With a constant concentration of bacterial culture (105 cfu/ml), the cement was partially substituted by weight with 5%, 7.5%, and 10% SF. After 7, 28, and 90 days of curing, all specimens were tested. The greatest results were obtained when 7.5% SF was substituted for cement in all of the mixes; mix A/2 was the best. After 90 days, adding B. Subtilis JC-3 bacteria to concrete in mix A/2 enhanced its compressive strength (CS) from 29.62 to 33.64 MPa for 5% SF, from 29.62 to 37.3 MPa for 7.5% SF, and from 29.62 to 34.04 MPa for 10% SF. In a similar vein, the strength of the splitting tensile strength (STS) at 90 days increased for 5%, 7.5%, and 10% of the sample size. It went from 2.73 to 3.24 MPa, 2.73 to 3.35 MPa, and 2.73 to 3.26 MPa. Concrete's increased CS and STS are thought to be caused by calcite precipitation that occurs when B. subtilis bacteria are added; SEM and EDS analysis supported this theory. Consequently, the concrete became denser due to the creation of additional C-S-H products and CaCO3 crystals in voids. Additionally, an economic analysis of every combination has been done. Furthermore, a regression equation was created utilising response surface methodology in order to evaluate the data from this experimental work and forecast the CS and STS with a minimum range of error. [6]

The Bacteria's influence on mechanical properties. A thorough correlation between the impact of bacteria on mechanical properties prior to and following self-healing activation is explored, as concretes possessing robust self-healing characteristics but lacking in mechanical properties would not be appropriate for structural applications. This work presents a standard model for such an index and uses multiple experimental results of bacterial self-healing concrete performance to demonstrate its use. This provides insight into the material's entire performance, including its healing and mechanical properties. [7]

The capacity of a novel bacterial species—B.pseudomycoides strain HASS3—to repair artificially damaged concrete samples was determined, isolated, and evaluated. The two variable-pressure scanning electron Both the fracture profile and the healing ratio's progression were evaluated using a VP-SEM and X-ray computed microtomography (X-ray mCT). A 0.4 mm crack mouth width was completely repaired by microbial precipitation, as demonstrated by the VP-SEM results. Calcite and vaterite were subsequently determined by XRD. In contrast, the maximal healing ratio in the deeper region of the crack was only 14% as compared to the crack mouth, based on the X-ray mCT results. Therefore, it is possible to draw the conclusion that bacteria-based concrete self-healing could serve as a long-term method of repairing cracks in the concrete's outer layer. [8]

The use of Bacillus subtilis JC-3 bacterial cell walls as a concrete admixture to enhance the mechanical properties of concrete. In line with this understanding, adding bacterial cell walls to concrete enhanced the carbonation of Ca(OH)2 and the creation of CaCO3. Additionally, after 28 days of curing, the bacterial cell walls considerably reduced porosity and raised concrete's compressive strengths by 15%. Bacterial cell walls have the potential to be a useful concrete admixture because the CaCO3 they produce can fill up the void, reduce porosity, and boost compressive strength in concrete.[9]

The practical and realistic method for creating enormous, bacterial concrete on a large scale. First, using this procedure, concrete-compatible microorganisms are isolated and identified. After that, the bacteria are simply put to the concrete in solution. In order to identify bacteria that would work well with concrete, two types of cement were used: Portland cement type 2 (PC2) for Hormozgan-Bandar Khamir, and Portland pozzolanic cement (PPC) for Darab city. The findings showed that there was a negligible impact of bacteria on the compressive strength of concrete. The percentages of water absorption in bacterial concrete samples containing PC2 and PPC were 0.07 and 0.19% higher, respectively, than in non-bacterial samples. Cracks could be patched by both kinds of bacteria. Uncontrolled fissures in concrete specimens were restored to a minimum width of 39.82 micrometres. [10]

The preparation procedure and life service requests may harm the internal structure of concrete, resulting in the formation of cracks that spread and grow over time. This increases the chance of failure because water will sweep in and corrode the rebar, shortening the concrete's lifespan. A natural ability to self-heal in cement can exist to some level as a result of the long-term hydration phenomena. Certain first fissures may close on their own if the appropriate humidity levels are reached. But over time, significant internal fissures will not be repaired by it, thus effective self-healing solutions must be created. The idea of self-healing emerged as a result of this need. An appropriate substitute for achieving healing in concrete is the biological approach. In this work, expanded clay was used to immobilise microorganisms, which were then added to concrete through aggregate replacement. [11]

The capacity of a substance to mend internal damage without the need for outside assistance is known as self-healing. When it comes to concrete, the process can be either autonomous or autogenous depending on the optimal mix composition and the use of additional capsules containing bacteria spores and/or a healing agent. Whereas the second method uses a synthetic material or bacteria that are either released into the crack from a broken capsule or activated by access to water and oxygen, the first method uses unhydrated cement particles as the healing material. Based on a careful assessment of both approaches, autogenous self-healing is found to be more effective, economical, safe, and simpler to integrate into large-scale systems. However, a deeper comprehension of the mechanism and variables influencing the process' efficacy is required. The primary drawbacks of the autonomous method were found to be its decreased workability, deteriorated mechanical qualities, low healing probability and efficiency, low bacteria and capsule survivability in the harsh concrete environment, extremely high cost, and absence of a comprehensive evaluation. [12]

The impact of bacterial additions on the properties of a cement paste matrix. The purpose of developing Type 1 and Type 2 bacteria-based additives was to increase the capacity of concrete to self-heal, which is primarily accomplished by mineral precipitations generated by bacteria. Using an X-ray diffraction (XRD) and scanning electron microscopy (SEM), the mineral precipitations in the liquid medium caused by two different kinds of bacteria-based additions were examined. The compressive strength decreased by approximately 14.7%, 6.8%, and 0.1%, respectively, after 3, 7, and 28 days of curing when the Type 1 addition was added to cement paste. But when the Type 2 addition was added to cement paste, the compressive strength decreased by roughly 1.6% and 2.2% after 3 and 7 days of curing, respectively, and increased by 8.1% after 28 days. Three days of rapid carbonation resulted in carbonation depths of 6.6 mm, 7.0 mm, and 6.5 mm for control specimens, specimens with Type 1 and specimens with Type 2 respectively. These findings indicated that, despite a small reduction in compressive strength, the two kinds of bacterially based additives might be utilised to create a self-healing concrete system.[13]

The utilisation of particular bacteria in concrete that can cause calcite precipitation in the concrete matrix makes this one of the most successful autonomous crack healing procedures possible. A state-of-the-art review of microbial concrete as a sustainable building material is provided in this publication. This section covers the exact criteria for choosing the right bacteria, how to apply them, and how the various bacteria affect the mechanical qualities of concrete, such as strength, permeability, and durability. The domains of investigation pertaining to microbial concrete that require examination to advance its suitability for extensive infrastructure development have been recognised.[14]

The use of the JNTU, India-developed bacterium Bacillus subtilis J JC-3 in concrete and provides the findings of experimental research done to examine the enhanced sustainability and durability properties of microbial concrete. When optimal bacterial cell concentration is added to concrete, its compressive strength, split tensile strength, and flexural strength all significantly increase as a result of calcite mineral precipitation obstructing pores during Bacillus subtilis JC3's microbial metabolism. Comparing the bacterial concrete mixes to controlled concrete mixes in low, medium, and high strength grades, the bacterial mixes demonstrated better stress values for the same strain levels, which led to an increase in elastic modulus. Comparing concrete samples treated with bacteria to control concrete, the results showed decreased porosity and water absorption. This indicates that the bacterial concrete takes longer for water to rise through capillary action than the control concrete, proving that the bacterial concrete is less porous. [15]

Introducing a particular amount of bacteria to the concrete such that, upon contact with water, the bacteria will precipitate calcium carbonate. This precipitate then functions as air field concrete to heal the fissures. Extensive workshop investigations have been conducted in this study to examine the impact of adding Bacillus Subtilis bacteria on the mechanical properties of concrete. Adding to this are the concrete's ability to withstand fire, its ability to lose weight and strength, and its ability to retain depth.[16]

Extensive laboratory experiments have been conducted in this work to examine the impact of adding Bacillus Subtilis bacteria JC-3 on the mechanical characteristics of concrete. Additionally, research is done on the fire resistance of concrete that has been produced by bacteria. SEM investigation of the microstructure of concrete is done on all mixtures for research purposes. This study discusses the experimental findings for two types of cement in M40 Grade concrete, specifically in Bacterial Induced Concrete and Plain Concrete. The findings demonstrate that, in comparison to regular concrete, bacterially generated concrete for OPC mix exhibits increases in compressive strength of 18%, flexural strength of 13.84%, and split tensile strength of 11.32%.[17]

Concrete's strength will be weakened and harm will result from an increase in cracks. Freeze-thaw cycles, shrinkage, and low bendable strength are some of the causes of cracking. The updated form of traditional concrete used in building is called bio-concrete (Bacillus Subtilis JC-3), which aids in the deterioration-related mending of microcracks. This paper reports on an experimental study that looked at the effects of bacteria on concrete. The results showed that the percentage of strength and weight loss was lower in the bacterially-influenced concrete when compared to the conventional concrete, and the same was true for water absorption and freezing-thawing of the bacterial concrete and higher in the conventional concrete. [18]

Concrete is renowned for being a very strong and adaptable module building material. It is widely used in the construction of industrial, numerical, cooling tower, chimney, building, and bridge infrastructure. One of the more damaging unintentional loads to which a structure may be exposed during its lifetime is fire. The intensity and duration of the injury will mostly determine its scale. The temperature and length of the fire alter the various properties of the steel reinforcement and the concrete. Visual observation, testing on core samples, and ultrasonic pulse velocity measurements can be the first steps in the assessment of concrete damaged by fire. Water that seeps through fractures reacts with bacteria to produce caco3 precipitates, which eventually cover the fissures entirely and create concrete without cracks. Laboratory experiments have been conducted to investigate the impact of introducing Bacillus Subtilis JC-3 bacteria on concrete. Here, the properties of bacteria-induced concrete that resist fire and lose weight are examined, and FEA analysis is used to examine the microstructure of the concrete. [19]

The impact of introducing E. Coli bacteria on mechanical attributes like durability, tensile, flexural, and compressive strengths have been investigated through thorough laboratory research. In addition to plain concrete specimens that were cast and tested for reference, BIC specimens were cured for 7, 14, 28, and 56 days after testing. Moreover, beams are cast for fatigue testing, and tests for plain concrete and BIC beams with stress ratios of0.6,0.7, and 0.8 were carried out. This report discusses the plain concrete and BICP experimental findings for the M40 grade of concrete. The findings demonstrate that, under the flexural failure load, the strength and fatigue parameters of BICP vary with stress ratios. The findings of this study demonstrate that, in comparison to ordinary concrete, bacterial concrete increases compressive strength by 12.5%, split tensile strength by 6.8%, and flexural strength by 8.5%. [20]

The impacts of solar radiation, wind speed, air temperature, pavement slab albedo, and other factors are taken into account by the heat switch model. at the spread of pavement temperatures. This dissertation examines the differences between published models that aim to predict pavement temperature, outlining the benefits and drawbacks of each. Software known as Finite Element Analysis (FEA) was specifically created for pavement evaluation. Warping pressure costs are compared with those of conventional and bacterial concrete pavements using ANSYS Finite Element Analysis software and manual computation. [21]

The impact of adding Bacillus Subtilis JC-3 bacteria to concrete's mechanical qualities has been investigated through a series of in-depth laboratory tests. Furthermore, standard specimen beams were cast for the fatigue test, and tests were performed on both normal and bacterial concrete for stress ratios of 0.6, 0.7, and 0.8. Next, the outcomes were contrasted. For two types of cement, the experimental findings of plain concrete and bacterially induced concrete pavement are reviewed for M40 grade concrete. According to the data, the bacterially induced concrete for OPC mix has an increase in compressive strength of 18%, flexural strength of 13.84%, and split tensile strength of 11.32% when compared to regular concrete. [22]

The goal of adding Bacillus subtilis JC-3 to concrete in order to boost its energy content and general durability for usage in contemporary construction. This microbe is a type of soil bacteria. Bacillus subtilis exhibits a metabolic activity that includes a phenomenon known as bio-calcification. Through a process known as "bio-calcification," a microbe secretes calcium precipitate into the environment. This precipitate, when combined with carbonate ions, generates CaCO3, which fills in the spaces in the concrete's texture and makes it more compact. As a result, the concrete mixer's pores contain more filler fabric, which boosts the electrical properties of the concrete. It has also been tested how long-lasting concrete beams exposed to alkaline, sulphate, and freeze-thaw conditions are after being treated with bacteria. The influence of various bacterial concentrations on the robustness of concrete was also examined. All of the cubes with bacteria were discovered to have ended higher than the cubes (without microbe). Longevity and general effectiveness increased as knowledge about microorganisms rose. [23]

Temperature difference is becoming increasingly important in crucial parts of pavement design. Variations in standard conditions affect dark top quality. Concerns about operating at a profit margin are influenced by bending, which could contribute to early-age solid breaking. Similar to this, a winding weight condition was established that relied on the finite element method (FEM) for stress assessment. The cross section and entire stage's thermal characteristics have an impact on the thermal characteristics of cement. At various ages, the chosen ternary mixes' mechanical and thermal characteristics, including their heat capacity, thermal conductivity, and coefficient of thermal expansion (CTE), were assessed. One method of creating "Bacterial Concrete" is to introduce bacteria into the solid to continuously support the calcite. The term "Microbiologically Induced Calcite Precipitation" (MICP) is applied to this miracle. By introducing living things inside the solid that can continuously enable calcite, a solid known as "Bacterial Concrete" can be created. "Microbiologically Induced Calcite Precipitation" (MICP) is the aforementioned miracle. [24]

The calcium carbonate precipitation caused by microbiologically induced calcite precipitation (MICP) extends the service life of concrete. Similar to how osteoblast cells in the human body heal bone fractures by mineralizing to reconstruct the bone, calcium carbonate fixes fractured concrete by solidifying on the surface of the crack. There are now two approaches under investigation: surface treatment with bacteria and nutrients, and injection of microorganisms that precipitate calcium carbonate. Using microorganisms that have the ability to cure itself, an attempt is being made to plug the gaps in this study. The possible bacterium known as "bacillus subtilus JC-3 " is grown and isolated. The ideal parameter will be taken into account. The fluctuation in the strength characteristics was investigated, and a bacterial liquid with a concentration of 105 per millilitre of water was coated on the fractured surface of concrete. The production of calcite precipitates on appropriate conditions supplied with a calcium supply is possible through the calcite formation of isolated bacteria. Comparing bacterial concrete to controlled conditions, it is found that the former's compressive strength has increased by 12.83%. [25]

The CKD utilised had a high leachate hardness (467 mg=L) and alkali (1,467 mg=L) content. After 20 days of treatment at 35 ~ 2°C, the powdered CKD treated with Bacillus halodurans strain KG1 showed a decrease in hardness (85.6%), alkalinity (67.3%), 46% K2O, and 27% SO3. In this study, concrete at 28 and 91 days of age is examined for its compressive and splitting tensile strength, water absorption and porosity, ultrasonic pulse velocity, and chloride permeability in relation to the partial replacement (10, 20, and 30%) of portland cement with bacterially treated CKD. Comparing the 10% bacterial-treated CKD with the control (CC) treatment, the concrete's compressive and cracking tensile strengths increased by 26.6 and 25.6% at 91 days of curing. There was a decrease in porosity (53%) and water absorption (64%). Similarly, there was a 22% decrease in chloride permeability. Increased calcium silicate hydrate (CSH) gel formation was shown by SEM and XRD studies, which produced a dense structure and poor permeability. [26]

Concrete that has had some of its properties altered by specific bacteria is known as bacterial concrete. Based on a review of the literature, Bacillus Sphaericus and Bacillus Pasturii were chosen to increase the strength and durability of concrete. Higher strength is obtained than controlled concrete and concrete made with Bacillus Pasteurii when 10% of the cement is replaced with fly ash enhanced with Bacillus sphaericus. Concrete containing Bacillus sphaericus exhibits 10.8% higher strength in compression testing, 29.37% higher strength in split tensile testing, and 5.1% higher strength in flexural testing when compared to controlled concrete. Compared to Bacillus Sphaericus, Concrete Made with Bacillus Pasteurii Provides Slightly Less Strength. [27]

The ability of bacteria that are a part of the concrete matrix—that is, bacteria that are immobilized—to repair. The experiment results indicate that immobilised microorganisms mediate mineral precipitation and, Furthermore, certain kinds of necessary food sources and microbes have no detrimental effects on the strength characteristics of concrete. Therefore, it is possible that mineral precipitation will cause bacterially controlled crack-healing in concrete. However, there are several places where the concept still has to be developed. To prevent corrosion of the embedded reinforcement and hence extend the material's lifetime, it is yet unclear if bacterial mineral precipitation successfully plugs fractures, that is, significantly lowers the permeability of cracked concrete. Additionally, it's important to choose bacterial species that will persist in the concrete matrix for the duration of the building, if not longer. If this is the case, the bacterial approach can effectively rival other (abiotic) self-healing mechanisms because these bacteria meet every single one of the specified requirements for the best possible self-healing agent. [28]

The varieties of bacteria utilised in concrete and their potential use as healing agents are reviewed in this research. When bacteria are added, the different characteristics of concrete change. Crack construction is one of the many limitations of employing concrete, a widely used building material. The formation of wider fractures allows CO2 and water to seep into the building materials, where upon they react with other substances to produce a striking decrease in strength and durability. Should the cracks not be repaired right away, it could result in more significant issues such as larger fractures, more water leakage, weakened joints, and more expensive repairs. Self-healing concrete is the greatest solution for such a scenario since it can cure the concrete before it spreads. An environmentally responsible way to address these issues is to add bacteria to the concrete and use calcium lactate food to nourish the bacteria when they proliferate. This review is centred on the examination of crack. the kinds of bacteria employed and their ability to cure. Concrete naturally contains microcracks. This results in the deterioration of structures because it breaks down concrete and allows harmful elements to seep into them. [29]

Concrete that cures itself naturally through bacterial growth requires no maintenance. Concrete fractures mend themselves when they come into touch with air, water, and moisture. This causes bacteria to become active and generate lime. Buildings with bacterial concrete have greater longevity, corrosion resistance, and require less maintenance. In the modern construction industry, bacterial concrete is recognised as a difficult composition that can increase the concrete's compressive strength and self-healing properties. The properties of conventional concrete are enhanced by bacteria, showing increases in strength of 13.75% in 3 days, 14.28% in 7 days, and 18.35% in 28 days.[30]

Crack is primarily to blame for diminishing the concrete's strength. Unavoidably, cracks create spaces on the surfaces of concrete, which allow water to seep through and cause internal corrosion in the material. This paper aims to investigate the role of different species of bacteria in concrete, which will contribute to the identification of the process causing cracks. As they mend the cracks in various patterns of fissures, different bacteria exhibit distinct traits. The fractures have closed to a depth of 5 μm, 7 μm, 0.2 mm, 0.25 mm, 0.3 mm, 0.4 mm, and so on. [31]

The addition of self-healing bacteria that deposit calcite to concrete is a suitable way to boost the material's compressive strength and decrease water seepage through the biomineralization process. Concrete specimens cast with bacterial solution show a significant increase in strength. The study has developed techniques or approaches to evaluate the impact of bacterial usage in concrete. Studies using different proportions and combinations of bacterial solution have been carried out on concrete slabs. For the purpose of testing the sealing capacity, bacterial solution is applied to the slab's surface. A comparison with traditional concrete has been made between the outcomes. In order to increase strength and ensure long-term sustainability, biological alterations of building materials are urgently needed. A feasible sustainable concrete repair technique is suggested by this study.[32]

The unique method known as Microbiologically Enhanced Crack Remediation has been created. This method uses a selective microbial plugging process to encourage the precipitation of calcium carbonate (calcite) through microbial metabolic activities. The concrete is referred to as "bacterial concrete" since urolytic bacteria are employed in this method. By weight of cement, the percentages of bacteria chosen for the investigation are 3.5% and 5%. Furthermore, calcium lactate was added at weight replacement rates of 5% and 10% for cement. This study examined a number of tests, including those measuring the concrete's elastic modulus, compressive strength, and fracture characteristics. [33]

One long-term solution for filling or repairing cracks in concrete is the use of microorganisms. Additionally, it affects the strength after a specific amount of crack formation as well as the compressive and split tensile strengths. Production of calcium carbonate (lime) acts as a long-term, permanent remedy by preventing cracks from reoccurring in the same spot. Based on the findings, it can be said that the product is less maintenance-intensive and more lasting. he self-healing effect increases with increased $CaCO_3$ precipitation. With a strength rise of 16.48%, the 28-day curing cube exhibits the largest improvement across all age groups. The self-healing cube has strengthened by 10.1%. The mended cubes show a 6%–6.5% improvement in strength. On their own, cracks wider than 0.8 mm cannot be repaired. Among those treated, cracks wider than 0.6 mm are not healed. Based on the aforementioned, it may be inferred that bacterial concrete with self-healing properties can outperform regular concrete. [34]

The performance of the concrete by utilising a certain microbial growth or filler. A similar idea gave rise to the creation of a very unique concrete called bacterial concrete, which repairs defects in mortars by introducing bacteria. Different bacteria have led researchers to suggest various forms of bacterial concrete. Here, a try was made utilising the bacteria known as "Bacillus subtilis JC-3." A cement concrete cube and cylinder were cast with four distinct bacterial proportions (5 ml, 10 ml, 15 ml, and 20 ml, respectively). This study demonstrated that adding bacteria at a cell concentration of ml of mixing water significantly increased the compressive strength. Visual examination reveals that the addition of the bacteria caused some of the pores to fill with material growth. It goes without saying that pore reduction brought on by this material expansion will boost material strength. After casting concrete cubes and a cylinder with and without the inclusion of bacteria, it was found that the addition of bacteria improved the cylinder's split tensile strength and the cubes' compressive strength. [35]

The goals of adding bacteria (Bacillus pasteurii) to concrete to increase its strength and overall durability. This microbe is a type of soil bacteria. One of Bacillus pasteurii's metabolic activities is the manifestation of a phenomena called bio-calcification. Through a process known as "bio-calcification," calcium precipitate is secreted externally by microorganisms. When this precipitate combines with carbonate ions to produce $CaCO_3$, it fills in the spaces in the texture of the concrete and increases its compactness. As a result, the filler material grows inside the concrete mixer's pores, increasing the strength of the concrete. Concrete cubes and beams that were put through testing of their compressive and flexural strengths both with and without the bacteria were used in a comparison study. It was discovered that the concrete specimens' cracks that had been subjected to loading had significantly increased in strength and healing. [36]

Modern construction relies heavily on concrete, which also contributes to the ozone layer's thinning and carbon dioxide emissions. Cement, water, chemical admixtures, fine and coarse aggregates are the ingredients of traditional concrete.

Shrinkage fractures may occur during the hardening process, causing problems with the structure. In order to overcome this, bioconcrete is used, which contains microorganisms that may precipitate calcium carbonate and aid in crack sealing so that the material can mend itself. Concrete microcracks can cause corrosion-related structural failure. This study examines the importance and effectiveness of utilising Bacillus megaterium in the preparation of bioconcrete. The compressive strength, split tensile strength, flexural strength, elastic modulus, and impact resistance of the bioconcrete made with Bacillus megaterium were 43.63, 4.01, 3.89, and 33750 N/mm^2, respectively. [37]

The implementation of an efficient and ecologically friendly alternative crack removal method for the damaged material is necessary to achieve durability while adhering to the principles of sustainable building. The use of bacterial self-healing concrete ensures a safe construction for a longer period of time by lowering maintenance and damage detection costs. Concrete that contains bacteria may be more durable. On the other hand, industrial use of it is not currently practiced. The substrates are not used on an industrial basis due to their high cost. While many research groups attempt to lower production costs in a variety of ways, bacterial concrete can be a useful answer to sustainability. [38]

Self-Repair In the building sector, concrete is a relatively new idea that not many people are familiar with. Concrete frequently develops fractures as a result of its poor tensile strength. Because these fractures make it easier for liquids and gases that can contain hazardous substances to pass through, they shorten the lifespan of concrete. Not only will the concrete be damaged if microcracks become big enough to reach the reinforcement, but the reinforcement will also corrode. Consequently, it's imperative to manage the crack width and to heal the cracks as soon as possible. Given the generally high costs associated with maintaining and repairing concrete structures, the goal of this research project is to produce low-cost self-healing. This partial replacement of fly ash decreased the cost by 22.45% in place of cement. The study also found that there has been a 3% improvement in the split tensile strength of concrete. diversity among bacteria. The study also found that at 3% fluctuation of bacteria, concrete's compressive strength has greatly increased. When compared to standard specimens, the inclusion of bacteria resulted in an increase in strength. In comparison to 1% and 2%, the crack healing results with 3% of bacteria were more compelling and comparatively faster. The study's findings indicate that using self-healing concrete can be a good substitute for conventional concrete sealers. This high-quality concrete sealer is also reasonably priced, eco-friendly, and increases the longevity of building materials. [39]

The concrete's self-healing qualities, which describe a crack's capacity to either repair itself or require outside intervention to fully recover. The bacterial species Bacillus subtilis is responsible for boosting concrete's strength and lowering its porosity after 28 days. Even though these species are safe for the environment and humans, they are used to strengthen concrete's resistance to alkaline, sulphate, and freeze-thaw conditions. This paper primarily discusses the activation of bacteria, the strength of bacteria-infused concrete as compared to regular concrete, and crack filling. [40]

Many studies conducted in the last few years on the application of bacterial concrete, often known as bio-concrete, to improve the mechanical, permeability, and durability properties of concrete. It includes research on various bacteria, their isolation methods, ways to add bacteria to concrete, how they affect the material's compressive strength and water absorption capabilities, as well as SEM and XRD analyses of bacteria-containing concrete. [41]

When self-healing concrete is applied, fewer costly maintenance and repair procedures are required. Still, not much research has been done on how long-lasting self-healing concrete. The resistance of self-healing concrete against chloride intrusion is discussed here in light of current findings. Chloride profiles and electron probe microanalysis showed that this technique was effective in reducing the amount of chloride that penetrated the crack and leaked into the concrete matrix for self-healing concrete with macro-encapsulated polyurethane. Additionally, the corrosion behaviour of specimens made of reinforced concrete that were repeatedly exposed to a NaCl solution was examined. According to the electrochemical results, corrosion in the propagation stage might be greatly decreased by autonomous crack repair. After 44 weeks of exposure, there was no visible deterioration on the rebars. On the other hand, after 10 weeks of exposure, broken specimens without an incorporated self-healing mechanism reached a condition of active corrosion, and after 26 weeks, the rebars showed obvious pitting damage. While bacteria-based treatments take many weeks to mend a 300 µm crack, encapsulated polyurethane self-heals in just one day. Nitrite, an intermediate metabolic substance produced by bacterial granules containing denitrifying cultures, shielded the reinforcement during the crack-healing process. [42]

Calcite, which increases the material's strength and endurance, is produced by the bacteria that repairs cracks in concrete. By introducing bacteria into the concrete, calcite will continuously precipitate, creating bacterial concrete. For this, Bacillus E Coli and Bacillus Subtilis JC-3 are employed. Concrete's characteristics are improved by Bacillus E. Coli and Bacillus Subtilis JC3, which are induced at a cell concentration of 10^5 cells/ml. In order to encourage self-healing cracks, this study advocates for the introduction of bacteria into concrete. Bacillus Subtilis JC3 concrete has a higher compressive strength than E. Coli-induced concrete. [43]

Cracks are among the most frequent issues that arise with concrete. Concrete will inevitably develop cracks, which weaken the material's components. Concrete that has cracks allows water and other salts to seep through, weakening the material and shortening its lifespan. Salt-induced corrosion of steel also erodes reinforced concrete under stress. Therefore, techniques for sealing cracks and restoring the strength of concrete structures must be developed. At the moment, environmentally hazardous fissures can be repaired with synthetic polymers, which has led to the development of biological treatment methods. In this work, concrete was treated with 105 cells/ml of bacteria as part of a biological healing method to seal cracks. The studies were conducted for 3, 7, and 28 days in order to assess the impact of Bacillus subtilis JC-3 on the compressive strength, tensile strength, and flexural test. Fly ash was partly incorporated in addition to the above procedure, in place of cement. Experiments were conducted and fly ash (0, 10 and 30%) was added to the concrete mix by weight of cement. The experimental findings demonstrate that concrete with and without bacteria that has 10% fly ash substituted has greater strength than regular concrete. [44]

The method known as bio mineralization that is studied in science (MICP). one type of soil bacterium that might cause calcite to precipitate is Bacillus subtilis. The current study examines the possible use of the bacterium Bacillus subtilis JC-3 to repair small cracks in cement concrete, so increasing its strength. For this investigation, concrete of M20 grade was utilised. The concrete mix was made in accordance with IS guidelines. After 28 days of curing, testing was done on specimens for compression using both CTM and NDT equipment, and the results are given. Concrete is intentionally cracked into small fissures less than one millimetre, and the bacterial culture-containing broth solution is injected into the fracture pattern. Utilising NDT technology to measure compressive strength upon healing, it was discovered that the strength requirements had slightly improved. [45]

Three different bacillus subtilis JC-3 cell concentrations (20×105, 20×106, and 20×107 cells/ml) were introduced into a concrete specimen. Crack width measurements are taken at 7, 14, and 28 days from the optimal cell concentration, respectively. Several techniques with healing agents were employed to compute the crack width by two (Wet & Dry). Compressive and tensile strength are improved in microbially treated concrete. Using scanning electron microscopy (SEM), the production of calcium carbonate was seen and visualised. The energy dispersive spectrometer (EDS) was used to analyse the sample's chemical makeup. X-ray diffraction (XRD) was used to identify and measure the bacteria in the concrete. [46]

The creation of a unique type of concrete called Bacterial Concrete, which repairs defects by introducing bacteria into the mortar and concrete. A concentration of 1x106 cells/ml of Bacillus sphaericus bacteria is employed in this investigation. Through the use of several concrete grades (M20, M25, and M30), tests such as compressive strength, split tensile strength, and flexural test are used to examine the characteristics of control concrete and bacterial concrete. The inclusion of bacteria at a cell concentration of 106 cells per millilitre of mixed water resulted in a considerable increase in strength, as demonstrated by this study, and calcium carbonate precipitation was deposited in microcracks. [47]

Self-healing technologies in particular holds great promise as a novel concrete crack treatment technique. When concrete is exposed to moisture, a natural process called self-healing can take place to fix cracks. Concrete's ability to mend itself can be sped up by adding fibres, bacteria, and mineral admixtures, among other substances. By lowering the water permeability following concrete damage, mineral admixtures have been used as a strategy for concrete fractures to mend themselves. When exposed to water, mineral admixtures (such as expanding agents and geo-materials) swell and fill up the fissures. Concrete self-heals, allowing the fibres to assist regulate the tight crack width while restoring the concrete's mechanical qualities. The bacteria that cause calcium carbonate to precipitate as a result of bacterial metabolism in an environment with high calcium levels are used in the bacteria additive self-healing technique. The bigger fissures are filled up by the precipitation of calcium carbonate. By lowering maintenance requirements and expenses, self-healing concrete can significantly increase a building's service life. In light of this, self-healing concrete may be a key technology that advances sustainable civil infrastructure. [48]

The ideal dosage of bacteria to employ, test and evaluate the compressive strength of concrete cubes, and investigate the qualities of cracked specimens by introducing the facultative aerobic, ureolytic, gram-positive (spore-forming) Bacillus Subtilis JC-3. The inclusion of bacteria was found to improve the compressive strength; this increase is mostly attributable to the precipitation of calcium carbonate caused by microorganisms on the surfaces of their cells and within the mortar's pores. It was observed that when the concentration of bacterial cells in a typical mortar grew to 106 cells/ml, the compressive strength increased as well. At 106 cells/ml, the compressive strengths increased to their maximum. When B. subtilis JC-3 is added to 45ml and 60ml of bacterial concrete for seven days, the percentage increase in compressive strength surpasses that of conventional concrete. [49]

Understanding the fundamental principles and procedure of self-healing concrete, which is utilised to repair structural defects in buildings, is made feasible by this study. The study also looks at the benefits and drawbacks of self-healing concrete and develops comparison standards for this concrete technology in the construction sector. Lastly, a cost comparison between self-healing concrete and regular concrete has been completed. Due to the use of vacuum technology, the process of adding nutrients and microbes to the pellets is extremely costly. It is possible to lower the price of self-healing concrete to Rs. 7283-7712 per cubic metre by incorporating a nutritional component using sugar. [50]

3. Major finding from literature review

- Depending on the kind of bacteria, cement grade, and other ingredients, the various types of microorganisms inside the concrete—including Bacillus Subtilus JC-3, Bacillus Aerius, Bacillus Pseudomycoides, Bacillus Sphaericus, Bacillus Pasteurii, Bacillus Megaterium, and E. Coli Batceria—resulted in an enrichment of compressive power. [1,2,3,4,6,8,9,10,13,15,16,17,19,20,22,25,27,36,39,40,43,44,45,46,47,48,49]
- Various commercial waste materials, including fly ash, silica fume, rice husk, and numerous others, are also utilised with self-recuperation concrete. [3,4,6,10,11,26,39,44]
- The mechanical properties of both conventional and bacteria-induced concrete, including tensile strength, flexural strength, durability, and permeability, SEM and XRD studies have been examined. [1,2,3,4,6,8,9,10,13,15,16,17,19,20,22,25,27,36,39,40,43,44,45,46,47,48,49]
- The highest compressive strength, flexural strength, split tensile strength and exceptional related behaviour of bio concrete are provided by bacteria at a 105 cells/ml and 106 cells/ml. [3,4,25,43,44,46,47,49]
- Since calcite precipitation reduced the concrete's water absorption, porosity, and permeability, it strengthened the concrete's resistance to alkaline, sulphate, and free-thaw conditions. [3,14,15,23]
- To evaluate the effects of Bacillus subtilis JC-3, the investigations were carried out for 3, 7, and 28 days. [1,2,3,4,6,8,9,10,13,15,16,17,19,20,22,25,27,36,39,40,43,44,45,46,47,48,49]
- In order to predict the temperature of the pavement Particularly for pavement evaluation, finite element analysis (FEA) software was created. [19,21,26]
- Production of calcium carbonate acts as a long-term, permanent remedy by preventing cracks. [4,10,28,31,34,44,48]
- After being treated with Bacillus Subtilus JC-3, it showed reduced alkalinity and hardness in cement kiln dust. Porosity, chloride permeability, and water absorption were all shown to be decreased. [26]
- Bacterial self-healing concrete ensures a safe construction for a longer period of time by lowering maintenance and damage detection costs. [38,50]

4. Conclusion

- The rapid pace of construction in emerging nations necessitates a high cement consumption for both new construction and structural maintenance. Utilising bacteria as a self-healing agent can improve a concrete structure's sustainability and durability.
- It has been demonstrated that the microbes specially Bacillus type used to create the concrete cubes and beams are effective at improving the concrete's qualities by achieving a very high initial strength improvement. As a result, we can assume that the calcium carbonate that was produced filled a portion of the void size, making the surface more compact and resistant to filtering.
- bacterial cell walls have the potential to be added to concrete as an additive that will improve not only mechanical performance but also other properties related to carbonation. Bacterial cell walls have the ability to speed up the carbonation process and change the physicochemical characteristics of concrete.
- Both the permeability of chloride ions and water penetration are decreased by bacteria. Compared to other bacteria, Bacillus has a faster rate of healing. Create an ionic or intermolecular hydrogen bond to reinforce the strong link between the molecules in the filled crack.
- The natural and pollution-free mineral precipitation caused by microbiological activities makes the application of this biological restoration technology particularly desirable.
- The majority of the extra expenses are composed mostly of calcium lactate, which is presently highly pricey. Due to the use of vacuum technology, the process of adding nutrients and microbes to the pellets is extremely costly. The amount of self-healing concrete may decrease if a diet high in sugar is included.

Bacterial concrete represents a revolutionary advancement in construction technology, offering numerous benefits that make it a compelling choice for various applications. Its self-healing capabilities not only extend the lifespan of concrete structures but also reduce maintenance costs and increase their resilience to environmental factors such as cracks and water ingress. integrating bacterial concrete into pavement construction presents a promising solution for enhancing longevity, minimizing maintenance requirements, and promoting environmental sustainability, making it a viable choice for future infrastructure projects.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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