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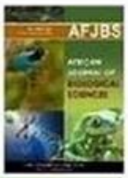

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SELF HEALING CONCRETE FOR SUSTAINABLE DEVELOPMENT OF CONSTRUCTION INDUSTRY WITH VARIOUS BACTERIA: A REVIEW

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Abstract: Choosing fitting structure materials is pivotal for supportable turn of events. Concrete, a material that is used a lot, has a big effect on the environment because it takes a lot of energy to make and is prone to cracking. Concrete durability in sustainable construction necessitates environmentally friendly and efficient crack repair methods. The structural longevity of bacterial self-healing concrete is enhanced by cost savings in damage detection and maintenance. Due to the high costs of the substrate, it is not widely used in industry, despite its potential to increase durability. In order to position bacterial concrete as a viable option for sustainability, ongoing research aims to reduce these costs.

Keywords: sustainable; self-healing; concrete; bacteria

1. GENERAL

Quick development, especially in agricultural nations, adds to ecological contamination, high energy utilization, and asset consumption, influencing the solace and strength of building occupants. Ecological building materials like silicate blocks, gypsum-based materials, paints, and wood have been introduced as a result of research that has highlighted the detrimental health effects of building materials since the 1970s [1]. Throughout their entire life cycle—from the sourcing of the raw materials to operation, renewal, disposal, or recycling—these materials are made to improve health and reduce the impact on the environment. Throughout their lifespan, sustainable building materials ought to minimize pollution, conserve energy, and be safe for human health. The selection of building materials by the construction industry in Europe is crucial to sustainable development. Reducing waste, pollution, and consumption of energy and resources is a priority for the European Union. Throughout the lifecycles of buildings, sustainable development principles are being applied to ensure a balance between economic, environmental, and social performance. Sustainable building materials should not harm people's health, use fewer resources, or have a negative impact on the environment [2].

Manageable structure materials add to maintainable scene plan and are delivered by organizations focused on reasonable social, ecological, and corporate arrangements. Researching these materials is pivotal from the underlying plan to the structure's finish of-life reusing. New materials and technologies that offer energy efficiency, water resource protection, improved indoor air quality, reduced life cycle costs, and durability are constantly sought after by planners, architects, engineers, and builders. Accomplishing these advantages requires the most recent headways in materials innovation and harmless to the ecosystem building rehearses. The environmental impact of materials throughout their entire lifecycle—from mining and processing to manufacturing, installation, reuse, and disposal—is reduced when sustainable materials are used in construction [3].

2. Overview of Concrete

Concrete is frequently utilized for construction in civil engineering due to its low cost and low maintenance requirements. Be that as it may, the creation and utilization of cement and support materials are exceptionally energy-concentrated and naturally difficult (Table 1). Concrete must be shielded from the outside world in order to improve its durability. Repairs are frequently required to extend the lifespan of structures because they deteriorate for a variety of reasons, including environmental impacts, overload, and accidental damage. Concrete cracks are a common defect that is caused by freeze-thaw reactions, shrinkage, hardening, and low tensile strength [4].

These cracks eventually cause facilities, buildings, or components to deteriorate. Epoxy resins, for example, are expensive and require constant upkeep. Repairing and maintaining concrete can be costly and sometimes impossible during the material's lifetime. Chemical repairs can also be harmful to the environment. For supportable development, taking on harmless to the ecosystem and successful break expulsion techniques is vital. Concrete can be fixed by using: - Self-healing treatment - Independent mending The self-healing process in autogenous healing makes use of calcium carbonate or hydration products like C-S-H, which are made from carbon monoxide dihydrate and water. Far reaching estimates like magnesium oxide and bentonite can likewise seal laughs out loud to around 0.18 mm. Utilizing bacteria, organic compounds, and materials encapsulated in pozzolan is part of autonomous healing. For better results, this method combines chemical factors like calcium lactate with biological factors like bacteria. Biomineralization can be applied to the surface or inside the substantial. Within technique brings calcite-accelerating microorganisms into the substantial, where microbial ureases hydrolyze urea, creating alkali and carbon dioxide. The pH of the reaction goes up, and the resulting insoluble calcium carbonate builds up in the concrete's pores. When cracks appear, the outside method seals them with calcium carbonate crystals produced by applying a biological mixture to the surface. There are two types of biomineralization: - Mineralization that is biologically controlled (BCM) - Mineralization that is induced by biology (BIM) For long-term concrete repair, these options look promising [5].

The first kind, biologically controlled mineralization (BCM), occurs when minerals are deposited in or on organic matrices or cell bubbles and are controlled by organisms. Mineral particles with a narrow size distribution and species-specific crystal habits are formed as a result of this control over mineral nucleation and growth by organisms. BCM is dependent upon metabolic and hereditary control, making it less delicate to outer ecological boundaries. Eukaryotic structures like fish otoliths and mollusk shells are made of BCM calcium carbonate. The subsequent kind, naturally incited mineralization (BIM), includes minerals framing as a side-effect of the response between life form action and the climate. BIM occurs as a result of chemical reactions involving metabolic byproducts and metabolic activity. Complex organic-inorganic structures with distinctive physicochemical properties are the result of this process, which necessitates precise control over size, morphology, and phase selection. BIM calcium carbonate typically forms when single-cell organisms, like bacteria, are present. This can happen passively through metabolic changes in the chemistry of the solution or actively through the provision of nucleation sites for mineralization [6].

3. Mechanism of Self-Healing

Natural cement, or self-mending substantial utilizing Microbially Actuated Calcite Precipitation (MICP), uses microorganisms to create calcium carbonate (CaCO3) to fill breaks in substantial materials. For this purpose, various bacteria, including Bacillus subtilis, Bacillus pseudofirmus, Bacillus pasteurii, and Bacillus sphaericus, are utilized. These microscopic organisms can make due in high-salt conditions and use metabolic cycles like sulfate decrease, photosynthesis, and urea hydrolysis to create calcium carbonate as a result. A few responses likewise hoist the pH to basic circumstances, making bicarbonate and carbonate particles that encourage with calcium particles in the substantial to frame calcium carbonate minerals [7]. Chemoorganotrophs, these bacteria are harmless to humans and generate energy by oxidizing simple organic compounds. During the production of the concrete, Bacillus species and bacterial nutrients, such as calcium compounds, nitrogen, and phosphorus, are added through this procedure. Until the concrete is damaged, these components remain dormant. At the point when breaks happen and water enters, the bacterial spores enact, filling in positive circumstances. Calcium carbonate, which solidifies on the damaged surface or within the material, effectively seals the cracks after soluble nutrients are converted into insoluble calcium carbonate. During their growth, the bacteria consume oxygen, which keeps reinforcement from corroding and makes concrete last longer. The reaction between calcium hydroxide and calcium chloride and the byproducts of bacterial metabolism that lead to the formation of calcite (calcium carbonate) results in the formation of calcium carbonate on the surface of the concrete [8].

4. The Effect of Bacteria and Biomineralization on the Properties of Concrete

Literature data indicates that introducing specific bacteria into concrete has several beneficial effects. One key benefit is improved diffusion kinetics due to changes in pore structure, which positively affects moisture transport and reduces damage from various ions. Embedding bio-calcium carbonate in damaged spaces and pores also increases the material's strength. Research is ongoing globally, with scientists investigating different bacterial species such as Bacillus subtilis, Bacillus pseudofirmus, Bacillus pasteurii, Bacillus sphaericus, Escherichia coli, Bacillus cohnii, and Bacillus balodurans, as well as varying cell concentrations (e.g., 10^3 cells/mL, 10^5 cells/mL, 10^8 cells/mL). Various additives are also explored to enhance material properties and support bacterial growth in concrete's high alkaline environment. The results of selected studies from the literature are summarized further in this paper [9-10].

4.1. The Effect of Bacteria on the Properties of Concrete

Microbial metabolic activity in concrete improves overall performance, including compressive strength, according to the findings. Another review [11] tracked down a critical expansion in cement's compressive strength by 42% at a centralization of 10^5 cells/mL and a 63% increment in elasticity following 28 days. They also noted that bacterial concrete has reduced water absorption and resists mass loss when exposed to acid. Chloride content tests revealed that bacteria increase compressive strength and reduce mass loss from chloride exposure. Bio-calcium carbonate filled voids and made the texture more compact and resistant to penetration when Bacillus pasteurii was used. Another investigation discovered that Bacillus subtilis can endure outrageous temperatures (−30°C to 700°C) and increment compressive strength. Early compressive strength was high, but it decreased over time. Maximum compressive strength was shown for Bacillus flexus, which is not typically associated with calcite precipitation. Study inspected concrete with GGBFS and silica rage, finding that 35% GGBFS in the blend brought about a compressive strength of 56 N/mm^2, while 12.5% silica smolder expansion arrived at 37 N/mm^2.

According to [12], the optimal compressive strength was attained at a concentration of approximately 105 bacterial cells per milliliter. Using 30% fly ash and 30% GGBS, Bacillus pasteurii replaced 70% of the cement in and significantly increased compressive strength by 30% and 20%, respectively. The ideal bacterial arrangement volume for most extreme ductile and flexural strength was 40-50 mL. The calcium lactate and 5% bacterial additives in the study resulted in a compressive strength of 49.5 MPa at 28 days, which was higher than the control concrete. The compressive strength was significantly increased when bacteria and 10% calcium lactate were added. According to, S. pasteurii and fly ash decreased chloride permeability by eightfold, reduced water absorption by fourfold, and increased compressive strength by 22 percent after 28 days. Bacillus pasteurii cultured in urea and calcium chloride had a compressive strength of 65 MPa at 28 days, compared to 55 MPa in controls without bacterial cells, according to a study. Compressive strength increased by 17% at 7 days and 25% at 28 days, according to the authors. However, the tensile strength of the bacterial samples and the controls did not significantly differ, with the exception of a slight increase of 0.33 MPa, as noted. A group of Bacillus cohnii and Bacillus pseudofirmus increased the mortar's compression strength by 10% after 28 days in [13].

Study utilized modern side-effects with lactose mother alcohol (LML) and corn steep alcohol (CSL) as supplement sources, keep a 17% expansion in compressive strength with LML and 35% with CSL at 28 days. Arthrobacter crystopoietes was found to be a good bacterial isolate for self-healing concrete by researchers. Bacillus subtilis was found to have a 28% increase in compressive strength, which was attributed to organic matter from bacterial biomass. By forming a calcite layer on the surface, a study found that Bacillus sphaericus reduced water absorption by 65-90% in repaired cracks. At a pH of 7 to 11, Bacillus sphaericus spores encapsulated in a chitosan-based hydrogel showed optimal performance, with a slight decrease in compression strength but a significant decrease in water flow, as shown. Study utilized spore exemplification with bioreagents in a hydrogel, diminishing water porousness by 68% and treating laughs hysterically to 0.5 mm. When Bacillus sphaericus was added to concrete with 10% fly ash, the authors [36] found that the concrete had 29.37 percent more tensile strength, 10.8 percent more compression strength, and 5.1% more flexural strength than the control. Peptone, yeast extract, and Bacillus subtilis were used in the study to reduce porosity and boost dynamic modulus strength.

The results lasted for 210 days. After 91 days, tests on Sporosarcina pasteuria-treated lightweight aggregate concrete [14] revealed an increased resistance to chloride ion penetration of 38%. After 240 days, the chloride ion diffusion of Sporosarcina pasteurii and Skutarcina ureae, which were immobilized with zeolite in a mortar, decreased by 60% and 54%, respectively, in other studies. Study segregated Bacillus cereus from carbide slag, accomplishing diminished water retention and chloride penetrability by 12.0% and 10.9%, separately, and recuperating breaks of 100-800 μm in 28 days, fundamentally diminishing porousness. Various studies used chloride ions and water adsorption to test durability by modifying flexural or compressive strength. The climate where bacterial concrete is found effects its strength, with protection from stress, water, and chloride stream, however acidic conditions and carbonate-corrosive consumption might present difficulties. Further exploration is expected to upgrade creation strategies and survey protection from other destructive conditions.

4.2. Eigenschafts of Self-Healing Caused by Bacteria

Specialists [15] noticed that Sporosarcina pasteurii essentially decreased water entrance profundity in concrete by framing a calcium carbonate interphase locale, bringing down penetrability. Other studies [16] examined the use of chemical compounds, microcapsules, and low-alkali cement materials to improve bacterial compatibility with Bacillus sphaericus for crack healing. Inorganic permeable materials like ceramsite, polyurethane, and extended perlite have been utilized to safeguard microorganisms in concrete, accomplishing make recuperating laugh hysterically to 1.24 mm following 28 days. At 105 cells/mL, the strength of self-compacting concrete was increased by 21 percent using rice husk ash, micro-silica, and Bacillus pasteurii. At 105 cells/mL, Bacillus subtilis provided the highest compressive strength, as well as enhanced permeability and crack repair. In extreme conditions, marine concrete with beads made of bacteria presented difficulties. Improved watertightness and flexural recovery were achieved by utilizing bacteria, PP fibers, and PVA fibers. Strength was increased and water absorption was reduced when biocarbon was combined with PP fibers or superabsorbent polymers and bacterial spores. Crack healing and strength recovery were significant with the use of iron oxide and bentonite nanoparticles and microparticles for bacteria immobilization. Reused totals with Bacillus subtilis actually fixed 1.1 mm wide breaks and reestablished 85% compressive strength.

4.3. Other Methods

Natural, chemical, biological, and special methods are the four categories that can be used to describe concrete self-healing mechanisms. The effectiveness of natural self-healing is limited to cracks up to 0.1 mm in width and is dependent on the composition of the concrete matrix as well as the presence of water and carbon dioxide. Crack-filling compounds are produced by reacting a curing agent with cement hydration products in the concrete mixture using chemical methods. The effectiveness of the chemical method is influenced by the type of curing agent, the characteristics of the carrier (such as capsules or tubes), and their distribution in the concrete. The efficacy of biological methods is influenced by capsule cutting randomness and the higher production costs compared to normal concrete. Biological methods depend on the viability of bacterial spores and the presence of water. Mineral additives are used in special methods, and their efficacy depends on how much and how well they are chosen, as well as whether there is no internal tension in the concrete from swelling. Mineral additives have been shown to close cracks up to 0.22 mm wide in water permeability tests [17].

5. Cost of Self-Healing Concrete Production

The authors of [18] looked at how much more expensive it was to use microbial concrete than regular concrete. This is one of the primary reasons why this material is not currently used in the construction industry in mass quantities. Microbial concrete costs between 2.3 and 3.9 times more than lower-quality conventional concrete, according to the cost analysis. The material's initial costs are an order of magnitude higher than those of conventional concrete due to the high cost of bacterial cultures used in its creation (bacteria and nutrients account for approximately 80% of the cost of raw materials). The creators look for additional decreases in the creation cost of bacterial cement in utilizing supplement fixings, i.e., reasonable modern waste with a high protein content, e.g., stromata, fluid corn or lactose mother alcohol from the starch business — which they manage in.

The process's total cost would decrease significantly as a result. Investors find it difficult to justify the high costs. Investors and architects are unaware of the ability of bacterial concrete to self-repair, thereby extending the building's lifespan and lowering its overall cost. They just see the significant expense of creation and, thusly, the at first significant expense of the material. Another issue is that cracks are not covered by the majority of contractors' ten-year building warranties. It's possible that the benefits of such concrete won't become apparent for several or even ten years. Thusly, the likelihood that workers for hire will put resources into this material is somewhat low. However, there are instances in which the advantages of self-healing concrete outweigh any economic considerations. In [16], several such instances are mentioned. There are problems described. where the safety of priceless items is more important than money. This material has not yet received a lot of attention in the construction industry. In any case, concerning the above cited writing information on lab testing and the outcomes got, this material is equipped for satisfying the expectations of the researchers. In order for the material to have a lower initial cost and be accepted by contractors, it is evident that additional research will be required to reduce the cost of culturing bacteria.

6. Ideas for the Future

Self-healing concrete compositions based on bacteria are the subject of ongoing research, and they have the potential to enhance the properties of the material. These materials have the ability to self-repair themselves in the event of damage by either automatically responding to agents from the outside or activating themselves from the outside (active self-repair). However, there are still obstacles, such as the construction industry's unfamiliarity with microbiological processes, concerns regarding the health effects of bacteria, performance variations based on location and environment, the requirement for standardized testing protocols, the capacity of bacteria to survive in alkaline concrete environments, and the need to reduce production costs [14].

While bacterial concrete's potential biological corrosion effects and long-term durability have not been thoroughly examined, many of these issues are the subject of ongoing research. Research shows that the bacteria Bacillus Sphaericus, Bacillus pasteurii, Bacillus subtilis, and Bacillus lexus that are used to make concrete are able to effectively precipitate calcite and are not harmful to human health. However, additional research is required to comprehend how these materials affect the growth and deposition of microbial spores in concrete environments.

Self-healing concrete materials have a lot of potential, as various research centers have found. Performance gets better with each new iteration or change to the bacterial and additive compositions. However, similar to concrete with nano-TiO2, it appears that full-scale implementation of concrete with bacterial components may not be required due to associated costs. Bacterial concrete could be used instead as a coating or topping plaster (facade), and ongoing research is looking into its use in concrete spraying or repair mortar [11].

It is difficult to predict the technological trajectory of bacterial concrete in the future because, despite its potential, it has not yet been widely used on an industrial scale. Creators of existing writing [14] have illustrated a few difficulties confronting bacterial cement, including: The construction industry is not well-versed in microbiological procedures. Worries about the apparent wellbeing chances related with microorganisms. Geographic and natural inconstancy influencing the item and execution of Microbially Initiated Calcium Carbonate Precipitation (MICP), requiring variation to nearby circumstances. The requirement for standard conventions for testing and acknowledgment measures. Ensuring that bacteria can thrive in the concrete's alkaline pH environment. Overcoming obstacles when using materials like polyurethane, silica gel, and microcapsules to encase bacterial cells lowering production expenses. Scientists are achieving promising results in their efforts to address these obstacles. However, the long-term durability of such materials and their potential effects on biological corrosion are a notable issue that has not been addressed in the literature. Although research indicates that the material can be protected by the calcium carbonate produced by bacteria, there are still concerns regarding its effect on the growth and deposition of other airborne microorganisms. Significantly, the bacterial species utilized in these materials, for example, Bacillus Sphaericus, Bacillus pasteurii, Bacillus subtilis, and Bacillus lexus, are not unsafe to human wellbeing and exhibit a high capacity to hasten calcite.

7. Assumptions

The following conclusions regarding bacterial concrete and its potential applications can be drawn from the literature review:

- When compared to conventional samples, Bacillus bacteria, such as Bacillus cohnii and Bacillus pseudofirmus, have a positive effect on compressive and bending strength. The species of Bacillus sphaericus improve concrete durability by reducing water absorption.
- In order to shield bacteria from environments with high pH, porous inorganic materials like ceramsite and zeolites are utilized. Sporosarcina pasteuria improves lightweight aggregate concrete's resistance to chloride ion penetration.
- Effective crack healing and reduced water permeability are demonstrated by expanded perlite particles immobilized by bacterial spores and wrapped in low-alkali material.
- To shield bacteria from alkaline reactions, a variety of substances, including silica gel, are utilized. - Autoclaved microorganisms or their spores decline porosity and porousness. Bacillus pasteurii decreases chloride permeability, increases concrete durability, and reduces water absorption.
- Exemplification of Bacillus sphaericus in shut microcapsules improves break treatment viability and brings down water penetrability. While decreasing the concentration of bacteria, PP and PVA fibers contribute to surface repair and watertightness.
- Sporosarcina pasteuria and Skutarcina ureae's chlorine ion diffusion is reduced by zeolite and glass fiber reinforcement. As bacterial immobilizers, recycled coarse aggregate (RCA) and 50% fine aggregate (FA) successfully repair cracks and restore compression strength by 85%.
- The properties of bacterial concrete will be better understood and production methods may become more cost-effective with additional full-scale testing in the coming years. This material meets expectations for long-term durability, minimal carbon dioxide emissions, low energy consumption, and effective repair and maintenance as a long-lasting solution to concrete industry challenges.
- Thusly, it lines up with the necessities of both the modern area and common populace for manageable development materials and designs.

References

1. Chen, Z.S.; Martinez, L.; Chang, J.P.; Wang, X.J.; Xionge, S.H.; Chin, K.S. Sustainable building material selection: A QFD- and ELECTRE III-embedded hybrid MCGDM approach with consensus building. *Eng. Appl. Artif. Intell.* **2019**, *85*, 783–807.

2. Akadiri, P.O.; Chinyio, E.A.; Olomolaiye, P.O. Design of a sustainable building: A conceptual framework for implementing sustainability in the building sector. *Buildings* **2012**, *2*, 126–152.

3. Huang, H.; Ye, G.; Damidot, D. Characterization and quantification of self-healing behaviors of microcracks due to further hydration in cement paste. *Cem. Concr. Res.* **2013**, *52*, 71–81.

4. Ravindranatha, R.; Kannan, R.N.; Likhit, M.L. Self-healing material bacterial concrete. *Int. J. Res. Eng.Technol.* **2014**, *3*, 656–659.

5. Reddy, V.S.; Seshagiri Rao, M.V.; Sushma, S. Feasibility Study on Bacterial Concrete as an innovative self-crack healing system. *Int. J. Mod. Trends Eng. Res.* **2015**, *2*, 642–647.

6. Ramakrishnan, V.; Deo, K.S.; Duke, E.F.; Bang, S.S. SEM investigation of microbial calcite precipitation in cement. In Proceedings of the 21st International Conference on Cement Microscopy, Las Vegas, NV, USA, 25–29 April 1999; pp. 406–414.

7. Achal, V.; Mukherjee, A.; Reddy, M.S. Biocalcification by Sporosarcina pasteurii using Corn steep liquor as nutrient source. *Ind. Biotechnol.* **2010**, *6*, 170–174.

8. Ramachandran, S.K.; Ramakrishnan, V.; Bang, S.S. Remediation of concrete using microorganisms. *ACI Mater. J.* **2001**, *98*, 3–9.

9. Jagannathan, P.; Satya Narayanana, K.S.; Devi Arunachalamb, K.; Kumar Annamalaib, S. Studies on the mechanical properties of bacterial concrete with two bacterial species. *Mater. Today Proc.* **2018**, *5*, 8875–8879.

10. Bhaskar, S.; Anwar, K.M.; Lachemi, M.; Wolfaardt, G.; Otini, M. Effect of self-healing on strength and durability of zeolite-immobilized bacterial cementitious mortar composites. *Cem. Concr. Compos.* **2017**, *82*, 23–33.

11. Wang, J.Y.; Soens, H.; Verstraete, W.; De Belie, N. Self-healing concrete by use of microencapsulated bacterial spores. *Cem. Concr. Res.* **2014**, *56*, 139–152.

12. Xu, J.; Wang, X. Self-healing of concrete cracks by use of bacteria-containing low alkali cementitious material. *Constr. Build. Mater.* **2018**, *167*, 1–14.

13. Zhang, J.; Liu, Y.; Feng, T.; Zhou, M.; Zhao, L.; Zhou, A.; Li, Z. Immobilizing bacteria in expanded perlite for the crack self-healing in concrete. *Constr. Build. Mater.* **2017**, *148*, 610–617.

14. America, F.; Shoaeib, P.; Bahramia, N.; Vaezia, M.; Ozbakkalogluc, T. Optimum rice husk ash content and bacterial concentration in self-compacting concrete. *Constr. Build. Mater.* **2019**, *222*, 796–813.

15. Gupta, S.; Kua, H.W.; Pang, S.D. Healing cement mortar by immobilization of bacteria in biochar: An integrated approach of self-healing and carbon sequestration. *Cem. Concr. Compos.* **2018**, *86*, 238–254.

16. Zajac, B.; Gołebiowska, I. Samoleczenie betonu. Cz. 2. Metody biologiczne i specjalne. *Inz˙. Apar. Chem.* **2016**, *55*, 160–161.

17. Shim, K.B.; Kishu, T.; Choi, S.C.; Ahn, T.H. Cementitious materials for crack self-healing concrete. *J. Ceram.Proc. Res.* **2015**, *16*, 1–13.

18. Bravo Silva, F.; Boon, N.; De Belie, N.; Verstraete, W. Industrial application of biological self-healing concrete: Challenges and economic feasibility. *J. Commer. Biotechnol.* **2015**, *21*, 31–38.