Journal of Civil Engineering and Environmental Technology
p-ISSN: 2349-8404; e-ISSN: 2349-879X; Volume 10, Issue 2; April-June, 2023, pp. 81-84

http://www.krishisanskriti.org/Publication.html

The Efficacy of Various Bacteria for Self-healing Concrete

Dinesh Chandra Pandey[1] and H. K. Sharma[2]

[1]M.Tech scholar, Department of Civil Engineering, NIT Kurukshetra, Haryana, India
[2]Professor, Department of Civil Engineering, NIT Kurukshetra, Haryana, India
E-mail: [1]dinesh_32112304@nitkkr.ac.in

Abstract—*The concrete industry anticipates achieving strength more quickly so that the work can be completed on time or earlier. High early strength cement and the use of a low water/cement ratio both meet this requirement. However, the aforementioned procedure leads to significant heating and drying shrinkage, a lower elastic modulus, and lower creep coefficients. Numerous techniques have been employed in the industry to lessen the effect of first cracks and to fix the overall cracks in the concrete. One such technology is self-healing bacterial concrete. This paper reviews earlier studies on the self-healing of concrete cracks by adding different bacteria, such as Bacillus subtilis, Bacillus sphaericus, Bacillus pasteurii, and Bacillus megaterium, to the concrete mixture. The impact of various bacteria on concrete's mechanical properties and the efficacy of various bacteria at self-healing were compiled. As a result, the efficacy of various bacteria is evaluated in terms of changes in mechanical strength. This self-healing concrete, which is based on bacteria, shows concrete's bright future.*

INTRODUCTION

For Self-healing bacterial concrete is a new technology that has gained significant attention in the civil engineering field. It involves embedding bacteria into concrete to repair cracks autonomously by producing calcium carbonate when triggered by the presence of water and oxygen. Bacillus subtilis, Bacillus sphaericus, Bacillus pasteurii, and Bacillus megaterium are the four bacterial strains extensively studied for their potential application in self-healing concrete. These bacteria produce enzymes that break down urea to release ammonium ions and create an alkaline environment, promoting calcium carbonate precipitation. This mechanism fills in the pores and microcracks in the concrete, making it denser and more resistant to damage, extending the lifespan of concrete structures, and reducing maintenance costs. However, there are still challenges to address, such as maintaining bacterial viability and activity during concrete production and harsh environmental conditions. Despite these challenges, the use of self-healing bacterial concrete has the potential to revolutionize the construction industry and reduce its carbon footprint.

LITERATURE REVIEW

Bacillus Subtilis

(Lakshmi, 2018) uses conducted a study to examine the efficacy of calcium lactate and Bacillus subtilis bacteria in decreasing concrete fractures. In the investigation, different proportions of calcium lactate and Bacillus subtilis bacteria (5, 10, and 15% of cement weight) were added to M40 grade concrete. By evaluating cantabro loss at different curing ages—3, 7, and 28 days—the researchers were able to assess the concrete's resilience to abrasion. As flexural strength grew, the cantabro loss decreased, according to the findings. Additionally, the addition of bacteria significantly improved both flexural strength and cantabro loss, with the highest results being attained at 10% bacteria in the concrete mix. According to the study, adding calcium lactate and Bacillus subtilis bacteria to concrete can dramatically alter its characteristics and increase its toughness.[1]

(Prasad and Lakshmi, 2020) found 5, 10, and 15% of the cement weight were used in an experiment to test the effectiveness of calcium lactate and Bacillus subtilis bacteria in treating cracks in M40 grade concrete. SEM analysis and Ultrasonic Pulse Velocity (UPV) testing were used by the researchers to assess the concrete's quality. The study discovered that 10% bacterial replacement in the concrete had the strongest results, and SEM examination revealed that the bacteria's inclusion caused the concrete to produce calcium carbonate, which assisted in crack healing. Up to 10% more bacterial solution increased the bacterial concrete's compressive strength and flexural strength values; above that point, hydration product saturation made the findings less favourable. The UPV experiments revealed that up to 10% of bacterial solution increased the concrete's velocity and quality, but any more exhibited unfavourable results. Overall, the study indicates that calcium lactate and Bacillus subtilis bacteria can enhance the strength and durability of concrete, especially when applied in the right amounts.[2]

(Durga, 2020) investigated the efficacy of utilising biological agents to encourage self-healing of cracks in concrete, enhancing the material's impermeable properties. To measure the rate of self-healing in concrete, the researchers ran mechanical and durability experiments. According to the findings, compared to conventional concrete, the bio-concrete mixtures had improved compressive strength by 22%, split tensile strength by 16%, and flexural strength by 11% after 28 days of curing. The density of the bio-concrete was found to be higher than that of conventional concrete, and the presence of bacteria enhanced the bio-concrete specimens' durability attributes. The calcite that had been used as a filler to seal the surface fractures in the concrete was thought to be the cause of the increase in compressive strength. The increase in split tensile strength was brought about by the bacterial strain's production of an EPS layer, whereas the biomaterial's secreted urease enzyme was responsible for the enrichment of flexural strength. Wave velocities increased as a result of enhanced CaCo3 production brought on by the nucleation effect of bacterial cell walls. The bio-concrete had reduced water absorption than conventional concrete, demonstrating that the bacterial precipitates filled the pores and crevices in the concrete. According to the results of the Sorpitivity test, the bio-concrete offers greater resistance to the infiltration of water into the concrete, reducing the porosity of the concrete in the process. The study's overall conclusion is that biological agents can improve the self-healing and durability qualities of concrete.[3]

(Mondal, Das and Chakraborty, 2017) In order to better understand how two different bacterial species—Bacillus Cereus and Bacillus Subtilis—affect concrete's compressive strength at various concentrations. According to the findings, both types of bacteria had an increase in compressive strength after seven and twenty-eight days. The best amount of each bacterium to achieve the greatest compressive strength varied. Bacillus Subtilis had an optimal concentration of 105 cells/ml, whereas Bacillus Cereus had an optimal concentration of 103 cells/ml. Additionally, compared to all three concentrations of Bacillus Cereus at both 7 and 28 days, the addition of Bacillus Subtilis at the ideal concentration produced a better compressive strength. The study discovered that data from Ultrasonic Pulse Velocity (UPV) measurements showed densification brought on by calcite precipitation by bacterial action, leading to an increase in compressive strength. Additionally, a rise in Rebound numbers was seen in the bacterial concrete when the Rebound Hammer test was performed; this could be the result of calcite deposition on the surface.[4]

(Shashank, Kumar.K and Nagaraja, 2022) seeks to study the impact of bacterial self-healing concrete on the behaviour of reinforced concrete beams during fracture. The M25 grade concrete with fly ash and silica fume underwent research on variables such beam deflection, load-bearing capacity, cracking pattern, energy absorption capacity, ductility factor, and ultimate moment carrying capacity. The findings demonstrated that changes in fracture behaviour and deflection, with a greater number of cracks but less width, increased the load-carrying capacity of self-healing concrete by up to 21%. Additionally, the beam's ductility rose by up to 45%, and its ability to absorb energy increased by at least 100%. The study came to the conclusion that because it increases a structure's longevity, bacterial concrete is a sustainable solution for the future building sector. A change in the fracture and deflection parameter of the reinforced concrete beam was detected as a result of the use of bacteria, which was found to improve the fracture behaviour of self-healing concrete. Furthermore, it was discovered that the use of bacteria increased all the beams' ultimate moment of resistance, ductility factor, energy absorption capacity, deflection at ultimate load, load carrying capacity, and deflection at ultimate load. In comparison to controlled concrete, it was seen that bacterial concrete had more fissures with smaller widths. This could be as a result of bacterial species filling microcracks with calcium carbonate precipitation, which may have helped to increase the load carrying capacity and deflection of the beams. Overall, the study showed that adding bacteria to concrete is doable and can enhance the way that concrete fractures.[5]

BACILLUS SPHAERICUS

(Nosouhian, Mostofinejad and Hasheminejad, 2015) To stop sulphate ion penetration and lessen the permeation qualities of concrete, Sporosarcina pasteurii, Bacillus subtilis, and Bacillus sphaericus bacteria were used as microbial surface treatments. The research revealed that bacterial treatment can enhance durability properties and lessen concrete degradation in sulphate conditions. It was found that the specimen's surface had a layer of calcium carbonate produced by bacteria that functioned to restrict the penetration of magnesium ions and slow down mass loss and expansion. Additionally, it was shown that bacterial treatment improved the concrete's resistance to chloride penetration as well as its ability to withstand minor increases in compressive strength. In comparison to other evaluated biological treatments, the study found that S. sphaericus bacteria applied to the surface of concrete at a specified cell concentration generated the most lasting concrete in a sulphate environment. Overall, improving concrete's durability and lowering water absorption may be accomplished through microbial surface treatment.[6]

(Madhu Sudana Reddy and Revathi, 2019) To improve crack filling and strength through biomineralization, create long-lasting cement concrete by adding various concentrations of Bacillus Sphaericus bacteria. Testing materials were examined for cube compressive strength, split tension, flexural strength, elastic modulus, and durability at various Bacillus Sphaericus bacterial concentrations. The findings revealed that fractured concrete specimens with bacteria saw less strength loss as a percentage than specimens without bacteria, and the optimal concentration for noticeably increasing strength was discovered to be 105 cells/ml. The SEM study also showed that calcium carbonate precipitation had occurred, which contributed to the concrete's increased strength and durability. It was also discovered that the bacteria's integration had no negative effects on the concrete. In summary, the research showed that adding Bacillus Sphaericus bacteria to concrete decreases cracks and improves durability, making it a useful method for strengthening the qualities of concrete.[7]

(P. Jagannathan, 2018) A modified version of concrete called "concluded bacterial concrete" incorporates particular bacteria to improve the material's characteristics. In order to increase the strength and durability of the concrete, Bacillus sphaericus and Bacillus pasteurii were selected based on a literature review.In comparison to controlled concrete and concrete prepared with Bacillus pasteurii, the researchers discovered that 10% of the cement may be replaced with fly ash enriched with Bacillus sphaericus. The concrete prepared with Bacillus sphaericus demonstrated a strength that was 10.8% higher in compression tests, 29.37% higher in split tensile tests, and 5.1% higher in flexure testing than control concrete. The strength of concrete made with Bacillus pasteurii was marginally inferior than that made with Bacillus sphaericus. It is desirable to utilise fly ash enhanced with Bacillus sphaericus in place of cement in concrete since it is less expensive, produces less CO2 emissions, and uses less energy during manufacture.[8]

(Nagar, 2021) discusses the partial replacement of ordinary Portland Cement (OPC) with calcined clay as a supplemental cementitious material (SCM) to reduce CO2 emissions in the cement manufacturing industry. Bacillus Sphaericus bacteria with a bacterial population of 108 cells/ml and calcined clay are used in the study to examine the self-healing properties of concrete. The findings demonstrate that bacteria-embedded concrete with calcined clay substitution improves compressive strength and decreases water absorption when compared to ordinary concrete. In all mixtures, with the exception of concrete with embedded bacteria, the study finds that compressive strength decreases as calcined clay percentage increases. By causing calcite to precipitate in the spaces between aggregate pores, the incorporation of bacteria greatly improves compressive strength. Because fine calcined clay is used to fill the pores, calcined clay concrete has a lower water absorption rate than ordinary concrete. Finally, it was discovered that the performance of bacterial concrete was good in that it achieved more strength and decreased permeability when compared to ordinary concrete.[9]

BACILLUS MEGATERIUM

(Nagarajan, 2017) A safe and economical bacteria called Bacillus megaterium can be created in a lab. When this bacterium is added to concrete, specifically at a concentration of 105 cells per ml of mixing water, the compressive strength of the resulting concrete cube is maximised. When compared to regular concrete, it has been demonstrated that using Bacillus megaterium can boost concrete's compressive strength by up to 10.92% at 28 days. The split tensile strength and flexural strength of concrete have also significantly increased when this bacteria is used in comparison to ordinary concrete. In conclusion, Bacillus megaterium can be safely employed to improve the strength properties of concrete and is simple to culture.[10]

(Nain, 2019) The researchers came to the conclusion that Bacillus megaterium, Bacillus subtilis, and their consortia were used to increase the compressive and tensile strength of concrete as well as to help microcracks mend more quickly. After pond-curing for 7 and 28 days, the bacteria were added to the water used in the concrete mix, and the finished blocks were tested for compressive and tensile strength. According to the findings, all three bacterial treatments had greater compressive and tensile strengths than regular concrete. With regard to compressive strength and tensile strength, B. megaterium demonstrated increases of 22.5% and 18.49%, respectively, while consortia demonstrated increases of 15.8% and 19.58%, respectively. The study also discovered that bacterial application can promote crack self-healing. Even after 7 days, it was discovered that B. megaterium was less effective than B. subtilis at getting precipitation. Overall, the research points to bacterial application as a workable solution for controlling microcracks and boosting concrete strength.[11]

BACILLUS PASTEURII

(Maheswaran, 2014) discusses the process of bio-mineralizing calcium carbonate in the cement mortar matrix using Bacillus cereus and Bacillus pasteurii in various cell concentrations to increase the compressive strength of cement mortar. In comparison to the control cement mortar, the inclusion of bacterial cultures from both species increased the compressive strength by 38% in the case of B. cereus and 29% in the case of B. pasteurii, the quick chloride permeability test verified that there was less chloride penetration in the B. cereus-infused concrete than there was in the control sample. The calcite precipitation was verified by characterisation studies using several experimental methods. Being able to prevent chloride from penetrating concrete structures and achieving a large improvement in strength with B. cereus in cement mortar is a crucial factor, especially in a maritime environment.[12]

(Chahal, Siddique and Rajor, 2012) results of an experimental examination into the impact of Sporosarcina pasteurii bacteria on the compressive strength and fast chloride permeability of fly ash concrete are presented. Fly ash was substituted for cement to variable degrees, resulting in three different bacteria concentrations. According to the findings, adding S. pasteurii to fly ash concrete increased its compressive strength and decreased its porosity and permeability. With 105 bacterium cells/ml, a maximum increase in compressive strength (22%) and a reduction in water absorption by four times were seen. The accumulation of bacteria on the cell surfaces inside the holes caused calcium carbonate to precipitate, which was the cause of this improvement. The durability and shelf life of concrete buildings were improved by the bacterial calcite deposition, which also caused a reduction in chloride permeability of roughly eight times. The study's conclusion is that the use of bacteria like S. pasteurii may enhance the strength and longevity of fly ash concrete by having a self-healing effect.[13]

CONCLUSION

The According to the available literature the bacteria incorporation in concrete seems a better option to reduce the maintenance cost of the structure. Bacteria incorporation increases the initial cost of the concrete but it reduces the maintenance cost. Bacillus subtilis bacteria is used by many researchers. At 10% bacterial content and the concentration of 105 cell/ml, bacillus subtilis shows an optimum behavior. For other bacteria more research to be needed to understand their behavior.

REFERENCES

[1] T. V. S. V. Lakshmi, C. Venkata, S. Rama Prasad, and T. V. S. Vara Lakshmi, "Effect of Bacillus subtilis on abrasion resistance of Bacterial Concrete," 2018. [Online]. Available: http://www.ripublication.com

[2] C. V. S. R. Prasad and T. V. S. V. Lakshmi, "Experimental investigation on bacterial concrete strength with Bacillus subtilis and crushed stone dust aggregate based on ultrasonic pulse velocity," in *Materials Today: Proceedings*, Elsevier Ltd, Jan. 2020, pp. 1111–1117. doi: 10.1016/j.matpr.2020.01.478.

[3] C. S. S. Durga, N. Ruben, M. S. R. Chand, and C. Venkatesh, "Performance studies on rate of self healing in bio concrete," in *Materials Today: Proceedings*, Elsevier Ltd, Jan. 2020, pp. 158–162. doi: 10.1016/j.matpr.2019.09.151.

[4] S. Mondal, P. Das, and A. K. Chakraborty, "Application of Bacteria in Concrete," 2017. [Online]. Available: www.sciencedirect.comwww.materialstoday.com/proceedings2214-7853

[5] B. S. Shashank, P. Kumar.K, and P. S. Nagaraja, "Fracture behavior study of self-healing bacterial concrete," *Mater. Today Proc.*, vol. 60, pp. 267–274, Jan. 2022, doi: 10.1016/j.matpr.2021.12.520.

[6] F. Nosouhian, D. Mostofinejad, and H. Hasheminejad, "Influence of biodeposition treatment on concrete durability in a sulphate environment," *Biosyst. Eng.*, vol. 133, pp. 141–152, May 2015, doi: 10.1016/j.biosystemseng.2015.03.008.

[7] B. Madhu Sudana Reddy and D. Revathi, "An experimental study on effect of Bacillus sphaericus bacteria in crack filling and strength enhancement of concrete," in *Materials Today: Proceedings*, Elsevier Ltd, 2019, pp. 803–809. doi: 10.1016/j.matpr.2019.08.135.

[8] P. Jagannathan, K. S. Satya narayanan, K. devi arunachalam, and S. kumar annamalai, "Studies on the mechanical properties of bacterial concrete with two bacterial species Abstract Bacterial Concrete Is a Concrete ,Where The Properties Of Concrete Are Modified Using Selected Bacteria. Bacillus Sphaericus And Bacillus Pasteurii Where Selected Based On Literature Review To Enhance The Strength And Durabulity Of Concrete. When 10% Of Cement Is," 2018. [Online]. Available: www.sciencedirect.comwww.materialstoday.com/proceedings

[9] A. K. Parashar, N. Gupta, K. Kishore, and P. A. Nagar, "An experimental investigation on mechanical properties of calcined clay concrete embedded with bacillus subtilis," in *Materials Today: Proceedings*, Elsevier Ltd, 2021, pp. 129–134. doi: 10.1016/j.matpr.2020.08.031.

[10] V. Nagarajan, T. Karthik Prabhu, M. Gowri Shankar, and P. Jagadesh, "A Study on the Strength of the Bacterial Concrete Embedded with Bacillus Megaterium," *Int. Res. J. Eng. Technol.*, 2017, [Online]. Available: www.irjet.net

[11] N. Nain, R. Surabhi, N. V. Yathish, V. Krishnamurthy, T. Deepa, and S. Tharannum, "Enhancement in strength parameters of concrete by application of Bacillus bacteria," *Constr. Build. Mater.*, vol. 202, pp. 904–908, Mar. 2019, doi: 10.1016/j.conbuildmat.2019.01.059.

[12] S. Maheswaran *et al.*, "Strength improvement studies using new type wild strain Bacillus cereus on cement mortar," 2014. [Online]. Available: https://about.jstor.org/terms

[13] N. Chahal, R. Siddique, and A. Rajor, "Influence of bacteria on the compressive strength, water absorption and rapid chloride permeability of fly ash concrete," *Constr. Build. Mater.*, vol. 28, no. 1, pp. 351–356, Mar. 2012, doi: 10.1016/j.conbuildmat.2011.07.042.