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Synergistic Effects of CTP and *Bacillus megaterium* on Concrete Properties

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Abstract

Concrete deterioration is primarily caused by shrinkage, temperature changes, and reinforcement corrosion, which lead to crack formation. Continuous external loading can cause cracks to widen and form a network of cracks, enabling the infiltration of harmful gases, liquids and moisture, which weakens the strength and in turn the durability of concrete. Consequently, implementing measures to prevent degradation and to enhance the longevity by increasing durability of concrete is crucial. Continuous research efforts all around the globe have focused on enhancing concrete strength and durability using high-quality materials, additives including Supplementary Cementitious Materials (SCMs), and fibers. Ceramic Tiles Powder (CTP), fly ash, silica fume, and other materials have gained attention as SCMs, with CTP showing potential due to its high silicate and aluminum oxide content. The use of *Bacillus megaterium* in CTP-embedded concrete has scarcely been studied, prompting this research to explore its feasibility. This present research work investigates the strength and durability of M30 grade concrete with use of *Bacillus megaterium* at a concentration of 10^5 cells/ml and with varying cement replacement percentages (5%, 10%, 15%, and 20%) using CTP. The test results indicate about 25% improvement in compressive strength of concrete with 10% cement replacement using CTP and *Bacillus megaterium* of concentration 10^5 cells/ml. Petrographic analysis showed better surface composition, while SEM (Scanning Electron Microscope) images revealed increased calcite precipitation and reduced voids.

Keywords: Bacterial Concrete, *Bacillus megaterium*, Biomineralization, Ceramic Tiles Powder, Durable Concrete.

Introduction

Concrete is a widely used construction material, and its demand continues to grow at an annual rate of approximately 2.5% (1). The development of cracks caused by various factors increases the deterioration rate and hence hampers strength and durability to a great extent. Hence, it is imperative to develop techniques to reduce crack development and/or repair the cracks that have developed. Past research efforts have shown the successful implementation of bacteria to heal the developed cracks through calcite formation. Calcite crystals begin to precipitate when the surrounding solution reaches a certain level of supersaturation, with bacterial cell walls serving as nucleation sites. Further densification of calcite crystals fills the concrete's microcracks and voids, resulting in improved strength and durability. This process is known as Microbiologically Induced Mineral Precipitation (MIMP). Bacterial spores are dormant and cannot germinate or reproduce immediately in fresh concrete, but they can become active once the environment becomes suitable.

Besides this, continuous research efforts are being employed to use SCMs. The presence of high silicate and aluminium oxide in CTP makes it a proper candidate to be employed as SCMs. The powder derived from ceramic tile waste contains reactive pozzolanic materials with a high silica content, which reacts with calcium hydroxide ($Ca(OH)_2$) to form additional calcium silicate hydrate (C-S-H) gel. Replacing cement with CTP utilizes tile waste, reduces cement usage, and enhances concrete strength and durability.

Extensive research confirms that cement production generates significant greenhouse gas emissions. Hence, continuous research efforts are being put into obtaining quality concrete with reduced cement content using SCMs. At the same time, it is equally important to achieve long-term performance from concrete, especially durability. Periodic maintenance/repair of concrete structures can sometimes be costly and time-consuming. Hence, continuous research efforts are

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being carried out regarding the self-healing of concrete. The following sections outline the research efforts carried out in the selected domain of self-healing concrete and the use of SCMs as a partial replacement of cement in concrete.

Bacterial Concrete

Numerous experimental research efforts undertaken in the past century have enhanced the quality of concrete because of the presence of bacteria. Figure 1 provides details of the microbes that researchers have used to improve the quality of concrete. In these research efforts, the optimal bacteria dosage was found to be between 10^5 cells/ml to 10^7 cells/ml. The extent of improvement in the quality of the concrete may vary based on the concentration of the bacteria.

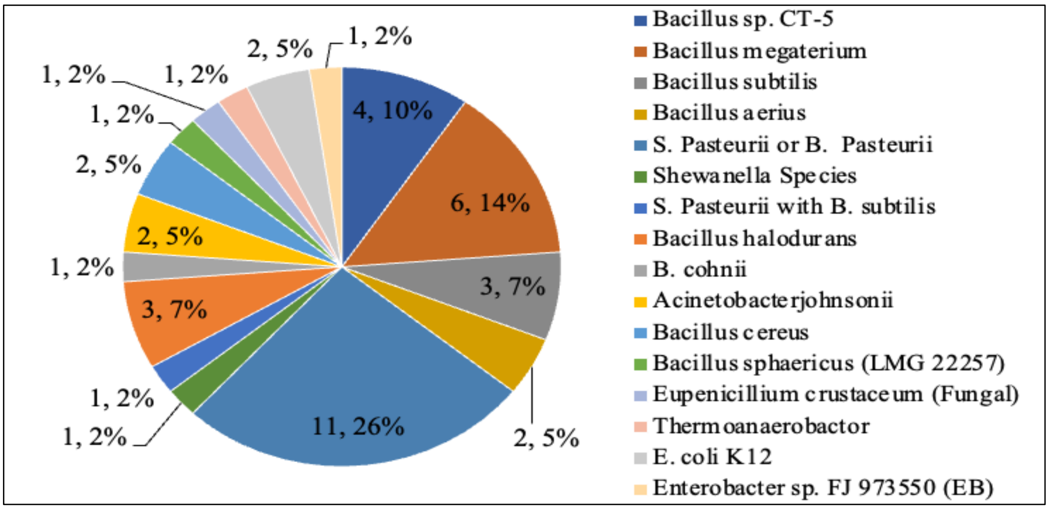

Figure 1: Percentage of Usage of Microbes in Concrete (2)

The process and metabolic reactions responsible for calcite deposition in concrete can be found in previous research work (3). Application of various *Bacillus megaterium* groups of bacteria with specific proposed dosages of bacteria concentration has shown an increase in compressive strength of concrete in the range of 10% to 55% (4–16). The experimental results obtained by past researchers demonstrate that adding S. pasteurii or Bacillus pasteurii type bacteria in different dosages results in 10% to 30% improvement in compressive strength (17–28). Applications of Bacillus Halodurans, Bacillus Cohnil, Thermoanaerobacter, E. coli K12, etc., resulting in improvements in concrete properties, can be found in past research efforts (29–35).

Suitability of Bacteria for Concrete Applications

Bacterial characteristics are crucial for its use in the concrete. The bacteria must be strong enough to survive in extreme heat, pressure, and moisture conditions. Bacteria must be endospore-forming and withstand the high pH of concrete. Additionally, they must be gram-positive, as gram-positive bacteria only produce endospores. Also, they must exhibit high urease activity to facilitate calcite formation. Most of the bacteria listed in Figure 1 possess these properties.

Ceramic Tiles Powder (CTP)

The ceramic tile manufacturing process requires high temperatures, typically achieved by burning various fuels, which significantly contribute to the carbon footprint. Also, the ceramic tile industry produces ceramic tile waste of about 2.5% of the total production capacity (2). Disposing ceramic tile waste on the open land is another critical environmental issue. From the EDS spectrum of the CTP presented in Figure 2 and the elemental composition shown in Table 1, it is evident that the CTP serves as a pozzolanic material, composed primarily of siliceous and aluminous compounds. CTP reacts with $Ca(OH)_2$ in presence of water to produce cementitious compounds. Hence, CTP can be a potential candidate for use in concrete as a material with partial cement replacement. Dedicated work in improving concrete properties using CTP can be found in research efforts of the past few decades (36).

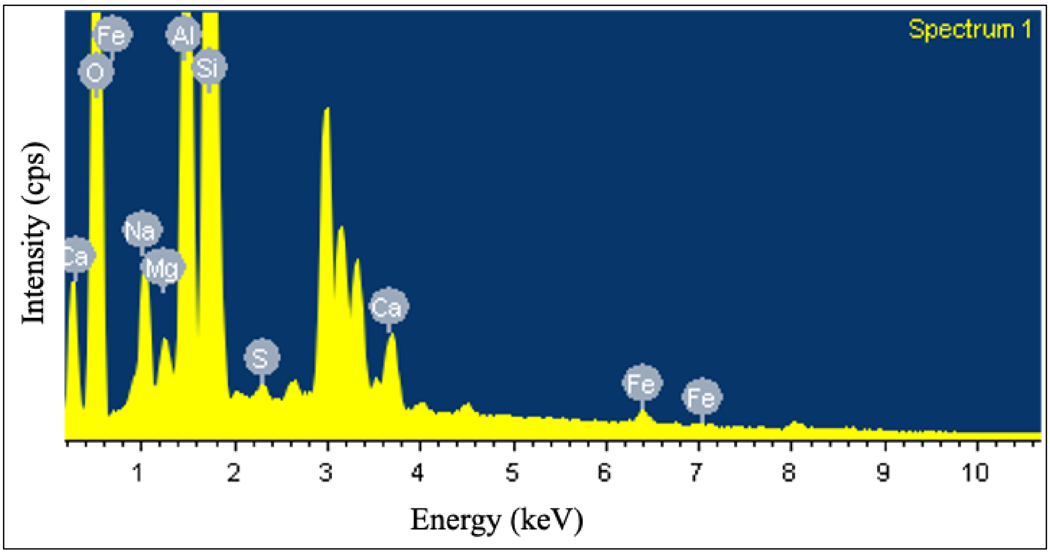

Figure 2: EDS Spectrum for CTP Sample

Table 1: Elemental Composition of CTP Sample for Concrete Application

Element	Weight (%)	Atomic (%)
O K	50.06	63.68
Na K	2.37	2.10
Mg K	0.69	0.58
Al K	8.92	6.73
Si K	35.51	25.73
S K	0.27	0.17
Ca K	1.48	0.75
Fe K	0.68	0.25

Materials and Methodology

A gap in research efforts in the existing literature volume in combining the use of SCMs, particularly CTP, and imparting self-healing properties using bacteria lead to the present research effort. The combination of *Bacillus megaterium* bacteria and Ceramic Tile Powder (CTP) has been chosen considering their complementary roles in enhancing concrete properties. *Bacillus megaterium*, known for its urease-producing ability that facilitates microbial induced calcite precipitation, which can improve durability and strength of concrete by filling voids in the concrete matrix. On the other hand, CTP, as a supplementary cementitious material, contributes to the concrete's strength through pozzolanic reactions. By combining these two additions, it is hypothesized that the microbial action of *Bacillus megaterium* will enhance the benefits of CTP, leading to a synergistic effect on the compressive strength and long-term durability of the concrete. Previous research efforts have highlighted the benefits of using bacterial agents like *Bacillus megaterium* and the effects of supplementary cementitious materials (other than CTP) on concrete performance (15, 17, 28, 31, 33). This research proposes the optimal percentage of cement replacement with CTP for the ideal dosage of the *Bacillus megaterium* strain MTCC 10086. The effects of incorporating bacteria and CTP into concrete are analyzed by comparing the compressive and tensile strengths of CTP-embedded bacterial concrete with those of the control M30 grade concrete mix. The following subsections outline the properties of various ingredients used to produce CTP-embedded bacterial concrete.

Morphology of CTP Particles

The morphology and surface characteristics of the CTP particles were analyzed using the Energy Dispersive X-ray Spectroscopy (EDS) spectrum. Figure 2 shows the EDS Spectrum for the CTP sample. Table 1 presents the elemental composition of the CTP sample for concrete use, along with their respective percentages.

Microbial Culture Collections

In this present experimental investigation, *Bacillus megaterium* strain MTCC 10086 procured from MTCC-Chandigarh, India, is employed. The N-broth liquid medium is used to culture and promote the growth of bacteria. The growth media is prepared by combining 28 gm of N-broth with 1 litre of distilled water with heat to dissolve N-broth entirely in water. The medium is sterilized in an autoclave at 121º Celsius with 15 pounds of pressure for 15 minutes, refer to Figure 3. After sterilization, the medium is cooled and distributed into different containers, while maintaining the prescribed temperature. The cultural media are now ready for deployment.

Properties of Concrete Ingredient

Following the guidelines of BIS:10262 (2019) concrete mix design is carried out to obtain M30 grade concrete (37). Fresh and defect-free Ordinary Portland Cement (OPC) from Ultratech is used in all concrete mixes. Cement was tested to verify BIS:12269 (2013) code requirements (38). Following the BIS:383 (2016) guidelines, coarse aggregates are mixed in a ratio of 30% for 20 mm size and 70% for 10 mm size, based on the total aggregate weight (39). The properties of coarse aggregate and fine aggregate are mentioned in Table 2.

The water quality used for concrete mixing is assessed according to the guidelines outlined in BIS:456 (2000) (40). Ceramic tile waste is obtained from the various ceramic industries near Morbi City. The collected waste is then crushed into a fine powder with a particle size of less than 90 micros under controlled conditions at YOR Laboratory, Rajkot. Physicochemical characteristics of cement and CTP obtained following the ASTM-C1240 (41) and ASTM-C618 12a (42) are shown in Table 3.

Figure 3: Sterilization of Medium in Autoclave

Table 2: Properties of Aggregates

	Fine Aggregates	Coarse Aggregates
Sp. Gravity	2.52	2.71
Zone	II	–
Water Absorption (%)	1.03	0.48

Table 3: Physicochemical Characteristics of Cement and CTP

	Cement	CTP
Colour	Gray	Creamy white
Sp. Gravity	3.15	1.217

Moisture content	--	0.19
Water absorption	--	19
Fineness	90 microns	75 microns
Chemical Composition by % of Mass		
SiO_2	23.29	65.04
CaO	61.87	0.66
Al_2O_3	6.14	22.56
Fe_2O_3	4.49	2.12
MgO	4.51	2.88
SO_3	3.13	0.10
$K_2O + Na_2O$	1.04	-

Concrete Specimens

Concrete cube specimens of 150 mm size for the compression test were prepared and tested following the procedures outlined in BIS: 516 (1959) (43), while concrete cylindrical specimens of 150 mm diameter and 300 mm height for the split tensile test were prepared and tested according to the guidelines specified in BIS: 3085 (1965) (44). As part of the current experimental investigation, six distinct M30-grade concrete mixes are considered. The first series comprises a control mix (M1), 0% CTP and 0% bacteria. In all other bacterial concrete mixes, 10% of the water is substituted with *B. megaterium* with cell concentration of 10^5 cells/ml each. The notations BC1 to BC5 represent bacterial concrete mixes with 0% to 20% cement replacement by CTP, in 5% intervals. Water-Cement ratio of 0.48 is used for each concrete mix. The quantity of concrete ingredients in each concrete mix is shown in Table 4. Each concrete mix containing three specimens is cured in portable water at 27º ± 2º Celsius for a predetermined time as specified in BIS:516 (1959) (43) and subsequently tested to determine the compressive and tensile strengths. The compressive and tensile strength of the concrete for each mix are represented by the average values obtained from three cubes and three cylinders, respectively.

Table 4: Ingredient Quantities for Concrete Mixes

Concrete Mix	**Cement (kg/m^3)**	**CTP (kg/m^3)**	**Coarse Agg. (kg/m^3)**	**Fine Agg. (kg/m^3)**	**Water (kg/m^3)**	**Bacteria (10^5 cells/ml) in ltr/m^3**
M1	387.50	(0%) 00.00	1222.70	681.61	199.03	00.00
BC1	387.50	(0%) 00.00	1222.70	681.61	179.13	19.90
BC2	368.13	(5%) 19.37	1222.70	681.61	179.13	19.90
BC3	348.76	(10%) 38.75	1222.70	681.61	179.13	19.90
BC4	329.39	(15%) 58.12	1222.70	681.61	179.13	19.90
BC5	310.02	(20%) 77.50	1222.70	681.61	179.13	19.90

Results and Discussion

This section presents a detailed discussion of the results from compressive strength and tensile strength tests, along with the microstructural examination using SEM and EDS techniques. Figure 4 shows the compressive strength of each concrete mix at different specimen ages. A comparison between mix BC1 and the control mix M1 clearly demonstrates that the compressive strength of the concrete increases with the addition of bacteria, continuing to improve with age, reaching a maximum enhancement of 7.3% at 56 days. The increase in compressive strength can be attributed to the additional deposition of calcium carbonate ($CaCO_3$) within the concrete matrix pores, produced by *Bacillus megaterium*. The urease enzyme produced by the bacteria promotes calcium carbonate mineralization by raising the pH through ammonia production. This, in turn, facilitates the formation of carbonate ions, which combine with calcium to form $CaCO_3$. This process is a fundamental aspect of microbial-induced calcite precipitation. Similar observations are found in other research works (8, 11, 18). The compressive strength is observed to increase further with the partial replacement of cement by CTP. Similar to other supplementary cementitious materials (SCMs) like fly ash, CTP enhances the compressive strength of concrete by promoting the hydration process through pozzolanic reactions and filling voids within the mix. The maximum increase in strength at 7 days, 28 days, and 56 days age is 22.9%, 24.57%, and 25.58%, respectively, achieved for 10% cement replacement with CTP, i.e. concrete mix BC3.

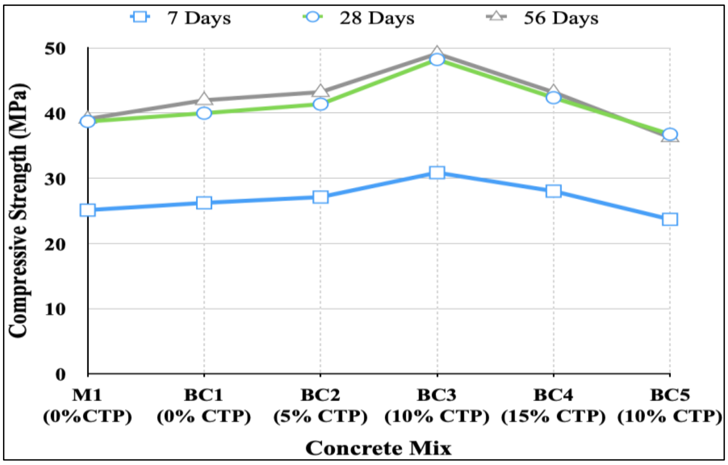

Figure 4: Compressive Strength of Concrete Specimens

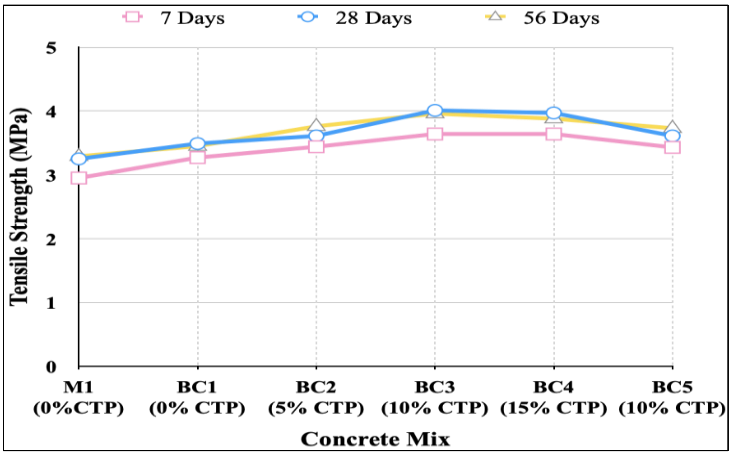

Figure 5: Tensile Strength of Concrete Specimens

A comparable trend of strength improvement is also observed in the tensile strength of the concrete mixes. It can be seen from Figure 5 that the increase in tensile strength of concrete specimens with addition of bacteria and CTP is highest at an early age of 7 days for all mixes. Similar to compressive strength results, the maximum improvement in tensile strength is achieved for concrete mix having 10% cement replacement with CTP. The tensile strength improvement relative to the control mix (M1) is 23.39%, 23.38%, and 20.36% at concrete ages of 7, 28, and 56 days, respectively, for concrete mix BC3, which contains a 10% cement replacement with CTP. The increase in both compressive and tensile strength of concrete mix BC3 is attributed to pozzolanic reactions and the enhanced microstructure resulting from the pore-filling ability of CTP, with 10% cement replacement being optimal. Interestingly, unlike compressive strength behaviour, the improvement in tensile strength diminishes at later ages, precisely at 56 days, compared to the values observed at 7 and 28 days across all specimens. Also, the tensile and compressive strength results showed minimal or no further improvement in both compressive and tensile strengths at 56 days compared to 28 days. This suggests that the beneficial effects of the bacterial agent on concrete strength are most pronounced during the early stages of curing, with little additional enhancement or no enhancement observed over time, likely due to the stabilization of microbial activity and the completion of the cement hydration process.

For SEM and EDS analysis, samples were collected from at least three different locations of each tested concrete specimen at 28 and 56 days of age. A consistent trend was observed across all samples from the tested specimens, and therefore, representative results from the SEM and EDS analysis of different concrete mixes are included in this paper. Figure 6 shows the 10μm size SEM image of control concrete specimen (M1), the concrete specimen prepared by 10% replacement of cement with CTP (BC1), and the bacterial concrete specimen prepared by 10% replacement of cement with CTP (BC3). It is clearly observed that in concrete mix BC1, the voids in the concrete matrix are filled with crystalline calcite deposits resulting from microbial-induced precipitation, caused by the presence of *Bacillus megaterium* bacteria in the concrete matrix. The reduction of voids is further evident in the concrete specimen BC3, which demonstrates the influence of additional C-S-H gel produced and the pore-filling ability of CTP, as can be seen in Figure 6(c). Figure 7 displays the 5μm size SEM image of the representative sample obtained from failed concrete specimens tested at 56 days of age.

Elemental analysis or chemical characterization of materials can be performed using energy-dispersive X-ray spectroscopy, which relies on the interaction between an X-ray excitation source and the sample. The EDS spectrum displays the energy emitted by elements on the vertical axis, and the horizontal axis represents the atomic number of these elements. Analysis of the EDS spectra from two separate locations on the specimen reveals a consistent distribution of all elements. Hence, as stated before the representative results from the EDS analysis of different concrete mixes are included in this paper. Figure 8 illustrates the peaks found when EDX was performed on control concrete (M1) and bacterial concrete (BC3).

The calcite precipitation due to bacteria is an ongoing process within the concrete matrix. It can be observed from Figure 6 and Figure 7 that both the bacterial concrete specimens (BC3), prepared by replacing 10% of the cement with CTP, and BC1, prepared without cement replacement with CTP, exhibit a higher amount of calcite and fewer cavities compared to the control mix (M1). This observation is further supported by the EDS spectrum shown in Figure 8(D) for the 56-day specimen, where the intensity of the Ca peak is significantly higher than that seen for the 28-day specimen in Figure 8(C). The increase in the percentage of Ca, as shown in Table 5 for the 56-day specimens compared to the 28-day specimens, indicates densification due to the precipitation of $CaCO_3$, which results from microbial-induced calcite precipitation.

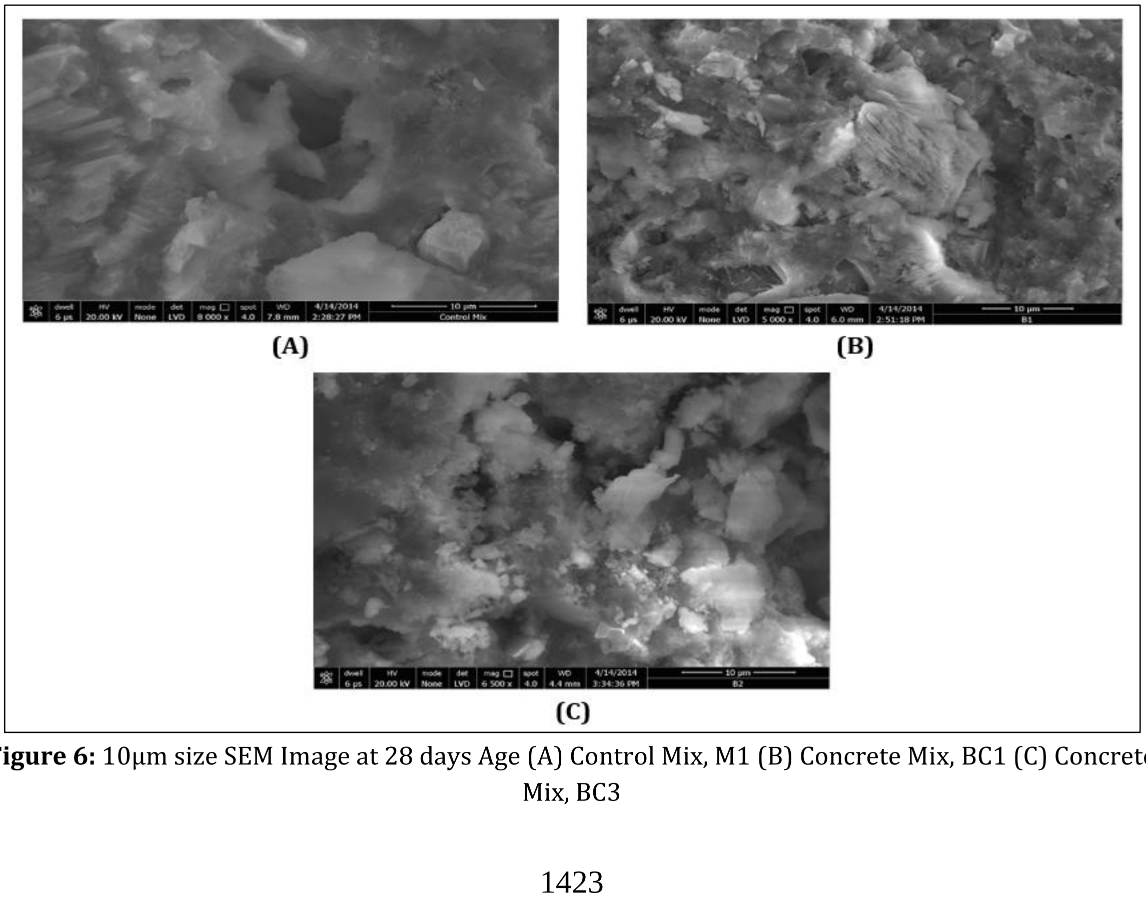

Figure 6: 10μm size SEM Image at 28 days Age (A) Control Mix, M1 (B) Concrete Mix, BC1 (C) Concrete Mix, BC3

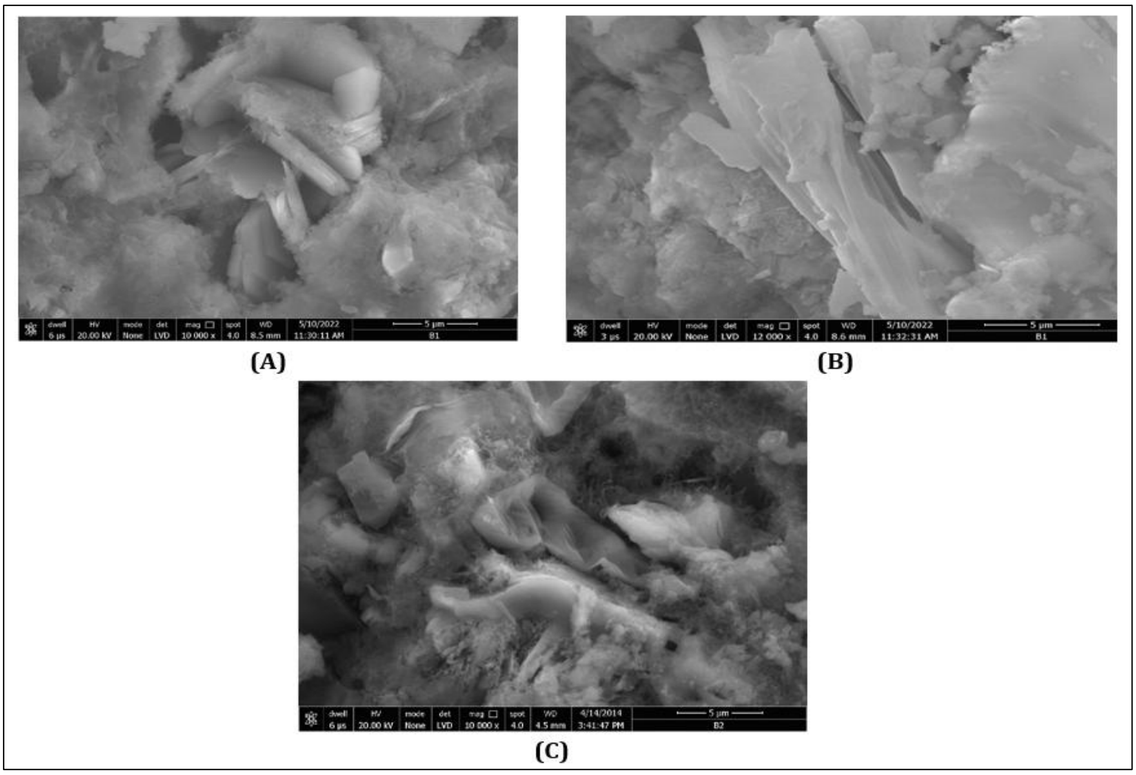

Figure 7: 5µm size SEM Image at 56 days Age (A) Control Mix, M1 (B) Concrete Mix, BC1 (C) Concrete Mix, BC3

Table 5: Elemental Composition of Concrete Mixes

Element	Weight (%)	Atomic (%)	Weight (%)	Atomic (%)	Weight (%)	Atomic (%)	Weight (%)	Atomic (%)
	Concrete Mix (M1) 28 days age		Concrete Mix (M1) 56 days age		Concrete Mix (BC3) 28 days age		Concrete Mix (BC3) 56 days age	
C K	4.32	8.11	4	7.45	2.84	5.13	4.58	8.19
O K	42.82	60.36	42.95	60.65	48.51	65.82	48.1	64.53
Al K	1.83	1.53	0.62	0.57	2.85	2.29	0.41	0.36
Si K	6.76	5.43	2.66	2.21	9.19	7.1	1.88	1.5
P K	0.13	0.09	9.71	7.74	0.12	0.08	6.27	4.79
S K	0.34	0.24	0.31	0.22	0.51	0.34	0.54	0.36
K K	0.31	0.18	0.67	0.39	0.29	0.16	0.11	0.06
Ca K	40.87	23	35.89	20.05	33.95	18.39	36.85	19.73
Fe K	2.62	1.06	3.19	1.28	1.75	0.68	1.26	0.49

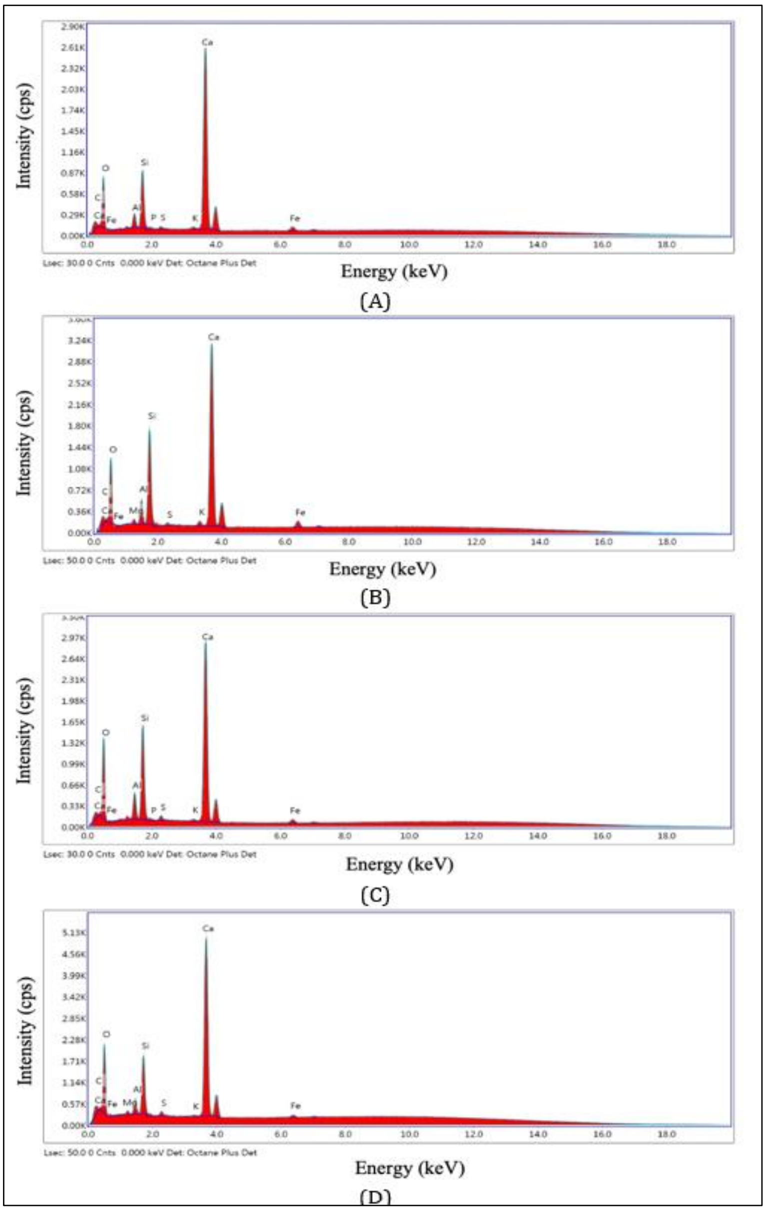

Figure 8: EDS Spectrum for (A) Control Mix (M1) at 28 Days (B) Control Mix (M1) at 56 Days (C) Concrete Mix (BC3) at 28 Days (D) Concrete Mix (BC3) at 56 Days

Conclusions

In the present work, a parametric analysis is carried out to evaluate the impact of using CTP as a supplementary cementitious material (SCM) in conjunction with bacteria, specifically *Bacillus megaterium* strain MTCC 10086, at 10^5 cells/ml. Various Concrete mixes with 5% to 20% cement replacement with CTP were designed following the guidelines stipulated in BIS 10262-2019 (37). Compared to the control mix specimens, the compressive and tensile strength improvements of about 25% are observed in CTP-embedded bacterial concrete specimens, BC3. The increase in strength of CTP-embedded bacterial concrete specimens over time is due to the densification of voids due to the bacterial metabolic activity within the concrete mix as well as due to pozzolanic reactions and the enhanced microstructure, which results from the pore-filling capacity of CTP, with the optimal cement replacement being 10%. This phenomenon has also been observed in SEM images of concrete samples obtained from tested specimens. SEM images of the bacterial concrete specimen reveal more calcite precipitation and a lesser degree of void formation. The EDS spectrum verifies the elements contained in the concrete sample. The analysis of the test results from the present study suggests that CTP has the potential to serve as a sustainable building material, enhancing the overall quality of concrete and showing good compatibility with bacteria.

Abbreviations

$Ca(OH)_2$: Calcium Hydroxide, CSH: Calcium Silicate Hydrate, CTP: Ceramic Tiles Powder, EDS: Energy Dispersive Spectroscopy, EDXS: Energy Dispersive X-ray Spectroscopy, MIMP: Microbiologically Induced Mineral Precipitation, SCMs: Supplementary Cementitious Materials, SEM: Scanning Electron Microscope.

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Author Contributions

Dr. Kishor B. Vaghela: conducted all experimental work, analyzed the results and prepared the report, Dr. Jayeshkumar Pitroda: guidance for conducting this study, and contribution in analysing the results, and Dr. Tushar Bhoraniya: provided valuable insights and support in data interpretation, manuscript refinement, and overall research validation.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethics Approval

No ethical clearance certificate applies to the present study.

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References

1. Zhu T, Paulo C, Merroun ML, Dittrich M. Potential application of biomineralization by Synechococcus PCC8806 for concrete restoration. Ecological Engineering. 2015;82:459–68.
2. Vaghela K, Pitroda J. To Investigate The Impact of Ceramic Tile Powder On Concrete Properties. International Journal of Engineering Trends. 2021;69(8):11–6.
3. Santhosh K, Ramchandran V. Remediation of concrete using Microorganisms- with B. Pasteurii. ACI Materials Journal. 2001;98(1):3-9.
4. Achal V, Mukherjee A, Reddy M. Effect of calcifying bacteria on permeation properties of concrete structures. Journal of Industrial Microbiology and Biotechnology. 2011;38(9):1229–34.
5. Achal V, Mukerjee A, Reddy M. Biogenic treatment improves the durability and remediates the cracks of concrete structures. Construction and Building Materials. 2013;48:1–5.
6. Park J, Kim W, Ghim S. Application of Bacillus subtilis 168 as a Multifunctional Agent for Improvement of the Durability of Cement Mortar. Journal of Microbiology and Biotechnology. 2012; 22 (11):1568–74.
7. Siddique R, Singh K, Singh M, Corinaldesi V, Rajor A. Properties of bacterial rice husk ash concrete. Construction Building Materials. 2016; 121:112–9.
8. Siddique R, Nanda V, Kadri E, Khan MI, Singh M, Rajor A. Influence of bacteria on compressive strength and permeation properties of concrete made with cement baghouse filter dust. Construction Building Materials. 2016; 106:461–9.
9. Siddique R, Rajor A. Strength and microstructure analysis of bacterial treated cement kiln dust mortar. Construction Building Materials. 2014; 63:49–55.
10. Andalib R, Zaimi M, Majid A, Warid M, Ponraj M, Keyvanfar A. Optimum concentration of Bacillus Megaterium for strengthening structural concrete. Construction Building Materials. 2016; 118:180–93.
11. Achal V, Pan X, Özyurt N. Improved strength and durability of fly ash-amended concrete by microbial calcite precipitation. Ecological Engineering. 2011; 37(4):554–9.
12. Krishnapriya S, Babu D, Prince A. Isolation and identification of bacteria to improve the strength of concrete. Microbiological Research. 2015; 174:48–55.
13. Chaurasia L, Bisht V, Singh L, Gupta S. A novel approach of biomineralization for improving micro and macro-properties of concrete. Construction and Building Materials. 2019;195:340–51.
14. Kaur G, Kaur N, Goyal S, Mukherjee A, Reddy M. Utilization of carbon dioxide as an alternative to urea in biocementation. Construction and Building Materials. 2016;123:527–33.
15. Khaliq W, Ehsan M. Crack healing in concrete using various bio influenced self-healing techniques. 2016;102:349–57.
16. Sunil P, Seshagiri R, Aparna P and Sasikala P. Performance of standard grade bacterial (Bacillus Subtilis) concrete. Asian J Civ Eng (Building Housing). 2010;11:43–5.
17. Santosh K, Ramkrishanan V, and Sookie S. Remediation of concrete using micro-organisam. ACI Materials Journal. 2001;98(1):9.
18. Chahal N, Siddique R, Rajor A. Influence of bacteria on the compressive strength , water absorption and rapid chloride permeability of concrete incorporating silica fume. Construction and Building Materials. 2012;37:645–51.
19. Nosouhian F, Mostofinejad D, and Hasheminejad H. Concrete durability improvement in a sulfate environment using bacteria. Journal of Materials in Civil Engineering, ASCE. 2015;28(1):04015064. 20. Mohan G, Shanthi A, Anand E, and Kalaichelvan G. Experimental investigation of bacterial concrete to improve compressive strength: A microbiology and civil engineering approach. The Indian Concrete Journal. 2015;89(6):24–30.

21. Achal V, Mukherjee A, Basu P, and Reddy M. Lactose mother liquor as an alternative nutrient source for microbial concrete production by Sporosarcina pasteurii. Journal of industrial Microbiology and biotechnology. 2009;36(3):433-8.
22. Abo-el-enein S, Ali A, Talkhan F, and Abdel-Gawwad H. Application of microbial biocementation to improve the physico-mechanical properties of cement mortar. Housing and Building National Research Center - HBRC Journal. 2013;9(1):36–40.
23. Ramakrishnan V, Panchalan R, and Bang S. Improvement of concrete durability by bacterial mineral precipitation. In: 11th International Conference on Fracture 2005, ICF11. 2005;2095–100.
24. Balam N, Mostofinejad D, and Eftekhar M. Effects of bacterial remediation on compressive strength, water absorption, and chloride permeability of lightweight aggregate concrete. Construction and Building Materials. 2017;145:107–16.
25. Maheswaran S, Dasuru S, Murthy A, Bhuvaneshwari B, Kumar V, Palani G, et al. Strength improvement studies using new type wild strain Bacillus cereus on cement mortar. Current Science. 2014;106(1):50-7.
26. Li P, Jin B. Healing of cracked concrete by *Sporosarcina pasteurii* mediated carbonate deposition. 2012;164:103–6.
27. Al-salloum Y, Abbas H, Sheikh Q, Hadi S, Alsayed S, and Almusallam T. Effect of some biotic factors on microbially-induced calcite precipitation in cement mortar. Saudi Journal of Biological Sciences. 2016;24(2):286-94.
28. Ghosh P, Mandal S, Chattopadhyay B, Pal S. Use of microorganism to improve the strength of cement mortar. Cement and Concrete Research. 2005;35(10):1980-3. https://doi.org/10.1016/j.cemconres.2005.03.005
29. Siddique R, Rajor A. Influence of bacterial treated cement kiln dust on the properties of concrete. Construction and Building Materials. 2014;52:42–51.
30. Zhang Z, Ding Y, Qian S. Influence of bacterial incorporation on mechanical properties of engineered cementitious composites (ECC). Construction and Building Materials. 2019;196:195–203.
31. Li P, Liu C, Zhou W. Improved strength and durability of concrete by bacterial carbonate precipitation. 3rd International Conference on Mechatronics, Robotics and Automation. 2015;4:119–22.
32. Li P, Liu C, Zhou W. Influence of bacterial carbonate precipitation on the compressive strength and water absorption of fly ash concrete. 3rd International Conference on Mechatronics, Robotics and Automation. 2015;(Icmra):123–126.
33. Jongvivatsakul P, Janprasit K, Nuaklong P, Pungrasmi W. Investigation of the crack healing performance in mortar using microbially induced calcium carbonate precipitation (MICP) method. Construction and Building Materials. 2019;212:737–44.
34. Kaur G, Siddique R, Rajor A. Influence of fungus on properties of concrete made with waste foundry sand. 2013;(April):484–91.
35. Biswas M, Majumdar S, Chowdhury T, Chattopadhyay B, Mandal S, Halder U, et al. Enzyme and microbial technology bioremediase a unique protein from a novel bacterium BKH1, ushering a new hope in concrete technology. Enzyme Microb Technol. 2010;46(7):581–7.
36. Amr S, Mahmoud R, and Samir I. The use of Ceramic Waste Powder (CWP) in making eco-friendly concrete. Ceramic Materials - Synthesis, Characterization, Applications, Recycling and Environmental Impact. IntechOpen. 2018:10-32.
37. Indian Standard IS. 10262. Concrete Mix proportioning - guideline (second revision)—specification. New Delhi. 2019. https://standardsbis.bsbedge.com/ (Search IS 10262:2019)
38. Indian Standard IS. 12269. Ordinary Portland cement 53 grade—specification. New Delhi. 2013. https://standardsbis.bsbedge.com/ (Search IS 12269:2013)
39. Indian Standard IS. 383. Coarse and Fine Aggregate Concrete Specifications—specification. New Delhi. 2016. https://standardsbis.bsbedge.com/ (Search IS 383:2016)
40. Indian Standard IS. 456. Plain And Reinforced Concrete Arches—specification. New Delhi. 2000. https://standardsbis.bsbedge.com/ (Search IS 456:2000)
41. American Society for Testing and Materials. ASTMC1240. Standard Specification for Silica Fume Used in Cementitious Mixtures. ASTM International (ASTM); 2020. https://www.astm.org/c1240-20.html
42. American Society for Testing and Materials. ASTMC618. Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete. San Antonio, TX: ASTM International (ASTM). 2019:5. https://www.astm.org/c0618-19.html
43. Indian Standard IS. 516 (1959) Method of Tests for Strength of Concrete—specification. New Delhi. 2004. https://standardsbis.bsbedge.com/ (Search IS 516:1959)
44. Indian Standard IS. 3085 (2002) Method of Test for Permeability of cement mortar and concrete—specification. New Delhi. 2002. https://standardsbis.bsbedge.com/ (Search IS 3085:1965)