IJCRT.ORG ISSN : 2320-2882
INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

Design And Evaluation Of Bacteria Induced Calcium Carbonated Precipitation For Self-Healing Construction Material In High Rise Building

[1]Sushil, [2]Er. Rajbala*
[1]M. Tech. Scholar, [2]Asst. Professor
[1, 2,] Department of Civil Engineering
[1 ,2,]Affiliation Address: Jan Jayak Chaudhary Devi Lal Memorial College of Engineering, Sirsa, Haryana, India

Abstract

This study presents the design and evaluation of Bacteria Induced Calcium Carbonate Precipitation (BICP) for self-healing concrete in high-rise buildings. Cracks in concrete compromise structural durability, safety, and increase maintenance costs, especially in inaccessible high-rise structures. BICP utilizes Bacillus subtilis bacteria capable of precipitating calcium carbonate ($CaCO_3$) within cracks, restoring mechanical integrity and reducing permeability. Optimal bacterial concentrations were determined by varying cell counts (10^0 to 10^8 cells/ml) across M20, M25, and M30 concrete grades. Concrete mixes containing 10^5 cells/ml demonstrated significant improvements in compressive strength (25% for M20, 21% for M25, and 22% for M30), split tensile strength, flexural strength (up to 27.07%), ultrasonic pulse velocity, and reduced Cantabro loss by 15–25%. XRF analysis confirmed the formation of $CaCO_3$ precipitates within healed cracks, validating the self-healing mechanism. BICP offers a sustainable, long-term crack repair strategy, enhancing durability and reducing environmental impact in modern construction.

Keywords: BICP, $CaCO_3$, Concrete, High-rise buildings.

1. Introduction

The durability and longevity of construction materials have always been critical considerations in the field of civil engineering, particularly for high-rise buildings that are subjected to significant environmental and mechanical stresses [1]. Cracking in concrete, one of the most commonly used construction materials, poses a major threat to the structural integrity, service life, and safety of such structures [2,3]. Although concrete possesses excellent compressive strength (CS), it remains vulnerable to crack formation due to shrinkage, thermal expansion, external loading, and environmental exposure [4]. These cracks can propagate over time, allowing water and harmful chemicals to penetrate, leading to corrosion of reinforcement, reduction in strength, and increased maintenance costs [5]. Conventional repair methods, including the use of sealants, polymer injections, and manual maintenance, are often expensive, labor-intensive, and temporary, making them unsuitable for large-scale or inaccessible structural components in high-rise buildings.

To address these problems, new studies have been done on novel self-healing techniques that could automatically heal micro-cracks in concrete, hence improving durability and lowering keep costs and mandating the service life of structures [6]. “Bacteria Induced Calcium carbonate precipitation (BICP)” is one of the promising bio-based approaches to self-healing in concrete among several other self-healing mechanisms [7]. BICP consists in the application of specialized bacteria that can precipitate “calcium carbonate ($CaCO_3$)” in cracks to basically seal the cracks and reverse the mechanical properties of the substantial [8]. The ureole process is a bio-mineralization reaction that takes place as a result of addition of the ureolytic or the calcite-precipitating bacteria to the Matrix of the concrete with proper nutrients [9]. As the cracks develop and water enters, the inactive bacteria then become active, utilize the available nutrients and crystallises $CaCO_3$ deposits to block the cracks and seal them accordingly hence decreasing the permeability [10].

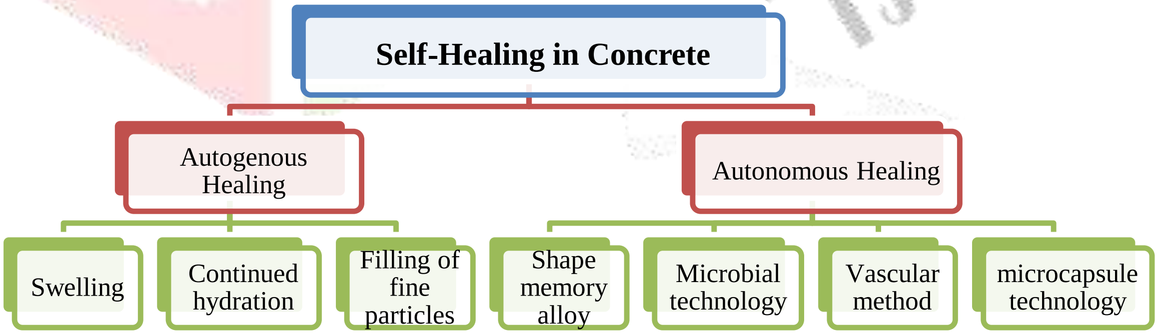

Figure 1: Self-healing in concrete [11].

The usage of BICP as a self-healing in construction material has many benefits particularly in high-rise constructions where manual repairs are cumbersome and structural integrity is most critical [12,13]. The study proposes engineering and testing of $CaCO_3$ Precipitation Bacteria-Induced Self-healing construction material in high-rise buildings. It consists in the choosing of effective strains of bacteria, in the optimization of nutrient composition, and in the inclusion of the self-healing system in concrete mixes that could be used in structures. In the study, the yield of BICP concrete is recorded by a number of experimental studies such as the level of crack-healing performance; tests of mechanical strength, the evaluation of water penetrate ability, and microstructural study. Here are the potential research objectives of the study follows as:

- To identify and select suitable bacterial strains capable of inducing calcium carbonate precipitation (MICP) for use in SHC applications.
- To design an optimized concrete mix incorporating bacterial agents and appropriate carriers (e.g., encapsulation materials) for effective delivery and survival in high-pH environments.
- To estimate the mechanical properties (CS, FS) of bacteria-infused concrete in comparison with conventional (control) concrete.
- To assess the self-healing efficiency of the bacterial concrete by analyzing crack closure and $CaCO_3$ deposition using visual inspection and microstructural techniques (e.g., XRD).

2. Literature Review

The recent efforts to use Microbially Induced Calcium Carbonate Precipitation (MICP) have gone a long way to aid self-healing and improve the long life of concrete. Sarkar et al. (2024) [14] showed that using calcareous fly ash and Bacillus cohnii endospores assisted MICP by providing extra Ca^{2+} ions to promote crack closure up to 0.8 mm, accomplishing a 40% reduction in pore diameters, increased strength, and improved durability while only increasing production costs by 7% and also decreasing emissions by 39% CO_2. Šovljanski et al. (2024) [15] combined MICP with wastewater treatment, and found out that using Bacillus licheniformis and Bacillus muralis led to BOD reduction of 99.52%, and find self-healing was quite prominent while also integrating sustainability with inevitably construction. In the same way Chen et al., (2024) [16] found that MICP could restore some bond strength to heat damaged lightweight aggregate concrete (LWAC), while also showing that the bacterial treatment could improve the strength by 20.3%.

The studies by Mohammed et al. (2024) [17] demonstrated increase in strength improvements from Sporosarcina koreensis and Bacillus flexus of up to 21.8% and cracks were completely sealed after 42 days. The study by Helal et al. (2024) [18] incorporated steel fibers and Bacillus sphaericus and achieved compressive strength improvements of 47% and some measure of durability in harsh sulfate conditions. The study by Xu et al. (2024) [19] used cellulose-based microcapsules that contain mineralizing bacteria and were able to heal cracks up to 0.3 mm wide and increase mechanical strength by 88.29%. Maurente et al. (2024) [20] demonstrated the importance of calcium availability with Bacillus subtilis and Sporosarcina pasteurii in closing cracks at 87.5 healing efficiency, while Xu et al. (2023) [21] demonstrated rapid crack healing of more than 90% sealed at 30 seconds with Bacillus cereus applied under extreme conditions and using CMC-Na as a thickener.

3. Methods and materials

3.1 Selection of bacterial and its cell count

B. subtilis is advocated for MICP in concrete due to its tolerance to alkalinity, spore-forming capability, high efficiency in calcite precipitation, safety profile, ease of culture, and shown efficacy in previous research.These features make it a superior alternative to B. sphaericus and E. coli for improving the self-healing and durability of concrete. The CS was applied to trial mixes with bacterial cell counts ranging from 10^0 to 10^8 cells/ml in order to determine the optimal cell count. M20, M25, and M30 are the concrete grades that are being explored for this purpose. According to Table 1, the grades with cell counts of 10^5 and 10^6 cells/ml had the maximum CS at 28 days on average.

Table 1: CS of diverse cell counts

Cell count (cells/ml)		**Grade**	
	M20 (MPa)	**M23 (MPa)**	**M30 (MPa)**
CC-10^0	27.44	32.13	37.62
10^1	28.30	33.41	38.46
10^2	28.71	36.12	38.56
10^3	29.11	37.61	39.72
10^4	31.08	38.26	41.62
10^5	**34.42**	**39.10**	**46.04**
10^6	**31.12**	**37.30**	**42.94**
10^7	30.26	35.17	40.71
10^8	29.03	33.90	39.85

3.2 Self-healing mechanism

Cracks in concrete constructions can appear over time due to environmental variables such temperature variations, load tension, and shrinkage. The formation of cracks in concrete allows water to penetrate the material. Bacteria that have been latent in concrete become active when exposed to water. Bacteria break down the nutrients (calcium lactate) in the concrete once they're activated. $CaCO_3$ is a byproduct of this metabolic activity. $CaCO_3$, which has just crystallized, settles into the cracks. The cracks are thoroughly sealed by this mineralization process, which restores the structural integrity of the concrete. The concrete structure's lifespan is increased as a result of the healing process, which stops further water and dangerous material infiltration.

New cracks could develop and water can penetrate the concrete again, but this time the self-healing process could recur. Because the bacteria can stay alive and self-renewing for a long time, they are capable of long-term wound healing. Working along the crack's depth, this method successfully closes cracks as narrow as 0.5 mm and prevents water and nutrients from starting. Although it effectively closes small to medium cracks, its efficacy diminishes with bigger or deeper gaps owing to restricted access to nutrients and water.

3.3 Materials and specimens

- **Cement**

The researchers in this study employed 43-grade OPC made in compliance with IS: 269-2015 (IS 2015). Cement testing revealed that the values in Table 2 for setting durations, fineness, and standard consistency were all within the acceptable range according to standards (IS 4031-1980).

Table 2: Characteristics of cement

Description	Standard consistency (%)	Fineness (%)	Sp. gravity	Setting time (min)	
				Initial	Final
OPC 43	32%	3.6%	3.14	40	600

- **Aggregate**

Table 3 shows the characteristics of the fine and coarse aggregates used in this investigation, which were made from naturally occurring minerals that were prevalent in the area.

Table 3: Characteristics of aggregates

Types of aggregates	Specific gravity	Fineness modulus (%)	Water absorption rate (%)	Bulk density (kg/m^3)	Abrasion resistance (%)	Aggregate crushing value (%)	Aggregates impact test (%)
Fine	3.53	3.6	1.32	1605			
Coarse	3.67	7.1	0.64	1714	27	25	23

- **Bacteria**

The “B. subtilis bacteria” used in this study were supplied by the “Hyderabad-based DVS BioLife Pvt. Ltd. Laboratory”. Figure 2 shows the experimental setup for the use of calcium lactate ($C_6H_{10}CaO_6$) as a nutrient in conjunction with the bacteria B. subtilis.

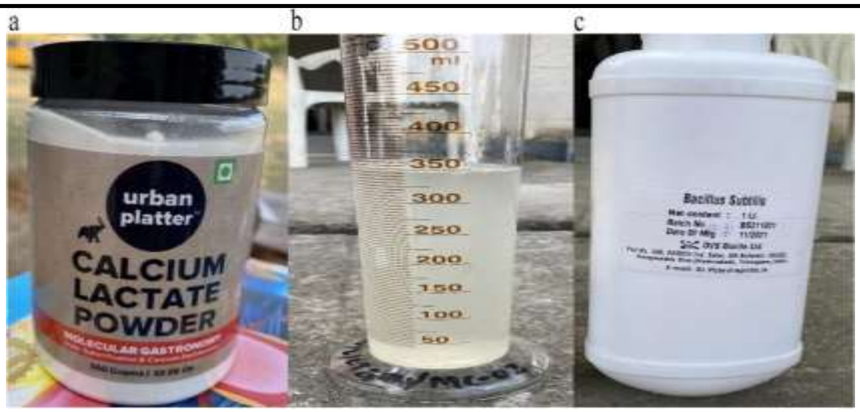

Figure 2: Presentation a calcium lactate, b B. subtilis sample, and c B. subtilis container

- **Mix proportions**

Table 4 details the quantities of cement, aggregates, water, bacteria, and calcium lactate that consider for different concrete classes.

Table 4: Mix proportions of grade concrete

Material description (kg/m^3)	**Grade**		
	M20	**M25**	**M30**
Cement binder	335	352	369
Fine aggregate	725	705	643
Coarse aggregate	1326	1293	1278
Bacteria (litres)	33.6	36	36.8
Calcium lactate	6.7	7.4	7.6

4. Result and Discussion

4.1 Compressive strength results

As seen in Figure 3, the strength of the conventional mix for M20, M25, and M30 classes of concrete was lower than that of the bacterial concrete of any grade. Strengths were also found to be greater for mixes containing 10^5 cells/ml compared to 10^6 cells/ml across all concrete grades.

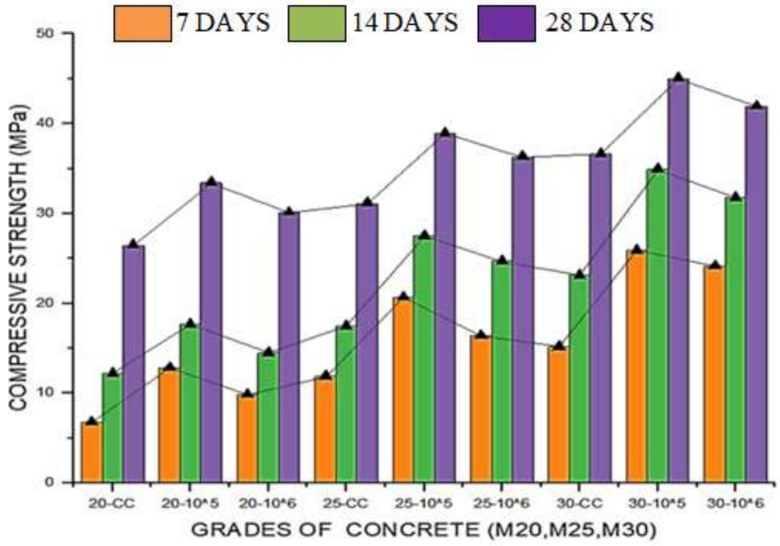

Figure 3: Different concrete grades' CS after 7, 14, and 28 days

4.2 Split tensile strength (STS) results

Figure 4 show that bacterial concrete outperforms conventional concrete in terms of STS. For all concrete classes, the results of the CS test and the STS were consistent: mixes with 10^5 cells/ml of cells had greater strengths than mixes with 10^6 cells/ml. The strength was enhanced when the bacterial cell counts were raised to 10^5 cells/ml of the precipitated calcite quantity.

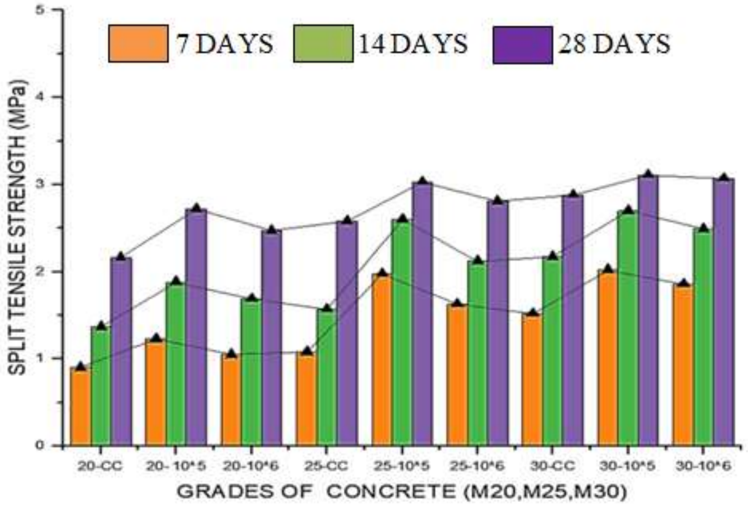

Figure 4: Different concrete grades' STS after 7, 14, and 28 days

4.3 Flexural strength (FS) results

FS of concrete is improved compared to regular concrete by the self-healing agent B. subtilis, as shown in this research. Improved CS, better concrete grades, and longer curing times were shown to be significantly correlated with greater FS. M20, M25, and M30 classes of bacterial concrete showed FS gains of 8.94%, 24.41%, and 27.07%, respectively, after 28 days when the cell concentration was 10^5 cells/ml (Figure 5).

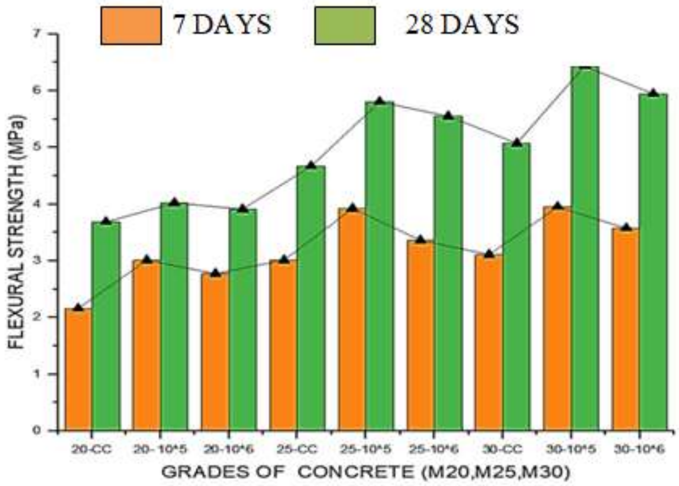

Figure 5: Different concrete grades' FS after 7, 14, and 28 days

4.4 The Chemical Composition of the Healing Crack Precipitate

The self-healing effectiveness of microbial concrete was tested by examining cracks in the material at different bacterial concentrations. The XRF analysis of the precipitate that developed on top of the cubes revealed a strong calcium (Ca) peak, as shown in Figure 6.

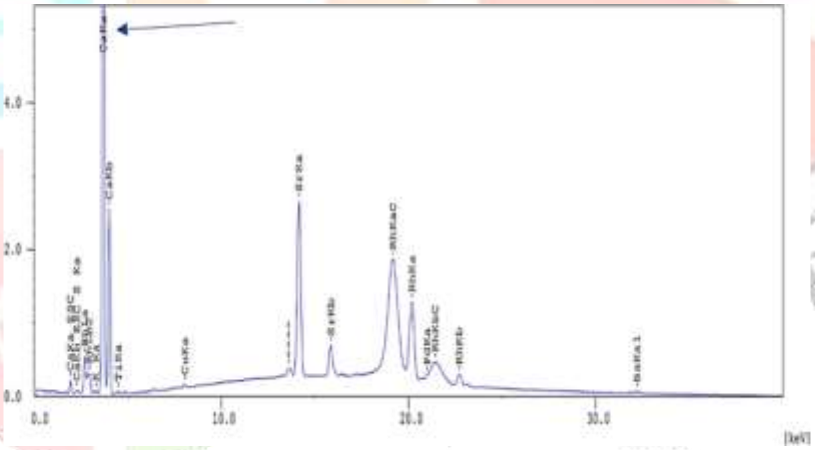

Figure 6: The XRF analysis of the precipitate

With respect to the cube specimen, Figure 7 shows the surplus of calcite that developed on top of the fractured area. It follows that the cube specimen contains a healing ingredient, calcite, which is very visible.

Figure 7: The ability of self-healing bacterial concrete to repair cracks on days 1 and 7

4.5 Ultrasonic pulse velocity (UPV) results

Standards such as IS 13311: 1992 state that non-destructive examination of both traditional and bacterial mixes is used to determine the quality grading of concrete. Pulse velocities were higher in bacterial concrete specimens (10^5 and 10^6 cells/ml) compared to the standard mixes of M20, M25, and M30 grade concrete. Bacterial cell counts of 10^5 cells/ml resulted in a somewhat greater acceleration of velocity. At 10^5 and 10^6 cells/ml, respectively, the conventional and bacterial mixtures exhibit a rising pulse velocity (Figure 8).

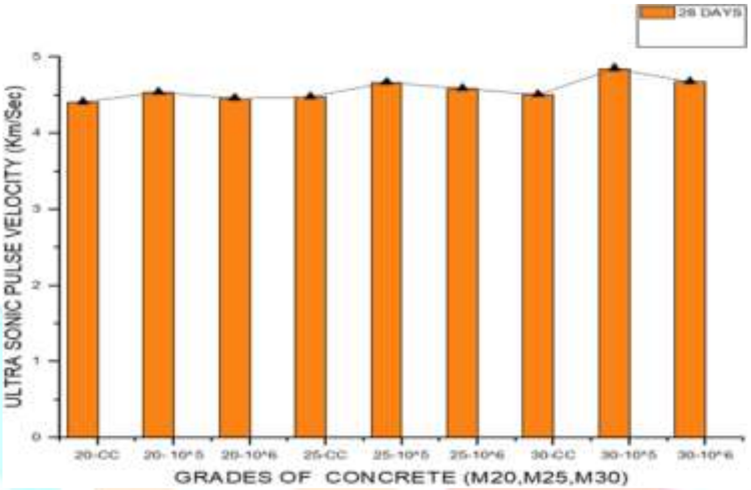

Figure 8: Evaluation of UPV of grades of concrete

4.6 Effect of B. subtillis bacteria on Cantabro loss

Figure 9 shows that the samples interacted not only with one another within the machine, but also with the abrasion machine's edges, the weights of which are used to evaluate pavement deterioration. The M20 grade of the standard concrete mix had the greatest loss. Both traditional and bacterial concrete mixes show a decline in Cantabro loss with increasing concrete grade. See Table 5 for the first loss percentages for conventional mixes of M20, M25, and M30 concrete grades: 15.53%, 15.21%, and 14.84%, respectively. Various bacterial concrete mixtures have shown a 15-25% reduction in Cantabro loss as compared to standard mixes. By introducing bacteria with an optimal cell density of 10^5 cells/ml, cantabro loss was significantly reduced.

Figure 9: Specimen forms during the 0 and 300 RPM Cantabro loss tests

Table 5: Cantabro values (%) for numerous mixes at 7, 14, and 28 days

Grade	% of bacteria	Cell count of bacteria	CAB loss at 7 days (%)	CAB loss at 14 days (%)	CAB loss at 28 days (%)
M20	0	0	17.60	17.10	16.54
	10	10^5	14.75	13.81	13.06
	10	10^6	15.26	14.62	13.45
M25	0	0	17.02	16.80	16.20
	10	10^5	14.42	13.62	12.57
	10	10^6	15.05	14.38	13.64
M30	0	0	16.82	16.46	15.85
	10	10^5	14.20	13.06	12.18
	10	10^6	14.71	14.05	12.75

5. Conclusion

The main objective of the present study was to design and test SHC, which involves addition of Bacillus subtilis bacteria into concrete to enrich these properties of concrete with regard to high-rise buildings. The methodology involved selecting optimal bacterial cell concentrations by testing various counts ranging from 10^0 to 10^8 cells/ml. Three concrete grades—M20, M25, and M30—were prepared with and without bacterial incorporation for comparative analysis. Key tests included CS, STS, FS, UPV, Cantabro loss, and chemical analysis of precipitates through XRF and XRD techniques. The results were significant and consistent across all parameters:

- **Compressive Strength:** At 28 days, bacterial concrete with 10^5 cells/ml exhibited CS improvements of 25% for M20 (from 27.44 MPa to 34.42 MPa), 21% for M25 (from 32.13 MPa to 39.10 MPa), and 22% for M30 (from 37.62 MPa to 46.04 MPa) compared to conventional concrete.
- **Split Tensile Strength:** Across all grades, bacterial concrete with 10^5 cells/ml showed superior STS, indicating enhanced resistance to crack propagation.
- **Flexural Strength:** A notable improvement in FS was observed, with increases of 8.94% for M20, 24.41% for M25, and 27.07% for M30 grades at 28 days.

Reference

1. Hoxha, Dashnor, Naima Belayachi, Xavier Brunetaud, and Sébastien Rémond. "A Critical Review on Durability of Sustainable Materials and Structures." In International Conference on Critical Thinking in Sustainable Rehabilitation and Risk Management of the Built Environment, pp. 181-199. Cham: Springer International Publishing, 2019.
2. Aruya, Grace Agbons, and Victor Kosidimma Chukwuemezie. "Causes of cracks on concrete structures and repair methods." International Journal Of Latest Engineering Research And Applications (IJLERA) 7, no. 9 (2022): 28-38.
3. ASKAR, MAND KAMAL, Y. A. M. A. N. AL-KAMAKI, and HISHAM KHALID. "CRACKS IN CONCRETE STRUCTURES CAUSES AND TREATMENTS: A."
4. Qu, Zhiwei, Yingda Zhang, Zihao Liu, Ruizhe Si, and Jie Wu. "A review on early-age cracking of concrete: Causes and control." Case Studies in Construction Materials (2024): e03848.
5. Golewski, Grzegorz Ludwik. "The phenomenon of cracking in cement concretes and reinforced concrete structures: the mechanism of cracks formation, causes of their initiation, types and places of occurrence, and methods of detection—a review." Buildings 13, no. 3 (2023): 765.
6. Hossain, Md Riad, Rabeya Sultana, Muhammad Mainuddin Patwary, Noel Khunga, Pankaj Sharma, and Sebastian Joya Shaker. "Self-healing concrete for sustainable buildings. A review." Environmental Chemistry Letters (2022): 1-9.
7. Wong, Pui Yan, Joyabrata Mal, Anna Sandak, Lijun Luo, Jianxiong Jian, and Nirakar Pradhan. "Advances in microbial self-healing concrete: A critical review of mechanisms, developments, and future directions." Science of The Total Environment (2024): 174553.
8. Zhang, Y. S., Y. Liu, X. D. Sun, W. Zeng, H. P. Xing, J. Z. Lin, S. B. Kang, and L. Yu. "Application of microbially induced calcium carbonate precipitation (MICP) technique in concrete crack repair: A review." Construction and Building Materials 411 (2024): 134313.
9. Erdmann, Niklas, and Dorina Strieth. "Influencing factors on ureolytic microbiologically induced calcium carbonate precipitation for biocementation." World Journal of Microbiology and Biotechnology 39, no. 2 (2023): 61.
10. Stanaszek-Tomal, Elżbieta. "Bacterial concrete as a sustainable building material?." Sustainability 12, no. 2 (2020): 696.
11. Kho, Yea Shiuan, Kwong Soon Wong, Nurul Noraziemah Mohd Pauzi, Meheron Selowara Joo, and Tony Hadibarata. "Self-Healing Concrete Utilizing Ureolysis Mechanism of Microbially Induced Calcite Precipitation (MICP): a Review." Iranian Journal of Science and Technology, Transactions of Civil Engineering (2024): 1-22.
12. Nduka, David O., John O. Ameh, Opeyemi Joshua, and Rapheal Ojelabi. "Awareness and benefits of self-curing concrete in construction projects: builders and civil engineers perceptions." Buildings 8, no. 8 (2018): 109.

13. Vedrtnam, Ajitanshu, Kishor Kalauni, and Martin T. Palou. "Ranking Bacteria for Carbon Capture and Self-Healing in Concrete: Performance, Encapsulation, and Sustainability." Sustainability 17, no. 12 (2025): 5353.

14. Sarkar, Manas, Moumita Maiti, Saroj Mandal, and Shilang Xu. "Enhancing concrete resilience and sustainability through fly ash-assisted microbial biomineralization for self-healing: from waste to greening construction materials." Chemical Engineering Journal 481 (2024): 148148.

15. Šovljanski, Olja, Vesna Bulatović, Tiana Milović, Jovana Grahovac, Tamara Erceg, Miroslav Dramićanin, and Ana Tomić. "Bioaugmentation of Industrial Wastewater and Formation of Bacterial–CaCO3 Coupled System for Self-Healing Cement." Buildings 14, no. 12 (2024): 4011.

16. Chen, How-Ji, Yung-Hsiang Lo, Chao-Wei Tang, and Han-Wen Chang. "Applying Microbial-Induced Calcium Carbonate Precipitation Technology to Improve the Bond Strength of Lightweight Aggregate Concrete after High-Temperature Damage." Applied Sciences 14, no. 4 (2024): 1416.

17. Mohammed, Tesfaye Alemu, Yonathan Muche Kasie, Eleyas Assefa, Yiglet Mebrat Getu, and Dereje Hailu Tufa. "Enhancing structural resilience: Microbial-based self-healing in high-strength concrete." International Journal of Concrete Structures and Materials 18, no. 1 (2024): 22.

18. Helal, Zinab, Hani Salim, Seleem SE Ahmad, Hesham Elemam, Ahmed IH Mohamed, and Mohamed AR Elmahdy. "Sustainable bacteria-based self-healing steel fiber reinforced concrete." Case Studies in Construction Materials 20 (2024): e03389.

19. Xu, Jian-Miao, Zhuo-Ting Chen, Feng Cheng, Zhi-Qiang Liu, and Yu-Guo Zheng. "Exploring a cellulose-immobilized bacteria for self-healing concrete via microbe-induced calcium carbonate precipitation." Journal of Building Engineering 95 (2024): 110248.

20. Maurente-Silva, Deividi Gomes, João Vitor Bitencourt Borowski, Vanessa Giaretton Cappellesso, Marilene Henning Vainstein, Angela Borges Masuero, and Denise Carpena Coitinho Dal Molin. "Effect of Exposure Environment and Calcium Source on the Biologically Induced Self-Healing Phenomenon in a Cement-Based Material." Buildings 14, no. 12 (2024): 3782.

21. Xu, Jian-Miao, Wei-Jie Wang, Zhuo-Ting Chen, Yuan-Yuan Zhou, Jia-Jia Pan, Feng Cheng, Zhi-Qiang Liu, and Yu-Guo Zheng. "Exploring a high-urease activity Bacillus cereus for self-healing concrete via induced CaCO3 precipitation." Applied Microbiology and Biotechnology 107, no. 20 (2023): 6351-6362.