Journal of ICT, Design, Engineering and Technological Science (JITDETS)
VOL. 5, NO. 2, pp. 24-29, 2021
DOI: https://doi.org/10.33150/JITDETS-5.2.4

ORIGINAL CONTRIBUTION

Investigating Cracks Prevention in Concrete Utilizing the Self-Healing Concept of Bacillus Subtilis Bacteria

Masaud Ahmad Khan[1*], Hamayun Khan[2], Muhammad Haris Javed[3], Zohaib Ullah[4], Atif Mehmood Khan[5], Khuda Bukhsh[6]

[1, 3, 4] CECOS University of IT and Emerging Sciences, Peshawar, Pakistan

[2] Balochistan University of Information Technology, Engineering, and Management Sciences (BUITEMS), Quetta, Pakistan

[5] National University of Science and Technology (NUST), Islamabad, Pakistan

[6] Bahauddin Zakariya University (BZU), Multan, Pakistan

***Abstract*— Concrete is the most common and widely used construction material. In the concrete structure, cracks are sometimes produced due to external loads and other reasons. Due to cracks, the concrete begins to take compression loads in the structure; therefore, repairing such cracks is essential. Different methods are used to repair the cracks in concrete, but in this thesis, we are working on bacteria base self-healing of cracks in concrete. For self-healing concrete different types of bacteria are used but we are using the bacteria named Bacillus subtilis in concrete. By adding bacillus subtilis and calcium lactate we find that the concrete becomes more strengthened and self-healed as compared to normal concrete. There are two methods of adding the bacteria to concrete which is direct adding an encapsulation method. We followed the direct application method in this method the bacteria is added directly to concrete. The test results show that the bacterial concrete has higher compression strength and self-healing concrete.**

***Index Terms*— Concrete Cracks, Self-Healing, Bacteria, Bacillus Subtilis, Calcium Lactate**

Received: 07 July 2021; **Accepted:** 29 October 2021; **Published:** 21 December 2021

I. INTRODUCTION

Concrete is the mixture of fine aggregates, coarse aggregates, and cements at a suitable proportion of water. Concrete is the most commonly used in building constructions. It is resilient, long-lasting, accessible locally, and adaptable [1]. It can withstand a certain amount of compressive force, but if more force is applied to the concrete than it can handle, cracks result from the external loads being applied, which reduces the concrete's strength. Crack repair is an extremely pricey process. Concrete cracks have an impact on the material's serviceability limit [2].

A. Self-healing

Self-healing technology has tremendous potential for repairing concrete cracks and extending the useful life of concrete structures while reducing the need for maintenance and repair. [3].

B. Self-healing Concrete

Concrete that develops limestone naturally to repair surface fractures is known as self-healing concrete. When the concrete is being mixed, specific strains of the bacterium species Bacillus, calcium lactate, calcium-based nutrition, nitrogen, and phosphorus are added [4]. The self-healing substances can slumber in the concrete for up to 200 years. The bacteria begin to feed on the calcium lactate, consume oxygen, and turn the soluble calcium lactate into insoluble limestone when a concrete structure is damaged and water seeps into the fractures that are present in it. Thus created limestone fills in any existing fissures. It is comparable to the natural healing process by which osteoblast cells mineralize to reform bone following a bone fracture [5, 6].

The bacterial conversion uses oxygen, which becomes a crucial component for the corrosion of steel to occur. Steel becomes more durable for use in building as a result. The bacterial conversion process can happen inside the microbial cell, on its surface, or even farther away inside the concrete. Frequently, the chemical process is altered by bacterial

activity, which results in oversaturation and mineral precipitation. The creation of bacterial concrete, a novel substance, was made possible by the application of bio mineralogy principles to concrete [7]. A novel type of concrete known as "bacterial concrete" contains microbiologically generated $CaCO_3$ precipitation added to specifically cement microcracks [8].

*Corresponding author: Masaud Ahmad Khan
†Email: engrmasaudkh@gmail.com

C. Bacteria Based Self-healing

We use bacteria as the self-hailing agent in bacterium-based self-hailing of concrete. It is employed to repair concrete cracks. One of these microorganisms is widely utilized and is proven to be efficient. When bacteria are combined with concrete, calcium carbonate precipitates are created, which fill in cracks and prevent further cracking [2]. Concrete that develops limestone naturally to repair surface fractures is known as self-healing concrete. When concrete is being mixed, specific strains of the bacterium species Bacillus, calcium lactate, calcium-based nutrition, nitrogen, and phosphorus are added [9, 10].

When a concrete building is damaged and water penetrates its cracks, bacteria start to absorb oxygen, feed on the calcium lactate, and transform the soluble calcium lactate into insoluble limestone. Thusly created limestone fills in any existing fissures. Another benefit of bacterial conversion is oxygen consumption [11]. The bacterial conversion uses oxygen, which becomes a crucial component for the corrosion of steel to occur. Steel becomes more durable for use in building as a result. The bacterial conversion process can happen inside the microbial cell, on its surface, or even farther away inside the concrete. Frequently, the chemical reaction is altered by bacterial activity, which results in oversaturation and mineral precipitation [12].

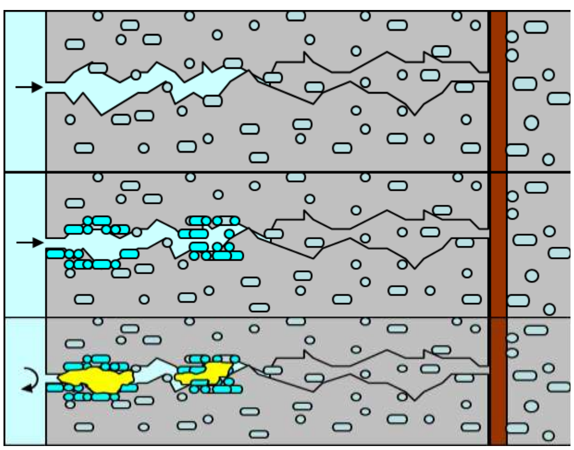

Fig. 1. Self-healing of concrete cracks due to bacteria

During the 20th and 21st centuries, concrete, a common material, saw widespread use throughout the world. One of the key signs of cement innovation advancement and general quality improvement is the prepared blended cement's rapid advancement, however, there are some brand-new problems [13]. The most obvious problem is the increased risk of breaking caused by non-load variables since concrete has low stiffness, such as shrinkage breaks, heated breaks, and synthetic reaction breaks [14]. Breaking increases the possibility of strong chemicals entering the substance, endangering the material's solidity. Normally, breaks are repaired by hand, which is inappropriate given that breakdowns are usually difficult to spot and are expensive to maintain and mend. Self-healing of cracked cement would be extremely profitable if done properly. However, the ability to repair breaks in the majority of common types of cement appears to be constrained. Recently, a different approach and natural process to address the limitations of considerable break mending has been proposed: microbes-initiated mineral precipitation [15]. To severely self-heal a significant break, Jonkers and colleagues first proposed the use of microscopic organisms to spur mineral precipitation innovation. For this type of break, the healing cycle occurs without the assistance of humans. According to their research, the specific tool for break recovery consists of a large network of connected spores of specific soluble base safe microorganisms that, after being initiated by break entrance water, build inorganic mineral accelerates by the transformation of natural antecedent mixtures. Following 100 days of submersion in water, test findings showed that make the recovery of giggle uncontrolled to 0.46 mm-wide breaks in bacterial cement but only up to 0.18 mm-wide cracks in charge instances [16]. For self-healing concrete, Wang used microcapsules to represent Bacillus sphaericus spores. The results showed that the widest break width repaired in the microbe's series examples was 970 lm, which was roughly several times wider than the non-microscopic organism series. The general water porousness in the sequence of microbes was several times less than that in the series of non-microscopic species. Many examination results showed that microscopic organisms' transporter defensive and water climate were required for this biotechnology application. The breaking of cement might happen at various ages and break width changes a great deal. Because of the unforgiving climate inside the substantial, the microscopic organisms would bite the dust over the long run regardless of whether embodied or immobilized in a defensive transporter. Likewise, the distinctions in natural conditions in reasonable design are extraordinary, some drenched in the water for quite a while, some in damp climates, and others in wet–dry conditions [17]. The genuine climate would affect the break-fix impact. Microbes-based self-healing concrete is a generally new procedure that assembles more outcomes to mimic genuine conditions before putting forth a concentrated effort recuperating concrete on a greater scale. In this investigation, microscopic organisms-based self-healing concrete was created by adding the microbial self-healing specialist which can work on self-healing limit mostly accomplished by microorganisms prompted mineral precipitations. The impact of break width, relieving ways, and breaking age on the break self-healing of concrete glue with microbial self-healing specialists was explored by the portrayal strategies for region fix rate and hostile to leakage fix rate [18].

Following are the objectives of this investigation.

- Bactria-based self-healing concrete will be self-repairing without any external repairing materials.
- The compressive strength and flexural strength will be increased as compared to the normal strength.
- It will provide a reduction in the permeability of concrete. Due to the self-healing property, the concrete will resist free-thaw attacks.
- It will reduce the corrosion of steel due to the crake's self-healing and the durability of steel reinforced concrete will be improved.

II. MATERIALS AND METHOD

Conduct the concrete literature review on bacteria self-healing. Cement, fine aggregate (sand), coarse aggregate (crushed stone), and bacteria are examples of materials that can be found locally and are used to create soil. To prepare the Smart concrete or Bacterial Concrete, mix material with the designed ratio and conduct the experimental program to determine the mechanical properties. The experimental work of this project is divided into the following phases:

- Collection of Materials
- Preparation of Bacterial concrete
- Curing
- Testing of samples

A. Collection of Material

In this research, all the materials used were locally available. Ordinary Portland cement was the cement used. For a mixture free of impurities, clean and drinkable water was used. The natural sand was used in a good combination. Crushed stone was used obtained from margalla hills. Bacteria were used from the soil.

B. Cement

It was purchased locally available Portland cement from Best Way Cement Company that complied with ASTM C150. The ASTM CIS4 standard was used to gauge the cement's fineness. Because the limit is 10 percent, the fineness test ASTM CI84 findings show a value of 7 percent, which is acceptable.

The results of the tests for the physical and chemical qualities of the obtained cement were provided by the manufacturer, best way Cement Company. These results are listed in the Table I.

TABLE I
PROPERTIES OF OPC

S/No	Properties	ASTMC150 Limits	Best Way Cement
1	Fineness	< 10	7
2	Soundness	< 10	2
3	Loss of ignition (LOI)%	3(Max)	2.0
4	Sulphur Anhydride (SO3)	3.5(max)	2.8
5	Insoluble residue (IR) %	0.75(Max)	0.3
6	Magnesium oxide (MgO)	6 (Max)	1.4

C. Fine Aggregate

As fine aggregates, naturally occurring sand from the area was utilized. To determine the best quality of sand, sand from various quarries was obtained and initially examined. Sand samples were gathered from several nearby quarries, including those producing Lawrencepur, Cherat, and Jahangira sand. Following the ASTM C136 test for the sieve analysis of fine aggregate, fineness modulus was computed for each sample. To gather information for the mix design, Lawrencepur sand was chosen for the concrete mix, and the following tests were carried out on it by ASTM standards: Sieve examination of fine aggregate performed by ASTM C136 - Tabled results of the ASTM C127 Specific Gravity and Absorption Test for Fine Aggregate are shown in the Table II.

TABLE II
SIEVE ANALYSIS RESULT OF SAND

Sieve No.	Weight Retained (gm.)	Percentage Retained(%)	Cumulative Percentage Retained(%)
#4	0	0	0
#8	13	2.7	2.7
#16	18	3.74	6.4
#30	87	18.09	24.53
#50	193	40.12	64.66
#100	129	26.82	91.48
Pan	41	8.52	99.99
Total	841	99.99	F.M = 2.90

D. Coarse Aggregate

The entire gross total reviewed around was used in the solid mixtures. In our company, the total thickness is pulverized stone. The total stone was collected from the Bahadur Kaley Peshawar Crush plant.

E. Isolation and Identification of Bacillus Subtilis from Soil Samples

1) Collection of soil samples

Ten soil samples total were gathered from various natural settings. Using a sterile spoon and dry plastic bags, 20 g of each sample were extracted at a depth of at least 5 cm. The soil samples were then taken to the lab and processed there under sterile conditions.

2) Isolation of Bacillus subtilis

A 250 ml Erlenmeyer flask containing 96 ml of sterile distilled water was filled with four grams of each soil sample and forcefully shaken for two minutes. The samples were heated in a water bath for 60 minutes at 60°C. The soil suspensions were then successively diluted with various aqueous dilutions ranging from 10-1 to 10 -4 in sterile distilled water. Each dilution of the soil samples was deposited in a volume of 100 l using the spreading method on a nutrient agar medium. At 35°C, the plates were incubated for 24 hours. The colonies with different morphological characteristics were divided and sub-cultured onto fresh nutrient agar medium to get pure culture (Al-Yousif, 2022).

3) Identification of Bacillus subtilis

Gram staining was used to initially identify Bacillus subtilis. The bacilli that generate rod-shaped spores and are Gram-positive were chosen for additional identification testing. Later identification tests were carried out, such as a penicillin susceptibility test, citrate hydrolysis, motility, Voges-Proskauer VP, Indole production, catalase, nitrate reduction, and H_2S generation.

Fig. 2. Identification of Bacillus subtilis

F. Calcium Lactate

The calcium lactate is used as a nutrient for Bacteria in Bacterial concrete. It is of food source for Bacteria. There is 4% Calcium Lactate added to the total mass of concrete.

Fig. 3. Calcium lactate

G. Mix Design

The mixed design was carried out to use the material with different ratios. All the arrangements were planned with the ratio of (1:2:4) with the variable percentage of Bacteria varies from 6% in the different batch of the concrete mix the quantity of the material are tabulated in the table which is as follows.

1) Preparation of bacterial concrete

Bacterial concrete can be prepared in two ways:

- By direct application

- By encapsulation in lightweight concrete

In the direct application method, initially, the material was weighted, and dry mixing for cement, Fine aggregates, and coarse aggregates And Dry Calcium Lactate are mixed. This was careful with hand mixing to achieve a uniform mixed color the duration of the mixing was 2-4 minutes in the water was used to mix deigns when the mix of done 6 molds (3 is normal concrete mold) cast according to literature review concrete was mixed in the ratio of 1:2:4 and was used 6% and Calcium Lactate was 4%, all the three cubes are fill with Bacterial concrete. Bacterial spores and calcium lactate is added to concrete directly when the mixing of concrete is finished.

Fig. 4. Preparation of bacterial concrete

2) Amount of materials used

The amount of material that is used while preparing mold samples is as follows. The total number of molds is six (6).

TABLE III
MATERIAL USED IN THE INVESTIGATION

Sr. No.	Material	Quantity
1	Water	0.07 liters
2	Cement	1 kg
3	Sand	2 kg
4	Coarse Aggregate	4 kg
5	Bacteria	6%
6	Calcium Lactate	4%
7	W/C Ratio	0.46

3) Curing

After 24 hours of casting, the mold is removed. The mold is then kept in a water tank for treatment with a relative humidity of 85 percent at a normal temperature.

The cure is a strategy used to maintain concrete hardness in humid and warm environments that support the component cement's gradual and proper setting. Hardened concrete's durability, hardness, water resistance, wear strength, bulk stabilization, and resistance to drying and freezing are all impacted by curing. If the concrete has been correctly or ineffectively indicated; batched, blended, put, and completed it will not work.

Fig. 5. Curing of concrete specimens

III. RESULTS AND DISCUSSION

Following are the results of the different tests discussed below

A. Compression and Tensile Strength Test

Mould sample with 1kg cement, 2 kg sand, and 4 kg Aggregate with 6% Bacteria (Bacillus Subtilis), 4% dry calcium lactate and use free impurities water 0.07 liter. On both regular and self-healing concrete, standard tests were performed. A concrete cube was tested for tensile and compressive strength over seven and fourteen days.

TABLE IV
COMPRESSIVE STRENGTH TEST RESULT FOR 7 DAYS AND 14 DAYS FOR BACTERIAL CONCRETE

Sr. No	Days	Normal (N/mm^2)	Bacterial Concrete (N/mm^2)
1	7	18.85	24.10
2	14	27	35.95

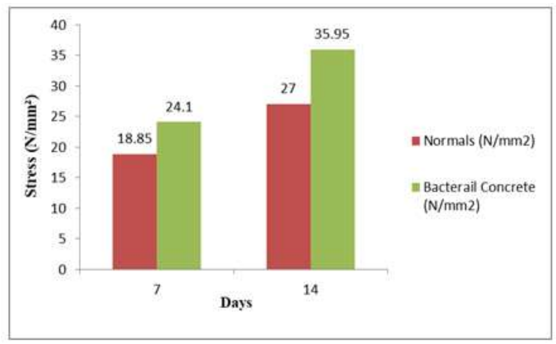

Fig. 6. Compressive strength graph of bacterial concrete

TABLE V
TENSILE STRENGTH TEST FOR 7 DAYS AND 14 DAYS OF BACTERIAL CONCRETE

Sr. No	Days	Normal (N/mm^2)	Bacterial Concrete (N/mm^2)
1	7	3.90	4.6
2	14	7.05	7.80

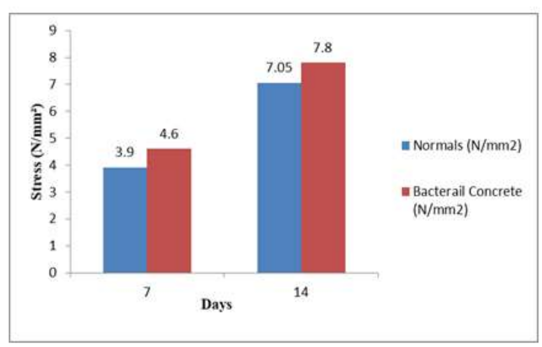

Fig. 7. Tensile strength graph of bacterial concrete

B. Discussion

After the test results, we observe that there is a huge difference accrued in bacterial concrete as compared to normal concrete. We checked that the bacterial concrete has more strength than normal concrete. According to lab tests of both (normal and bacterial) concrete, we find that the bacterial concrete was highly compressive strength as well as high tensile strength. Most important point is that the bacterial concrete was self-repairing concrete without any external aids. Bacterial concrete has increased the compressive and flexural strength as compared to normal concrete. The purpose of this research is to better understand how bacteria that cause discomfort, like Bacillus subtilis and Bacillus pasteurize species, are used to treat concrete fractures. The initiative has examined many bacterial species that can be employed as concrete healers. Additionally, this study has shown that bacteria enhance the compressive strength of concrete and Portland cement mortar cubes. Using bacteria has the advantage of reducing water penetration and chloride ion permeability. The findings of this study suggest that utilizing "bacterial concrete" as a concrete sealant can be an environmentally friendly, cost-effective alternative that also improves the longevity of building materials.

C. Scanning Electronic Microscopy (SEM)

Following are the images showing the SEM analysis outcome.

Fig. 8. SEM assessment of bacterial concrete

The SEM results are divided into parts i.e., A and B indicating controlled concrete and bacterial concrete samples respectively. The images resulting from SEM analysis show an obvious sign of concrete healing of cracks as compared to the controlled sample having approx. same crack width after the SEM analysis performed before and after the healing period [19].

IV. CONCLUSION

Concrete that is capable of autogenously filling in cracks without the aid of outside sources is known as self-healing concrete. There are several ways to create self-healing concrete, according to earlier studies, however, adding bacteria as the self-healing agent makes the concrete environmentally benign. This study examines the factors that are crucial in creating bacterial self-healing concrete. As the primary source of self-healing compounds, bacteria must meet certain criteria to be collected. Most studies used the Bacillus genus, but many also used non-axenic bacteria to create self-healing concrete. A self-healing concrete has a variety of bacteria and nutrient concentrations as well, which produces a wide range of performance. The majority of studies show that adding bacteria, with or without nutrients, hurts the mechanical qualities of concrete. However, some of the research suggests that mechanical strength has the opposite effect. Therefore, how the bacteria are mixed will also affect how much of an impact they have on the strength of the concrete. The addition of self-healing microorganisms could help increase the permeability of concrete. This study focused on measuring the performance of bacterial self-healing concrete and investigating the production methods. Concrete can naturally heal thanks to Bacillus subtilis bacteria's capacity to metabolically change calcium lactate into calcium carbonate. To maintain concrete's capacity for self-healing over its entire lifespan, it is crucial to protect the bacteria that live inside of it. Concrete will have a slow initial setting time and weak bonding if the percentage of bacteria and calcium lactate is higher. Concrete won't be very water resistant. In comparison to regular concrete of similar composition, bacterial concrete is stronger.

ACKNOWLEDGMENT

Foremost, we would like to express our sincere gratitude to our colleagues and other senior faculty members for their continuous support in this research work. Their motivation, enthusiasm, and immense knowledge granted us the ability to achieve this milestone. We would like to thank lab engineers and lab assistants for their support and facilities provided during the entire experimental work.

References

[1] W. Q. Chin, Y. H. Lee, M. Amran, R. Fediuk, N. Vatin, A. B. H. Kueh, and Y. Y. Lee, ``A sustainable reuse of agro-industrial wastes into green cement bricks,'' *Materials*, vol. 15, no. 5, pp. 1-18, 2022. doi: https://doi.org/10.3390/ma15051713

[2] S. Dinesh, R. Shanmugapriyan, and S. N. Sheen, ``A review on bacteria-based self-healing concrete,'' *Imperial Journal of Interdisciplinary Research*, vol. 3, no. 1, pp. 2454-1362, 2017.

[3] D. Gardner, R. Lark, T. Jefferson, and R. Davies, ``A survey on problems encountered in current concrete construction and the potential benefits of self-healing cementitious materials,'' *Case Studies in Construction Materials*, vol. 8, pp. 238-247, 2018. doi: https://doi.org/10.1016/j.cscm.2018.02.002

[4] V. M. Ramdas, P. Mandree, M. Mgangira, S. Mukaratirwa, R. Lalloo, and S. Ramchuran, ``Review of current and future bio-based stabilisation products (enzymatic and polymeric) for road construction materials,'' *Transportation Geotechnics*, vol. 27, pp. 1-56, 2021. doi: https://doi.org/10.1016/j.trgeo.2020.100458

[5] A. Ghoneim, H. Hassan, and L. Aboul-Nour, ``Self-repairing polyethylene fiber-reinforced-concrete with bacillus subtilis bacteria a review,'' *International Journal of Engineering & Technology*, vol. 9, no. 2, pp. 437-447, 2020.

[6] S. Sung, J. Lim, S. Palikhe, K. Han, S. Kim *et al.*, ``Development of the system form for concrete casting in the girder bridge slab-purlin hanging system,'' *Journal of Advances in Technology and Engineering Research*, vol. 2, no. 2, pp. 18-21, 2016. doi: https://doi.org/10.20474/jater-2.1.4

[7] B. Gautam, ``Bacteria based self healing concrete-a bacterial approach,'' *The International Journal of Engineering and Science*, vol. 1805, pp. 23-19, 2018.

[8] S. Morsali, G. Yucel Isildar, A. Tahni *et al.*, ``The application of bacteria as a main factor in self-healing concrete technology,'' *Journal of Building Pathology and Rehabilitation*, vol. 4, no. 1, pp. 1-6, 2019. doi: https://doi.org/10.1007/s41024-019-0045-9

[9] S. Dessai, N. Panandikar, R. Ramarajan, and V. Pillai, ``Behaviour of self healing mechanism for crack resistance,'' in *UKIERI Concrete Congress: Concrete: The Global Builder,* Punjab, India, 2019.

[10] T. Kim, B. Choi, J. Park, S. Hong, S.-K. Park *et al.*, ``Study of the measurement and stability estimation of concrete roadbed slab at high-speed train in bridge-earthwork transition zone,,'' *Journal of Advances in Technology and Engineering Research*, vol. 2, no. 2, pp. 41-51, 2016. doi: https://doi.org/10.20474/jater-2.2.3

[11] K. Pappupreethi, R. Ammakunnoth, and P. Magudeaswaran, ``Bacterial concrete: A review,'' *International Journal of Civil Engineering and Technology*, vol. 8, no. 2, pp. 588-594, 2017.

[12] N. De Belie, E. Gruyaert, A. Al-Tabbaa, P. Antonaci, C. Baera, D. Bajare, A. Darquennes, R. Davies, L. Ferrara, and T. Jefferson, ``A review of self-healing concrete for damage management of structures,'' *Advanced Materials Interfaces*, vol. 5, no. 17, pp. 1-28, 2018. doi: https://doi.org/10.1002/admi.201800074

[13] C. Shi, B. Qu, and J. L. Provis, ``Recent progress in low-carbon binders,'' *Cement and Concrete Research*, vol. 122, pp. 227-250, 2019. doi: https://doi.org/10.1016/j.cemconres.2019.05.009

[14] T. Ogundairo, D. Adegoke, I. Akinwumi, and O. Olofinnade, ``Sustainable use of recycled waste glass as an alternative material for building construction-a review,'' in *IOP Conference Series: Materials Science and Engineering,* Ota, Nigeria, 2019. doi: https://doi.org/10.1088/1757-899X/640/1/012073

[15] R. R. Thakor, K. B. Vaghela, and J. R. Pitroda, ``Effect of bacteria on durability of concrete: A review,'' *Studies in Indian Place Names*, vol. 40, no. 60, pp. 276-291, 2020.

[16] H. M. Jonkers, A. Thijssen, G. Muyzer, O. Copuroglu, and E. Schlangen, ``Application of bacteria as self-healing agent for the development of sustainable concrete,'' *Ecological Engineering*, vol. 36, no. 2, pp. 230-235, 2010. doi: https://doi.org/10.1016/j.ecoleng.2008.12.036

[17] J. Wang, H. Soens, W. Verstraete, and N. De Belie, ``Self-healing concrete by use of microencapsulated bacterial spores,'' *Cement and Concrete Research*, vol. 56, pp. 139-152, 2014. doi: https://doi.org/10.1016/j.cemconres.2013.11.009

[18] J. Wang, ``Self-healing concrete by means of immobilized carbonate precipitating bacteria,'' Ghent University, Ghent, Belgium, Phd thesis, 2013.

[19] M. A. H. Abdullah, N. A. H. Abdullah, and M. F. Tompang, ``Development and performance of bacterial self-healing concrete-a review,'' in *IOP Conference Series: Materials Science and Engineering,* Kaluza, Slovakia, 2018. doi: https://doi.org/10.1088/1757-899X/431/6/062003