An Experimental Investigation of Sustainable Bacterial Concrete: A Review

Amish N. Patel [1], Dr. J. R. Pitroda [2], Prof. Kishor B. Vaghela [3]

[1]M. Tech. (Civil) Construction Engineering and Management, BVM Engineering College, Vallabh Vidyanagar-388120, Gujarat, India
[2]Associate Professor, PG Coordinator Construction Engineering and Management, Civil Engineering Department, BVM Engineering College, Vallabh Vidyanagar-388120, Gujarat, India
[3]Assistant Professor, Applied Mechanics Department, Government Engineering College Rajkot, Gujarat, India.

Abstract - *In the construction sector, concrete is the preferred material, Due to its use, there are vast research and opportunities. Through the research, by using a concrete structure there are characteristics like physical and mechanical properties and as a cementitious material its environmental impact through the making of cement and service life of a structure. For this purpose, there are two phases one is construction and the second is service life. In the construction phase, there is a reduction in cement by partial replacement of such similar cementitious material shows that it makes sustainable concrete, and in a second phase by using microbial-induced calcite precipitation (MICP) bacteria by making bacterial concrete. This paper shows that by using this method going with ceramic waste powder as supplementary cementitious material and bacillus megaterium as microbial induced calcite precipitation MICP bacteria with a suitable concentration in concrete is the best feasible combination solution to introducing and investigating sustainable bacterial concrete. In last literature shows that this both individually improves the Mechanical properties of concrete.*

Key Words: **Bacteria, Bacterial concrete, Ceramic Waste, sustainable concrete, compressive strength, Durability of concrete, Mineral precipitation**

1. INTRODUCTION

1.1 General

Cement is a strong and inexpensive material in construction, making it the most extensively used building material on the planet. However, one disadvantage is that its huge manufacturing has detrimental environmental consequences. Cement and aggregate material are essential components of construction, and they must be manufactured and mined on a big scale and delivered over considerable distances, as a result, energy consumption, greenhouse gas emissions, and landscape degradation have grown. Cement manufacturing is projected to produce 7% of worldwide anthropogenic CO_2 emissions.**[1]**

The expanding industrial sector is resulting in significant waste in a solid form as output. The use of this waste in construction has piqued the curiosity of numerous experts who are experimenting with garbage as a cement substitute in concrete. In certain ways, this also contributes to reduced greenhouse gas emissions. CO_2 is emitted during the cement manufacturing process, which contributes significantly to greenhouse gas emissions. It was established that using ceramic waste in the construction business helps to achieve sustainability while also lowering the construction cost of materials. **[2]**

An innovative method of Bacterial self-healing that uses ($CaCO_3$) calcite precipitation to repair or healed open micro-cracks in concrete. Adding bacteria to the cement-based building has shown to be an excellent cost-cutting and ecologically friendly method to extend the life of structures. This biotechnology boosts the structure's durability.**[3]**

A microbiological technique is used, in which bacteria, urea, and a calcium supply are combined to generate calcium carbonate crystals, which reduce cracking, enhance impermeability, and improve concrete mechanical qualities. Cement is one of the most used concrete and rare building materials. Cement alternatives are also actively investigated and employed due to high consumption. Waste material alternatives are widely used because they are environmentally friendly. **[4]**

To increase the performance of concrete, filling capacity additives can be used. Some natural waste materials have a better chance of partially replacing standard Portland cement in the creation of less porous concrete. The necessity for a different form of concrete is supported by construction issues and the complexity of mixed design employing waste resources. A new study area that has been developed and researched under bacterial concrete, has been used in concrete for materials that have cementitious that cure themselves utilizing the bio-mineralization mechanism. The goal of putting bacteria into concrete is to cause calcite to precipitate in pores and small cavities. **[5]**

Microbiological Induced Calcite Precipitation refers to the production of calcium carbonate by microorganisms by their metabolic activity to improve the characteristics of concrete (MICP). These specific microbes can live for up to 100 years, are completely harmless to humans, and can be readily cultivated. These tiny creatures can function in moisture, a wide range of pH, and temperatures conditions. Bacterial spores and their calcium nutrition sources should be mixed into the concrete at the same time as the other materials. At the time of mixing, bacterial spores remain latent, allowing them to withstand the pressure created by the mixing process. These bacteria can influence the formation of calcite once the urea enzyme is produced. The precipitation of calcite crystals begins at one supersaturation level, which is produced by different nucleation on the microorganism cell wall. As crystal forms inside the concrete, it densifies it by filling micro-cracks and porous areas and also improves the mechanical properties of concrete. **[6]**

1.2 OBJECTIVE

These are the objectives of conducting this study.

1. To study the behavior of ceramic waste in sustainable concrete by partially replacing it with cement.
2. To study the physical properties and mechanical properties of Bacterial concrete.
3. To study the durability of bacterial concrete and introduce an eco-friendly and low-cost construction material.

1.3 NEED FOR STUDY

The needs of the following study are listed below:

1. Less Maintenance and improves the life span of concrete of the structure by using sustainable bacterial concrete.
2. Utilization of Ceramic Industry Waste in making of Sustainable Concrete to reduce the environmental hazard.
3. To provide the Best Feasible solution for the utilization of ceramic industry waste and reduce cement consumption in the construction sector.

2. LITERATURE REVIEW

The following literature review is based on An Experimental Investigation of Sustainable Bacterial Concrete: A Review

2.1 BACTERIA

Nidhi Nain et.al (2019) Microbial-induced calcite precipitation (MICP) is a function that occurs during and after the treatment of concrete fractures. Bacillus megaterium, Bacillus subtilis, and a few combinations of bacteria have all been found in concrete to aid in the self-healing of fissures caused by shrinkage enhancement and settling processes. This study aimed to address the issue of micro-crack management as well as to see whether certain bacteria may help improve concrete's mechanical properties. When compared to standard concrete, the bacteria Bacillus subtilis, Bacillus megaterium, and their consortia demonstrated increases in compressive strength of 14.3 %, 22.5 %, and 15.8 %, respectively. Although the tensile strength of concrete increased by 25.3 %, 18.49 %, and 19.58 % when bacteria Bacillus subtilis, Bacillus megaterium, and their consortia were used, the tensile strength of concrete improved by 25.3 %,18.49 %, and 19.58 %, respectively. **[7]**

S. Krishnapriya et.al (2015) The goal of this study is to develop and know the calcite precipitating bacteria, as well as to determine whether these bacteria are good for usage in concrete to improve their strength. To calcium carbonate precipitation in the form of calcite, they must have a strong urease activity. Concrete cubes cast with B. licheniformis BSKNAU, and B. megaterium MTCC 1684, B. megaterium BSKAU showed a significant improvement in strength and full fracture healing. This shows that these bacterial strains are suitable for usage in concrete. The Cracks are filled in concrete with calcite, which was observed using a scanning electron microscope, which can be ascribed to increased strength and crack healing. **[8]**

Sandip Mondal, Aparna Ghosh et.al (2018) Microbial concrete's effective fracture healing capabilities improve its Physical properties and mechanical properties. According to studies on microbial concrete, the increase in compressive strength is greatest at a different concentration, which is not always the largest among the bacterial concentrations investigated. The explanation for the occurrence of such an ideal bacterial concentration for increasing concrete compressive strength has remained unknown thus far. The presence of this ideal bacterial concentration has been investigated to determine the cause. The results show that 10^7 cells/ml is good for crack healing and 10^5 cells/ml improves the compressive strength of concrete. **[9]**

C. Venkata Siva Rama Prasad et.al (2020) In the continuing bacterial concrete, the cracks are developed in reinforced structures of healing proportion are grown. e.g., Houses, RCC Pipes Pavements, and canal lining. Concrete cracks require routine maintenance as well as specialized treatment, which can be costly. Another method involves microbiologically induced calcite ($CaCO_3$) used in concrete. For concrete grade M40, the investigation was conducted utilizing Bacteria (bacillus subtilis) and calcium lactate to cure fractures in concrete at varying percentages of cement weight, 5,10, and 15 percent. The maximum strength in concrete is achieved at 10% bacterial replacement, and SEM images showed the calcite precipitation. **[4]**

Partheeban Pachaivannan et.al (2020) The requirement for extreme sturdiness for structures exposed to the hard environment, such as the seafloor, tunnels, sewage pipelines, and structures for powerful, chemical waste containing toxic compounds and radioactive components, will not be met by Ordinary Portland Cement today. This research focuses on increasing the energy and overall performance of concrete used in modern construction by incorporating microorganisms. A comparison was done between concrete cubes and beams that had been examining mechanical properties, which were cast with and without microorganisms. At the 28 days, compressive and tensile strength was 19.51 % and 17.8% increase respectively compared to the conventional concrete. **[5]**

2.2 SUSTAINABILITY

Farshad Ameri et.al (2019) The goal of this research is to study self-compacting concrete by utilizing the content of rice husk ash (RHA) and bacterial concentration. Where replacement of Cement to the rice husk ash by weight varies from 0%, 5%, 10%, 15%, 20%, and 30% in concrete. There was micro silica is used at a dosage of 10% by the weight of cement. To reduce the microcracks bacterial cells with different concentrations of 10^3, $10^{5,}$ and 10^7 cells/ml were used with rice husk ash in concrete. All these different mix designs analysing by energy-dispersive X-ray spectroscopy (EDS) and scanning electron microscopy (SEM). In a study, 10^5 cells/ml of bacterial concentration gives good compressive strength and 10^7 cells/ml gives a good durability feature. On day of 28 ideal mixes with Rice husk ash of 15% gives a 12% raise of compressive strength compared to the nominal mix. **[6]**

2.3 CERAMIC WASTE

R. Johnson Danie et.al (2021) An experiment was conducted to see if waste material collected from ceramic manufacturing plants might be used as a substitute for sand in concrete. As a result of this ceramic waste, natural sand extraction may be restricted, and the nominal cost of river sand is rose when compared to all other aggregate supplies. Fine aggregate replacement materials in pulverized and waste powder ceramic tiles range from 0% to 5%, 10%, 15%, and 20%. Fine aggregate was replaced by a grade of M30 concrete and variable ratios of 0 to 20% pottery were used to generate the mix patterns (crushed tiles). An experiment was conducted to determine the workability of fresh concrete. **[7]**

Ankur Gupta et.al (2020) To make a composite material, stone dust and ceramic waste are mixed. Stone dust and ceramic waste replace natural sand and stone, respectively. Several mechanical tests are performed on the produced composite to measure its strength in compression, flexure, and shear. By increasing the stone dust concentration from 0% to 100% in 20% increments, seven different types of samples were formed. The waste of ceramic aggregate was kept constant at 20% in all experiments except in nominal concrete samples. The greatest strength was attained in the S40C20 sample (stone dust-40% and ceramic-20%) for mechanical properties. As a consequence, sand and coarse aggregates can be partially substituted in composite material production by stone dust and waste ceramic aggregates in suitable percentage amounts. **[8]**

Rajat Kumar Goyal et.al (2021) Ceramic waste is gaining popularity among researchers as an alternate aggregate resource for building. Often there are more ceramic product wastes, such as electrical insulators and sanitary wares have gotten more attention, and floor tile wastes and ceramic walls haven't gotten nearly as much. Ceramic tiles were used as compressed coarse aggregate at levels of 0 percent, 5 percent, 10 percent, 15 percent, 20 percent, and 25 percent to replace natural aggregates in concrete. According to the findings, ceramic waste increases the mechanical properties of concrete to a certain degree of replacement. To achieve acceptable quality, ceramic waste has the potential to be employed as a replacement by partial in concrete constructions. At appropriate compaction factors, adding an amount of 15% waste of ceramic to the cement in all concrete mixes increases mechanical characteristics. **[9]**

Lucía Reig et.al (2021) In this study it possesses pozzolanic activity when ceramic sanitary ware waste is combined with Portland cement. Ceramic sanitary ware waste units were broken until they became smaller fine particles. For the investigation, these tests were performed SEM-EDX, XRD, and the mechanical properties and microstructure of samples cured at 20°C for up to 365 days. Although ceramic sanitary ware waste s pozzolanic activity was slow at first, it improved with the time of curing, and mortars containing up to 25 wt. percent of ceramic waste fulfilled the requirements set for other pozzolanic materials like fly ash. **[10]**

3. MAJOR FINDINGS FROM THE LITERATURE REVIEW

1. Most of the Paper used Bacillus subtilis, Bacillus megaterium as MICP bacteria.
2. Various Concentrations of Bacteria where 10^5 cell/ml leads to the best Mechanical Properties.
3. Partial replacement of cement up to 20% by Ceramic waste in concrete gives the best result for enhanced Mechanical Properties.
4. Bacterial concrete improves physical and mechanical properties.
5. Ceramic Waste Concrete improves physical and mechanical properties.

Table 1: Different types of microbes with changes in the concentration used by researchers to develop the compressive strength

SR. NO	Author & Journal Detail	Bacteria/ Bacterial concentration	Increased in Compressive strength
1.1	Nidhi Nain et.al (2019)	Bacillus subtilis (10^8 cell/ml)	22.5%
1.2	Sandip Mondal et.al (2018)	Bacillus subtilis (10^5 cell/ml)	27%
1.3	C. Venkata Siva Rama Prasad et.al (2020)	Bacillus subtilis (10^5 cell/ml)	12%
1.4	Partheeban Pachaivannan et.al (2020)	Bacillus subtilis (250 ml)	19.51
1.5	Madhan Kumar M et.al (2020)	Bacillus subtilis (30 ml)	13%
2	S. Krishnapriya et. al (2015)	Bacillus Megaterium (10^5 cell/ml)	16.1%
3.1	Santosh Ashok Kadapure et. al (2016)	Bacillus sphaericus NCIM NO 2478(10^5 cell/ml)	16%
3.2	Ankit Agarwal et. l (2019)	Bacillus sphaericus(20 ml)	14%
4	Mingyue Wu et. al (2020)	Bacillus cereus CS1(9.6 x10^8 cell/ml)	2.5%
5	Navneet Chahal et. al (2012)	Sporosarcina pasteurii(10^5 cell/ml)	8.5%

4. CONCLUSIONS

It is based on an investigation of Bacterial concrete and Ceramic concrete. The following is a summary of the findings:

1. Growing demand for cement in the construction industry increases the cost of construction thus replacement of cement or consumption of cement is required.
2. Due to the hazardous gaseous emission in the environment industrial materials require recycling or reuse.
3. In a new era of bacteria in construction improves the Mechanical and physical characteristics of concrete.
4. Using ceramic waste and bacteria improvise different characteristics of concrete.

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