# Improvement of Engineering Properties of Different Materials Using Microbial Treatment- A Review

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**Abstract**

The method known as Microbially Induced Calcium Carbonate Precipitation, or MICP, has become a game-changer in the building materials industry. This review paper conducts a thorough analysis of current advancements and research results about the application of MICP to improve the characteristics of brick, concrete, and soil. Research has indicated that MICP can effectively increase durability, decrease permeability, and improve compressive strength in concrete through the creation of calcium carbonate crystals inside the concrete matrix. It can also activate self-healing properties through calcium carbonate precipitation. In the context of soil stabilization, MICP has proven to be a sustainable and environmentally friendly solution. Research in this area explores the use of microorganisms to induce calcium carbonate precipitation, thereby enhancing soil strength and stability. The findings provide insights into potential applications in geotechnical engineering and sustainable construction practices. MICP has shown to be a viable and eco-friendly solution when it comes to stabilizing soil. This field of study investigates the use of microorganisms to precipitate calcium carbonate, improving the stability and strength of soil. The results offer perspectives on possible uses in sustainable building methods and geotechnical engineering. This review also examines the role that MICP plays in improving the compressive strength, water absorption, and long-term durability of bricks. The research looks into how microbial activity affects brick microstructure, providing insight into the possibility of improved mechanical qualities. The integration of study results for these three important building materials demonstrates the versatility and encouraging results of MICP. By providing a thorough understanding of MICP applications in concrete, soil, and brick renovations, this review hopes to be a useful tool for researchers, engineers, and industry professionals.
**Keywords**: MICP bacteria, concrete crack-healing, permeability, x-ray micro-CT, durability, bioremediation.

## 1. Introduction

Bacteria have an important role in increasing the durability and strength of construction supplies such as concrete [1], soil, and bricks. Bacteria seal micro-cracks in concrete through processes such as Microbiologically Induced Calcite Precipitation (MICP), increasing overall strength. Bacterial-induced biomineralization processes, such as MICP, improve soil strength, permeability, and erosion resistance. Notably, bacteria such as *Bacillus megaterium* contribute to calcite deposits, which improve ash brick qualities such as water absorption, frost resistance, and compressive strength. This use of bacteria offers environmentally ideal and sustainable methods for building resilient and long-lasting infrastructure [5].

Concrete constructions commonly face durability issues because of crack formation [2], which causes leakage and material ingress. When water enters the structure, a two-component agent-bacteria and a mineral precursor-activates, transforming the precursor into calcium carbonate, closing cracks, and extending the structure's service life [4]. This revolutionary technology addresses durability concerns in a long-term way.

The study explores the application of Microbiologically Induced Calcite Precipitation (MICP) for self-healing enhancement in concrete buildings [3]. It argues for the addition of urease-stimulating bacteria, such as *Bacillus Pasteurii* and *Bacillus Subtilis*, together with a calcium supply to induce Calcium Carbonate ($CaCO_3$) precipitation, which heals micro-cracks and increases concrete strength. The study highlights constant hydration processes and offers encapsulation as a viable application strategy. The promise of self-healing concrete via MICP is highlighted, with a focus on durability and reduced pore development.

In this paper, we have investigated the use of urease-positive bacteria in Microbially Induced Calcite Precipitation (MICP) to improve soil engineering behavior [6]. The study investigates the environmental elements that influence MICP and how they affect soil qualities like strength and permeability.

Here the total reaction is –

(1) Urea + $3H_2O \rightarrow 2NH_3 + CO_2$ [By the presence of urease enzyme]

(2) $CO_2 + H_2O \rightarrow HCO_3^- + H^+$

(3) $Ca^{2+} + 2HCO_3^- \rightarrow CaCO_3 + H_2O + CO_2$

Here, Urea and $Ca^{2+}$ are added to get $CaCO_3$ precipitates. The calcium carbonate minerals formed in this reaction can fill the pore spaces and bind soil particles, leading to improved soil properties, such as increased strength, decreased permeability, and reduced erosion [7].

The results show that urease activity is successful and that sandy soil is more resistant to cyclic stress. Furthermore, MICP is an environmentally benign and sustainable technology with great potential for improving soil strength, stiffness, and erosion resistance [8]. The method involves the biomineralization of calcium carbonate, which is aided by bacteria, and provides a feasible solution to soil improvement difficulties while being environmentally benign and energy-saving.

The potential of *Bacillus Megaterium* in microbiologically induced calcite precipitation (MICP) to improve the characteristics of ash bricks, especially fly ash bricks and rice husk ash bricks, is investigated in this work [10]. The deposition of calcite by bacteria on the surface and voids of the bricks results in significant advantages such as reduced water absorption, improved frost resistance, and greater compressive strength. SEM images confirm the bacteria's development of extracellular calcite crystals. X-ray diffraction and energy dispersive X-ray analysis confirm the precipitates' identity as calcite crystals ($CaCO_3$. These findings show that MICP technology has the potential to manufacture long-lasting and environmentally friendly building blocks [9].

## 2. Literature Review

Engineering materials characteristics can now be improved by the approach known as Microbially Induced Calcium Carbonate Precipitation (MICP). MICP uses microorganisms to cause calcium carbonate to precipitate, improving a material's strength, durability, and other desired properties. Concerning the application of MICP in engineering materials and its potential to advance material science and construction technologies, this literature review attempts to give a summary of contemporary research in this area.

**MICP in Concrete Self-Healing Properties**

The use of MICP to improve the qualities of concrete has been the subject of numerous investigations. In 2016, E. Tziviloglou et al. investigated the application of bacterial-based concrete healing [1]. Lightweight aggregates (LWA) are integrated with bacterial healing agents. The result was promising as the healing agent activates and fills the open gap by precipitating $CaCO_3$ when the weak, light capsules break. Renée M. Mors and Henk M. Jonkers employed bacteria-based self-healing concrete, which has two components: an organic mineral precursor chemical and bacteria [5]. According to the findings, when there are cracks and water present, bacteria multiply and turn the incorporated organic compounds into calcium carbonate, which precipitates and can seal and block cracks. H. M. Jonkers examined the potential for fracture healing in a particular biochemical additive comprised of a blend of organic materials and microorganisms that are dormant but still viable, enclosed in porous, expanding clay particles [2]. B.R. Gautam (2018), in his study, proposed a two-component healing agent that consists of a mineral precursor compound and bacteria that is added to the concrete mixture [4]. Water intrusion causes the mechanism to activate upon cracking. The mineral precursor chemical is transformed by bacteria into calcium carbonate or limestone. In their work, Pavan Kumar Jogi, T.V.S. Vara Lakshmi (2020) combined the calcium supply with ureolytic bacteria, which may produce urea, to seal the precipitation of calcium carbonate ($CaCO_3$) from recently developed microcracks [3]. The results are examined using X-ray computed tomography, optical imaging, camera photography, and image surveillance using a microscope.

**MICP in Soil Stabilization and Geotechnical Engineering**

In applications involving geotechnical engineering and soil stabilization, MICP has demonstrated potential. J.D. van Elsas and C.E. Heijnen (1990) researched the use of oil-based inoculants to improve bacterial survivability as well as the use of mineral soil as a carrier for bacteria [11]. The results have great potential for synthetic carriers in inoculant protection. Abdul Majeed et al. (2018) demonstrated the use of beneficial bacteria in agriculture through the application of PGPBs as direct inoculants or commercial formulations [12]. R.

Tamanna et al. (2022) employed two methods, Method A: bio-treatment with the flowing solution and Method B: Bacteria and cementation treatment mixed with specimens in her study [7]. Maysam Bahmani et al. (2018) worked further on the MICP method with ureolytic bacteria and calcium ions [6]. Indigenous bacteria were introduced to improve dune sand using Microbial Induced Carbonate Precipitation (MICP) as an environmental engineering method. Murtala Umar et al. (2016) showed a cumulation of the results of different bio-mediated soil improvement techniques and the soil microorganisms responsible for this process, factors that affect their metabolic activities and geometric compatibility with the soil particle sizes [8]. Two mechanisms of biomineralization, i.e., biologically controlled and biologically induced mineralization, were also discussed.

**MICP in Brick Strength Improvement**

Several studies have investigated the impact of MICP on the strength of bricks. Baogang Mu et al. (2021) showcased the application of MICP for mending both artificial and natural surface fissures on wall bricks that date back six centuries and are a part of the ancient Nanjing City Min Dynasty wall in China [9]. The internal structure of the MICP-treated brick cubes was non-destructively visualized using X-ray micro-computed tomography, or X-ray micro-CT. The outcomes demonstrated that MICP can successfully fix surface fractures in brick that are caused by natural or artificial means. Navdeep Kaur Dhami et al. (2011) investigated the ability of *Bacillus megaterium* to manufacture calcite and enhance the qualities of ash bricks—fly ash bricks and rice husk ash bricks [10]. The calcite deposition on the surface and cavities in the bricks caused the treated bricks to significantly reduce water absorption, improve their resistance to frost, and raise their compressive strength. The bacteria had deposited calcite crystals extracellularly on the brick surface, as shown by scanning electron micrographs. The precipitates generated as $CaCO_3$ are calcite crystals, as proven by energy-dispersive X-ray analysis and X-ray diffraction.

## 3. Result

**MICP in Concrete Self-Healing Properties**

| **IMPROVEMENT OF CONCRETE USING MICP** | | | | | |
|---|---|---|---|---|---|
| **Paper** | **Bacteria** | **Test** | **Parameter** | **Result** | **Conclusion** |
| Bacteria-Based Self-Healing Concrete to Increase Liquid Tightness Of Cracks | Alkaliphilic bacteria of the genus Bacillus | Compressive Strength Test | Compressive Strength | The Compressive strengths of One Control Mixture with non-impregnated LWA(CTRL), One mixture with impregnated LWA (B) concrete specimen at 28 days was found to be 29MPa and 28.8 MPa respectively. | Concrete with non-treated Alkaliphilic bacteria has only increased compressive strength of 0.7%. |
| | | Flexural Strength Test | Flexural Strength | The Flexural strengths of One Control Mixture with non-impregnated LWA(CTRL), One mixture with impregnated LWA (B) concrete specimen at 28 days was found to be 6.2 MPa and 5.8 MPa respectively. | Concrete with non-treated Alkaliphilic bacteria has only increased Flexural strength of 6.5%. |

| IMPROVEMENT OF CONCRETE USING MICP | | | | | |
|---|---|---|---|---|---|
| **Paper** | **Bacteria** | **Test** | **Parameter** | **Result** | **Conclusion** |
| | | Density Test | Density | The Density of One Control Mixture with non-impregnated LWA(CTRL)<br>One mixture with impregnated LWA (B) concrete specimen 1652 kg/m$^3$ and 1546 kg/m$^3$ respectively. | Concrete with non-treated Alkaliphilic bacteria has only increased Density of 6.42%. |
| Bacteria Based Self-Healing Concrete – A Bacterial Approach | • *Bacillus pasteurizing*<br>• *Bacillus sphaericus*<br>• *Escherichia coli*<br>• *Bacillus subtilis*<br>• *Bacillus cohnii*<br>• *Bacillus balodurans*<br>• *Bacillus pseudofirmus* | Compressive Strength Test | Compressive Strength | The Compressive strengths of Normal Concrete and Bacterial Concrete specimen at 28 days was found to be 30 MPa and 38.95 MPa respectively. | Concrete treated with the mentioned bacillus bacteria has increased Compressive strength by 23%. |
| | | Flexural Strength Test | Flexural Strength | The Flexural strengths of Normal Concrete and Bacterial Concrete specimen at 28 days was found to be 7.05 MPa and 7.8 MPa respectively. | Concrete treated with the mentioned bacillus bacteria has increased Flexural strength by 9.6%. |
| Bacteria-Based Self-Healing Concrete – An Introduction | Alkaliphilic spore-forming bacteria<br>Selected species from the genus Bacillus | | | Bacteria-based self-healing concrete system developed on a lab scale. Further research is needed for practical application. | |
| Bacteria-Based Self-Healing Concrete | Alkali-resistant spore-forming bacteria<br>Specific alkali-resistant bacteria related to the genus Bacillus | | | Bacterial concrete can efficiently heal cracks and decrease material permeability. The proposed bio-chemical healing agent shows promise but requires further optimization. | |
| Self-Healing Concrete Based on Different Bacteria: A Review | • *Bacillus subtilis*<br>• *Sporosarcina pasteurii* | Self–healing test | Crack | *Bacillus Pasteuri* and *Bacillus subtilis* are the most effective bacteria for healing cracks in concrete. | Microbial concrete is a cost-effective and environmentally friendly alternative that improves the |

| IMPROVEMENT OF CONCRETE USING MICP | | | | | |
|---|---|---|---|---|---|
| **Paper** | **Bacteria** | **Test** | **Parameter** | **Result** | **Conclusion** |
| | | | | | durability of building materials |

**MICP in Soil Stabilization and Geotechnical Engineering**

| IMPROVEMENT OF SOIL USING MICP | | | | | |
|---|---|---|---|---|---|
| **Paper** | **Bacteria** | **Test** | **Parameter** | **Result** | **Conclusion** |
| Methods for the Introduction of Bacteria into Soil<br>A Review | • *Thiobacillus Ferrooxidans*<br>• *Pseudomonas*<br>• *Acinetobacter*<br>• *Alcaligenes*<br>• *Arthrobacter sp.* | Assessment of inoculant survival and effectiveness | Inoculant Survival | Synthetic carriers have great potential for inoculant protection | |
| Plant Growth Promoting Bacteria: Role in Soil Improvement, Abiotic<br>and Biotic Stress Management of Crops | *Plant growth promoting bacteria (PGPB)*<br>• *Bacillus pumilus*<br>• *Mesorhizobium sp.*<br>• *Variovorax paradoxus*<br>• *Burkholderia phytofirmans*<br>• *P. libanensis*<br>• *Arthrobacter sp.*<br>• *Brevibacterium sp.*<br>• *Streptomyces sp.*<br>• *Azospirillum brasilense*<br>• *Bacillus amyloliquefaciens*<br>• *Pseudomonas fragi.* | **Soil Fertility test**<br>Soil nutrient analysis | **Soil Fertility**<br>Soil nutrient | Plant growth-promoting bacteria (PGPB) can improve soil fertility.<br>PGPB can help crops cope with biotic and abiotic challenges. Disease suppression of bacterial and fungal pathogens<br>Improvement in growth of tomato, pepper, and cucumber crops | |
| Improvement of Sandy Soils Using Locally Available Urease-<br>Positive Bacteria-Induced Calcite Precipitation Technique. | Locally available urease-positive bacteria<br>*Bacillus Pasteurii* | Needle penetration Test and Cyclic Triaxial Tests | Needle penetration resistance | Amount of precipitated calcite: 45.57kg/m$^3$ (Method A), 14.50 kg/m$^3$ (Method B)<br>Needle penetration resistance: around 2.5 times higher for treated specimen - | Method B was more efficient than Method A due to having 68.2% less calcite precipitation. |

| IMPROVEMENT OF SOIL USING MICP | | | | | |
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| **Paper** | **Bacteria** | **Test** | **Parameter** | **Result** | **Conclusion** |
| | | | | MICP improved engineering behavior of sandy soil | |
| Biological Process of Soil Improvement in Civil Engineering: A Review | • *Bacillus, Sporosarcina*<br>• *Spoloactobacilus*<br>• *Clostridium* | Strength/stiffness and Permeability Test | Strength/stiffness and Permeability | Bio-mediated soil improvement technique shows potential in geotechnical engineering. | |

**MICP in BRICK STRENGTH IMPROVEMENT**

| IMPROVEMENT OF BRICKS USING MICP | | | | | |
|---|---|---|---|---|---|
| **Paper** | **Bacteria** | **Test** | **Parameter** | **Result** | **Conclusion** |
| Microbial-Induced Carbonate Precipitation Improves Physical and Structural Properties of Nanjing Ancient City Walls | *Sporosarcina pasteurii* (CGMCC 1.3687), an ureolytic bacterium | Compressive Strength Test | Compressive Strength | The failure load of the MICP remediation cube sample was 33.56 ± 9.07 (kN) and the failure load of the c was 19.00 ± 1.98 (kN). The compressive strength of the MICP remediation cube sample was 17.33 ± 4.69 MPa and the compressive strength of the non-MICP remediation cube sample was 9.84 ± 1.02 MPa. | The failure load in the MICP remediation cube increased by 43.38% which led to an increased compressive strength of 43.22% compared to non- MICP remediation cube sample |
| | | Water-Resistance Test | Softening point | The water- resistance of the sample can be identified through the analysis of the softening point. The softening point of the MICP remediation cube sample was (0.84 ± 0.03) and the softening point. of the non-MICP remediation cube sample was 0.78 ± 0.05. | The softening point of the MICP remediation cube sample increased by 7.14% which shows that incorporating MICP increases the water resistance of the sample. |
| | | X-ray micro-CT | Pores | The total pores' volume of the tested brick cube was 5.31 × 103 $mm^3$, occupying 5.91% of the total cube (43.92 × 45.60 × 44.85 $mm^3$). The natural cracks | The volume of MICP filler occupied 17.3% of the total pores and 20.8% of the natural cracks |

| IMPROVEMENT OF BRICKS USING MICP | | | | | |
|---|---|---|---|---|---|
| **Paper** | **Bacteria** | **Test** | **Parameter** | **Result** | **Conclusion** |
| | | | | volume was 4.45 × 103 $mm^3$, occupying 83.7% of the pores in the brick cube. After treatment, the MICP particles filled the natural cracks, forming a filler with a volume of 9.25 × 102 $mm^3$. | |
| | | X-ray Scanning Visualization X-ray Fluorescence (XRF) | Minerals | From the the XRD analysis, the results shows that the ancient brick is dominated by a quartz phase (ca. 80%), followed by a hercynite and a feldspar one, small quantities of calcite were also detected (less than 2%). Findings From the XRF analysis show that the metal oxides in ancient brick included silica ($SiO_2$), calcium oxide (CaO), alumina ($Al_2O_3$), and iron oxide ($Fe_2O_3$). The predominant component in the ancient brick and MICP filler is SiO2. | The main component present in both the ancient brick and MICP filler is $SiO_2$. The ratio of CaO in the ancient brick is 3.25%, while in the MICP filler it is 4.31%. The MICP filler has a higher ratio of 'other elements' (21.35%) compared to the ancient brick (12.37%). |
| Improvement In Strength Properties of Ash Bricks by Bacterial Calcite | *Bascillus megaterium* | Compressive Strength Test | Compressive Strength | The compressive strengths at 28 days of the Bacteria treated rice husk (30%) Ash brick (B-RHAB) were found 12.8 MPa, the untreated rice husk (30%) Ash brick (U-RHAB) was found 9.7 MPa, the Bacteria treated Fly Ash (30%) brick (B-FAB) was found 14.94 MPa, Untreated Fly Ash (30%) brick (U-FAB) was found 11.68 MPa. | The compressive strength of the Bacteria treated Fly Ash (30%) brick (B-FAB) was found 14.94 MPa which is 35.15 greater than the lowest compressive strength among the four specimens. This explains that bacteria-treated bricks with Fly Ash will strengthen the masonry structures more |

| IMPROVEMENT OF BRICKS USING MICP | | | | | |
|---|---|---|---|---|---|
| **Paper** | **Bacteria** | **Test** | **Parameter** | **Result** | **Conclusion** |
| | | | | | than any other treatments. |
| | | Water Absorption Test | Water Absorption | The water absorption of the B-RHAB, U-RHAB, B-FAB, U-FAB was found 15%, 7.5%, 13.5%, 12.5% respectively. | The water absorption is 46% more in the non-bacteria-treated rice husk than in the bacteria-treated rice husk. On the other hand, the non-bacteria treated fly ash will absorb 44% more than the bacteria-treated fly ash brick. |
| | | Microbiological sand plugging | Microbiological sand plugging | It was found that the column was tightly packed while the control sand collapsed immediately after opening the plastic column | |
| | | Freeze and thaw on Compressive Strength | Effect of freeze and thaw on Compressive Strength | Due to the freeze-thaw effect, the compressive strengths of the Bacteria treated rice at 28 days husk (30%) Ash brick (B-RHAB) was found 11.23 MPa, the untreated rice husk (30%) Ash brick (U-RHAB) was found 8.62 MPa, the Bacteria treated Fly Ash (30%) brick (B-FAB) was found 12.63 MPa, Untreated Fly Ash (30%) brick (U-FAB) was found 10.93 MPa. | When there is the effect of freeze-thaw the compressive strength of the (B-FAB) was found 31.75% more than the lowest found strength which naturally explains for a country with a severely colder climate, masonry structures built with bacteria-treated fly ash will provide more safety. |

## 4. Conclusion

Incorporating Microbially Induced Calcium Carbonate Precipitation (MICP) significantly boosts concrete's compressive strength by 43.22% and enhances water resistance by 7.14%. The MICP remediation cube surpasses the non-MICP cube in failure load by 43.38%, highlighting its potential for robust construction. Analysis of pores and cracks reveals that MICP filler occupies 17.3% of total pores and 20.8% of natural cracks, contributing to increased structural integrity. X-ray Diffraction (XRD) and X-ray

Fluorescence (XRF) investigations indicate that $SiO_2$ is a major component in both ancient brick and MICP infill. Bricks treated with bacteria-infused fly ash demonstrate a 35.15% increase in compressive strength, underscoring their advantages in masonry construction. Studies on water absorption reveal that bacteria-treated rice husks and fly ash bricks absorb significantly less water than their untreated counterparts. Microbiological sand plugging trials showcase the effectiveness of MICP in densely packed columns, while freeze-thaw resistance tests underscore safety improvements in extremely cold regions.

Concrete treated with a specific bacillus bacteria show enhanced compressive and flexural strength. They increased by 23% and 9.6%, respectively. Density studies indicate a 6.42% increase, further fortifying the material's toughness. Conversely, treatments with alkaliphilic bacteria result in marginal improvements in compressive strength, flexural strength, and density.

The application of Bacillus bacteria in self-healing concrete leads to a 23% improvement in compressive strength. *Bacillus Pasteuri* and *Bacillus subtilis*, in particular, prove effective in repairing cracks. The summary emphasizes the diverse roles of bacteria in enhancing engineering qualities, with specific strains tailored for particular applications. Bacillus strains are identified as crucial for improving concrete strength, while MICP holds promise in soil improvement and geotechnical engineering. The choice of bacteria depends on the desired property, influencing sustainable and resilient construction methodologies.

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