Experimental Investigation On Bacterial Concrete

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Abstract: Concrete is one of the most widely used construction materials, but its durability is often affected by the formation of cracks that permit the ingress of water and harmful chemicals. This study investigates the performance of bacterial concrete prepared using *Bacillus subtilis* bacteria as a self-healing agent. The bacteria produce calcium carbonate through Microbial Induced Calcite Precipitation (MICP), which seals microcracks and improves the durability of concrete. Laboratory investigations were carried out on conventional concrete and bacterial concrete specimens prepared with different bacterial concentrations. The specimens were tested for compressive strength and flexural strength after 7 and 28 days of curing. Scanning Electron Microscopy (SEM) was also conducted to observe calcium carbonate precipitation inside the concrete matrix. Experimental results indicated that bacterial concrete exhibited higher compressive and flexural strength than conventional concrete. The self-healing action reduced permeability and improved the overall durability of the concrete. The study concludes that bacterial concrete is an environmentally sustainable material capable of extending the service life of structures while reducing maintenance costs.

Keywords - Bacterial Concrete, Bacillus subtilis, Self-Healing Concrete, Microbial Induced Calcite Precipitation, Calcium Carbonate, Sustainable Construction.

1. INTRODUCTION

Concrete is one of the most widely used construction materials and plays a vital role in modern infrastructure. It is commonly used in buildings, bridges, dams, roads, and tunnels due to its high compressive strength, durability, and cost-effectiveness. Concrete can be moulded into various shapes, making it suitable for different structural applications. However, despite these advantages, conventional concrete has certain limitations that affect its long-term performance.One of the major issues with conventional concrete is the formation of cracks. These cracks may occur due to shrinkage, temperature changes, heavy loads, or environmental factors. Initially, cracks may be small, but they tend to grow over time. The presence of cracks allows water and harmful chemicals to enter the concrete, leading to corrosion of steel reinforcement and weakening of the structure. This results in reduced durability, increased maintenance costs, and a shorter service life. Repairing cracks using traditional methods can be expensive and sometimes ineffective.To address these problems, bacterial concrete has been developed as a self-healing material. This innovative concrete contains bacteria such as Bacillus subtilis along with nutrients. These bacteria remain inactive within the concrete until cracks form and moisture enters. Once activated, they initiate a biological process that helps repair the cracks.The bacteria produce calcium carbonate through a process called Microbial Induced Calcite Precipitation (MICP). The calcium carbonate crystals fill the cracks and pores in the concrete, preventing further damage and improving durability. This self-healing property enhances the strength and lifespan of concrete structures while reducing maintenance needs.This study focuses on comparing conventional concrete with bacterial concrete. Tests such as compressive strength and flexural strength are conducted to evaluate their performance. Additionally, Scanning Electron Microscopy (SEM) is used to observe the formation of calcium carbonate within the concrete.The results are expected to show that bacterial concrete has better strength, durability, and crack-healing ability compared to conventional concrete. It also offers an environmentally friendly solution by reducing repair work and extending the life of structures.

1.1 Introduction To Bacterial Concrete

Bacterial concrete, also called bio-concrete or self-healing concrete, is a new material designed to fix the problems of regular concrete. This concept involves embedding specific strains of bacteria in the concrete mix. These bacteria stay dormant until moisture and oxygen seep in through cracks. Once activated, the microorganisms start a process that produces calcium carbonate ($CaCO_3$), which fills the cracks and restores the concrete's strength. This self-healing feature greatly improves durability, reduces permeability, and lowers the need for external repairs.Among the various microorganisms researched, Bacillus subtilis has proven to be one of the best options for bacterial concrete. This bacterium is a spore-forming, Gram-positive microbe that can endure the highly alkaline conditions of concrete for long periods. In its dormant spore state, it survives tough conditions without losing the ability to germinate when conditions become favourable. When cracks occur and water enters the mix, the spores germinate and use nutrients like calcium lactate to produce $CaCO_3$ crystals, which serve as a natural sealing agent.Adding bacteria to concrete has many benefits compared to traditional crack repair methods. Unlike external repair techniques, which are labor-intensive and short-term, bacterial concrete offers a self-sufficient and ongoing healing method throughout the structure's lifetime. Besides sealing cracks, it improves compressive and flexural strength, increases resistance to environmental issues like freeze-thaw cycles and chloride damage, and boosts overall structural durability.This technology supports the global movement toward sustainable construction by cutting down on material waste, reducing repair costs, and extending the lifespan of structures. Despite challenges such as breeding costs, large-scale implementation, and long-term bacterial effectiveness, bacterial concrete is a groundbreaking innovation that could change the future of civil engineering materials

1.2 Background Of Concrete And Its Limitations

Concrete is the foundation of modern infrastructure and is the most widely used construction material in the world. Its popularity comes from its strong compressive strength, durability, ability to be molded into various shapes, and cost-effectiveness. Concrete serves as the main material for building residential, commercial, and industrial structures, including buildings, dams, roads, tunnels, and bridges. Conventional concrete mainly consists of cement, aggregates, water, and sometimes additives. This combination creates a strong and versatile material that fits many structural needs. Despite these benefits, concrete has notable limitations that impact its long-term performance. One major issue is its low tensile strength compared to its compressive strength, making it naturally brittle. This brittleness leads to cracks under tension, shrinkage, thermal changes, and external loads. These cracks become weak spots, weakening the structure and reducing its durability. Cracks not only lower the load-bearing capacity of concrete but also allow water, chlorides, sulfates, and other harmful chemicals to enter. This speeds up the corrosion of the steel reinforcement within the concrete, weakens the structure, and shortens its lifespan. Furthermore, environmental factors like freeze-thaw cycles, carbonation, and alkali-aggregate reactions worsen concrete damage. Because of this, regular maintenance, repair, and rehabilitation are necessary, which raises the overall lifecycle cost of concrete structures. While concrete has been a key part of construction for centuries, its limitations, especially its tendency to crack and deteriorate over time, present significant challenges for sustainable infrastructure. These issues have led researchers to investigate new materials and methods, such as self-healing bacterial concrete, to improve durability, lower maintenance needs, and enhance the sustainability of concrete structures

2. METHODOLOGY

Concrete mixes were prepared for both conventional concrete and bacterial concrete under identical conditions to ensure a fair comparison of their performance. The bacterial concrete was produced by incorporating *Bacillus subtilis* bacteria into the concrete mix, while the conventional concrete was prepared without bacterial addition. Standard cube and beam moulds were used to cast the test specimens according to relevant testing standards. During casting, proper compaction was carried out to remove entrapped air and achieve a dense, uniform concrete structure. After casting, the specimens were demoulded after 24 hours and cured in clean water for 7 and 28 days to allow sufficient hydration and strength development.Following the curing period, the mechanical properties of both concrete types were evaluated through laboratory testing. Compressive strength tests were conducted on cube specimens using a compression testing machine to determine the load-carrying capacity of the concrete. Flexural strength tests were performed on beam specimens to assess their resistance to bending and cracking under applied loads. The test results obtained at both curing ages were carefully recorded and compared.To examine the self-healing capability of bacterial concrete, Scanning Electron Microscopy (SEM) analysis was carried out on selected specimens. SEM images were used to identify the formation and distribution of calcium carbonate ($CaCO_3$) crystals produced by the metabolic activity of *Bacillus subtilis*. The precipitation of these crystals within cracks and pores confirmed the self-healing mechanism of bacterial concrete.Finally, the results of compressive strength, flexural strength, and SEM analysis were compared with those of conventional concrete. This comparison enabled the evaluation of improvements in mechanical performance, crack-healing efficiency, and overall durability, thereby determining the effectiveness of bacterial concrete as an environmentally friendly and sustainable construction material.

3. ANALYSIS OF BACTERIAL CONCRETE

The analysis of bacterial concrete was carried out to evaluate the influence of Bacillus subtilis on the mechanical and durability properties of concrete. The investigation focused on comparing conventional concrete with bacterial concrete by conducting standard laboratory tests after curing periods of 7 and 28 days. The incorporation of bacteria promotes the formation of calcium carbonate ($CaCO_3$) through the process of Microbial Induced Calcite Precipitation (MICP), which fills microcracks and pores within the concrete matrix. This natural self-healing mechanism improves the strength and durability of concrete while reducing water permeability.

The experimental program included preparation of bacterial culture, concrete mixing, casting of cube and beam specimens, curing under controlled conditions, and testing for compressive strength and flexural strength. In addition, Scanning Electron Microscopy (SEM) was performed to examine the microstructure and confirm the deposition of calcium carbonate crystals within the concrete. The experimental observations demonstrated that bacterial concrete exhibited higher mechanical strength and improved crack-healing capability compared to conventional concrete, making it a promising material for sustainable construction

3.1 Preparation of Bacterial Culture

The bacterial culture was prepared using *Bacillus subtilis*, a non-pathogenic and spore-forming bacterium widely used in self-healing concrete research due to its ability to precipitate calcium carbonate. A nutrient-rich culture medium was prepared by dissolving peptone, beef extract, sodium chloride, and distilled water in the required proportions. The prepared medium was sterilized in an autoclave at **121°C for 15–20 minutes** to eliminate unwanted microorganisms and ensure a contamination-free environment. After sterilization, the medium was allowed to cool before inoculating it with *Bacillus subtilis* under sterile laboratory conditions. The inoculated culture was then incubated at a temperature of **30–37°C for 24 hours** to promote active bacterial growth and multiplication. Once sufficient bacterial growth was achieved, the culture was used during concrete mixing by incorporating it into the mixing water. This ensured uniform distribution of the bacteria throughout the concrete specimens,enabling effectivecalcium carbonate precipitation and enhancing the self-healing capability and durability of the concrete.

Fig.1 (Autoclave)

3.2 Experimental Investigation

The concrete specimens were prepared according to the designed mix proportion and cast into standard moulds. Cube specimens measuring 150 mm × 150 mm × 150 mm were prepared for compressive strength testing, while beam specimens were cast for flexural strength evaluation. All specimens were demoulded after 24 hours and cured in water until the testing period of 7 and 28 days.After curing, compressive strength and flexural strength tests were conducted using standard testing machines. The test results were recorded and compared with those of conventional concrete to determine the improvement achieved through bacterial incorporation

Fig.2 (Testing Of Flexural)

Fig.2 (compressive Testing)

3.3 Microstructural Analysis

Microstructural analysis was carried out using Scanning Electron Microscopy (SEM) to study the internal structure of bacterial concrete. The SEM images revealed the presence of calcium carbonate crystals deposited by Bacillus subtilis, which filled microcracks and pores within the cement matrix. The denser microstructure obtained through bacterial activity resulted in improved mechanical strength, lower permeability, and enhanced durability. These observations confirmed the effectiveness of bacterial concrete as a self-healing material suitable for sustainable construction applications.

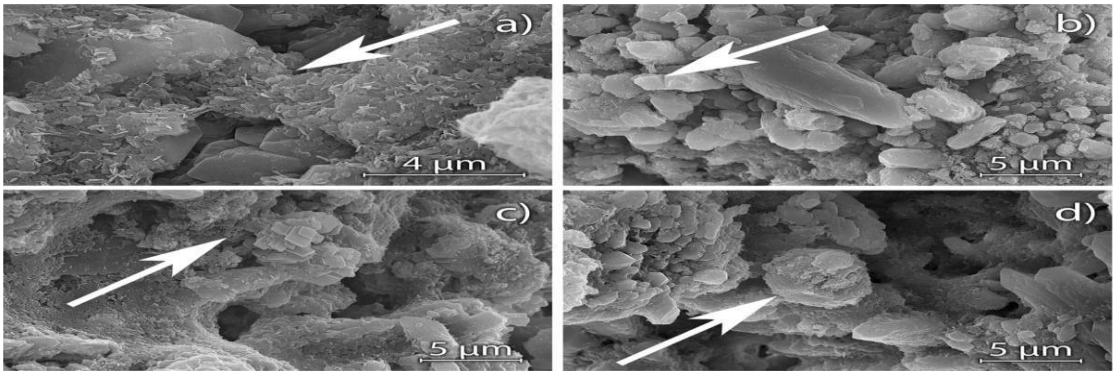


Fig.3 (sem Analysis)

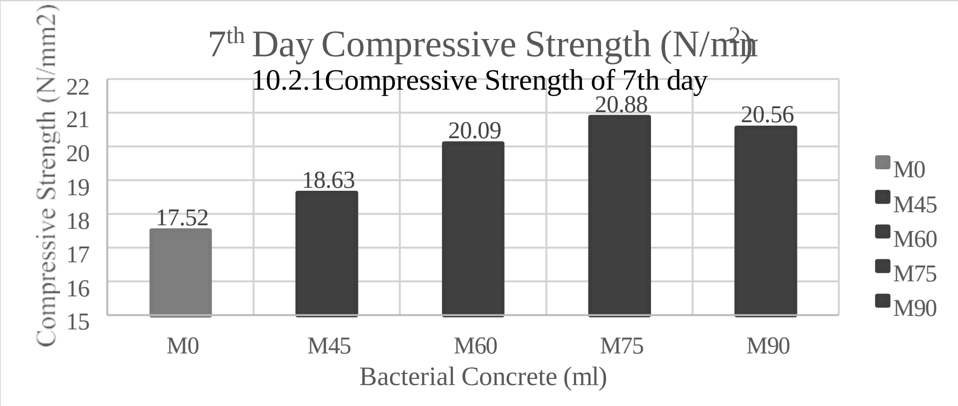
RESULT AND DISCUSSION

The experimental investigation was conducted to evaluate the influence of *Bacillus subtilis* bacteria on the mechanical properties and microstructural characteristics of concrete. The study compared conventional concrete (M0) with bacterial concrete prepared using different bacterial concentrations (M45, M60, M75, and M90). The specimens were cured for 7 and 28 days and subjected to compressive strength, flexural strength, and Scanning Electron Microscopy (SEM) analysis. The experimental results clearly demonstrated that the incorporation of bacteria significantly improved the strength, durability, and self-healing capability of concrete. The enhancement in performance is primarily attributed to the process of Microbial Induced Calcite Precipitation (MICP), through which the bacteria produce calcium carbonate ($CaCO_3$) crystals that fill pores and microcracks within the concrete matrix.

4.1 Compressive Strength

Compressive strength is one of the most important parameters used to assess the quality and structural performance of concrete. The compressive strength tests were conducted on cube specimens after 7 and 28 days of water curing. The results revealed a gradual increase in compressive strength with increasing bacterial concentration up to the M75 mix. The control specimen (M0), which contained no bacteria, achieved compressive strengths of **17.52 MPa** and **26.18 MPa** after 7 and 28 days, respectively. The bacterial concrete specimens showed consistently higher strengths than the control mix at both curing periods.Among all the mixes, **M75** exhibited the highest compressive strength, recording **20.88 MPa** at 7 days and **34.86 MPa** at 28 days. This represents an improvement of approximately **33%** over conventional concrete at 28 days. The increase in strength confirms that the bacterial activity effectively enhanced the internal structure of the concrete by filling microvoids and cracks with calcium carbonate deposits. The calcite crystals acted as natural fillers, reducing porosity and increasing the density of the cement matrix.Although the M90 mix also demonstrated improved strength compared to conventional concrete, a slight reduction was observed when compared with the M75 mix. This suggests that an excessive bacterial concentration may not always contribute to further strength enhancement. Higher bacterial content may reduce the efficiency of microbial activity due to nutrient limitations or uneven bacterial distribution within the concrete matrix. Therefore, the M75 mix was identified as the optimum bacterial dosage for achieving maximum compressive strength.The compressive strength results clearly indicate that bacterial concrete possesses superior load-carrying capacity and can effectively withstand higher compressive stresses than conventional concrete. These improvements make bacterial concrete suitable for structural applications where high strength and long-term durability are required.

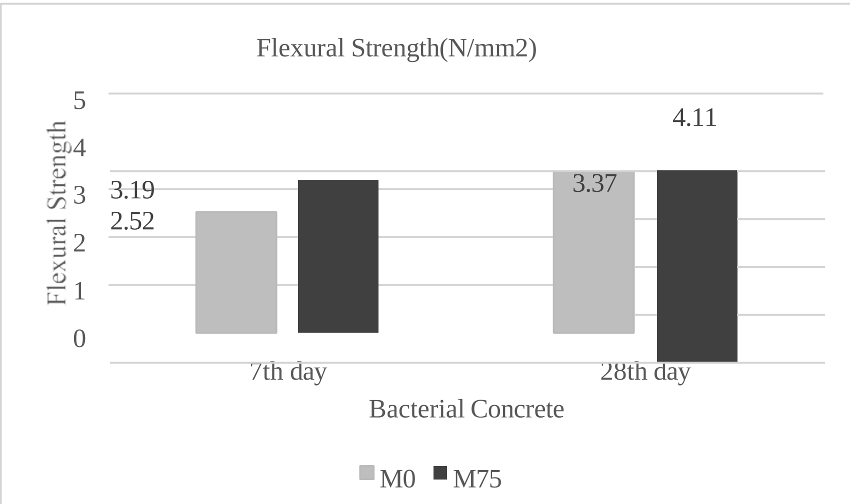
Mix details of bacterial concrete (solution in ml)	Compressive strength(N/mm^2)	
	7th Day	**28th Day**
M0	17.52	26.18
M45	18.63	28.23
M60	20.09	31.56
M75	**20.88**	**34.86**
M90	20.56	32.56



4.2 Flexural Strength

Flexural strength is another important mechanical property that measures the ability of concrete to resist bending and tensile stresses. Concrete is naturally weak in tension, and cracks usually initiate due to tensile forces. Therefore, improving flexural strength is essential for increasing the durability and service life of concrete structures.The flexural strength tests were conducted on beam specimens after 7 and 28 days of curing. The conventional concrete mix (M0) recorded flexural strengths of **2.52 MPa** and **3.37 MPa** at 7 and 28 days, respectively. In contrast, the bacterial concrete specimen with the optimum bacterial dosage (M75) achieved flexural strengths of **3.19 MPa** at 7 days and **4.11 MPa** at 28 days.The improvement in flexural strength can be attributed to the precipitation of calcium carbonate crystals within the internal cracks and pores of the concrete. These crystals effectively bridge microcracks and improve the bond between cement paste and aggregates. As a result, crack propagation is delayed, and the concrete becomes more resistant to bending stresses.The enhanced flexural performance also demonstrates the self-healing capability of bacterial concrete. When moisture enters through small cracks, dormant bacterial spores become active and utilize calcium lactate as a nutrient source to produce calcium carbonate. This process naturally seals the cracks, preventing further crack growth and reducing the possibility of structural deterioration. Consequently, bacterial concrete exhibits greater resistance to tensile stresses and provides improved structural integrity compared to conventional concrete.

Mix details of bacterial concrete(solution in ml)	Flexural Strength (N/mm^2)	
	7th day	28th day
M0	2.52	3.37
M75	3.19	4.11



4.3 Microstructural Analysis (SEM)

Scanning Electron Microscopy (SEM) was employed to investigate the internal microstructure of bacterial concrete and verify the occurrence of calcium carbonate precipitation. SEM images of conventional concrete revealed relatively larger pores, voids, and discontinuities within the cement matrix. These pores serve as pathways for water and aggressive chemicals, eventually leading to reinforcement corrosion and deterioration of concrete.In contrast, SEM images of bacterial concrete displayed dense deposits of calcium carbonate crystals distributed throughout the cement matrix. These crystals were observed filling pores, microcracks, and capillary voids, producing a much denser and more compact internal structure. The calcite deposits significantly improved the bonding between cement particles and aggregates, thereby increasing the overall strength of the concrete.The SEM observations strongly support the mechanical test results. The reduction in porosity and improvement in matrix density explain the significant increase in compressive and flexural strengths obtained for bacterial concrete. Furthermore, the dense microstructure reduces water absorption and permeability, thereby enhancing the durability of the concrete under aggressive environmental condition

Discussion

The experimental results clearly demonstrate that bacterial concrete prepared using *Bacillus subtilis* significantly outperforms conventional concrete in terms of mechanical strength, durability, and self-healing capability. The increase in compressive and flexural strengths confirms the effectiveness of Microbial Induced Calcite Precipitation (MICP) as a natural crack-healing mechanism. Calcium carbonate produced by bacterial activity fills microcracks before they develop into larger structural defects, thereby preserving the integrity of the concrete.The optimum bacterial dosage identified in this study was **M75**, which provided the highest compressive and flexural strengths. This indicates that bacterial concentration plays a crucial role in determining the effectiveness of the self-healing process. While moderate bacterial content promotes efficient calcium carbonate precipitation, excessive bacterial dosage may reduce performance due to insufficient nutrients or overcrowding of bacterial cells.The reduced porosity observed through SEM analysis also indicates improved resistance to water penetration, chloride ingress, sulphate attack, and reinforcement corrosion. These characteristics are particularly important for structures exposed to harsh environmental conditions such as marine structures, bridges, tunnels, dams, and water-retaining structures. The self-healing ability minimizes maintenance requirements and reduces repair costs throughout the service life of the structure.From a sustainability perspective, bacterial concrete offers significant environmental benefits. The increased service life of concrete structures reduces the demand for reconstruction and repairs, thereby lowering cement consumption and associated carbon dioxide emissions. Although the initial production cost of bacterial concrete is slightly higher than conventional concrete due to bacterial culture preparation, the long-term economic benefits outweigh the additional initial investment because of reduced maintenance expenses and improved durability.Overall, the experimental findings confirm that the incorporation of *Bacillus subtilis* is an effective approach for developing high-performance self-healing concrete. The significant improvements in compressive strength, flexural strength, crack-healing efficiency, and microstructural properties demonstrate the potential of bacterial concrete as an advanced and sustainable construction material. With further research and large-scale implementation, bacterial concrete has the potential to revolutionize the construction industry by enhancing structural durability, minimizing maintenance requirements, and supporting environmentally responsible infrastructure development.

5.CONCLUSION

conventional concrete. The incorporation of bacteria significantly enhances the mechanical and durability properties of concrete by promoting the formation of calcium carbonate ($CaCO_3$) through the process of Microbial Induced Calcite Precipitation (MICP). This natural self-healing mechanism effectively seals microcracks and pores that develop within the concrete matrix, thereby reducing permeability and preventing the ingress of water and harmful chemicals. As a result, bacterial concrete exhibits improved compressive strength, flexural strength, and overall structural performance compared to conventional concrete.The experimental investigation demonstrated that bacterial concrete possesses better crack-healing capability, resulting in a denser and more durable internal structure. The deposition of calcium carbonate not only restores the integrity of cracked concrete but also enhances resistance to environmental deterioration, such as chloride penetration and moisture attack. These improvements contribute to a longer service life of concrete structures while minimizing the need for frequent maintenance and costly repair works.Although the initial production cost of bacterial concrete is slightly higher due to the preparation of bacterial cultures and nutrient media, the long-term economic benefits outweigh this additional investment. Reduced maintenance costs, increased durability, and extended structural lifespan make bacterial concrete a cost-effective solution for modern construction. Furthermore, the technology supports sustainable development by reducing material consumption, lowering environmental impacts associated with repair and reconstruction, and promoting eco-friendly construction practices.Based on the experimental findings, bacterial concrete has significant potential for application in bridges, buildings, tunnels, marine structures, pavements, retaining walls, water-retaining structures, and other reinforced concrete infrastructures where durability, self-healing capability, and long-term performance are essential. Continued research and large-scale implementation can further establish bacterial concrete as a reliable construction material for future sustainable infrastructure development.

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