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Experimental Investigation of Self-Healing Bacterial M30 Concrete for Water Tank Applications

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Abstract: Concrete water tanks are highly vulnerable to cracking, leakage, permeability, and durability deterioration due to continuous exposure to hydrostatic pressure and environmental effects. Conventional repair techniques are often costly and temporary in nature. This study investigates the performance of self-healing bacterial M30 concrete for water tank applications using microbial-induced calcium carbonate precipitation (MICP) technology. *Bacillus subtilis* bacteria were incorporated into M30 concrete at two bacterial concentrations, namely BC-1% and BC-2%, and compared with conventional concrete. Experimental investigations were carried out to evaluate compressive strength, split tensile strength, flexural strength, water absorption, permeability, and crack-healing efficiency. Results revealed that bacterial concrete significantly improved mechanical strength and durability characteristics due to calcite precipitation within pores and cracks. The BC-2% mix exhibited the highest crack-healing efficiency and lowest water permeability. The study concludes that bacterial self-healing concrete can provide a sustainable and durable solution for water-retaining structures by reducing leakage, improving durability, and extending service life.

Keywords: Self-healing concrete, bacterial concrete, *Bacillus subtilis*, M30 concrete, water tanks, microbial-induced calcium carbonate precipitation.

1. Introduction

Concrete is one of the most extensively used construction materials in the world because of its high compressive strength, durability, versatility, and economic feasibility. It is widely utilized in buildings, bridges, dams, pavements, and water-retaining structures due to its ability to withstand heavy loads and harsh environmental conditions. Reinforced concrete structures, particularly water tanks, are continuously exposed to hydrostatic pressure, moisture, shrinkage stresses, thermal variations, and chemical attacks during their service life. These conditions often lead to the development of cracks within the concrete matrix, which significantly affect structural integrity, impermeability, and long-term durability. Cracks permit the ingress of water, chlorides, sulfates, and other harmful substances, accelerating reinforcement corrosion and deterioration of the concrete structure (Neville, 2011).

Water-retaining structures such as overhead tanks, underground reservoirs, and treatment plants are particularly vulnerable to leakage and permeability-related problems because even minor cracks can result in substantial water loss and reduction in service life. Conventional repair techniques including epoxy injection, grouting, and surface sealing are often labor-intensive, costly, and temporary in nature. Furthermore, maintenance operations in water tanks are difficult due to continuous exposure to moisture and restricted accessibility. Therefore, the development of advanced concrete materials capable of autonomously repairing cracks and improving durability has become an important area of research in modern construction engineering (ACI Committee 350, 2006).

Self-healing concrete has emerged as an innovative and sustainable solution for minimizing the adverse effects of cracking in concrete structures. The concept of self-healing concrete is inspired by biological healing mechanisms observed in living organisms, where damaged tissues repair themselves automatically without external intervention. In concrete technology, self-healing mechanisms are broadly classified into autogenous healing and autonomous healing systems. Among various autonomous healing approaches, bacterial self-healing concrete has gained significant attention due to its environmentally friendly nature and efficient crack-sealing capability (Van Tittelboom & De Belie, 2013).

Bacterial concrete technology utilizes specific microorganisms capable of precipitating calcium carbonate through microbial-induced calcium carbonate precipitation (MICP). In this process, bacteria such as *Bacillus subtilis* remain dormant within the concrete matrix in the form of spores and become activated when cracks develop and water penetrates into the structure. Upon activation, bacterial metabolic activity produces calcite crystals that fill pores and cracks, thereby restoring impermeability and improving structural durability. The deposition of calcium carbonate not only seals cracks but also reduces permeability, enhances compressive strength, and improves resistance against environmental deterioration (Jonkers et al., 2010; De Muynck et al., 2010).

Several researchers have reported that bacterial concrete exhibits superior mechanical and durability performance compared to conventional concrete. Studies have demonstrated improvements in compressive strength, tensile strength, crack resistance, and water tightness due to microbial calcite precipitation within the concrete matrix. The self-healing action effectively reduces porosity and limits the movement of water and aggressive ions through the concrete structure. These characteristics make bacterial concrete particularly suitable for hydraulic and water-retaining structures where impermeability and crack resistance are essential performance requirements (Achal et al., 2011; Wang et al., 2014).

Despite the promising potential of bacterial concrete, limited research has specifically focused on the application of bacterial self-healing M30 concrete for water tank structures under practical service conditions. Most previous studies have concentrated primarily on general strength enhancement and crack-healing behavior without detailed evaluation of durability properties such as permeability, water absorption, and sorptivity under continuous moisture exposure conditions. Therefore, the present study aims to experimentally investigate the mechanical properties, durability performance, and self-healing efficiency of bacterial M30 concrete for water tank applications using *Bacillus subtilis* bacteria. The findings of this research may contribute to the development of sustainable, durable, and low-maintenance water-retaining infrastructure systems.

2. Materials and Methodology

2.1 Materials Used

Ordinary Portland Cement (OPC) 53 grade conforming to IS 12269:2013 was used as the primary binding material for the preparation of both conventional and bacterial M30 concrete mixes due to its high early strength and suitability for structural and water-retaining applications. The cement exhibited a specific gravity of 3.15, an initial setting time of 38 minutes, and a final setting time of 520 minutes, indicating satisfactory hydration and setting characteristics for concrete production. Natural river sand conforming to Zone II grading as per IS 383:2016 was used as fine aggregate because of its good particle distribution and workability characteristics. The fine aggregate possessed a specific gravity of 2.64, fineness modulus of 2.72, and water absorption of 1.2%, which contributed to improved packing density and reduced void content within the concrete matrix. Crushed angular coarse aggregates of 20 mm nominal maximum size were used to achieve better interlocking and strength characteristics in concrete. The coarse aggregate exhibited a specific gravity of 2.78, water absorption of 0.6%, and aggregate crushing value of 18%, indicating good mechanical stability and resistance against crushing under load. Potable water conforming to IS 456:2000 was utilized for mixing and curing of all specimens to ensure proper hydration and strength development. In addition to conventional concrete ingredients, *Bacillus subtilis* bacteria were incorporated into bacterial concrete mixes because of their excellent resistance to highly alkaline concrete environments and efficient microbial-induced calcium carbonate precipitation capability. Calcium lactate was used as the nutrient and calcium source to promote bacterial metabolic activity and calcite formation for autonomous crack healing. The physical properties of the materials used in the study are summarized in Table 1.

Table 1. Physical Properties of Materials

Property	Cement	Fine Aggregate	Coarse Aggregate
Specific Gravity	3.15	2.64	2.78
Water Absorption	—	1.2%	0.6%
Fineness Modulus	—	2.72	—
Aggregate Crushing Value	—	—	18%
Initial Setting Time	38 min	—	—
Final Setting Time	520 min	—	—

2.2 Bacterial Concrete Mix Proportions

Three different concrete mixes were prepared in the present study to evaluate the influence of bacterial incorporation on the mechanical and durability performance of M30 concrete for water tank applications. The first mix consisted of conventional concrete (CC) without bacterial addition and served as the control mix for comparison. The second and third mixes were bacterial concrete mixes designated as BC-1% and BC-2%, containing 1% and 2% bacterial solution respectively. All concrete mixes were designed in accordance with the requirements of M30 grade concrete while maintaining a constant water–cement ratio of 0.45 to ensure uniformity in workability and hydration characteristics. Ordinary Portland Cement was used at 400 kg/m³ in all mixes, while the quantities of fine aggregate and coarse aggregate were maintained at 650 kg/m³ and 1200 kg/m³ respectively. Water content was fixed at 180 kg/m³ for all mixes to achieve the desired consistency and workability. In bacterial concrete mixes, calcium lactate was incorporated as a nutrient and calcium source for microbial-induced calcium carbonate precipitation. BC-1% contained 5 kg/m³ calcium lactate, whereas BC-2% contained 10 kg/m³ calcium lactate to support enhanced bacterial activity and crack-healing efficiency. A superplasticizer dosage of 4 kg/m³ was added uniformly in all mixes to improve workability without increasing water content. *Bacillus subtilis* bacteria were incorporated into BC-1% and BC-2% mixes because of their excellent survival capability under highly alkaline concrete conditions and their effective calcite precipitation behavior. The detailed mix proportions of conventional and bacterial M30 concrete are presented in Table 2.

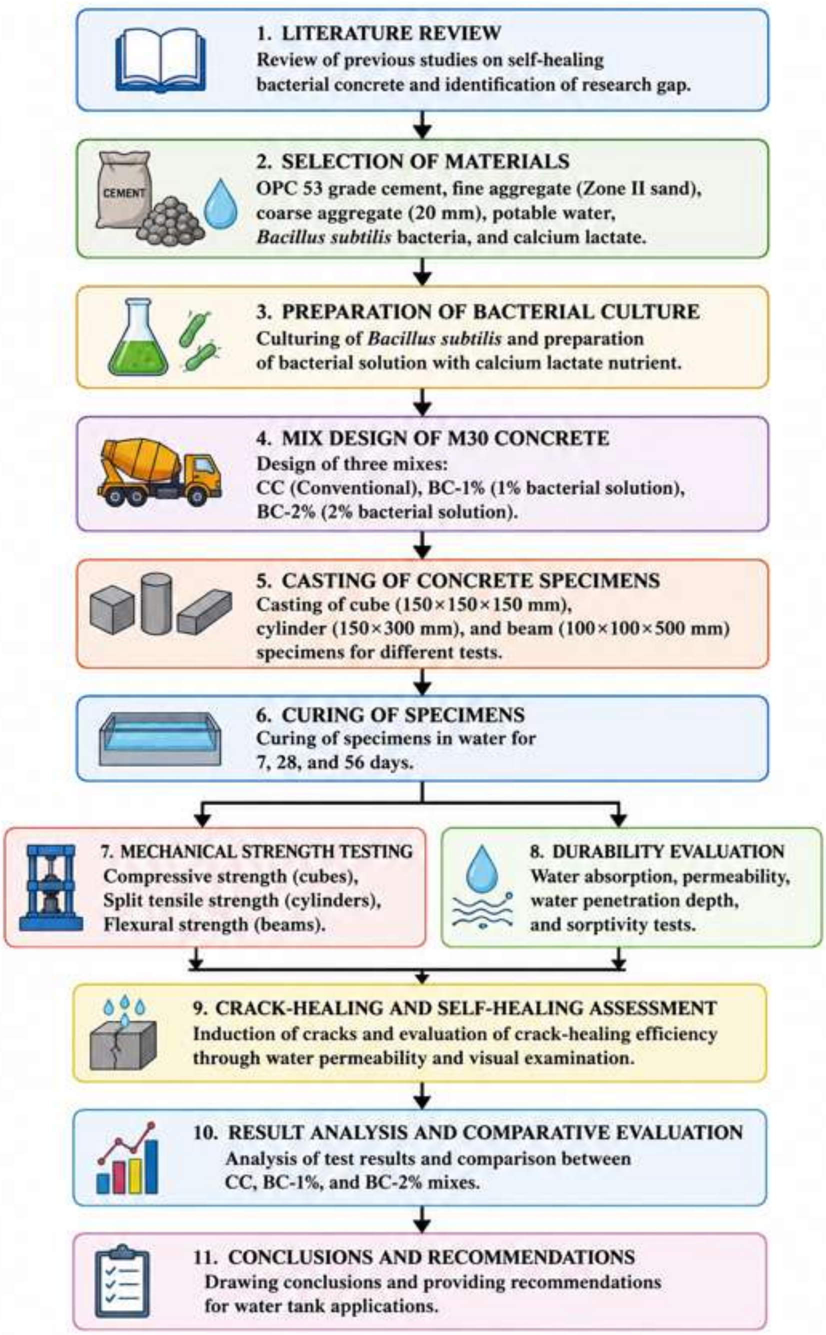
Table 2. M30 Concrete Mix Proportions

Material	CC (kg/m³)	BC-1% (kg/m³)	BC-2% (kg/m³)
Cement	400	400	400
Fine Aggregate	650	650	650
Coarse Aggregate	1200	1200	1200
Water	180	180	180
Water-Cement Ratio	0.45	0.45	0.45

Calcium Lactate	—	5	10
Superplasticizer	4	4	4
Bacterial Species	—	*Bacillus subtilis*	*Bacillus subtilis*

3. Experimental Program

The experimental program was designed to evaluate the mechanical, durability, and self-healing performance of bacterial M30 concrete for water tank applications. The investigation included comprehensive laboratory testing of conventional concrete (CC) and bacterial concrete mixes (BC-1% and BC-2%) to assess the influence of microbial-induced calcium carbonate precipitation on concrete behavior. The experimental study primarily focused on compressive strength, split tensile strength, flexural strength, water absorption, permeability, sorptivity, and crack-healing efficiency under controlled curing conditions. Mechanical strength tests were conducted to determine the load-carrying capacity and crack resistance of bacterial concrete, while durability tests were performed to evaluate permeability resistance and moisture absorption characteristics essential for water-retaining structures. Standard cube specimens of size 150 mm × 150 mm × 150 mm were cast for compressive strength testing in accordance with IS 516:2018. Cylinder specimens of dimensions 150 mm diameter and 300 mm height were prepared for split tensile strength evaluation as per IS 5816:1999, whereas beam specimens of size 100 mm × 100 mm × 500 mm were cast for flexural strength testing. All specimens were properly compacted, demoulded after 24 hours, and cured in clean water for predetermined curing periods of 7, 28, and 56 days before testing. The experimental methodology adopted in the present investigation is illustrated in Figure 1, which presents the sequence of material selection, bacterial culture preparation, concrete mixing, specimen casting, curing, testing, and result analysis.



1. LITERATURE REVIEW
Review of previous studies on self-healing bacterial concrete and identification of research gap.

2. SELECTION OF MATERIALS
OPC 53 grade cement, fine aggregate (Zone II sand), coarse aggregate (20 mm), potable water, *Bacillus subtilis* bacteria, and calcium lactate.

3. PREPARATION OF BACTERIAL CULTURE
Culturing of *Bacillus subtilis* and preparation of bacterial solution with calcium lactate nutrient.

4. MIX DESIGN OF M30 CONCRETE
Design of three mixes:
CC (Conventional), BC-1% (1% bacterial solution), BC-2% (2% bacterial solution).

5. CASTING OF CONCRETE SPECIMENS
Casting of cube (150×150×150 mm), cylinder (150×300 mm), and beam (100×100×500 mm) specimens for different tests.

6. CURING OF SPECIMENS
Curing of specimens in water for 7, 28, and 56 days.

7. MECHANICAL STRENGTH TESTING
Compressive strength (cubes), Split tensile strength (cylinders), Flexural strength (beams).

8. DURABILITY EVALUATION
Water absorption, permeability, water penetration depth, and sorptivity tests.

9. CRACK-HEALING AND SELF-HEALING ASSESSMENT
Induction of cracks and evaluation of crack-healing efficiency through water permeability and visual examination.

10. RESULT ANALYSIS AND COMPARATIVE EVALUATION
Analysis of test results and comparison between CC, BC-1%, and BC-2% mixes.

11. CONCLUSIONS AND RECOMMENDATIONS
Drawing conclusions and providing recommendations for water tank applications.

Figure 1. Research Methodology Flowchart

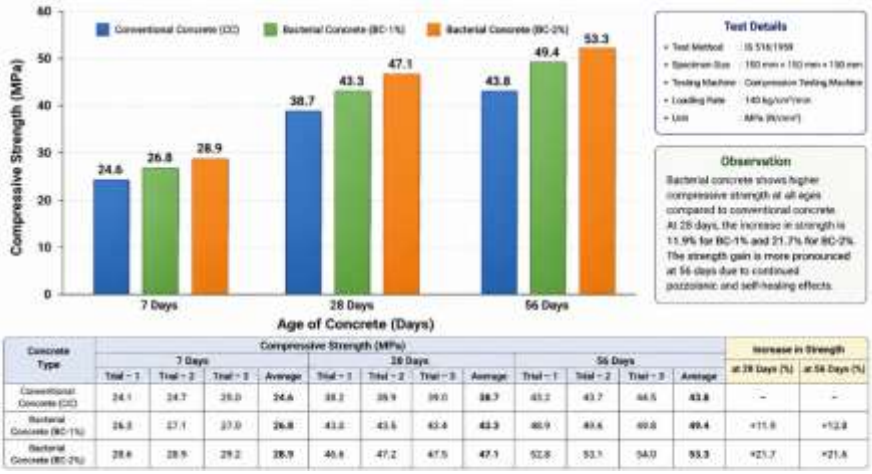
4. Results and Discussion

4.1 Compressive Strength

The compressive strength test was conducted to evaluate the load-carrying capacity and strength development of conventional and bacterial M30 concrete specimens at different curing ages. The experimental results revealed that bacterial concrete exhibited significantly higher compressive strength compared to conventional concrete at all curing periods. The improvement in strength is primarily attributed to the microbial-induced calcium carbonate precipitation process occurring within the concrete matrix. The calcite crystals formed by *Bacillus subtilis* bacteria filled internal pores, capillary voids, and microcracks, resulting in a denser and more compact concrete structure with enhanced bonding between cement paste and aggregates. The conventional concrete (CC) exhibited average compressive strengths of 24.6 MPa, 38.7 MPa, and 43.8 MPa at 7, 28, and 56 days respectively. In comparison, the bacterial concrete mix BC-1% achieved average compressive strengths of 26.8 MPa, 43.3 MPa, and 49.4 MPa, while BC-2% exhibited the highest strengths of 28.9 MPa, 47.1 MPa, and 53.3 MPa at corresponding curing ages. The BC-2% mix demonstrated approximately 21.7% higher compressive strength than conventional concrete at 56 days, indicating the positive influence of higher bacterial concentration on strength enhancement. The continuous increase in compressive strength with curing age suggests that bacterial activity and calcite precipitation contributed to progressive densification of the concrete matrix over time. The detailed compressive strength results are presented in Table 3, while the comparative variation in strength development among different mixes is illustrated in Figure 2.

Table 3. Compressive Strength Results

Concrete Type	Curing A	Trial–1 (MP	Trial–2 (MP	Trial–3 (MP	Average Strength (MP
Conventional Concrete (C	7 Days	24.1	24.7	25.0	24.6
	28 Days	38.2	38.9	39.0	38.7
	56 Days	43.2	43.7	44.5	43.8
Bacterial Concrete (BC-1	7 Days	26.3	27.1	27.0	26.8
	28 Days	43.0	43.5	43.4	43.3
	56 Days	48.9	49.6	49.8	49.4
Bacterial Concrete (BC-2	7 Days	28.6	28.9	29.2	28.9
	28 Days	46.6	47.2	47.5	47.1
	56 Days	52.8	53.1	54.0	53.3



Bacterial concrete shows higher compressive strength at all ages compared to conventional concrete. At 28 days, the increase in strength is 11.9% for BC-1% and 21.7% for BC-2%. The strength gain is more pronounced at 56 days due to continued pozzolanic and self-healing effects.

Figure 2. Compressive Strength Comparison

4.2 Split Tensile Strength and Flexural Strength

The split tensile strength and flexural strength tests were conducted to evaluate the tensile behavior, crack resistance, and bending performance of conventional and bacterial M30 concrete specimens. Concrete is inherently weak in tension, and therefore enhancement in tensile and flexural strength is highly important for improving crack resistance and durability in water-retaining structures. The experimental results indicated that bacterial concrete exhibited significantly higher tensile and flexural strength compared to conventional concrete at all curing ages. The improvement in strength can be attributed to microbial-induced calcium carbonate precipitation within the concrete matrix, which enhanced crack-bridging action, reduced porosity, and improved the interfacial bonding between cement paste and aggregates. The calcite crystals produced by *Bacillus subtilis* bacteria effectively filled pores and microcracks, thereby limiting crack initiation and propagation under tensile and flexural loading conditions. The conventional concrete (CC) exhibited average tensile strengths of 2.17 MPa, 2.98 MPa, and 3.46 MPa at 7, 28, and 56 days respectively. In comparison, BC-

1% achieved average strengths of 2.37 MPa, 3.35 MPa, and 3.89 MPa, while BC-2% demonstrated the highest tensile strengths of 2.61 MPa, 3.71 MPa, and 4.29 MPa at corresponding curing ages. The BC-2% mix exhibited approximately 24% higher tensile strength than conventional concrete at 56 days, indicating superior crack resistance and improved mechanical performance due to higher bacterial concentration. The enhanced tensile and flexural behavior of bacterial concrete confirms its ability to resist crack propagation and improve the structural durability of water-retaining concrete structures. The detailed split tensile and flexural strength results are presented in Table 4.

Table 4. Tensile and Flexural Strength Results

Concrete Type	**Curing A**	**Trial–1 (MP**	**Trial–2 (MP**	**Trial–3 (MP**	**Average Strength (MP**
Conventional Concrete (C	7 Days	2.12	2.18	2.21	2.17
	28 Days	2.91	2.99	3.04	2.98
	56 Days	3.38	3.50	3.50	3.46
Bacterial Concrete (BC-1	7 Days	2.31	2.40	2.40	2.37
	28 Days	3.26	3.38	3.42	3.35
	56 Days	3.79	3.92	3.95	3.89
Bacterial Concrete (BC-2	7 Days	2.55	2.62	2.66	2.61
	28 Days	3.57	3.72	3.84	3.71
	56 Days	4.18	4.31	4.39	4.29

4.3 Durability Performance

Durability tests were conducted to evaluate the resistance of conventional and bacterial M30 concrete against moisture ingress, permeability, and capillary water absorption, which are critical performance parameters for water-retaining structures such as water tanks. The experimental investigation included water absorption, water penetration depth, coefficient of permeability, and sorptivity analysis. The results clearly indicated that bacterial concrete exhibited significantly improved durability characteristics compared to conventional concrete due to microbial-induced calcium carbonate precipitation within the concrete matrix. The calcite crystals formed by *Bacillus subtilis* bacteria effectively filled pores, capillary voids, and microcracks, resulting in a denser and more impermeable concrete structure. Conventional concrete (CC) exhibited the highest water absorption values of 5.42% and 4.91% at 28 and 56 days respectively, indicating greater porosity and moisture penetration. In contrast, BC-1% and BC-2% showed considerably lower water absorption values, with BC-2% exhibiting the minimum values of 3.16% and 2.66% at corresponding curing ages. Similarly, water penetration depth was significantly reduced in bacterial concrete mixes, where BC-2% showed only 12 mm penetration depth at 56 days compared to 28 mm in conventional concrete, demonstrating superior impermeability and crack-sealing capability. The coefficient of permeability also decreased substantially with bacterial incorporation, as BC-2% exhibited the lowest permeability coefficient of 2.34×10^{-12} m/s at 56 days compared to 5.12×10^{-12} m/s for CC. Furthermore, sorptivity analysis revealed that bacterial concrete had lower capillary water absorption due to reduced pore connectivity and refined microstructure. The sorptivity coefficient decreased from 0.116 mm/$\sqrt{\text{min}}$ in conventional concrete to 0.058 mm/$\sqrt{\text{min}}$ in BC-2% at 56 days, indicating enhanced resistance against water ingress and moisture-related deterioration. The overall results confirm that bacterial concrete significantly improves the durability, impermeability, and long-term performance of concrete structures exposed to continuous moisture and hydrostatic pressure conditions. The detailed durability test results are summarized in Table 5.

Table 5. Durability Test Results

Durability Parameter	**Concrete Type**	**Curing A**	**Measured Values**	**Observation**
Water Absorption (%)	Conventional Concre (CC)	28 Days	5.42	Highest water absorption due higher porosity
		56 Days	4.91	Slight reduction with curing
	Bacterial Concre (BC-1%)	28 Days	4.16	Reduced absorption due calcite precipitation
		56 Days	3.66	Improved impermeability
	Bacterial Concre (BC-2%)	28 Days	3.16	Significant reduction in moistu penetration
		56 Days	2.66	Lowest water absorpti observed
Water Penetration Dep (mm)	Conventional Concre (CC)	28 Days	32	Higher permeability and po connectivity
		56 Days	28	Minor improvement with curin
	Bacterial Concre (BC-1%)	28 Days	24	Reduced water penetration
		56 Days	20	Improved crack sealing effect
	Bacterial Concre (BC-2%)	28 Days	16	Dense concrete matrix formed
		56 Days	12	Maximum resistance permeability
Coefficient Permeability ($\times 10^{-12}$ m/s	Conventional Concre (CC)	28 Days	5.84	Highest permeability coefficie
		56 Days	5.12	Slight decrease after curing
	Bacterial Concre (BC-1%)	28 Days	4.18	Improved impermeability
		56 Days	3.62	Better pore refinement
	Bacterial Concre (BC-2%)	28 Days	2.96	Significant permeabili reduction
		56 Days	2.34	Best durability performance
Sorptivity Coefficie (mm/$\sqrt{\text{min}}$)	Conventional Concre (CC)	28 Days	0.128	Higher capillary absorption
		56 Days	0.116	Limited improvement
	Bacterial Concre (BC-1%)	28 Days	0.098	Reduced capillary wat movement
		56 Days	0.084	Improved resistance to moistu ingress
	Bacterial Concre (BC-2%)	28 Days	0.071	Lower pore connectivity
		56 Days	0.058	Lowest sorptivity observed

4.4 Discussion

The experimental investigation demonstrated that the incorporation of *Bacillus subtilis* bacteria significantly enhanced the mechanical and durability performance of M30 concrete for water tank applications. The results obtained from compressive strength, split tensile strength, flexural strength, water absorption, permeability, and sorptivity tests confirmed the effectiveness of microbial-induced calcium carbonate precipitation (MICP) in improving the overall quality and impermeability of concrete. The bacterial concrete mixes BC-1% and BC-2% consistently outperformed conventional concrete (CC) at all curing ages, indicating the positive influence of bacterial activity on concrete microstructure and crack-healing behavior. The improvement in performance is primarily attributed to the precipitation of calcite crystals within pores, capillary voids, and microcracks, which resulted in a denser and more compact concrete matrix with enhanced particle bonding and reduced porosity.

The compressive strength results revealed that bacterial concrete exhibited significantly higher strength compared to conventional concrete, particularly at later curing ages. The BC-2% mix achieved the highest compressive strength of 53.3 MPa at 56 days, representing approximately 21.7% improvement over CC. This increase in strength indicates that bacterial calcite precipitation contributed to progressive densification and pore refinement within the concrete matrix. Similarly, the split tensile and flexural strength results demonstrated improved crack resistance and tensile behavior in bacterial concrete due to enhanced crack-bridging action and improved interfacial bonding between aggregates and cement paste. The higher tensile strength observed in BC-2% confirms that bacterial incorporation effectively minimized crack propagation under loading conditions.

The durability performance of bacterial concrete was also considerably superior to that of conventional concrete. Water absorption, permeability, and sorptivity values decreased substantially with bacterial incorporation, indicating improved resistance against moisture ingress and water penetration. The BC-2% mix exhibited the lowest water absorption (2.66%), minimum permeability coefficient (2.34×10^{-12} m/s), and lowest sorptivity coefficient (0.058 mm/√min) at 56 days. These reductions demonstrate that bacterial calcite precipitation effectively blocked capillary pores and reduced interconnected voids within the concrete matrix. The improved impermeability characteristics are particularly beneficial for water-retaining structures such as water tanks, where continuous exposure to hydrostatic pressure and moisture can accelerate deterioration and leakage problems. The self-healing capability of bacterial concrete therefore contributes significantly to enhancing long-term durability and service life of hydraulic structures.

The comparative performance of BC-1% and BC-2% indicates that higher bacterial concentration produced more effective calcite precipitation and crack-sealing efficiency. However, the results also suggest the importance of optimizing bacterial dosage to achieve maximum benefits without adversely affecting workability and uniformity of the concrete mix. Overall, the study confirms that bacterial self-healing concrete offers a sustainable, durable, and low-maintenance alternative to conventional concrete for water tank applications. The integration of microbiological processes with concrete technology has demonstrated significant potential for developing smart construction materials capable of autonomously repairing cracks and improving infrastructure resilience under aggressive environmental conditions.

5. Conclusion

The present study experimentally investigated the performance of self-healing bacterial M30 concrete for water tank applications using *Bacillus subtilis* bacteria and microbial-induced calcium carbonate precipitation (MICP) technology. Based on the experimental findings, it can be concluded that bacterial incorporation significantly improved both the mechanical and durability characteristics of concrete compared to conventional M30 concrete. The bacterial concrete mixes BC-1% and BC-2% consistently exhibited superior performance in terms of compressive strength, split tensile strength, flexural strength, permeability resistance, and moisture absorption behavior. The improvement in concrete performance is mainly attributed to the formation of calcite crystals produced by bacterial activity, which filled pores, microvoids, and cracks within the concrete matrix, resulting in a denser and more impermeable structure.

The compressive strength results demonstrated that bacterial concrete achieved significantly higher strength values than conventional concrete at all curing ages. Among the investigated mixes, BC-2% exhibited the highest compressive strength of 53.3 MPa at 56 days, representing substantial improvement over conventional concrete. Similarly, split tensile and flexural strength values increased considerably due to enhanced crack-bridging action and improved bonding between cement paste and aggregates. The improved tensile performance confirms the effectiveness of bacterial calcite precipitation in minimizing crack propagation and enhancing structural stability under loading conditions.

The durability evaluation further confirmed that bacterial concrete possessed superior impermeability and moisture resistance characteristics. Water absorption, permeability coefficient, water penetration depth, and sorptivity values were significantly reduced in bacterial concrete mixes due to pore refinement and crack sealing caused by microbial calcite deposition. The BC-2% mix demonstrated the best durability performance with minimum water absorption, lowest permeability coefficient, and reduced capillary water absorption. These characteristics are highly beneficial for water-retaining structures such as water tanks, where continuous exposure to moisture and hydrostatic pressure can accelerate leakage and deterioration. The self-healing capability of bacterial concrete therefore provides an effective solution for improving water tightness, reducing maintenance requirements, and extending the service life of hydraulic structures.

Overall, the findings of this research confirm that bacterial self-healing concrete is a sustainable, durable, and environmentally friendly construction material suitable for water tank applications. The integration of microbiological processes with concrete technology offers significant potential for the development of smart infrastructure materials capable of autonomously repairing cracks and improving long-term structural performance. Future research may focus on large-scale field implementation, optimization of bacterial dosage, long-term monitoring under actual service conditions, and economic feasibility analysis for practical engineering applications.

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