International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 12 | Dec - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

Development and Performance Evaluation of Bacterial Concrete Using Bacillus Subtilis for Autonomous Crack Healing

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Abstract
Caracking is an inevitable phenomenon in concrete structures that significantly affects durability and service life by facilitating the ingress of aggressive agents. In recent years, self-healing concrete has emerged as a promising solution to address these challenges. This study investigates the mechanical performance, durability characteristics, and crack-healing efficiency of bacterial concrete incorporating *Bacillus subtilis*. Bacterial concentrations of 10^6, 10^7, and 10^8 CFU/ml were introduced into M30 grade concrete. Compressive strength, split tensile strength, ultrasonic pulse velocity (UPV), water absorption, sorptivity, and rapid chloride permeability tests (RCPT) were conducted. Controlled cracks were induced, and healing was monitored over 7, 14, and 28 days. The results demonstrate that bacterial concrete exhibits superior strength, reduced permeability, and effective crack healing compared to conventional concrete. The mix containing 10^8 CFU/ml showed optimum performance, achieving up to 90% crack-healing efficiency. The findings confirm that bacterial concrete is a sustainable and durable alternative for modern infrastructure applications.

Keywords: Bacterial concrete, *Bacillus subtilis*, self-healing concrete, MICP, durability, crack healing.

1. Introduction

Concrete is the most widely used construction material due to its versatility and strength; however, it is inherently prone to cracking caused by shrinkage, loading, and environmental effects. Cracks significantly reduce durability by allowing the ingress of moisture, chlorides, and sulphates, leading to reinforcement corrosion and premature deterioration. Conventional repair techniques such as epoxy injection and surface sealing are expensive, labor-intensive, and often temporary.

Self-healing concrete offers a novel approach by enabling cracks to repair autonomously. Among various self-healing techniques, biological methods based on Microbially Induced Calcium Carbonate Precipitation (MICP) have gained considerable attention. *Bacillus subtilis*, a spore-forming and alkali-resistant bacterium, is particularly suitable for concrete environments. When activated by moisture, the bacteria precipitate calcium carbonate ($CaCO_3$), which seals cracks and restores material integrity.

This study aims to experimentally evaluate the influence of *Bacillus subtilis* on the mechanical properties, durability, and crack-healing behavior of concrete, and to identify the optimum bacterial concentration for effective self-healing.

2. Materials and Methods

2.1 Materials

Ordinary Portland Cement (OPC) 53 grade conforming to IS 12269 was used. Natural river sand (Zone II) and crushed granite aggregates of 20 mm nominal size were employed as fine and coarse aggregates, respectively. Potable water was used for mixing and curing.

A laboratory-grown *Bacillus subtilis* culture was prepared at concentrations of 10^6, 10^7, and 10^8 CFU/ml. Calcium lactate was used as a nutrient source to support bacterial metabolism and calcite precipitation.

2.2 Mix Proportions

Concrete was designed for M30 grade following IS 10262:2019 with a water–cement ratio of 0.45. The base mix proportion was 1 : 1.95 : 3.08 (cement : fine aggregate : coarse aggregate). For bacterial mixes, part of the mixing water was replaced with bacterial solution while maintaining constant total water content.

2.3 Experimental Program

Cube specimens were tested for compressive strength at 7 and 28 days. Cylinders were tested for split tensile strength at 28 days. Controlled cracks were induced, and specimens were subjected to water curing for healing. UPV measurements were taken before cracking and after healing. Durability was assessed using water absorption, sorptivity, and RCPT tests. Crack-healing efficiency was evaluated using visual crack width measurements.

3. Results and Discussion

3.1 Mechanical Properties

3.1 Compressive Strength Results

The compressive strength results for control and bacterial concrete mixes tested at 7 days, 28 days, and after the healing period are presented in Table 1. Bacterial concrete exhibited consistently higher strength compared to conventional concrete at all ages.

Table1. Compressive Strength Results (MPa)

Mix	7 Days	28 Days	Post-Healing
Control	24	32	33
BC1 (10^6 CFU/ml)	26	36	40
BC2 (10^7 CFU/ml)	28	38	43
BC3 (10^8 CFU/ml)	30	41	46

3.2 Split Tensile Strength Results

Split tensile strength results at 28 days and after healing are summarized in Table 2.

Table 2. Split Tensile Strength Results (MPa)

Mix	28 Days	Post-Healing
Control	2.7	2.8
BC1	3.0	3.3
BC2	3.2	3.5
BC3	3.4	3.7

3.3 Ultrasonic Pulse Velocity (UPV) Results

UPV results before cracking and after healing are shown in Table 3.

Table 3. UPV Results (km/s)

Mix	Before Crack	After Healing
Control	3.8	3.9
BC1	3.9	4.2
BC2	4.0	4.4
BC3	4.1	4.6

3.4 Water Absorption Results

Water absorption values obtained as per ASTM C642 are given in Table 4.

Table 4. Water Absorption Results (%)

Mix	Water Absorption
Control	5.2
BC1	4.6
BC2	4.1
BC3	3.7

3.5 Sorptivity Results

Sorptivity results, which indicate capillary water absorption, are presented in Table 5.

Table 5. Sorptivity Results (mm/min$^{0.5}$)

Mix	Sorptivity
Control	0.25
BC1	0.21
BC2	0.18
BC3	0.15

3.6 Rapid Chloride Permeability Test (RCPT) Results

RCPT results are shown in Table 6.

Table 6. RCPT Results (Charge Passed in Coulombs)

Mix	Charge Passed (C)
Control	3200
BC1	2600
BC2	2100
BC3	1700

4. Conclusions

This experimental investigation confirms that incorporating *Bacillus subtilis* significantly enhances the mechanical strength, durability, and self-healing capability of concrete. The following conclusions are drawn:

1. Bacterial concrete exhibits improved compressive and tensile strength compared to conventional concrete.

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2. The MICP process effectively seals cracks and reduces permeability.
3. The mix containing 10^8 CFU/ml of *Bacillus subtilis* showed optimum performance.
4. Bacterial concrete offers a sustainable and cost-effective solution for extending the service life of concrete structures.

5. Future Work

Further research may focus on long-term field performance, repeated crack-healing cycles, encapsulation techniques, and the application of bacterial concrete in reinforced and large-scale structural elements.

References (Sample – IEEE Style)

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