

# Study On Strength Development and Crack Healing in Bacterial- GGBS Concrete

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**Abstract**—Concrete is one of the most widely used construction materials in civil engineering due to its high compressive strength and versatility. However, it is prone to cracking because of its low tensile strength, which affects durability and structural performance. These cracks allow the ingress of water and harmful substances, leading to reinforcement corrosion and reduction in service life. This study focuses on the investigation of both strength enhancement and self-healing characteristics of bacterial concrete incorporating Ground Granulated Blast Furnace Slag (GGBS) as a partial replacement of cement. In this experimental study, cement was replaced by 40% GGBS, and bacterial concentrations of 2%, 3%, and 5% were used. The bacteria *Bacillus subtilis* were utilized due to their ability to precipitate calcium carbonate. Concrete cubes were cast and tested for compressive strength at 7, 14, and 28 days. Artificial cracks were induced using metal strips to study the self-healing capability. The results indicated that bacterial GGBS concrete exhibited improved compressive strength compared to conventional and conventional GGBS concrete. A maximum increase in compressive strength of 26.7% was observed at 28 days in Bacterial GGBS concrete. Additionally, the formation of a white calcium carbonate ( $\text{CaCO}_3$ ) layer inside cracks confirmed the self-healing mechanism. The study concludes that bacterial GGBS concrete not only enhances strength but also provides an effective self-healing mechanism, making it a sustainable and durable solution for modern construction practices.

**Index Terms**—Self-healing concrete, GGBS, bacterial concrete, strength enhancement, crack healing, sustainable construction.

## I. INTRODUCTION

Concrete is one of the most widely used construction materials in the world due to its high compressive

strength, durability, and versatility. It plays a vital role in the construction of buildings, bridges, roads, and other infrastructure. However, concrete has a major limitation in that it is weak in tension and tends to develop cracks over time. These cracks may be caused due to shrinkage, temperature variations, external loading, or environmental effects. The presence of cracks allows the ingress of water, carbon dioxide, and harmful chemicals, which can lead to corrosion of reinforcement and deterioration of the structure.

To overcome these problems, researchers have explored the use of supplementary cementitious materials and innovative technologies. One such material is Ground Granulated Blast Furnace Slag (GGBS), which is a by-product of the steel industry. The use of GGBS in concrete helps in improving long-term strength, reducing permeability, and enhancing durability. It also contributes to sustainability by reducing the consumption of cement and lowering carbon emissions.



Fig. 1: Ground Granulated Blast Furnace Slag (GGBS)

In addition to GGBS, the concept of self-healing concrete has gained significant attention in recent years. Self-healing concrete has the ability to repair its

own cracks without external intervention. One of the most effective methods of achieving self-healing is through the use of bacteria. Bacteria such as *Bacillus subtilis* can produce calcium carbonate ( $\text{CaCO}_3$ ) when activated in the presence of moisture and nutrients. This calcium carbonate precipitates within the cracks and seals them, thereby restoring the structural integrity of the concrete.

The present study focuses on the combined use of GGBS and bacterial concrete to enhance both strength and self-healing properties. By integrating these two approaches, it is possible to develop a sustainable and durable construction material capable of improving the service life of structures.

## II. LITERATURE REVIEW

Several researchers have investigated the use of bacteria in concrete for improving its properties.

Islam M. Riad et al. (2025) investigated bacterial self-healing in Ultra High-Performance Concrete (UHPC). The study reported a compressive strength of 168.9 MPa with 2.5% bacterial addition and a reduction in water permeability by 22–29%, indicating improved durability.

Sukanyarat Khamsa Zerlinda et al. (2025) studied the use of sugarcane waste materials with bacterial endospores. The results showed reduced water absorption and rapid crack healing within 4 days.

Dhiraj Ahiwale and Rushikesh Khartode (2019) reported that bacterial concrete using *Bacillus subtilis* improved compressive strength by 23%, tensile strength by 8%, and flexural strength by 7%.

L. H. Anneza et al. (2021) evaluated ureolytic and sulphate-reducing bacteria in concrete and observed an increase in compressive strength from 36 MPa to 42.5 MPa.

Rajneesh Vashisht et al. (2018) studied calcite-precipitating bacteria and found an improvement in compressive strength up to 34.6% along with effective crack sealing.

D. Suresh and K. Nagaraju (2015) analyzed the use of GGBS as a partial replacement of cement and

concluded that it enhances durability and sustainability.

Santosh Kumar Karri et al. (2015) investigated GGBS replacement levels and observed improved compressive strength and resistance to chemical attack.

E. Tziviloglou et al. (2016) examined bacterial self-healing using lightweight aggregates and found improved crack healing and water tightness under wet-dry cycles.

H.M. Jonkers et al. (2010) introduced bacterial self-healing concrete and demonstrated that bacteria can seal cracks up to 0.5 mm through calcium carbonate precipitation.

V. Wiktor and H.M. Jonkers (2011) studied encapsulated bacteria in concrete and reported significant reduction in permeability and improved crack sealing efficiency.

V. Achal, A. Mukherjee, and M.S. Reddy (2011) investigated microbial concrete and found enhancement in compressive strength and durability due to calcite precipitation.

W. De Muynck, N. De Belie, and W. Verstraete (2010) studied microbial carbonate precipitation and confirmed its effectiveness in improving durability and protection of concrete.

S.S. Bang et al. (2010) reported that bacterial concrete improves resistance to freeze-thaw cycles and reduces permeability.

S.K. Ramachandran et al. (2001) demonstrated early research on bacterial concrete and showed improved compressive strength and crack remediation.

P. Ghosh et al. (2005) studied microbial treatment in concrete and found that it enhances strength and reduces crack width.

From the above studies, it is evident that both GGBS and bacterial concrete individually improve the performance of concrete. However, limited research

has been conducted on their combined effect, which forms the basis of the present study.

Further studies have also emphasized the role of bacteria in enhancing the durability of concrete. The process of microbial induced calcium carbonate precipitation helps in reducing porosity and permeability, thereby improving the overall performance of concrete structures. The deposition of calcium carbonate within cracks acts as a natural sealing agent, which significantly increases the service life of the structure.

In addition to bacterial concrete, the use of Ground Granulated Blast Furnace Slag (GGBS) has gained importance in modern construction. GGBS contributes to improved workability, reduced heat of hydration, and enhanced resistance to chemical attacks. It also plays a significant role in sustainable construction by reducing the carbon footprint associated with cement production.

Researchers have also studied the combined use of bacteria and supplementary cementitious materials. The integration of bacterial action with GGBS-based concrete has shown promising results in terms of both strength enhancement and crack-healing efficiency. However, the interaction between bacterial activity and GGBS composition requires further detailed investigation.

From the above discussion, it is evident that although individual benefits of bacterial concrete and GGBS are well established, their combined performance is not extensively explored. This highlights the need for further experimental studies focusing on both strength and self-healing characteristics.

### III. RESEARCH GAP

1. There is a lack of standardized procedures for the preparation and application of bacterial concrete in construction.
2. Long-term durability and performance under varying environmental conditions have not been fully investigated.
3. The optimum percentage of bacterial concentration for achieving maximum strength and healing efficiency is not clearly defined.

4. Limited experimental data is available on the combined effect of GGBS and bacterial concrete.

5. Practical implementation and large-scale application require further research and validation.

6. There is a lack of comprehensive studies analyzing the combined effect of GGBS and bacterial concentration on self-healing efficiency for different crack widths, and the optimum bacterial percentage for maximum healing performance is not clearly established.

### IV. METHODOLOGY

#### A. Materials Used

The materials used in this study include Ordinary Portland Cement (OPC 43 Grade), fine aggregate, coarse aggregate, Ground Granulated Blast Furnace Slag (GGBS), bacterial culture (*Bacillus subtilis*), and potable water. The fine aggregate used was clean river sand, and the coarse aggregate consisted of crushed stone of suitable size. GGBS was used as a partial replacement of cement to improve durability and long-term strength.

#### B. Mix Design

Concrete of M25 grade was prepared for the experimental study. A water-cement ratio of 0.45 was maintained throughout the mixes. Cement was partially replaced with 40% GGBS. Bacterial concentrations of 2%, 3%, and 5% by weight of cement were used to study their effect on compressive strength and self-healing properties.

#### C. Preparation of Bacterial Solution

The bacterial solution was prepared using *Bacillus subtilis*, which is capable of producing calcium carbonate. Jaggery was used as a nutrient medium to support bacterial growth. A measured quantity of jaggery was dissolved in water and mixed thoroughly to form a nutrient solution. The bacterial culture was then added to this solution and allowed to incubate for a period of 24 hours to activate the bacteria before mixing with concrete.



Fig. 2. Prepared Bacterial Solution

**D. Casting of Specimens**

Concrete cubes of size 150 mm × 150 mm × 150 mm were cast for testing. The materials were mixed thoroughly in proper proportions to obtain a uniform mix. The concrete was then placed in molds and compacted properly using standard methods to eliminate air voids. The specimens were left undisturbed for 24 hours before demolding.

**E. Crack Induction**

Artificial cracks were induced in the concrete specimens using thin metal strips inserted during the casting process. After curing, the metal strips were carefully removed to create controlled cracks. These cracks were used to study the self-healing capability of bacterial concrete.



Fig. 3. Metal Strip Insertion in Concrete

**F. Curing of Specimens**

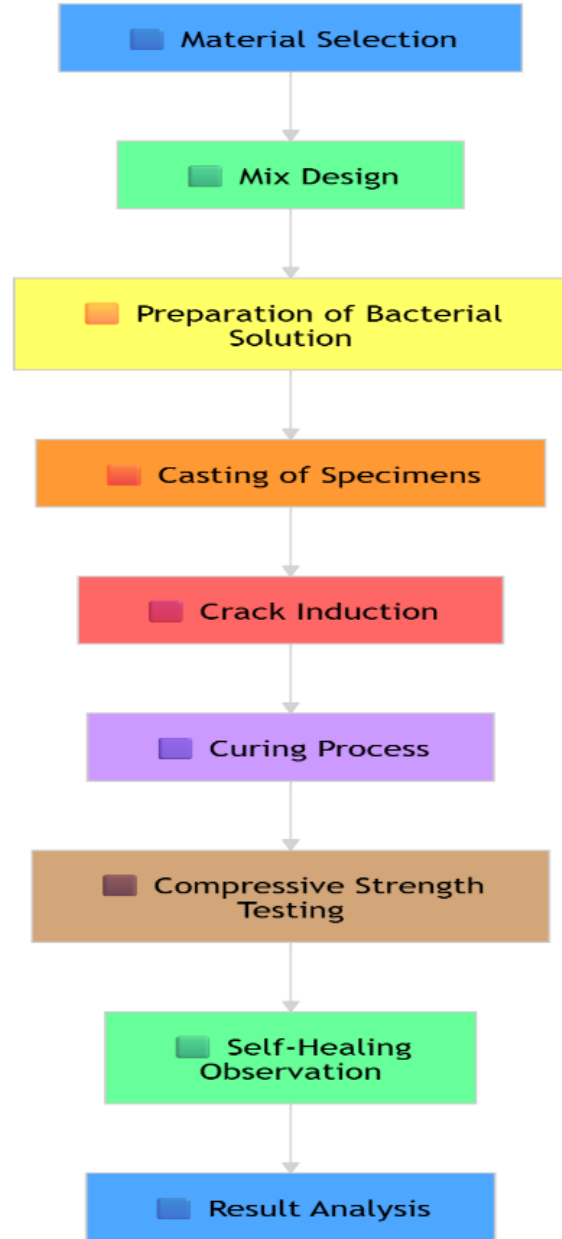
After demolding, the concrete specimens were cured in water for periods of 7, 14, and 28 days. Proper curing was maintained to ensure hydration and to activate bacterial activity within the concrete matrix.

**G. Testing Procedure**

Compressive strength tests were conducted on the concrete cubes at 7, 14, and 28 days using a

compression testing machine. The load was applied gradually until failure, and the maximum load was recorded to calculate compressive strength.

**H. Methodology Flowchart**



**V. RESULTS AND DISCUSSION**

**A. Compressive Strength Results**

The compressive strength of concrete was tested at 7, 14, and 28 days for conventional concrete, GGBS concrete, and bacterial GGBS concrete. The results obtained are presented in Table 1.

Table 1. Compressive Strength Results

Curing Days	Conventional (MPa)	GGBS (MPa)	Bacterial GGBS (MPa)
7 Days	16.2	13.57	18.13
14 Days	20.87	19.2	22.17
28 Days	25.07	28.73	31.77

The results indicate that bacterial GGBS concrete exhibits higher compressive strength compared to both conventional and GGBS concrete at all curing periods.

**B. Compressive Strength Graph**

The variation of compressive strength with curing days is represented graphically to compare the performance of different concrete mixes.

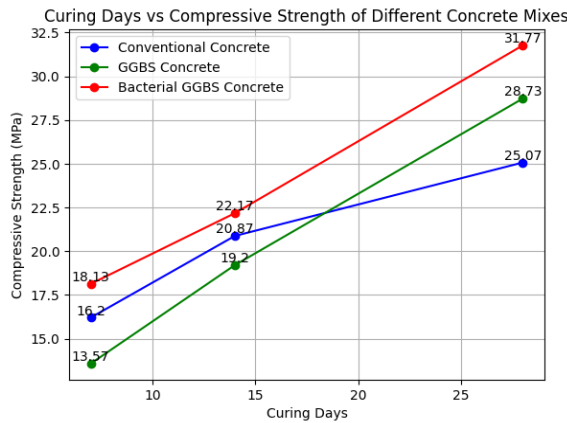


Fig 4. Compressive Strength vs Curing Days

**C. Discussion on Strength Enhancement**

From the experimental results, it is observed that the inclusion of GGBS improves long-term strength due to its pozzolanic reaction, which contributes to the formation of additional calcium silicate hydrate (C-S-H) gel. However, early strength gain is slightly lower compared to conventional concrete.

The addition of bacteria further enhances the strength by filling cracks within the concrete matrix. The bacterial activity results in the formation of calcium carbonate, which improves the internal structure and bonding of concrete.

**D. Self-Healing Observation**

The self-healing capability of bacterial concrete was evaluated by observing the cracks induced in the specimens. It was found that the cracks were partially or completely filled after the curing period.



Fig. 5. Microscopic View Showing

The formation of a white precipitate inside the cracks confirms the presence of calcium carbonate, which is produced by bacterial activity. This indicates that the bacterial concrete possesses effective self-healing properties.

**E. Self-Healing Performance Analysis**

The self-healing performance of bacterial concrete was evaluated for 2%, 3%, and 5% bacterial concentrations by measuring crack width reduction over 7, 14, and 28 days. The results showed that crack width decreased with curing time for all mixes. Among the different concentrations, 3% bacteria exhibited the highest healing efficiency, with significant crack closure observed within 28 days. The 2% mix showed comparatively slower healing due to lower bacterial activity, while the 5% mix showed slightly reduced performance, possibly due to bacterial overcrowding and limited nutrient availability. Smaller cracks healed more effectively, whereas larger cracks showed only partial healing. The healing mechanism is attributed to calcium carbonate precipitation through Microbially Induced Calcium Carbonate Precipitation. Overall, 3% bacterial concentration was found to be optimum for effective self-healing of concrete.

The self-healing behavior of bacterial GGBS concrete was evaluated by measuring the reduction in crack width over different curing periods. Cracks of widths 0.10 mm, 0.40 mm, 0.45 mm, and 0.80 mm were considered. The of results 3% bacteria are presented in the following table 2.

Table 2. Self-Healing Result of 3% bacteria

Cracks of widths	7 Days	14 Days	28 Days
0.10	0.03	0.01	0.0
0.40	0.25	0.12	0.03
0.45	0.28	0.15	0.07
0.80	0.60	0.48	0.32

#### F. Discussion on Self-Healing Behavior

The bacteria present in the concrete become active in the presence of moisture and nutrients. These bacteria convert available compounds into calcium carbonate, which deposits within the cracks and seals them. This process not only improves durability but also reduces maintenance requirements and extends the service life of concrete structures.

### VI. CONCLUSION

Based on the experimental investigation carried out on conventional concrete, GGBS concrete, and bacterial GGBS concrete, the following conclusions are drawn:

1. The use of Ground Granulated Blast Furnace Slag (GGBS) as a partial replacement of cement improves the long-term compressive strength of concrete due to its pozzolanic reaction.
2. The incorporation of bacteria (*Bacillus subtilis*) enhances both the strength and durability characteristics of concrete.
3. Bacterial GGBS concrete exhibited higher compressive strength compared to conventional and GGBS concrete at all curing periods.
4. A maximum increase of approximately 26.7% in compressive strength was observed at 28 days.
5. The formation of white calcium carbonate ( $\text{CaCO}_3$ ) precipitate within the cracks confirms the self-healing mechanism of bacterial concrete.
6. The bacterial activity reduces porosity and improves the internal microstructure of concrete.
7. The combined use of GGBS and bacteria results in a sustainable, durable, and efficient construction material.

### VII. FUTURE SCOPE

1. Further research can be conducted to study the long-term durability of bacterial concrete under different environmental conditions.

2. Different types of bacteria can be explored to enhance self-healing efficiency.
3. The application of bacterial concrete in marine structures, bridges, and underground constructions can be investigated.
4. Large-scale implementation and practical feasibility of bacterial concrete need to be studied.
5. Cost analysis and economic feasibility for commercial applications can be further evaluated.

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