

Self-Healing Concrete – A Sustainable Way In Construction

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Abstract: Self-healing concrete provides a creative and sustainable solution to cracking, a big problem in construction. Conventional concrete is considered strong and adaptable. However, over time, it is prone to cracking due to temperature variations, shrinkage, Creep and mechanical stresses. Such cracks compromise the durability of the concrete and usually require costly and time-consuming repairs. Self-healing concrete offers a biogenic alternative, especially along with external bacterial treatment. This study investigates the healing efficiency of concrete by external application of bacterial solution to concrete cracks. This specimen will be cast using nominal concrete. Later, the specimens are tested for Ultrasonic pulse velocity, flexural behaviour and visual inspection of self-healing concrete will be studied. We've used iron Beam moulds of size 50cm x 10cm x 10cm and cube moulds of 15cm x 15cm x 15cm for casting the specimens. These specimens will then be cured and tested for UPV, visual inspection at 7 and 14 days after bacterial treatment. In this study, the hair cracks and micro cracks up to 0.5mm by using the bacterial treatment. are healed and the velocities are increased from 1.5% to 5.05% by bacterial specimens compared to velocities of cracked specimens.

Keywords: *Self-healing concrete, Concrete Cracks, External application, UPV, Visual inspection, Shrinkage.*

1. Introduction: Concrete is a composite material made of fine and coarse aggregates that are held together cohesively by a liquid cement that hardens with time. Concrete is one of the most widely used construction materials due to its strength, durability, and versatility. Concrete is one of the most widely used construction materials in the world; yet, its sustainability is the subject of significant debate. While concrete has some inherent sustainable qualities, its manufacture and use pose significant environmental issues. The production of Portland cement, the major ingredient in concrete, is a significant source of global carbon emissions. It is highly susceptible to cracking due to environmental exposure, mechanical stress, and structural aging. These cracks, if left untreated, can lead to serious structural deterioration, requiring

extensive maintenance and repairs that are both costly and resource-intensive. One promising innovation addressing this challenge is self-healing concrete, which has the ability to autonomously repair cracks and restore its structural integrity. The concept of self-healing in concrete dates back to 1877, Ferdinand Cohn discovered that certain bacteria from the genus *Bacillus* could survive extreme conditions and potentially contribute to the healing of concrete. However, it was not until 2011 that Henk Jonkers and his team conducted extensive research and testing on bio-based self-healing concrete, validating its effectiveness. The key principle behind bio-based self-healing concrete lies in the use of *Bacillus* bacteria, which can remain dormant within the concrete matrix for up to 200 years. Upon contact with water, these bacteria become active and metabolize a supplied nutrient source, such as calcium lactate. This biological reaction leads to the precipitation of calcium carbonate (CaCO_3), effectively filling and sealing the cracks. Various strains of *Bacillus* bacteria, including *Bacillus pasteurii*, *Bacillus sphaerius*, *Bacillus subtilis*, *Bacillus cohnii*, *Bacillus halodurans*, and *Bacillus pseudofirmus*, have demonstrated significant potential in self-healing applications. Unlike intrinsic methods that incorporate bacteria directly into the concrete mix, this research focuses on an external application approach, where a bacterial solution is applied to pre-existing cracks. When bacterial solution infiltrates the cracks, the dormant bacteria activate, metabolizing calcium lactate to produce CaCO_3 , thus sealing the cracks. Moreover, traditional cement production is a major contributor to global CO_2 emissions, releasing approximately 7% to 9% of total industrial CO_2 emissions. By integrating self-healing bacterial technology, the need for frequent repairs and additional cement production can be minimized, thereby reducing the overall environmental footprint of the construction industry. This study explores the potential of a bio-based self-healing approach by leveraging microbial-induced calcite precipitation.

2. Materials: Bacteria (*Bacillus Subtilis*): *Bacillus subtilis* is a rod-shaped, gram-positive, endospore-forming bacterium that can be found in

soil and vegetation. It is known to withstand harsh living conditions by forming very resistant endospores that allow it to wait until favorable conditions arise. This characteristic makes it highly

effective for use in the production of self-healing concrete. It can produce calcium carbonate that effectively seals microcracks. It is non-pathogenic and safe for environmental applications



Fig. 1 Bacillus Subtilis

It increases compressive strength and reduces permeability after healing. It reduces the need for traditional repairs, thus lowering carbon emissions from additional cement production

Table 1 Specifications of Bacillus subtilis

Description	Specifications
Product name	Plant's buddy Bacillus Subtilis
Appearance	Colorless
pH	6.50
Concentration	2×10^9 CFU/ml
Liveable Temperature	$15 - 55$ C

Source Obtained from the platform of amazon.

Calcium lactate: Calcium lactate is an organic calcium salt that is obtained from lactic acid and calcium carbonate. It is a white crystalline powder and is water-soluble. Serves as a carbon source, enabling bacterial growth and metabolic activity within the cracked zone. Enhances the production of calcium carbonate, which is chemically similar to the mineral matrix of concrete and promotes strong, durable healing. Calcium lactate is biodegradable and safe for both users and the environment, aligning with the sustainable goals.



Fig. 2 Calcium Lactate

Table 3 Specifications of Calcium Lactate

Description	Specifications
Product name	Urban Platter Calcium Lactate
Appearance	White Powder
pH	6.00
Specific Gravity	1.5
Temperature	20 – 50°C

Source obtained from the Amazon platform

Material Quantities: The above-listed Quantities of materials are only for one cube of dimension 150mm x 150mm x 150mm and one beam of dimension 500mm x 100mm x 100mm. The total quantity can be measured by multiplying the quantity of one specimen by the number of specimens required.

4Table 3: Material Quantities

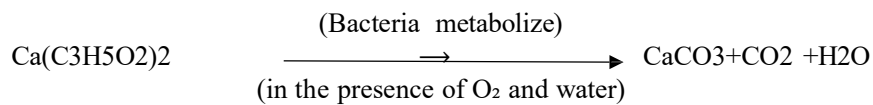
Specimen	Cement Kg	Sand Kg	Coarse Aggregate Kg	Steel (mainbar) Kg	Steel (stirrups) Kg	Water Litres
Cube	1.36	2.27	4.25	--	--	0.61
Beam	2.01	3.36	6.3	0.711	0.474	0.90

Bacterial treatment: The Bacterial solution is prepared by Bacillus subtilis and calcium lactate. Calcium lactate is converted into a liquid form by diluting the powder into 1 litre of water to attain 0.5 M. Where M is the Molar mass of calcium lactate (I.e., 308.3g/mol). Equal volumes (1:1 ratio) of bacterial solution and calcium lactate solution were mixed just before application. The solution is injected considering the length and width of the cracks.
Bacterial Solution = Twice of length and width of crack

The length and width of crack is measured using vernier calipers instrument.



Fig. 3 Bacterial solution



3. Results & Discussion

Compressive Strength: The compressive strength test, where the load is stopped to measure initial strength is often referred to as an initial set strength test. It is used for the generation of hair and micro cracks in cubes.

The corresponding load values at the point of controlled crack formation were carefully recorded. These load values were then used to calculate the initial compressive strength of each cube using the formula:

$$\text{Compressive Strength} = \frac{\text{Load}}{\text{Cross-section Area}}$$

The initial Compressive Strength values served as a baseline for comparison against post-healing strengths to determine the effectiveness of the externally applied bacterial solution.

Table. 4 Initial Compressive Strength Values

Sample	Initial load (KN)	Initial Compressive Strength (N/mm ²)
1	900	40
2	910	40.44
3	1000	44.44
4	1000	44.44
5	1000	44.44
6	1100	48.88

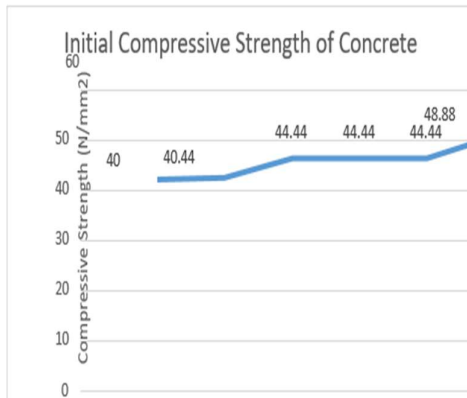


Fig. 4 Graphical representation of Initial Compressive strength

The graphical representation shows the initial compressive strength of six concrete specimens after curing. It highlights a general increase in strength, starting from 40 N/mm² for specimen 1 to a maximum of 48.88 N/mm² for specimen 6. Specimens 2 to 5 display relatively consistent results, especially specimens 3 to 5, which all show a strength of 44.44 N/mm², indicating uniform material properties and curing conditions. The increasing trend suggests good early-age strength development, which is crucial for decisions such as formwork removal or early loading.

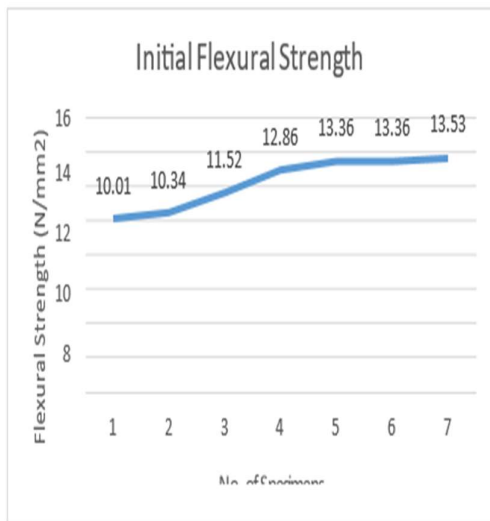


Fig. 5 Graphical Representation of Initial Flexural Strength The graphical representation shows the initial Flexural strength of six concrete specimens

Flexural Strength: The bending strength of a beam-like specimen is ascertained using the flexural strength test with two-point loading. This technique creates a constant bending moment between the load points and zero shear in that area by applying two equal loads symmetrically at one-third spans of the specimen. The test is frequently used to ascertain the material's initial flexural strength or limit of proportionality, which shows its capacity before the onset of permanent deformation, when the load is stopped at a specific point. It is used for the generation of hair and micro-cracks in cubes.

Table 5: Initial Flexural Strength Values

Sample	Initial load (KN)	Initial Flexural Strength (N/mm ²)
1	55	10.01
2	59	10.34
3	65	11.52
4	77	12.86
5	80	13.36
6	80	13.36
7	81	13.53

after curing. It highlights a general increase in strength, starting from 10 N/mm² for specimen 1 to a maximum of 13.53 N/mm² for specimen 6. Specimens 2 to 4 display relatively consistent results, especially specimens 5 to 7 which all show a major increase in strength indicating uniform material properties and curing conditions. The increasing trend suggests good early-age strength development, which is crucial for decisions such as formwork removal or early loading. Up to 4–5 times higher than traditional M20, excellent for beams, slabs, and pavements. Ideal for structural members subjected to significant bending or dynamic loads. After Bacterial Treatment some set tests are conducted. The results and discussion were explained in detail as follows:

Ultrasonic Pulse Velocity (UPV): The UPV Test has been conducted after the day of Crack development and Completion of 7 and 14 days of bacterial treatment of both cube and beam specimens. UPV Test results after 7 days of bacterial treatment for both cube and beam specimens.

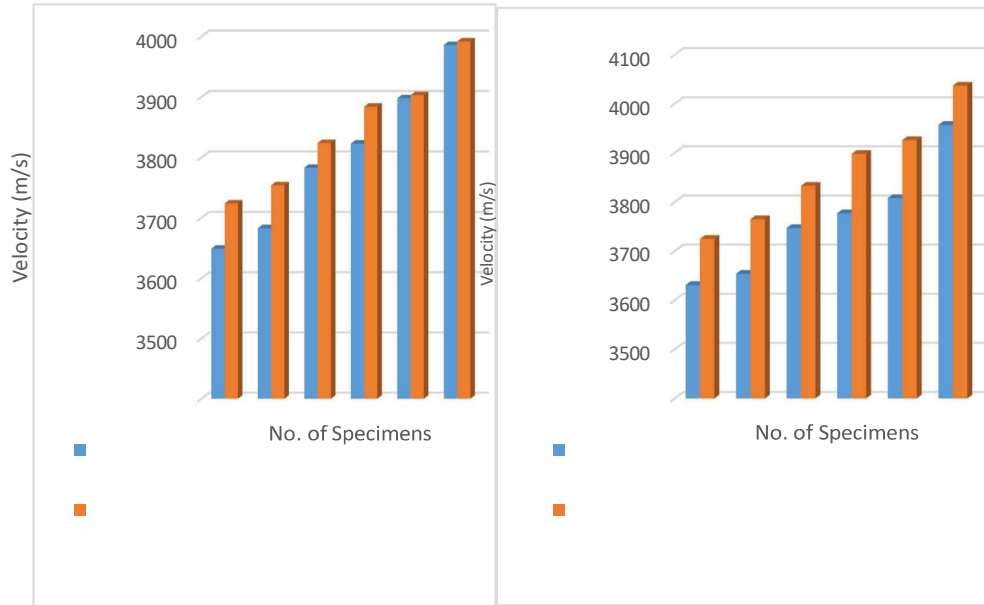


Fig. 6 Graphical representation of UPV Test after 7 days of bacterial treatment for cube and beam specimens.

The figure presents the results of the Ultrasonic Pulse Velocity (UPV) Test conducted on both cube and beam concrete specimens after inducing cracks and following 7 days of Bacterial Treatment. The blue bars show UPV values *after cracks were formed* and The orange bars show UPV values *after 7 days of bacterial treatment*. For both cube and beam specimens, the UPV values **increased** after 7 days of bacterial treatment compared to the values after cracks formed.

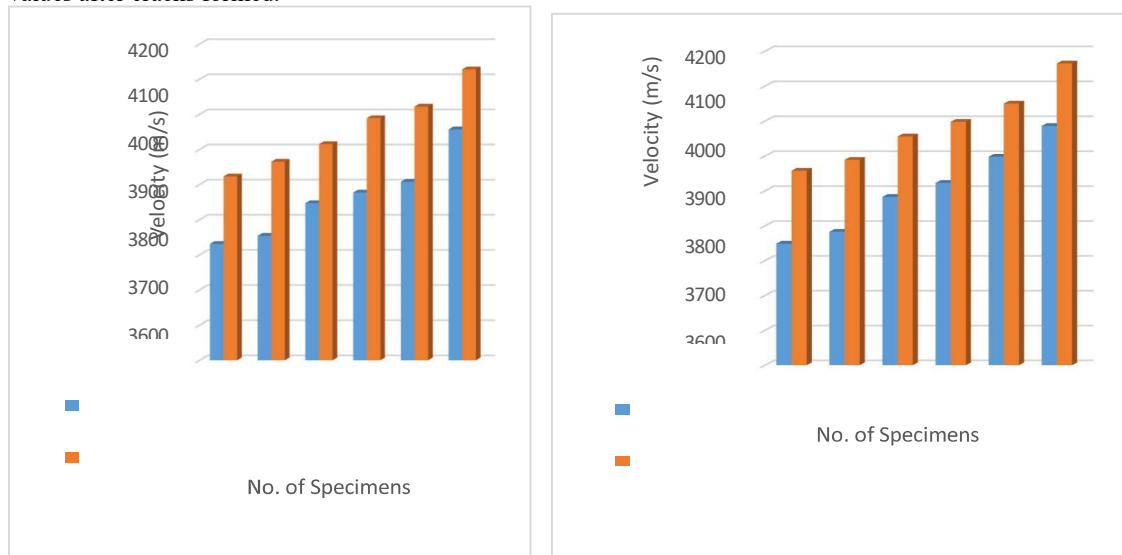


Fig.7 Graphical representation of UPV Test after 14 days of bacterial treatment for cube and beam specimens.

The UPV results show significant improvement after 14 days of bacterial treatment. The blue bars show UPV values *after cracks were formed* and the

orange bars show UPV values *after 7 days of bacterial treatment*. Cube specimen velocities increased from 3649–3986 m/s to 3724–3992 m/s,

and beam specimens from 3631–3957 m/s to 3725–4037 m/s. Bacterial activity effectively healed cracks, enhancing concrete density, continuity, and structural integrity over time.

The results of the UPV test unequivocally show how well bacterial treatment works to repair cracks in concrete specimens that are cube-shaped and beam-shaped. UPV increased in cube specimens from 3649–3986 m/s to 3724–3992 m/s and in beam specimens from 3631–3957 m/s to 3752–4037 m/s following a 7-day treatment period. UPV values were further improved by extending the treatment to 14 days; cubes reached 3858–4165 m/s and beams

3823–4128 m/s. The steady rise suggests that the concrete matrix became denser and cracks were gradually sealed by bacterially induced calcite precipitation. Higher UPV values were consistently seen in beam specimens, indicating more efficient healing. In general, bacterial treatment enhances the

Visual Inspection: Visual inspection included looking at the surface of cracked specimens both before and after bacterial treatment to look for indications of healing progress, such as visible crack closure, changes in surface texture, and calcite deposition.



Fig.8 Visual inspection after 3 days of bacterial treatment



Fig.9 Visual inspection after 7 days of bacterial treatment



Fig.10 Visual inspection after 14 days of bacterial treatment

The above pictures showed how bacterial concrete gradually heals itself. According to visual observations, bacterial activity started within three days, and the surfaces of cracks showed the first indications of calcite precipitation. As bacteria started to colonize and deposit minerals, this signal the start of the self-healing process. Hairline cracks showed signs of healing after 7 days of bacterial treatment. The concrete matrix's continuity and compactness were noticeably improved by the partial sealing of the smaller cracks by calcite deposition. This suggested a successful early phase of self-healing. Significant sealing of the hairline and microcracks was visible after 14 days. The concrete's surface and internal continuity were largely restored when the cracks were mostly filled with calcite deposits. The concrete was significantly densified and strengthened as a result of the longer duration, which permitted more thorough bacterial activity.

Conclusion

1. This study demonstrates the potential of bacterial self-healing concrete for long-term crack repair. Calcite precipitation is started by bacterial activity, which successfully repairs microcracks and hairline (0.5–1 mm) cracks.
2. By improving the concrete's continuity, density, and integrity, progressive crack sealing helps it regain its structural performance. This creative method increases resilience and durability, providing a viable way to lower maintenance expenses and dependency on traditional repair techniques.
3. Long-term structural safety is improved and sustainable building methods are supported by bacterial self-healing concrete. Long-term durability, deeper crack healing, and bacterial formulation optimization for wider use in construction should all be investigated in future research.

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