

## **The Potential Of Living Concrete As A Sustainable Alternative For Regenerating Structures Exposed To Aggressive Environments: A Comprehensive Review**

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### **Abstract**

Concrete is one of the most widely used construction materials worldwide; however, it is highly susceptible to cracking and long-term deterioration caused by mechanical stress, environmental exposure, and chemical aggression. Structural cracks compromise durability, permeability resistance, and reinforcement protection, resulting in costly maintenance interventions. Living concrete, also known as bio-concrete or self-healing concrete, has emerged as a promising biotechnological innovation capable of autonomously repairing cracks through biologically induced calcium carbonate precipitation. This review presents a comprehensive analysis of the mechanisms, preparation methods, chemical processes, mechanical performance, sustainability aspects, advantages, limitations, and current applications of living concrete. The study consolidates experimental evidence demonstrating improved compressive strength, flexural resistance, reduced permeability, and enhanced durability compared to conventional concrete. Although higher initial costs remain a barrier, long-term economic and environmental benefits suggest that living concrete represents a transformative technology for resilient infrastructure.

**Keywords:** Living concrete; Self-healing concrete; Biomineralization; Calcium carbonate precipitation; Sustainable construction; Structural durability.

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### **1. Introduction**

Concrete remains the backbone of modern infrastructure, used extensively in bridges, tunnels, marine structures, residential buildings, and industrial facilities

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. Despite its versatility, workability, and structural capacity, conventional concrete presents intrinsic weaknesses, particularly susceptibility to cracking due to:

- Plastic shrinkage
- Thermal expansion and contraction
- Foundation settlement

- Excess water-cement ratio
- Mechanical loading
- Environmental exposure

Cracks allow water and oxygen ingress, accelerating reinforcement corrosion and significantly reducing service life. Maintenance operations are costly, time-consuming, and sometimes disruptive.

To address these limitations, researchers developed **living concrete**, incorporating specific bacteria capable of inducing calcium carbonate ( $\text{CaCO}_3$ ) precipitation when activated by moisture infiltration

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. This biological mechanism enables autonomous crack sealing, reducing permeability and enhancing structural longevity.

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## 2. Concrete Deterioration Mechanisms

Concrete deterioration arises from multiple interacting factors:

### 2.1 Physical Factors

- Shrinkage cracking
- Freeze–thaw cycles
- Mechanical impact

### 2.2 Chemical Factors

- Carbonation
- Sulfate attack
- Chloride penetration
- Alkali–silica reaction

### 2.3 Environmental Factors

- Marine exposure
- High humidity
- Thermal fluctuations
- Aggressive soils

Cracks larger than 0.6 mm may compromise structural safety, while smaller fissures increase permeability and accelerate degradation

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### 3. Concept of Living Concrete

Living concrete integrates **biotechnology and materials engineering** by embedding bacterial spores and nutrients into the concrete matrix.

The fundamental concept relies on:

- Dormant bacterial spores (mainly *Bacillus* species)
- Calcium lactate as nutrient
- Water ingress activation
- Biomineralization process

The bacteria remain inactive for decades (up to 200 years under ideal conditions) until cracks allow water penetration

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### 4. Bacterial Species Used in Living Concrete

Effective bacterial candidates must:

- Survive high alkalinity (pH ~12–13)
- Form endospores
- Produce calcium carbonate
- Remain environmentally safe

Commonly studied species include:

- *Bacillus pasteurii*
- *Bacillus sphaericus*
- *Bacillus subtilis*
- *Bacillus cohnii*

- *Bacillus pseudofirmus*
- *Bacillus balodurans*
- *Escherichia coli* (experimental)

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Among these, *Bacillus subtilis* and *Bacillus sphaericus* are widely reported due to their high urease activity and survivability.

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### 5. Preparation Methods

Two main methods are employed:

#### 5.1 Direct Addition

Bacterial spores and calcium lactate are mixed directly into fresh concrete.

Advantages:

- Simpler process
- Lower cost

Limitations:

- Reduced bacterial survival due to mechanical stress
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#### 5.2 Encapsulation Method

Bacteria and nutrients are encapsulated in expanded clay pellets or biodegradable carriers before mixing.

Advantages:

- Higher bacterial protection
- Improved healing efficiency

Limitations:

- Increased cost
- Up to 20% volume occupation

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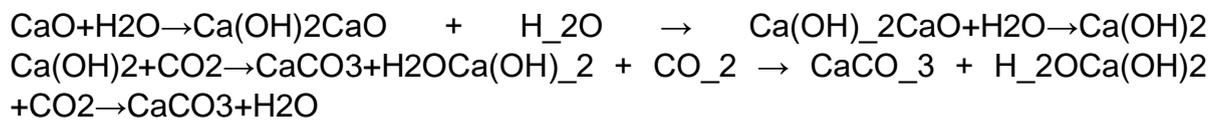
Encapsulation is currently considered the most effective technique.

## 6. Chemical and Biological Mechanism

When water enters cracks:

1. Bacteria germinate
2. Calcium lactate is metabolized
3. Carbon dioxide is produced
4. Calcium carbonate precipitates

Simplified reactions:



The precipitation fills cracks and solidifies within approximately three weeks

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An additional benefit is oxygen consumption during metabolism, which may reduce steel corrosion risk.

## 7. Mechanical Performance

Experimental comparisons indicate superior performance.

### 7.1 Compressive Strength

Age (Days) Conventional (N/mm<sup>2</sup>) Bio-Concrete (N/mm<sup>2</sup>)

7	20.84	27.09
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28	29.99	39.98
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### 7.2 Flexural Strength

Age (Days) Conventional (N/mm<sup>2</sup>) Bio-Concrete (N/mm<sup>2</sup>)

7	3.92	4.60
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**Age (Days) Conventional (N/mm<sup>2</sup>) Bio-Concrete (N/mm<sup>2</sup>)**

28                    7.06                    7.85

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**7.3 Microstructural Analysis**

Scanning Electron Microscopy (SEM) reveals:

- Reduced porosity
- Increased density
- Fewer voids

This densification explains improved mechanical performance.

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**8. Contemporary Applications**

Living concrete is especially suitable for:

- Marine structures
- Bridges
- Tunnels
- Underground facilities
- Historical monument restoration

Jonkers (2015) described it as a revolutionary approach inspired by nature

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Its application reduces maintenance frequency and increases infrastructure resilience.

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**9. Sustainability and Environmental Impact**

Living concrete aligns with sustainable construction principles:

- Reduced maintenance interventions
- Lower material replacement demand

- Extended service life
- Decreased CO<sub>2</sub> footprint over lifecycle

However, production of calcium lactate and encapsulation materials contributes to initial environmental cost.

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## 10. Advantages and Limitations

### 10.1 Advantages

- Autonomous crack healing
- Increased compressive strength
- Reduced permeability
- Corrosion mitigation
- Environmental compatibility
- Extended service life

### 10.2 Limitations

- 30–40% higher initial cost
- Limited availability
- Technical complexity
- High encapsulation cost
- Research still evolving

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In Brazil, estimated costs are approximately R\$360/m<sup>3</sup> versus R\$260/m<sup>3</sup> for conventional concrete

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## 11. Economic Considerations

Although initial cost is higher, lifecycle analysis suggests:

- Reduced repair costs

- Lower structural downtime
- Decreased long-term maintenance

Jonkers (2016) argues economic benefits become evident over time

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## 12. Future Perspectives

Future research directions include:

- Cost reduction strategies
- Alternative nutrient sources
- Improved encapsulation materials
- Large-scale field validation
- Integration with smart monitoring systems

Living concrete represents a step toward **intelligent materials**, capable of responding autonomously to environmental stimuli.

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## 13. Conclusion

Living concrete offers a transformative solution to one of civil engineering's oldest challenges: crack formation and durability reduction. Through biomineralization, bacteria-based systems restore structural integrity and enhance performance.

Although cost and scalability remain barriers, the technology demonstrates strong potential to revolutionize infrastructure resilience, particularly in aggressive environments. Continued research and industrial-scale implementation may position living concrete as a standard material for high-performance, sustainable construction in the coming decades.

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