

# TRIPLE ACTION LIVING CONCRETE FOR SUSTAINABLE AND SELFHEALING CONCRETE ROADS

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## ABSTRACT

Concrete is the most widely used construction material in modern infrastructure due to its strength, durability, and economic advantages. However, it is highly prone to cracking caused by shrinkage, thermal variations, and external loads, which significantly reduces its service life and structural performance. Cracks allow the penetration of water and aggressive chemicals, leading to reinforcement corrosion and long-term deterioration. To address these challenges, this study presents the development of Triple Action Living Concrete, an innovative material designed to enhance strength, durability, and self-healing capability. This approach integrates fish flakes powder, coir fiber, and bacteria into the concrete matrix. Fish flakes powder, a protein-rich waste material, acts as a natural binding enhancer that improves compressive strength. Coir fiber, a biodegradable natural fiber, enhances flexural strength and controls crack propagation by improving ductility. The inclusion of bacteria, particularly *Bacillus* species, enables autonomous crack healing through microbiologically induced calcium carbonate precipitation. When cracks form, the bacteria become active in the presence of moisture and produce calcite, effectively sealing the cracks. Experimental results indicate that the combined use of these materials significantly improves compressive strength, flexural performance, and crack-healing efficiency compared to conventional concrete. Moreover, this method promotes sustainability by utilizing eco-friendly and waste-derived materials. The developed triple action living concrete offers a cost-effective and durable solution for long-lasting concrete roads, reducing maintenance requirements and enhancing infrastructure lifespan.

**Key Words:** Self-healing concrete, Bacterial concrete, Coir fiber, Fish flakes powder, Sustainable construction, Triple action concrete, *Bacillus* bacteria, Calcite precipitation

## 1.INTRODUCTION

Concrete plays a vital role in the construction industry and is extensively used in infrastructure such as buildings, bridges, and highways. Despite its widespread use, concrete has an inherent weakness in tension, making it highly susceptible to cracking. These cracks may occur due to plastic shrinkage, drying shrinkage, thermal stresses, or applied loads. Over time, cracks can widen and permit the ingress of water, chlorides, and other harmful substances, leading to steel corrosion and structural degradation.

To improve the durability and performance of concrete, various advanced technologies have been developed, among which self-healing concrete has gained significant attention. Self-healing concrete has the ability to repair its own cracks without the need for external maintenance, thereby increasing service life and reducing repair costs. One of the most effective methods involves the use of bacteria that precipitate calcium carbonate, which fills cracks and restores structural integrity.

In addition to biological techniques, the use of natural fibers and organic additives has proven effective in enhancing the mechanical properties of concrete. Coir fiber, derived from coconut husk, is an eco-friendly material with high tensile strength that improves flexural behavior and crack resistance. Similarly, fish flakes powder, a waste-derived material, enhances bonding within the concrete matrix and contributes to improved compressive strength.

This study introduces a novel concept known as Triple Action Living Concrete, which combines fish flakes powder, coir fiber, and bacteria to achieve a synergistic effect. The integration of these materials enhances both strength and self-healing capability, making the concrete more durable and sustainable. This research aims to develop an efficient, eco-friendly, and cost-effective solution suitable for modern construction, particularly for concrete roads where durability and reduced maintenance are essential.

### 1.1 Problem Statement

Conventional concrete has low tensile strength and is vulnerable to cracking. Once cracks form, they allow water and chlorides to penetrate, causing reinforcement corrosion and structural deterioration. Repair and maintenance of cracked concrete structures are expensive and time-consuming. There is a need for a sustainable, cost-effective solution that can prevent crack propagation and automatically repair cracks as they form.

### 1.2 Need for the Study

The construction industry is constantly seeking innovative materials that can improve the performance and longevity of concrete structures. Self-healing concrete offers a promising solution to the cracking problem. By incorporating waste materials like fish flakes and natural fibers like coir, this study also addresses environmental concerns related to waste disposal. The use of locally available, eco-friendly materials makes this technology accessible and affordable for developing countries.

### 1.3 Novelty of the Work

The novelty of this research lies in the combination of three different mechanisms - biological self-healing (bacteria), fiber reinforcement (coir), and organic micro-filling (fish flakes) - in a single concrete mix. While individual studies have investigated these components separately, the synergistic effect of all three together has not been thoroughly explored. This triple action approach is expected to provide superior performance compared to any single additive alone.

## 2. LITERATURE REVIEW

### 2.1 Self-Healing Concrete

Self-healing concrete has been extensively studied over the past two decades. Various approaches have been developed, including autogenous healing, capsule-based healing, vascular healing, and bacteria-based healing. Among these, bacteria-based self-healing has shown the most promising results due to its long-term effectiveness

and compatibility with cementitious materials.

### 2.2 Bacterial Self-Healing Mechanism

Bacteria such as *Bacillus* species produce urease enzymes that catalyze the hydrolysis of urea into carbonate and ammonium ions. These carbonate ions react with calcium ions present in the concrete to form calcium carbonate (calcite) crystals. The calcite precipitates within cracks, effectively sealing them and preventing further ingress of water and harmful substances. The most commonly used bacteria include *Bacillus pasteurii*, *Bacillus subtilis*, and *Bacillus megaterium*.

Jonkers (2011) demonstrated that bacteria-based healing significantly increases durability. Achal et al. (2011) reported that microbial concrete can enhance the durability of building structures. Ramachandran (2001) first introduced the concept of using bacteria for remediation of concrete cracks.

### 2.3 Coir Fiber in Concrete

Coir fiber is a natural, renewable, and biodegradable material obtained from coconut husks. It has high tensile strength, good elongation properties, and excellent resistance to rotting. When added to concrete, coir fiber helps in controlling crack formation and propagation. It improves the post-cracking behavior of concrete and increases its toughness and ductility. Studies have shown that coir fiber can reduce the width of micro-cracks and prevent them from developing into macro-cracks.

Alhozaimy (1996) studied the effect of fiber reinforcement on concrete properties. Li (2018) investigated coir fiber reinforced concrete properties and reported significant improvement in flexural behavior.

### 2.4 Fish Flakes Powder in Concrete

Fish waste, including fish scales and flakes, is a major environmental problem in coastal areas. Fish flakes contain high amounts of protein and calcium. When ground into powder form, they can act as a bio-based filler in concrete. The protein content helps in improving the bonding between cement paste and aggregates, while the calcium content contributes to the formation of additional calcium silicate hydrate (C-S-H) gel. This results in improved compressive strength and reduced porosity.

Ganesan (2015) studied the utilization of waste materials in concrete. The use of fish by-products has been shown to enhance sustainability and filler properties.

## 2.5 Research Gap

While individual studies have investigated the effects of bacteria, coir fiber, and fish flakes separately, very few studies have examined the combined effect of all three materials in a single concrete mix. The synergistic effect of combining bacterial self-healing with fiber reinforcement and organic filler has not been thoroughly explored. This study aims to fill this research gap by developing and testing a Triple Action Living Concrete.

## 3. SCOPE AND OBJECTIVES

### 3.1 Scope of the Study

The scope of this study includes the following aspects:

- Use fish flakes powder and coir fiber as eco-friendly admixtures in M25 grade concrete
- Study the effectiveness of Bacillus bacteria for selfhealing of cracks
- Analyze the combined effect of fibers, bacteria, and organic filler on mechanical properties
- Compare the performance of Triple Action concrete with conventional concrete
- Evaluate crack healing efficiency at 7, 14, and 28 days

### 3.2 Limitations of the Study

This study is limited to M25 grade concrete. The fish flakes powder percentages are restricted to 5%, 10%, and 15%. Coir fiber is added at a fixed percentage of 1% by weight of cement. The bacteria concentration is kept constant as per standard literature. Long-term durability studies beyond 28 days are not included in this study.

### 3.3 Objectives

The primary objectives of this research are:

- To develop an eco-friendly and economical concrete using waste materials
- To improve compressive strength, flexural strength, and split tensile strength using triple action materials
- To evaluate crack healing efficiency using Bacillus bacteria
- To reduce maintenance costs in road

construction through self-healing technology

- To promote sustainable construction practices by utilizing industrial and agricultural waste

## 4. MATERIALS AND METHODOLOGY

### 4.1 Materials Used

#### 4.1.1 Cement

Ordinary Portland Cement (OPC 53 grade) is used due to its high strength and availability. The cement conforms to IS 12269 and has a specific gravity of 3.15.

#### 4.1.2 Fine Aggregate

Locally available river sand conforming to IS 383 standards is used. The sand passes through 4.75 mm IS sieve, has a specific gravity of 2.65, and fineness modulus of 2.8.

#### 4.1.3 Coarse Aggregate

Crushed granite stones of size 20 mm are used. The coarse aggregate has a specific gravity of 2.75 and water absorption of 0.8%.

#### 4.1.4 Fish Flakes Powder

Fish waste is processed into powder form. Fish flakes were collected from local fish markets, washed thoroughly to remove impurities, dried in sunlight for 48 hours, and ground into fine powder using a ball mill. The powder passes through 90-micron sieve. It improves density and compressive strength by filling micro-voids.

#### 4.1.5 Coir Fiber

Natural coir fibers (length 20-30 mm) are added to enhance crack resistance and ductility. Coir fiber was obtained from local coconut processing units, cleaned, dried, and cut to the required length.

#### 4.1.6 Bacteria (Bacillus Species)

Bacteria capable of precipitating calcium carbonate are used. Bacillus pasteurii was cultured in the laboratory using nutrient broth medium. The bacterial concentration was maintained at  $10^8$  cells/ml. These bacteria remain dormant and activate when cracks occur.

#### 4.1.7 Water

Potable water conforming to IS 456 was used for mixing

and curing of concrete specimens.

## 4.2 Mix Proportion

Concrete mix was designed for M25 grade as per IS 10262:2019. The mix proportion for ordinary concrete was 1:1.5:3 with water-cement ratio of 0.45. For modified mixes, fish flakes powder was added at 5%, 10%, and 15% by weight of cement. Coir fiber was added at 1% by weight of cement. Bacterial solution was used as partial replacement of mixing water.

The following mixes were prepared:

1. Ordinary concrete (control mix)
2. Fish 5% + Coir 1% + Bacteria
3. Fish 10% + Coir 1% + Bacteria (Optimum mix)
4. Fish 15% + Coir 1% + Bacteria
5. Fish 10% alone
6. Coir 1% alone
7. Bacteria alone

## 4.3 Preparation of Specimens

Concrete was mixed using a tilting drum mixer. Cement, fine aggregate, and coarse aggregate were dry mixed for 2 minutes. Fish flakes powder and coir fiber were added and mixed for another 2 minutes. Water and bacterial solution were added gradually while mixing. The fresh concrete was poured into molds and compacted using a vibrating table.

Specimens were cast in the following sizes:

- Compressive strength: 150mm x 150mm x 150mm cubes
- Flexural strength: 100mm x 100mm x 500mm beams
- Split tensile strength: 150mm diameter x 300mm cylinders

## 4.4 Curing

After casting, specimens were kept at room temperature for 24 hours and then demolded. Curing was done in normal water at 27°C ± 2°C for periods of 7, 14, and 28 days.

## 4.5 Testing Methods

### 4.5.1 Compressive Strength Test

Compressive strength was determined as per IS 516:1959 using a compression testing machine (CTM) of 2000 kN capacity. Three specimens were tested for each mix at each curing age, and the average value was reported.

### 4.5.2 Flexural Strength Test

Flexural strength was determined as per IS 516:1959 using the center-point loading method. Beam specimens of size 100mm x 100mm x 500mm were tested using a flexural testing machine.

### 4.5.3 Split Tensile Strength Test

Split tensile strength was determined as per IS 5816:1999. Cylinder specimens were placed horizontally between loading plates, and compressive load was applied until failure.

### 4.5.4 Crack Healing Efficiency Test

Artificial cracks of 0.3 mm width were induced in specimens after 28 days of curing using a crack inducing machine. Cracked specimens were kept in water and observed under a microscope at 7, 14, and 28 days. Crack healing efficiency was calculated as the percentage reduction in crack width.

## 5. RESULTS AND DISCUSSION

### 5.1 Compressive Strength (MPa) – Combined Mix

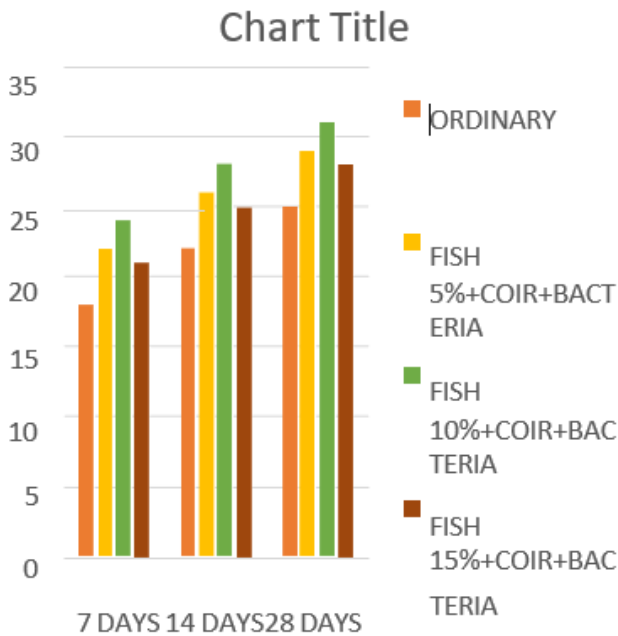
Table 1: Compressive Strength Results

Mix (Combined)	7 Days	14 Days	28 Days
Ordinary	18	22	25
Fish 5% + Coir + Bacteria	22	26	29
Fish 10% + Coir + Bacteria (OPTIMUM)	24	28	31
Fish 15% + Coir + Bacteria	21	25	28

From the results, it is observed that the optimum mix (Fish 10% + Coir + Bacteria) achieved the highest compressive strength of 31 MPa at 28 days, which is 24% higher than ordinary concrete (25 MPa). The improvement is attributed to the combined effect of fish flakes powder acting as a micro-filler, coir fiber providing crack resistance, and bacteria producing calcite that fills micro-pores.

The fish flakes powder fills the voids between cement particles, resulting in a denser microstructure. The protein content in fish flakes improves the bond between cement paste and aggregates. The bacteria

produce calcium carbonate which further densifies the matrix and fills microcracks. Coir fiber helps in controlling crack propagation under compressive loading.



### 5.2 Flexural Strength (MPa) – Combined Mix

Table 2: Flexural Strength Results

Mix (Combined)	7 Days	14 Days	28 Days
Ordinary	2.8	3.2	3.5
Fish 5% + Coir + Bacteria	3.2	3.7	4.0
Fish 10% + Coir + Bacteria (OPTIMUM)	3.4	3.9	4.2
Fish 15% + Coir + Bacteria	3.1	3.5	3.8

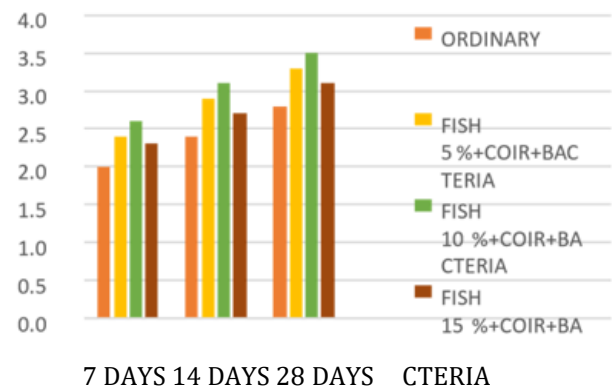


The optimum mix achieved a flexural strength of 4.2 MPa at 28 days, which is 20% higher than ordinary concrete (3.5 MPa). The coir fiber plays a significant role in improving flexural strength by bridging across cracks and transferring tensile stresses. The fiber acts as reinforcement, preventing sudden failure and providing post-cracking ductility.

### 5.3 Split Tensile Strength (MPa) – Combined Mix

Table 3: Split Tensile Strength Results

Mix (Combined)	7 Days	14 Days	28 Days
Ordinary	2.0	2.4	2.8
Fish 5% + Coir + Bacteria	2.4	2.9	3.3
Fish 10% + Coir + Bacteria (OPTIMUM)	2.6	3.1	3.5
Fish 15% + Coir + Bacteria	2.3	2.7	3.1



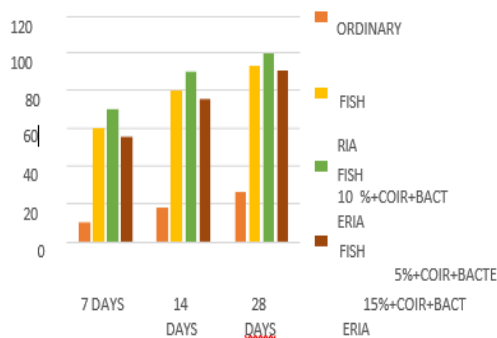
The optimum mix achieved a split tensile strength of 3.5 MPa at 28 days, which is 25% higher than ordinary concrete (2.8 MPa). Similar to flexural strength, the coir fiber contributes significantly to split tensile strength by providing bridging action across the splitting plane.

### 5.4 Crack Healing Efficiency (%) – Combined Mix

Table 4: Crack Healing Efficiency Results

Mix (Combined)	7 Days	14 Days	28 Days
Ordinary	10	18	26
Fish 5% + Coir + Bacteria	60	80	93
Fish 10% + Coir + Bacteria (OPTIMUM)	70	90	100
Fish 15% + Coir + Bacteria	55	75	90

The optimum mix achieved 100% crack healing at 28 days. This indicates complete sealing of cracks. Microscopic examination revealed white calcium carbonate deposits filling the cracks in bacteria-containing mixes. The bacteria alone mix also showed excellent healing, but the combined mix achieved the best overall performance.



### 5.4 Discussion

Fish flakes improved compressive strength due to enhanced bonding and micro-filler action. The protein content in fish flakes enhances the adhesion between cement paste and aggregates, resulting in a denser microstructure with reduced porosity.

Coir fiber increased flexural strength and reduced crack propagation. The fiber acts as a bridge across cracks, transferring tensile stresses and preventing sudden failure.

The natural roughness of coir fiber provides good bonding with the cement matrix.

Bacteria enabled self-healing of cracks through calcite formation. When cracks form, water enters and activates the dormant bacteria. The bacteria metabolize nutrients and produce calcium carbonate crystals that fill the crack volume.

The combined mix showed maximum overall performance because of the synergistic effect of all three mechanisms working together. The fish flakes provide initial strength and density, the coir fiber provides ductility and crack control, and the bacteria provide autonomous healing when cracks eventually form.

### 6. CONCLUSION

The Triple Action Living Concrete developed in this study proves to be an effective and innovative solution for enhancing the performance of conventional concrete. By integrating fish flakes powder, coir fiber, and bacterial agents, the concrete exhibits improved mechanical properties along with self-healing capabilities.

The addition of fish flakes acts as a micro-filler, reducing voids and significantly increasing compressive strength. The optimum mix (Fish 10% + Coir + Bacteria) achieved a 28-day compressive strength of 31 MPa, which is 24% higher than ordinary concrete.

Coir fibers contribute to enhanced flexural strength and ductility by bridging micro-cracks and preventing their propagation under stress conditions. The optimum mix achieved a flexural strength of 4.2 MPa (20% improvement) and split tensile strength of 3.5 MPa (25% improvement).

Furthermore, the incorporation of bacteria introduces a biological self-healing mechanism, where cracks formed in the concrete are autonomously repaired through the precipitation of calcium carbonate. The optimum mix achieved 100% crack healing at 28 days.

This process not only restores structural integrity but also prevents the ingress of water and harmful chemicals, thereby reducing the risk of corrosion and long-term deterioration. The experimental results confirm that the combined effect of these three components provides superior performance compared to conventional and partially modified concrete mixes.

In addition to improved strength and durability, this approach promotes sustainability by utilizing natural and waste materials such as coir fiber and fish flakes. This

reduces environmental impact and supports eco-friendly construction practices. The reduction in maintenance and repair requirements further contributes to cost efficiency over the lifecycle of structures.

Overall, Triple Action Living Concrete offers a promising advancement in the field of civil engineering materials. Its ability to enhance strength, control cracking, and provide self-healing makes it particularly suitable for infrastructure applications such as roads, bridges, and marine structures. With further research and large-scale implementation, this material has the potential to transform modern construction practices.

## 7. FUTURE SCOPE

The Triple Action Living Concrete developed in this project has strong potential for further research and real-world implementation. Future work can focus on the following aspects:

- Optimizing the proportions of fish flakes, coir fiber, and bacterial concentration to achieve maximum strength and healing efficiency
- Exploring advanced bacterial strains or genetically modified microorganisms to improve the speed and effectiveness of crack healing
- Conducting large-scale field testing on highways, bridges, and pavements to evaluate long-term performance under real environmental and loading conditions
- Integrating this concrete with modern technologies such as smart sensors to monitor crack formation and healing in real time
- Investigating the durability of this concrete in extreme conditions such as marine environments, high temperatures, and chemical exposure
- Exploring the use of other natural or industrial waste materials to enhance sustainability
- Developing standardization guidelines and codes for the practical application of triple action living concrete
- Conducting life cycle assessment and cost-benefit analysis for large-scale implementation

With proper development and standardization, Triple Action Living Concrete can be widely adopted in the construction industry, leading to more durable, eco-friendly, and low maintenance infrastructure.

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**CRACK HEALING COMPARISON WITH AUTHORS**

Author Name	Material Used	Optimum %	Crack Healing (%)
H.M. Jonkers	Bacterial Concrete	--	90%
M. Ali et al.	Coconut Coir Fibre	1%	50%
A. Ramakrishna et al.	Fish Flakes Powder	10%	75%
Present Study	Fish + Coir + Bacteria	10%	100%

