



# Performance Assessment of Self-Healing ECC Reinforced with Banana Fiber And Mineral Admixtures

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Published online: May 2026

DOI Link: <https://doi.org/10.64971/j.cph.eijtem.v13.i2.19.2026>

## Abstract:

The brittleness of ordinary concrete, which renders it prone to cracking and reduces the longevity of buildings, is addressed with Engineered Cementitious Composites (ECC). By replacing conventional synthetic fibers with banana fiber, this study investigates the creation of a sustainable, self-healing ECC while lowering material costs and environmental effects. With a fiber content ranging from 0.5% to 2.0% by volume, the mechanical characteristics of banana fiber reinforced ECC were assessed; 1.5% was found to be the ideal amount. To improve matrix densification and self-healing properties at this fiber level, 30% of the fly ash in the mixture was substituted with silica fume. Regular concrete and conventional ECC were compared to the mechanical properties of ECC grades M25, M30, M40, and M45, including density, compressive strength, flexural strength, and split tensile strength. The results showed that the banana fiber reinforced ECC had a lower density, controlled crack propagation, and performed better in tensile and flexural strength than ordinary concrete. The mixture with 1.5% banana fiber and silica fume demonstrated better fiber matrix bonding and lower porosity. This study concludes by suggesting banana fiber-based self-healing ECC as a practical, sustainable, and long-lasting substitute for sustainable building methods.

## Keywords:

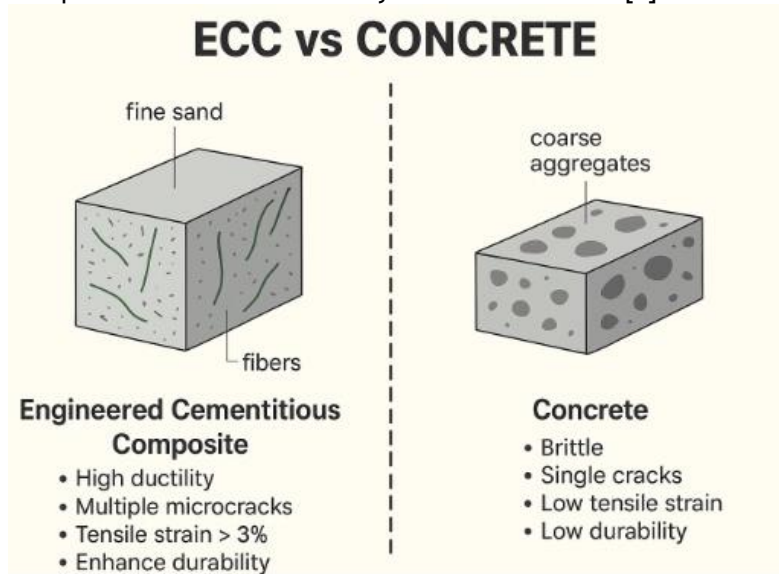
Engineered Cementitious Composites, Banana Fiber, Silica Fume, Mechanical Properties.

## 1. Introduction

A common building material, concrete is prone to corrosion from cracking, which reduces its longevity. Significant study has been conducted on self-healing concrete for autonomous damage restoration since self-healing materials can increase toughness by decreasing crack width. Due to the drawbacks of traditional autogenous healing, which relies on constant hydration, artificial techniques like bacterial concrete and microencapsulated agents are being investigated [1-3]. Although it increases expenses, fiber reinforcing is still required to solve the brittleness and insufficient tensile strength of regular concrete. Known for their ductility and tensile strength, ECC offer a sustainable substitute for steel reinforcement that could reduce building costs [4].

Bendable concrete, known as Engineered Cementitious Composite (ECC), significantly improves upon traditional concrete in durability, ductility, and mechanical performance. Unlike traditional concrete, which is brittle and fails abruptly under tensile strength, ECC showcases regulated microcracking and strain-hardening behavior, preserving structural integrity even under extreme loading conditions [5]. The key difference in composition lies in ECC's exclusion of coarse aggregates, utilizing a homogeneous mix of fly ash, fine sand, cementitious binders, and polymer fibers, enabling tensile strain capacities of 3-5%, compared to the mere 0.01-0.03% of regular concrete. This allows ECC to deform considerably without catastrophic failure, making it suitable for seismic, impact-resistant, and flexible applications. While the compressive strength of concrete and ECC can be similar, ECC excels in tensile and flexural characteristics, providing improved flexural toughness and load-carrying capacity, particularly in thin structural applications. Additionally, ECC exhibits superior

durability due to its ultra-tight microcracks, which prevent deterioration from corrosion and allow for self-healing with ambient moisture, thus extending service life and reducing maintenance costs. The use of industrial waste materials also contributes to ECC's lower carbon footprint and environmental sustainability [6-8]. In summary, ECC offers enhanced ductility, fracture control, durability, and resilience compared to conventional concrete. Despite traditional concrete's cost-effectiveness and ease of production, ECC's exceptional properties make it an ideal candidate for critical infrastructure, merging the strengths of ductile materials and high-strength concrete, and achieving mechanical performance unmatched by standard concrete [9].



**Figure 1 ECC Vs Conventional concrete**

The ability of ECC to sustain ultra-fine crack widths (less than 50-100  $\mu\text{m}$ ) is a major factor in their self-healing mechanism. Through continuous hydration and mineral precipitation, this trait promotes autogenous healing [10-12]. ECC optimally conditions natural healing processes by producing many microcracks instead of a single broad crack when mechanical forces are applied. These microcracks are filled by the constant hydration of unreacted cement particles, moisture ingress, and the consequent development of calcium silicate hydrate (C-S-H) gel. Furthermore, when dissolved calcium ions mix with ambient carbon dioxide, calcium carbonate ( $\text{CaCO}_3$ ) crystals are formed, further sealing the fractures. By encouraging water attraction, which quickens carbonation and hydration, the addition of fibers—especially PVA fibers—improves this process. Together, these processes reduce permeability, seal microcracks, lowering permeability, and restoring mechanical qualities [13].

In order to investigate the mechanical and durability characteristics of self-compacting concrete, Morteza H. Beigi et al. (2013) examined forty distinct mix designs that included steel, polypropylene, and glass fibers as well as different quantities of nanosilica. The control sample showed a water to cementitious material ratio of 0.39 and contained neither fibers nor nanosilica. Compression strength and toughness tests were used to evaluate mechanical qualities; L-Box and slump flow tests were used to examine rheological behavior; and water absorption and quick chloride ion penetration tests were used to analyze durability. The findings showed that adding fibers and nanosilica significantly improved the concrete's mechanical properties [14].

By comparing six ECC mixes to M40 grade concrete using durability tests like resistivity and absorption, Lin et al. (2012) examined the efficacy of ECC as a protective layer for concrete. Their results demonstrated the enhanced durability of ECC by demonstrating that an ideal ECC mix design could lower the chloride diffusion coefficient by 90.8% [15].

Gurkan Yildirim et al. (2015) used mixes with different binders and a constant water to cementitious ratio to investigate the effects of cracking and self-healing on the gas permeability of ECC. Testing showed that self-healing greatly enhanced gas permeability recovery; after one month, the best designs achieved 96% recovery. The study highlighted how important material design and microcracks are to the results of gas permeability [16].

Zhigang Zhang et al. (2014) concentrated on the mechanical characteristics and self-healing behavior of ECC with different fly ash contents. According to their findings, healed specimens showed decreased sorptivity and charge passage, while increasing fly ash volume decreased compressive strength but increased deflection capacity [17].

By permitting microcracking under tensile stress, ECC's creation addressed the brittleness of conventional concrete. According to Li (1993), this design significantly outperformed traditional fiber-reinforced concrete in terms of tensile strain capacity. Because of fiber bridging, ECC has greater tensile and flexural strengths, according to Victoria and Li (2007) [18].

According to reports, ECC is more durable than conventional concrete because it efficiently controls fracture width, lowers permeability, and improves resistance to chloride penetration. Because of their increased resistance to chemical assaults and freeze-thaw cycles, which are strengthened by the inclusion of mineral admixtures, structures produced from ECC are considered appropriate for hostile settings [19-22].

Studies showing improved hardness and crack resistance when employing fibers like jute and banana have sparked interest in the investigation of natural fibers as sustainable reinforcements. Notably, chemically treated banana fiber has demonstrated promise in enhancing mechanical qualities; nonetheless, its use in ECC frameworks is still somewhat unexplored.

The goal of self-healing concrete technologies, which are divided into autogenous and autonomous healing techniques, is to seal cracks on their own. By precipitating calcium carbonate within fissures, bacterial self-healing efficiently fixes cracks up to 0.5 mm, highlighting a major achievement in increasing the service life of concrete structures.

## 2. Methodology of this study

An experimental flowchart demonstrates the methodical approach used in this study to create and assess ECC reinforced with banana fiber. Choosing ingredients like cement, fly ash, silica fume, fine aggregates, water, superplasticizer, and fibers is the first step in the process. After that, these ingredients are measured and combined to make a uniform mixture. To guarantee adequate hydration and strength development, specimens are then cast in traditional molds, compressed, and allowed to cure for seven and twenty-eight days. After curing, a number of tests are performed, such as compressive strength, flexural strength, and self-healing assessments. The permeability characteristics and efficacy in crack management are clarified by additional evaluations, such as water absorption tests and crack width studies. The flowchart clearly outlines each phase of the technique, which ends in data analysis to establish ideal mix proportions.

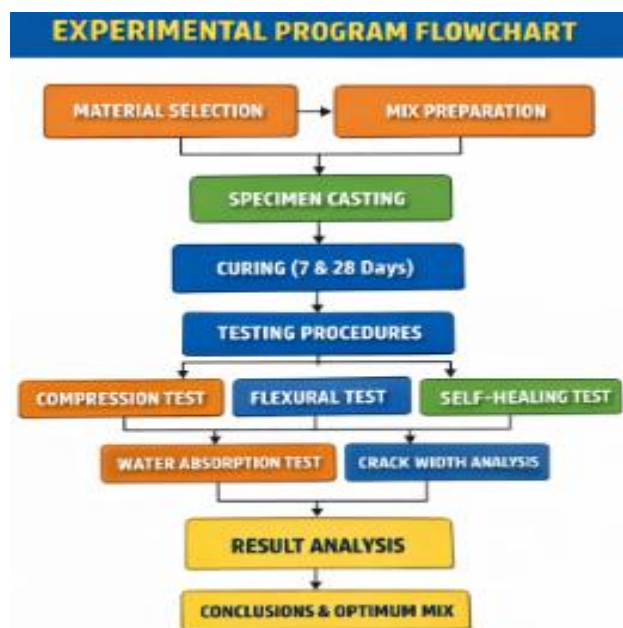


Figure 2 Methodology of the study

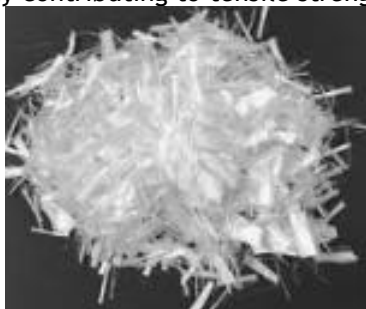
## 3. Materials used

The important choices of materials and procedures for self-healing concrete, especially Engineered Cementitious Composites, are described in this chapter. It describes key components such as cement, fine aggregate, fly ash, silica fume, super plasticizer, and fibers, assessing their qualities in comparison to accepted norms and offering a method for preparing specimens.

Ordinary Portland cement of 53 grades was used as the binding material in accordance with IS 8112:1989, and its physical characteristics were assessed by a number of tests. Bacterial and normal specimens were prepared using OPC grade 53, which had a standard consistency of 29.5% and a specific gravity of 3.13 in accordance with IS 12269:2013. The study used sand that was sourced locally and had a specific gravity of 2.60 in accordance with IS:2386 (1963) and a fineness modulus of 2.70 in accordance with IS:383 2016 for grading zone II. Crushed granite with a fineness modulus of 2.02 made up the coarse aggregates, which were screened in accordance with IS: 383-2016 guidelines and kept in a clean container to prevent dust contamination.

In accordance with IS 456:2000 regulations, potable water was used for concrete casting and curing, guaranteeing full cement hydration and avoiding contamination. Furthermore, Class F fly ash from a thermal power plant was added to ECC as an additional cementitious material to improve long-term strength and workability while limiting fracture breadth. Because of its pozzolanic activity, silica fume was utilized to promote matrix densification and self-healing by substituting 30% of fly ash by weight in certain mixes.

Synthetic, hydrophilic PVA fibers, which are well-known for their excellent mechanical qualities and capacity to bridge cracks, were used in ECC formulations. By preserving microcrack widths and enhancing durability through improved chemical bonding with hydration products like calcium silicate hydrate (C-S-H), PVA fibers improve autogenous self-healing. The study also contrasted banana fiber-reinforced ECC with PVA fiber-based ECC, emphasizing banana fibers as eco-friendly, lignocellulosic materials that provide low density, high flexibility, and moderate tensile strength because of their composition, which is mainly cellulose, hemicellulose, and lignin, with cellulose significantly contributing to tensile strength.



**Figure 3 PVA fibers**



**Figure 4 Banana fiber**

**Table 1 Properties of fibers used**

Property	PVA Fiber	Banana Fiber
Length (mm)	12	17
Diameter ( $\mu\text{m}$ )	40	143
Density ( $\text{g}/\text{cm}^3$ )	1.3	1.35
Tensile Strength (MPa)	1654	568
Elastic Modulus (GPa)	40	18
Surface Nature	Hydrophilic	Hydrophilic (after treatment)

### 3.1 Mix design

By replacing PVA fibers with banana fibers at volume fractions of 0.5%, 1.0%, 1.5%, and 2.0%, the ideal fiber concentration was found. Additionally, to improve matrix densification and self-healing efficiency, 30% of the fly ash by weight was replaced with silica fume. In addition to a control standard ECC mix with PVA fibers and non-fiber cement mortar, many ECC mixes were created by methodically changing the amount of banana fiber, silica fume levels, and self-healing agents. An ideal self-healing ECC mix was found using this experimental approach, exhibiting enhanced mechanical performance, durability, and crack repair.

**Table 2 ECC Specimen details**

S.No	Mix ID	Description
1	NC	Normal concrete (Control)
2	ECC-PVA	Conventional ECC with PVA fiber
3	ECC-BF-0.5	ECC with 0.5% banana fiber
4	ECC-BF-1.0	ECC with 1.0% banana fiber
5	ECC-BF-1.5	ECC with 1.5% banana fiber
6	ECC-BF-2.0	ECC with 2.0% banana fiber
7	ECC-BF-SF	ECC with banana fiber + silica fume

**Table 3 Mix Proportions of ECC for Different Grades**

Component	M25 ECC (kg/m <sup>3</sup> )	M30 ECC (kg/m <sup>3</sup> )	M40 ECC (kg/m <sup>3</sup> )	M45 ECC (kg/m <sup>3</sup> )
Cement	350	380	420	450
Fly Ash (Class F)	450	500	550	600
Silica Fume	0-20	20	25	30
Fine Sand	850	900	950	1000
Water	260	250	240	230
Water-Binder Ratio (w/b)	0.28	0.26	0.24	0.22
Superplasticizer	1.2% of cement	1.2% of cement	1.3 % of cement	1.3 % of cement
Fibre Content	0.5-2.0% (by volume)	0.5-2.0% (by volume)	0.5-2.0% (by volume)	0.5-2.0% (by volume)

### 3.2 Casting and curing

Using mineral oil on molds to facilitate demolding, the ECC was combined and cast into specimens for mechanical property evaluation. The mixture was stacked and manually crushed to attain uniform banana fiber dispersion. Cubes for compressive strength, prisms for flexural strength, and cylinders for split tensile strength were among the specimens that met ASTM and Indian criteria. Specimens were cured in a water tank for 28 days after being cast, covered with polyethylene, and left at room temperature for a day to reduce moisture loss. In order to evaluate the ECC's density, tensile, compressive, and flexural strengths, this approach made sure it was properly hydrated.



**Figure 5 Casting and curing of specimens**

#### 4. Results and discussion

##### 4.1 Compressive strength

Through compressive strength testing, the study assessed the load-bearing capacity of self-healing ECC reinforced with banana fiber. Because of their dense matrix and efficient crack management, ECC blends were shown to have better compressive strengths than regular concrete. Up to 1.5% of banana fiber content boosted compressive strength; however, at 2.0%, fiber clumping and decreased workability caused a minor decrease. Out of all the grades (M25 to M45), the ECC-BF-SF combination with 1.5% banana fiber and 30% silica fume had the highest compressive strength. The addition of silica fume strengthened the fiber-matrix link, increased matrix density, and improved pore connectivity, proving that banana fiber, when utilized properly, can successfully boost compressive strength.

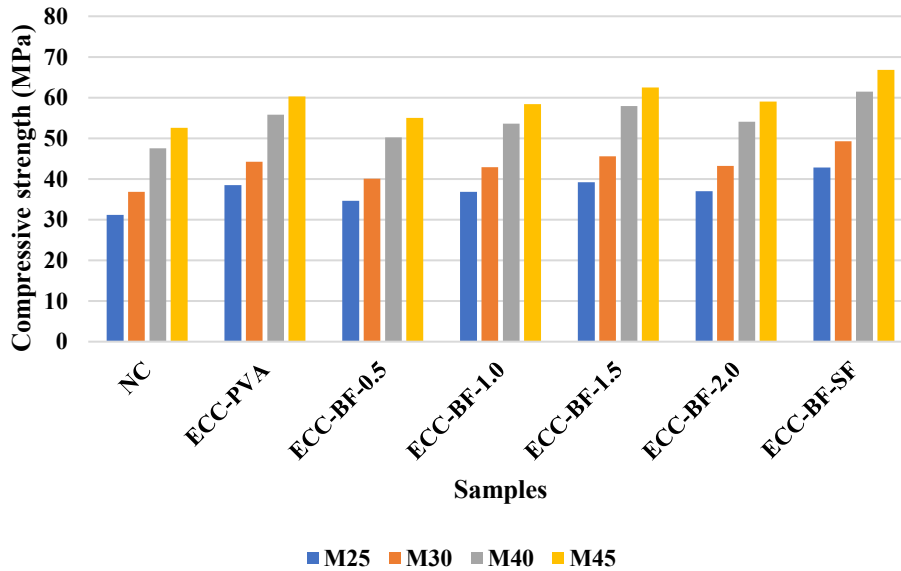


Figure 6 Compressive strength results

##### 4.2 Flexural strength test

The findings showed that ECC combinations perform better than ordinary concrete in terms of flexural strength, with samples reinforced with banana fiber showing numerous tiny cracks as a result of strain-hardening. Ductility and energy absorption were greatly improved by adding up to 1.5% banana fiber. With the benefit of both silica fume refining and banana fiber bridging, the ECC-BF-SF blend demonstrated the highest flexural strength. The efficiency of banana fiber in enhancing ECC's performance and fracture resistance was demonstrated by a little decrease in strength at 2.0% fiber content, which was ascribed to increased voids and decreased fiber dispersion.

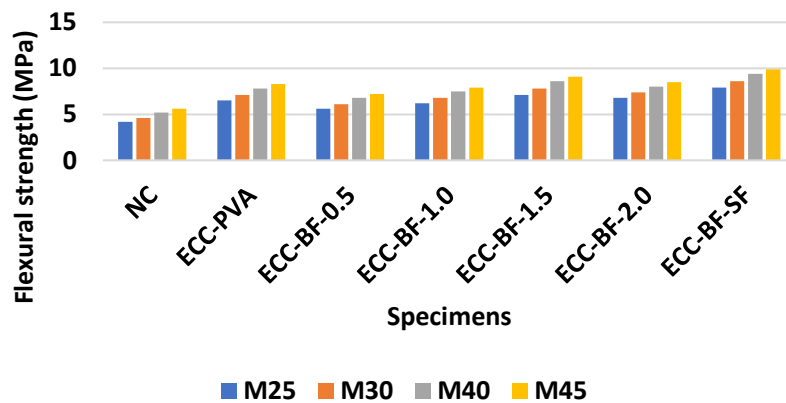


Figure 7 Flexural strength test

### 4.3 Split tensile test

ECC mixes performed better in the split tensile strength test than ordinary concrete in terms of tensile resistance. Strength was improved by banana fiber's ability to bridge microcracks, especially when the fiber level was 1.5%. Furthermore, silica fume increased the ECC-BF-SF mixture's tensile strength. However, because of unequal stress distribution and fiber balling, a 2.0% fiber content resulted in a decrease in strength. All things considered, ECC mixes showed excellent tensile behavior that supported efficient self-healing.

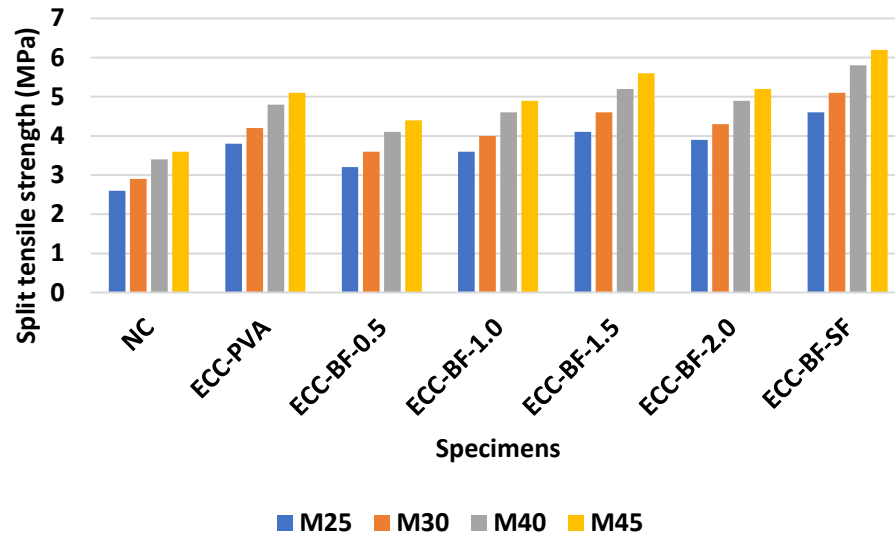


Figure 8 Split Tensile Strength outcomes

### 4.4 Measurement of Crack Width

According to the study, ECC have better fracture control behavior than traditional concrete in all grades (M25-M45). With fracture widths ranging from 500  $\mu\text{m}$  (M25) to 350  $\mu\text{m}$  (M45), the control mix showed notable brittle failure. ECC mixtures, on the other hand, showed ductile behavior with microcracks ranging from 90  $\mu\text{m}$  (M25) to 60  $\mu\text{m}$  (M45). The ECC-BF-1.5 mix, in particular, performed exceptionally well because of its ideal capacity for self-healing. Due to problems with fiber dispersion, the ECC-BF-2.0 had broader cracks (120-180  $\mu\text{m}$ ), whereas the ECC-PVA mix demonstrated better fracture control (70-100  $\mu\text{m}$ ). Because of its dense matrix and excellent bonding, the ECC-BF-SF combination produced the smallest crack widths (50-80  $\mu\text{m}$ ). Because of their greater strength and less microcrack propagation, higher-grade ECCs showed smaller crack widths, which ultimately promoted durability and self-healing.

Table 4 Crack Width ( $\mu\text{m}$ )

Mix ID	M25	M30	M40	M45
NC	500	450	400	350
ECC-PVA	100	90	80	70
ECC-BF-0.5	150	130	120	110
ECC-BF-1.0	120	100	90	80
ECC-BF-1.5	90	80	70	60
ECC-BF-2.0	180	160	140	120
ECC-BF-SF	80	70	60	50

### 4.5 Self-Healing Efficiency Test

According to a study on the self-healing effectiveness of ECC mixes (M25-M45), they have a considerable capacity to repair cracks, with optimal healing taking place at up to 1.5% fiber content. The remarkable healing range of 75% to 85% was demonstrated by ECC-BF-1.5. This efficiency was improved by elements including calcium carbonate precipitation, continuous hydration, and fiber bridging. Due to uneven fiber distribution, healing efficacy somewhat decreased to 65%-74% at 2.0% fiber concentration. The healing effectiveness of ECC-PVA remained between 72% and 80%. Because of its tiny microstructure, the ECC-BF-SF combination demonstrated the best efficiency at 80%-90%. ECC's exceptional self-healing qualities were

highlighted by higher grades, which showed better healing efficacy, especially at ideal fiber concentrations.

**Table 5 Healing Efficiency (%)**

Mix ID	M25	M30	M40	M45
ECC-PVA	72	75	78	80
ECC-BF-0.5	60	64	67	70
ECC-BF-1.0	68	73	76	79
ECC-BF-1.5	75	80	83	85
ECC-BF-2.0	65	70	72	74
ECC-BF-SF	80	84	87	90

#### 4.6 Water absorption test

As fiber content rose to 1.5%, ECC's matrix density improved and water absorption dropped (7.0%-6.0% for M25-M45), with the control mix (NC) having the highest values. Due to improved particle packing and fiber crack-bridging effects, the ECC-BF-1.5 mix shown additional absorption reductions (5.3%-4.4%), indicating reduced porosity and improved internal structure. Poor compaction and fiber clustering were associated with an increase in absorption (4.6%-5.5%) at 2.0% fiber content. Because silica fume filled the micro-voids, the ECC-BF-SF combination produced the lowest absorption values (5.0%-4.0%). The conclusion emphasizes how adding silica fume and optimizing fiber concentration significantly improve ECC impermeability.

**Table 6 Water Absorption (%)**

Mix ID	M25	M30	M40	M45
NC	7.0	6.7	6.3	6.0
ECC-PVA	6.5	6.2	5.8	5.5
ECC-BF-0.5	6.0	5.6	5.2	5.0
ECC-BF-1.0	5.7	5.3	4.9	4.7
ECC-BF-1.5	5.3	4.9	4.6	4.4
ECC-BF-2.0	5.5	5.1	4.8	4.6
ECC-BF-SF	5.0	4.6	4.2	4.0

## 5. Conclusions

The experimental investigation found that when utilized as a sustainable reinforcement material, banana fiber can significantly improve the mechanical performance of self-healing ECC. In order to preserve workability and increase split tensile, flexural, and compressive strengths, the ideal fiber content was found to be 1.5% by volume. Superior strength, crack resistance, and matrix densification were shown by ECC using 1.5% banana fiber and 30% silica fume; however, a greater fiber content (2.0%) resulted in reduced workability and slight strength decreases because of fiber aggregation. According to the study, banana fiber ECC outperformed conventional concrete in terms of ductility and strain-hardening behavior, as well as fracture management and self-healing efficiency (up to 87%). By lowering water absorption, silica fume was used to increase durability and impermeability. All things considered, banana fiber ECC is a reasonably priced, eco-friendly choice for sustainable building.

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Sai Kumarreddy Kummitha et.al, Performance Assessment of Self-Healing ECC Reinforced with Banana Fiber And Mineral Admixtures, Excel International Journal of Technology, Engineering and Management, 2026; Volume -13, Issue-2\_Page\_165-173. DOI Link:

<https://doi.org/10.64971/j.cph.eijtem.v13.i2.19.2026>



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