



Mechanical and Durability Evaluation of Fiber Reinforced High Performance M25 Concrete with SCM Modifications

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Abstract:

The environmental effects of cement production and durability concerns are major difficulties for concrete, the most used building material in the world. M25 grade concrete reinforced with banana fiber and enhanced with cementitious materials (SCMs) such as fly ash and ground granulated blast furnace slag (GGBS) is the subject of this investigation. Ten concrete mixes with different percentages of Fly Ash (10-20%), GGBS (10-20%), and Banana Fiber (0.25-0.5%) were made for the study. By adding banana fiber as a percentage of the binder's weight, a ternary mixing technique made it possible to replace up to 30% of the cement. After 28 days, the specimens were subjected to a number of tests, including compressive strength, split tensile strength, flexural strength, rapid chloride penetration test (RCPT), density evaluation, and water absorption, in accordance with standard casting and curing protocols. With a compressive strength of 39.4 MPa, the ideal mix which contained 15% Fly Ash, 15% GGBS, and 0.5% Banana Fiber surpassed ordinary concrete by about 21%. With gains of 34% in split tensile strength and 30% in flexural strength, the addition of banana fiber greatly aided in bridging cracks. In comparison to the control mix, durability also improved, with chloride permeability being minimized by 53% and water absorption decreased by 29%. The density stayed within acceptable bounds, suggesting adequate homogeneity and compaction. The study concludes that, in comparison to conventional concrete, ternary mixed banana fiber reinforced concrete exhibits qualities typical of high-performance concrete (HPC), including superior resistance to cracking and overall durability, in addition to meeting the structural requirements for M25 grade.

Keywords: Performance characteristics, Durability, Banana fibers, Environmental sustainability, Mechanical properties.

1. Introduction

In order to produce HPC, current sustainability initiatives are encouraging the use of industrial wastes like fly ash in place of cement. Compared to regular concrete, HPC has better mechanical qualities and durability because to its superior mineral admixtures and lower water-to-binder ratios. However, volume instability continues to be a major obstacle to its use in constructions like large-span bridges and high-rise buildings. In addition to contributing to HPC's improved performance, its unique internal chemical and structural characteristics such as heat development and pozzolanic activity also have an impact on how it shrinks in comparison to regular concrete [1,2]. Concrete is the most often used material in the construction sector and has developed to fulfill high performance requirements. HPC benefits from optimum constituent combinations, improved durability against environmental conditions, and energy absorption for earthquake resistance. It outperforms traditional concrete, is made for certain uses and settings, and seeks to increase structural strength while cutting down on building time. The production of Portland cement rises in response to the rising demand for concrete, which greatly increases CO₂ emissions. As a result, alternative materials are being investigated to reduce their negative effects on the environment. HPC's exorbitant prices prevent wider adoption despite its benefits. Basalt fiber has emerged as an environmentally benign substitute for

reinforcement in reinforced concrete, which uses a variety of fibers to reduce permeability and cracking.



Figure 1. Environmental impact of cement production

However, there is still insufficient research on the application of HPC made with manufactured sand, particularly concerning its durability in marine environments in northern China. The rise of the building industry and the transportation sector are strongly linked to the growth in housing manufacturing. The demand for cement has increased recently, which has been made worse by the move to substitute ingredients like GGBS and quarry powder [3-5]. The strengths of Indian calcium bentonite grout combinations vary, and the production process of regular Portland cement raises environmental issues [6]. Because of its high compressive strength and durability, concrete continues to be the most popular building material, especially in coastal areas where sea salt infiltration is a concern. The market value of feldspar, which is scarce, is expected to be impacted by the growing demand for ceramic tiles. Supplementary cementitious materials are gradually replacing regular OPC in order to reduce CO₂ emissions from cement products [7]. While the addition of pozzolans, such as silica fume, improves mechanical and thermal stability, ash exhibits less reactivity than OPC. Greenhouse gas emissions can be considerably decreased by using Sugarcane Bagasse Residue in place of OPC in concrete [8-10].

The purpose of the literature review is to examine the body of knowledge regarding a certain subject and identify any gaps in the field. It presents important research on concrete, a common building material, with a focus on the effects of mineral admixtures such as GGBS and RHA on its performance. Numerous studies have demonstrated the advantages of RHA, especially its capacity to take the place of cement in HPC mixes, improving mechanical qualities including workability, durability, and compressive strength while also lessening the impact on the environment. For example, when RHA was added under ideal curing circumstances, Bhattacharjee et al. (2016) and Muntohar et al. (2017) reported notable improvements in concrete's strength qualities and decreased permeability [18-19]. Further studies by Ramli et al. (2016) and Kamaruddin et al. (2018) corroborated these results, pointing out that RHA can boost resistance to sulfate attack and chloride ion penetration, hence enhancing the long-term durability of concrete. According to Safiuddin et al. (2016), the addition of RHA also improved workability and decreased heat of hydration [20-22].

On the other hand, because of its pozzolanic qualities when combined with calcium hydroxide, GGBS was recognized for its vital role in concrete. The differences between GGBS and OPC hydration reactions were examined, highlighting the fact that GGBS enhances concrete's durability, especially in harsh conditions. Higher percentages of GGBS lead to reduced chloride ion permeability and increased resistance to sulfate assaults, according to notable research like Maiti & Agarwal (2009) and Pavia & Condren (2008) [23-24].

Due to a smaller pore structure that results in lower permeability, research has repeatedly shown that concrete with GGBS has better durability metrics than concrete constructed just with OPC. According to research, RHA improves these qualities by lowering porosity and promoting improved moisture absorption, increasing the likelihood of long-term durability. An important development in

sustainable construction techniques is the successful integration of pozzolans like RHA and GGBS, which provide affordable solutions while satisfying performance requirements in structural applications. Additionally, the review shows how the content of RHA affects the properties of the concrete that results. The best replacement levels for RHA, up to 25%, are effective in improving mechanical and durability-related properties, confirming its value as an additional cementitious material.

The synergistic effects of integrating many supplemental cementitious materials, such as GGBS and RHA, in HPC have been further highlighted by recent studies. Researchers have shown that using these elements together greatly improves concrete's microstructural qualities in addition to its mechanical qualities. For example, RHA helps create more calcium silicate hydrate (C-S-H) gel, which results in a denser matrix and increased compressive strength (Ganesan et al., 2008) [11]. In a similar vein, Habeeb and Fayyadh (2009) emphasized that RHA's high silica concentration and fineness are essential for improving pore structure and lowering permeability [12]. These effects are enhanced when combined with GGBS since GGBS uses latent hydraulic reactions to promote long-term durability and strength growth (Sharma & Khan, 2017) [13]. Furthermore, it has been discovered that using these mineral admixtures lowers the carbon footprint of concrete by using less cement, making it a sustainable substitute for contemporary building techniques (Mehta & Monteiro, 2014) [14].

Recent studies have concentrated on the performance of RHA and GGBS-based concrete under harsh climatic conditions and sophisticated analytical techniques, in addition to mechanical and durability enhancements. RHA-blended concrete has outstanding resistance to acid attack and chloride ion penetration, which is crucial for marine and coastal constructions, according to studies by Zhang and Malhotra (1996) and Chindaprasirt et al. (2007). Furthermore, more precise predictions of the strength and durability properties of such blended concretes have been made possible by developments in modeling techniques, such as the use of Artificial Neural Networks (ANN) (Nazari & Riahi, 2011) [15-17]. These models offer a dependable tool for maximizing concrete performance by taking into account a variety of input parameters, such as replacement amounts, curing conditions, and mix proportions. Despite these developments, more experimental and analytical research is still required to fully understand the long-term performance and combined effects of RHA and GGBS in various environmental conditions, particularly in relation to permeability and durability.

This study examines the properties of M25 grade concrete are affected by SCM such fly ash and GGBS. It looks into the mechanical characteristics of the concrete, the workability of fresh mixes with different SCM to fiber ratios, and the reinforcement offered by banana fibers. The flexural, split tensile, and compressive strengths of modified concrete mixtures, together with their permeability and water absorption characteristics, are important assessments. By contrasting the modified mixes with a conventional control mix of M25 concrete, the study seeks to determine the ideal ratio of fly ash, GGBS, and banana fiber for improved performance. Finding out whether the new concrete compositions display performance characteristics similar to high-performance concrete is the ultimate objective.

2. Materials and methods

2.1 Background

The research of concrete's permeability and durability is covered in length in this chapter, with an emphasis on materials, mix design, specimen preparation, curing, and testing techniques. Aggregates (coarse and fine) and cement (Grade 53 OPC) underwent a thorough quality assessment. By adding natural banana fibers and additional cementitious ingredients including fly ash and GGBS, concrete's tensile strength and crack resistance were significantly improved. In order to minimize water-to-cement ratios and maximize workability, additives were used. The techniques followed Indian and ASTM standards, guaranteeing the precision and repeatability of the experiments.

This chapter describes the materials utilized, mix design, specimen preparation, curing, and testing procedures in order to assess the permeability and durability characteristics of concrete. In order to ensure compliance with ASTM and Indian requirements, mechanical properties were evaluated to link strength with durability, and an experimental software was created to investigate the effects of material composition on traits like water permeability and chloride penetration.

2.2 Materials used

2.2.1 Cement

Grade 53 OPC complying with IS 12269 was used, and quality was confirmed by necessary property checks. Setting times, standard consistency (30%), and specific gravity (3.15) were crucial factors that ensured efficient hydration and strength development.



Figure 2 Cement

2.2.2 Fine Aggregate

To improve workability and fill spaces between coarse aggregates, IS 383-compliant natural river sand was chosen. Specific gravity (2.62) and water absorption (1.2%) showed excellent grading results.



Figure 3 Fine aggregates

2.2.3 Coarse Aggregate

Due to their better strength contributions, crushed angular aggregates up to 20 mm in size were utilized. Specific gravity (2.75) and low water absorption (0.8%) were significant aggregate characteristics.



Figure 4 Coarse aggregates

2.2.4 Water

In order to sustain hydration processes, only contaminant-free potable water was utilized for mixing and curing.

2.2.5 Additional Cementitious Substances

Through pozzolanic activity, supplemental materials such as fly ash GGBS were used to partially replace cement, increasing the density and durability of the concrete.

The use of Class F fly ash, which is pozzolanic, resulted in reduced permeability and increased strength.

Concrete characteristics are further enhanced by the pozzolanic and hydraulic qualities provided by GGBS.



Flyash



GGBS

Figure 5 Additional Cementitious materials

2.2.6. Natural Fiber Reinforcement

To increase tensile strength and crack resistance, banana fibers were used. Their cellulose content improves ductility and sustainability by facilitating efficient fracture bridging.

Banana fiber was utilized as a natural reinforcing material to improve the tensile performance and crack resistance of M25 grade concrete. Because of its high cellulose content, this biodegradable fiber, which comes from the pseudo-stem of the banana plant, has a tensile strength of 400-600 MPa and a modulus of elasticity of 17-32 GPa. For the best possible integration into the concrete matrix,

fibers were treated to a consistent length of 30 mm. By bridging microcracks, banana fiber enhances concrete's flexural strength, split tensile strength, and post-cracking behavior. Although too much fiber might increase water absorption and impair workability, an optimal fiber content of 0.25 to 1.0% by volume improves mechanical characteristics. This study shows that banana fiber improves M25's ductility, toughness, and crack resistance.



Figure 6 Banana fiber extraction process in nature

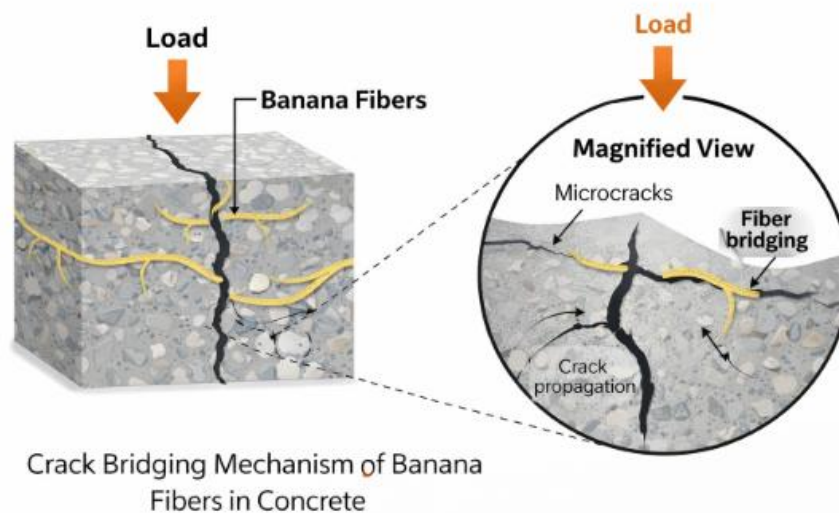


Figure 7 Banana fibers reinforcing concrete cracks

2.2.7. Chemical Combinations

In order to maximize mix performance through experimental evaluations, a superplasticizer was added to enable low water-cement ratios without compromising workability.

2.3 Mixture proportions

In accordance with IS 10262:2019, the concrete mix design was carried out with the intended mean strength in mind, taking into account the standard deviation, necessary durability, permeability, and water-to-cement ratio. Admixture dosages and aggregate proportions were adjusted in trial blends to achieve the required strength and workability. The final mix contained 410 kg/m³ cement, 670 kg/m³ fine aggregate, 1290 kg/m³ coarse aggregate, and 188 kg/m³ water, resulting in a water-cement ratio of 0.45.

In order to maintain homogeneity and reduce voids, the materials were mixed in a robotic mixer, then carefully cast in clean molds and compacted using a table vibrator. The specimens were demolded and put in curing tanks after a day.

Specimens were cured by immersing them in clean water at $27 \pm 2^\circ\text{C}$, which improved hydration and decreased capillary porosity. Concrete slump was tested for consistency during the Slump Cone Test, which was used to evaluate workability at intervals of 7, 14, and 28 days.

Table 1. Specimen details

Specimen ID	Fly Ash (%)	GGBS (%)	Fiber (%)	Mix Description
M1 (Control)	0	0	0	Conventional concrete without SCM and fiber
M2	10	0	0	Concrete with 10% fly ash replacement
M3	20	0	0	Concrete with 20% fly ash replacement
M4	0	20	0	Concrete with 20% GGBS replacement
M5	10	10	0	Concrete with combined SCM (Fly ash + GGBS)
M6	20	10	0	Concrete with higher SCM content
M7	10	10	0.25	Concrete with SCM and 0.25% fiber
M8	20	10	0.25	Concrete with higher SCM and fiber
M9	10	10	0.5	Concrete with SCM and 0.5% fiber
M10	15	15	0.5	Concrete with balanced SCM and fiber content

A number of experiments were carried out:

the RCPT measured resistance to chloride ion penetration, guided by ASTM C1202 standards; water permeability tests used constant head equipment to measure flow rates, indicating durability; and compressive strength tests followed IS 516, evaluating concrete load capacity. In order to evaluate durability, the sorptivity test calculated the capillary suction rate in unsaturated concrete.

Table 2 Specimen Details and Testing Program

Sl. No	Test Name	Specimen Size	No. per Mix	No. of Mixes	Total Specimens
1	Compressive Strength	150×150×150 mm	3	4	12
2	Split Tensile Strength	150×300 mm	3	4	12
3	Water Permeability	150 dia × 150 mm	3	4	12
4	RCPT	100 dia × 50 mm	3	4	12
5	Sorptivity	100 dia × 50 mm	3	4	12

2.4 Experimental method

For a variety of tests, such as compressive strength, split tensile strength, water permeability, RCPT, and sorptivity, an organized experimental program was described. At least three specimens were utilized for each test to guarantee accuracy and repeatability of findings. The approach and strict procedures used to assess the permeability and durability characteristics of concrete were summarized in this chapter.

The concrete mix design followed IS 10262:2019, concentrating on reaching the desired mean strength while taking permeability and durability into consideration by carefully choosing the water-to-cement ratio. The final mix proportions were 410 kg/m³ cement, 670 kg/m³ fine aggregate, 1290 kg/m³ coarse aggregate, and 188 kg/m³ water, establishing a water-cement ratio of 0.45. Trial blends were developed and improved for strength and workability.

A mechanical mixer was used to prepare the specimens in order to guarantee consistency. Clean molds were used, and excessive compaction was avoided to prevent segregation. Testing was done

at 7, 14, and 28 days during the crucial curing process, which involved submerging specimens in clean water at regulated temperatures for hydration.

The Slump Cone Test, which was used to evaluate workability, showed a progressive decline in slump values with higher replacement percentages of substitute materials, such as fly ash and banana fiber, suggesting the need for modifications to preserve uniformity without compromising strength.

Compressive strength tests were conducted in accordance with IS 516 standards, and the results indicated that mixes containing SCM had improved strength. The best mix, which included 15% fly ash and 15% GGBS supplemented with 0.5% banana fiber, achieved 39.4 MPa, which was 21% higher than the control mix.

Because of the improved bonding between SCM and banana fiber, the split tensile strength showed improvements, especially in the ideal blend that produced a 34% increase. As a result of improved matrix densification, flexural strength also increased, with a notable 30% increase in the ideal blend. Higher SCM and fiber content were associated with decreased absorption rates, according to water absorption tests; the ideal blend showed 2.7% absorption. This implies that increased durability is associated with microstructural density.

In the RCPT, the unique mix designs dramatically reduced chloride permeability, with the ideal mix rated as having "Very Low" permeability at 1500 Coulombs, underscoring the benefits of using SCMs and fibers in strengthening resistance to corrosion.

Density experiments confirmed that adding SCMs generally changed densities; the ideal mixture averaged 2445 kg/m³. This confirms favorable correlations between density and compressive strength across studied mixes and is indicative of better particle packing and compaction.

Concrete became less workable as the proportion of cement replacement rose; nonetheless, a 20% replacement maintained acceptable slump levels for structural applications without the need for extra admixtures. SCMs such as fly ash and GGBS greatly improved the mechanical qualities of M25 grade concrete. More calcium silicate hydrate (C-S-H) gel was produced by the pozzolanic reactions between Fly Ash and GGBS, resulting in a denser microstructure and improved compressive, tensile, and flexural strengths. By the 28-day mark, the ternary blend of 15% fly ash, 15% GGBS, and 0.5% banana fiber had a compressive strength of 39.4 MPa, which is almost 21% higher than the control mix because of better fiber reinforcing and particle packing.

By bridging microcracks and improving ductility and crack management, banana fiber dramatically boosted split tensile strength. Additionally, the tensile strength (3.82 MPa) of the optimized blend was 34% higher than that of the control. Fiber addition significantly increased flexural strength; the optimized mix's flexural strength of 5.32 MPa is almost 30% higher than that of the control mix, making it appropriate for applications subjected to flexural stresses.

Water absorption fell by 29% in the enhanced mix compared to the control, owing to better pore refinement and reduced microcracking from fiber inclusion, boosting long-term durability. According to the results of the Rapid Chloride Penetration Test (RCPT), the ternary blend exhibited low to very low permeability and a 53% reduction in charge passed when compared to ordinary concrete. This suggests that the blend has superior chloride ion resistance, which is advantageous for harsh environmental applications.

The typical density ranges of 2400-2450 kg/m³ were maintained by all mixtures, with ternary blends exhibiting minor increases in density because of improved packing and microstructural integrity. Fly Ash and GGBS worked better together than they did separately, especially when it came to early hydration and chloride resistance, which increased the strength and longevity of structural concrete. By using renewable and biodegradable resources, the addition of these SCMs and banana fiber reduced carbon emissions and cement consumption while also promoting sustainable building methods. The optimal combination of 15% fly ash, 15% GGBS, and 5% banana fiber demonstrated exceptional mechanical and durability qualities, making it appropriate for demanding structural applications such as slabs, columns, and beams.

3 Results and discussion

3.1 Workability test

The study assesses the workability of concrete in a variety of mixtures, emphasizing the influence of additional fibers and cementitious ingredients. With a slump value of 85 mm, the control mix (M1) showed the highest workability for typical M25 concrete. Because of the higher binder content, mixes M2 and M3 (with fly ash) showed minor reductions to 80 mm and 76 mm, but they were still suitable for structural application. Maintaining medium workability, Mix M4 with GGBS recorded 82 mm. Slump values were further reduced to 78 mm and 74 mm when fly ash and GGBS were added to mixes M5 and M6. Because of the fibers higher internal friction and water absorption, the addition of banana fibers to mixtures M7 and M8 resulted in more notable reductions, down to 70 mm and 66 mm. Mixes

M9 and M10 with 0.5% fiber showed the lowest results, at 60 mm and 58 mm, respectively, suggesting restricted workability. Overall, the results indicate that although increasing fiber content and additional ingredients decrease workability, all mixes stay within permissible bounds for concrete applications, with possible mitigation through the use of superplasticizers or water-reducing admixtures.

Table 3 Workability results

Mix ID	Fly Ash (%)	GGBS (%)	Fiber (%)	Slump Value (mm)	Workability Classification
M1	0	0	0	85	Medium
M2	10	0	0	80	Medium
M3	20	0	0	76	Medium
M4	0	20	0	82	Medium
M5	10	10	0	78	Medium
M6	20	10	0	74	Medium
M7	10	10	0.25	70	Medium-Low
M8	20	10	0.25	66	Medium-Low
M9	10	10	0.5	60	Low
M10	15	15	0.5	58	Low

3.2 Compressive Strength Test

After 28 days, the concrete's compressive strength was assessed in accordance with Bureau of Indian Standards procedures. The control mix M1 (conventional M25) attained 32.4 MPa. Mix M2's strength was raised to 34.8 MPa by adding 10% fly ash, while mix M3's strength was marginally reduced to 33.6 MPa by adding 20% fly ash. Mix M4 produced 35.5 MPa (9.6% improvement) with 20% GGBS. Mix M6's strength dropped to 34.1 MPa when 20% fly ash and 10% GGBS were added, suggesting possible negative effects of excessive replacement. But mix M5 (10% fly ash + 10% GGBS) increased strength by 11.7% to 36.2 MPa. In M7 (0.25% fiber) and M9 (0.5% fiber), the addition of banana fiber increased compressive strength to 37.8 MPa and 38.6 MPa, respectively. M10 (15% fly ash + 15% GGBS + 0.5% fiber) performed the best, with a strength of 39.4 MPa (21.6% increase). These improvements are ascribed to the advantageous qualities of banana fiber and GGBS as well as pozzolanic reactions that produce C-S-H gel. According to the study's findings, adding these ingredients greatly improves M25 concrete's durability and compressive strength.



Figure 8 Compressive strength test

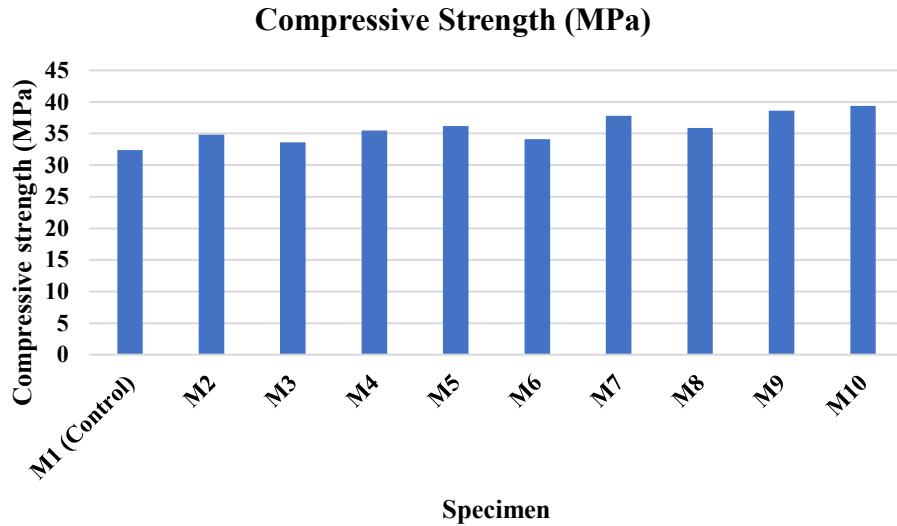


Figure 9 Compressive strength test outcomes

3.3 Split Tensile Strength

The control mix's tensile strength was 2.85 MPa. Due to better bonding, the addition of SCM resulted in a slight improvement in tensile strength. The inclusion of banana fiber resulted in the most improvement. Fiber bridges microcracks and works as a crack-arresting substance, slowing the spread of cracks. When compared to the control, Mix M10's tensile strength increased by 34%, suggesting that fiber addition significantly improves tensile performance.



Figure 10 Split Tensile Strength test

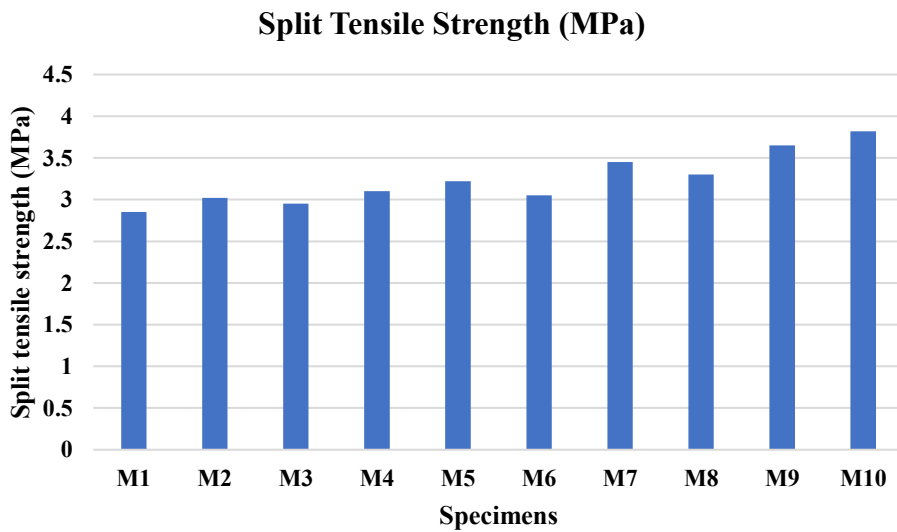


Figure 11 Split Tensile Strength test outcomes

3.4 Flexural Strength Test

Because of improved matrix densification, flexural strength increased with SCM replacement. The flexural performance was greatly improved by the inclusion of banana fiber. Fiber enhances energy absorption capability and post-cracking behavior. When compared to the control mix, Mix M10's flexural strength was almost 30% higher.



Figure 12 Flexural Strength test

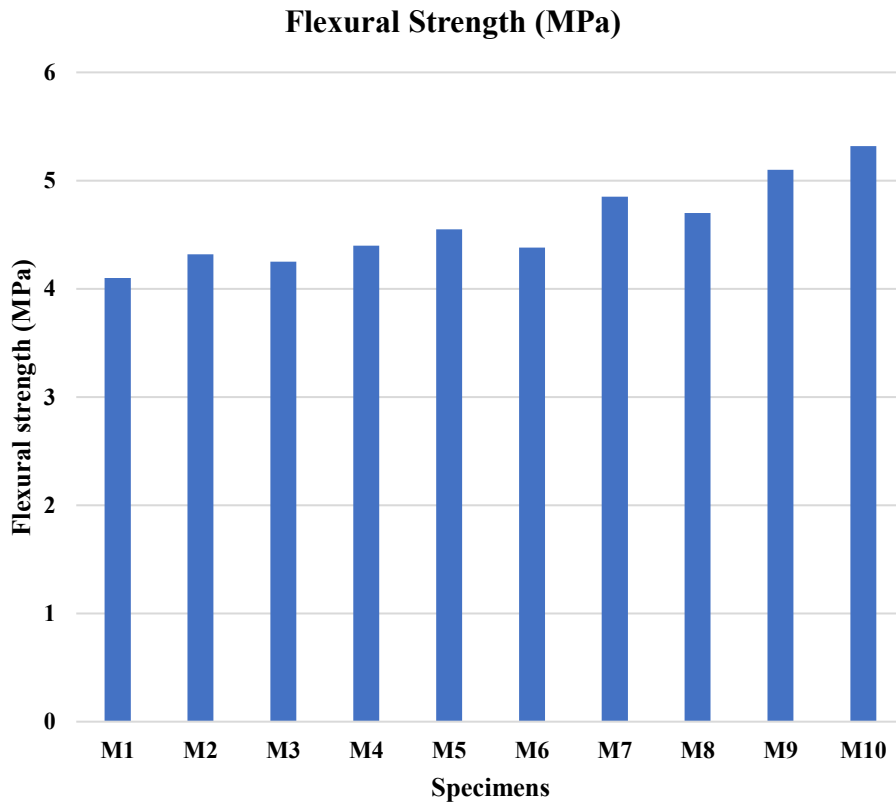


Figure 13 Flexural Strength test results

3.5 Density

The control mix had a density of 2430 kg/m³, which is normal for regular concrete, according to density tests on concrete mixes. Density was impacted by the inclusion of SCMs; fly ash caused a minor drop at higher replacement levels, whereas GGBS maintained a similar specific gravity and improved packing density. Consistent densities were produced using ternary mixes; the best mix (M10) achieved 2445 kg/m³ and better compaction. Density was slightly raised by adding banana fiber, and higher dosages had no negative effects. Density and compressive strength were discovered to be positively correlated, with higher density often leading to higher strength because of superior microstructural compactness and fewer voids. These density measurements are consistent with compressive performance and durability studies.

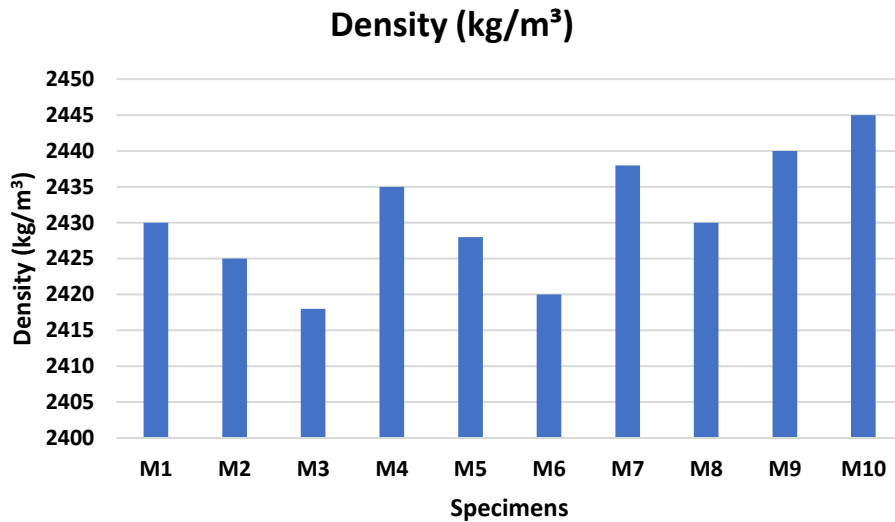


Figure 14 Density results

3.6 Water absorption test

Using water absorption experiments, the study evaluated the durability of M25 grade concrete mixes containing fly ash, GGBS, and banana fiber. With water absorption values ranging from 3.8% for the control mix to 2.7% for the M10 mix, the results showed that increased SCM concentration and fiber addition produced a denser microstructure, boosting resistance to moisture and chemical assaults. Because of improved particle packing and pozzolanic reactions that produced C-S-H gel, the addition of 10% and 20% fly ash dramatically decreased water absorption; however, the effect dropped at higher levels. Because of their latent hydraulic capabilities, GGBS blends demonstrated significantly lower water absorption than those containing only fly ash. Mixes containing both fly ash and GGBS performed better than others; M10 reduced water absorption by 29%.



Figure 15 Water Absorption test

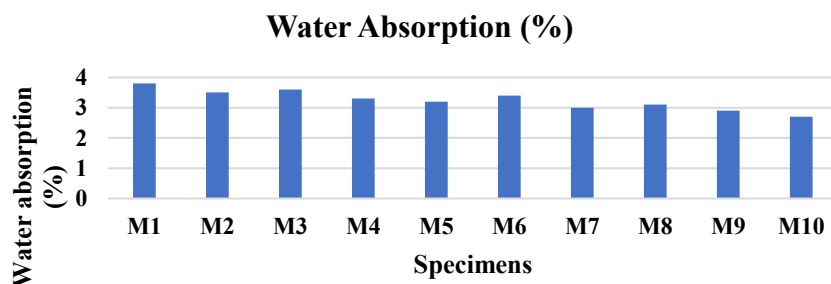


Figure 16 Water Absorption test outcomes

3.7 RCPT test

The RCPT is used to assess concrete's resistance to chloride ion penetration; lower charges signify greater resistance. SCMs improved chloride resistance by lowering the charge passed, according to the test; a control mix registered 3200 Coulombs, indicating "Moderate" permeability. Fly ash was used to improve pore structure and reduce calcium hydroxide content, which boosted resistivity. Even better results were obtained with GGBS, which dramatically decreased pore connectivity and changed blends from moderate to low permeability. The "Very Low" permeability of ternary mixtures,

especially M10 with 1500 Coulombs, was 53% lower than the control. By reducing fracture breadth and fortifying the mixture, banana fiber also improved chloride resistance. Overall, the combination of SCMs and fiber showed significant improvements in microstructure and enhanced resistance to salt-induced corrosion.



Figure 17 RCPT test
Table 4 RCPT test results

Specimen ID	Charge Passed (Coulombs)	Chloride Permeability
M1	3200	Moderate
M2	2800	Moderate
M3	2600	Moderate
M4	2400	Low
M5	2100	Low
M6	2300	Low
M7	1900	Low
M8	2000	Low
M9	1700	Very Low
M10	1500	Very Low

4. Conclusion

The study examines the effects of adding banana fiber to M25 grade concrete and substituting cement with SCMs such as fly ash and GGBS. A 20% replacement was found to maintain an acceptable slump for structural usage without the need for further admixtures, even if workability reduced with greater replacement percentages. By improving the microstructure, the addition of SCMs greatly improved the mechanical characteristics of concrete, increasing its tensile, compressive, and flexural strengths. After 28 days, the optimized mix containing 15% fly ash, 15% GGBS, and 0.5% banana fiber reached a compressive strength of 39.4 MPa, a 21% improvement because of improved particle packing and pore refinement, compared to the control mix's 32.4 MPa.

With a split tensile strength of 3.82 MPa, which was 34% greater than that of regular concrete, banana fiber successfully bridged microcracks and assisted in controlling crack development. This new concrete is appropriate for applications needing improved performance under bending strains because its flexural strength also increased by around 30%, reaching 5.32 MPa. Because of the fiber's microstructural densification and decreased microcracking, water absorption dropped by 29%, demonstrating increased durability and resilience against environmental deterioration.

The ternary blended fiber-reinforced mixes showed low to very low permeability in comparison to the intermediate permeability of the control mix, which reduced chloride ion penetration by about 53%, according to the Rapid Chloride Permeability Test (RCPT). All mixes had densities within conventional ranges, however ternary blends had somewhat higher densities because of their better internal structure.

All things considered, combining Fly Ash and GGBS produced better outcomes in terms of mechanical strength, durability, and sustainable practices, reducing the usage of cement and associated carbon emissions. For structural applications in difficult conditions, the ideal blend of 15% fly ash, 15% GGBS, and 5% banana fiber was shown to improve crack resistance.

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