



EVALUATION OF THE STRUCTURAL AND DURABILITY CHARACTERISTICS OF CONCRETE WITH VARIOUS FIBER REINFORCEMENTS.

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Abstract: The study covers the variants of fiber reinforcements applied on the structure for the analysis of durability & strength of the concrete. Increasing requirements for raw materials and high-performance concrete in modern construction motivates the exploration of raw reinforcement. The results are stronger in rebound, even under the threat of tension, thermal stress. It is majorly focused on the result of the concrete consisting different types of fiber like natural fiber (bamboo), steel fiber, glass fiber, synthetic fibers, polypropylene fiber etc, which shows the outcomes in reference of mechanical properties, which also helps in determining compressive strength, tensile strength & flexural strength. In today's time, the biggest attention is given to cracks and leakage in the construction line. And to reduce this, in earlier times, rice husk was used which was mixed with soil to void all these problems. This thesis explains how we can use different types of fiber in different place of construction. Also, the durability of fiber reinforced concrete fiber reinforcement concrete is weighed through resistance to water absorption, Scanning Electron Microscopy, Static Analysis, abrasion and many more. The results through experiments point out each fiber type to refine the overall performance of concrete, with particular focusing on the capability to improve the failures that is crack control, long term serviceability and toughness, Durability. Fiber reinforcement plays multifaceted role in structure to enhance load carrying capacity and durability. Scanning Electron Microscopy gives surface morphology, and details about phase distribution. The results give important understanding of maximization of fiber reinforcement in concrete mixtures for a wide scope of structural & environmental uses. This thesis also helps us understand the properties of different types of fiber and their physical and characteristic these help us to Development of Hybrid Fiber Systems, Optimization of Fiber Dosage and Distribution. The range allows for the selection of fiber and its types & dosages to achieve desired performance in concrete for specific engineering Solutions.

Keywords: Fiber reinforcements Concrete, Compressive Strength, Workability, Dataset, Fiber Types (e.g., Bamboo, Steel, Glass, Synthetic, Polypropylene), Durability, Scanning Electron Microscopy, Mechanical properties, Construction Material Optimization.

1. Introduction

1.1 General

Concrete is one of the most widely used construction materials globally due to its high compressive strength, versatility, and durability, serving as the foundation of modern infrastructure such as roads, bridges, dams, and buildings. Despite these advantages, conventional concrete has inherent drawbacks that limit its long-term performance, the most critical being its relatively low tensile strength and brittle nature, which often result in cracking under stress, thermal fluctuations, or environmental exposure. Such cracks compromise structural integrity, reduce service life, and lead to costly maintenance or even failure under extreme loading. The imbalance arises from concrete's composition, as the mixture of cement, aggregates, and water provides excellent compressive resistance but poor tensile capacity. To overcome these deficiencies, fiber-reinforced concrete (FRC) has been developed, incorporating discrete fibers uniformly within the matrix to act as crack arrestors, bridge developing fissures, and distribute applied loads more evenly. The role of fiber reinforcement is crucial, as it enhances tensile and flexural strength, improves toughness and impact resistance, increases fatigue performance, and provides greater ductility, enabling concrete to withstand higher levels of deformation before failure. Steel fibers, for instance, significantly improve post-crack behavior and toughness, making them effective in pavements, slabs, and tunnel linings. Glass fibers contribute to improved durability against chemical attack and weathering, while polypropylene fibers effectively control shrinkage cracking during curing and provide resistance to freeze-thaw cycles. Natural fibers such as bamboo, hemp, and jute are gaining attention for their sustainability and eco-friendly potential, though their effectiveness depends on treatment to reduce water absorption and improve

bonding. Basalt fibers, a relatively new addition, exhibit high tensile strength and excellent chemical resistance, making them suitable for aggressive environments.

The sustainability dimension further strengthens the case for FRC, with natural fibers offering eco-friendly alternatives and hybrid fiber systems combining the strengths of different types to provide balanced improvements in strength, durability, and sustainability. In summary, FRC represents a significant advancement in construction materials technology by overcoming the fundamental shortcomings of plain concrete. Steel and synthetic fibers offer superior strength and toughness, glass and basalt fibers provide enhanced chemical durability, polypropylene fibers address shrinkage and freeze–thaw resistance, and natural fibers contribute to sustainable construction practices. When used effectively, fiber reinforcement transforms concrete into a more durable, ductile, and resilient material capable of meeting the complex demands of modern infrastructure while promoting long-term sustainability.

1.2 Role of Fiber Reinforcement in concrete

Fiber reinforcement is one of the most effective techniques for overcoming the deficiencies of plain concrete. By incorporating short, discrete fibers uniformly within the cementitious matrix, FRC provides improved crack resistance and enhanced structural performance. Fibers bridge developing cracks, distribute stresses more evenly, and delay crack propagation, thereby improving the post-crack behavior of the material. The inclusion of fibers also increases toughness, impact resistance, and fatigue performance, ensuring that the concrete can withstand dynamic and cyclic loads. Fibers serve not only to resist cracking but also to enhance the material's ductility, allowing concrete members to undergo greater deformation before failure.

This property is particularly valuable in structures exposed to seismic loading, industrial impacts, and heavy traffic. Furthermore, fiber addition reduces shrinkage cracking, especially during curing, which often weakens conventional concrete. The type and dosage of fibers play a crucial role in determining these benefits. Commonly used fibers include steel, glass, polypropylene, carbon, and natural fibers such as bamboo, hemp, and jute. Each type contributes differently to the mechanical and durability characteristics of FRC, making fiber selection application-specific.

1.3 Structural Properties of Fiber-Reinforced Concrete

The structural benefits of FRC are wide-ranging: increased tensile and flexural capacity, improved toughness and impact resistance, reduced shrinkage and thermal cracking, enhanced fatigue resistance, and extended service life through decreased permeability and crack propagation. The structural improvements from fiber addition can be summarized as follows:

- The structural benefits of FRC are wide-ranging: increased tensile and flexural capacity, improved toughness and impact resistance, reduced shrinkage and thermal cracking, enhanced fatigue resistance, and extended service life through decreased permeability and crack propagation.
- Increased Tensile Strength: Fibers reduce the likelihood of cracking under tensile loads by distributing stresses across the concrete matrix.
- Enhanced Flexural Strength: Fiber-reinforced beams and slabs show greater resistance to bending stresses, improving load-carrying capacity.
- Improved Toughness and Impact Resistance: High-strength fibers such as steel increase energy absorption, making concrete suitable for heavy-duty applications.
- Better Crack Resistance: Fibers act as bridges across cracks, improving post-crack behavior and service life.
- Reduced Shrinkage and Thermal Cracking: Polypropylene and synthetic fibers help prevent drying shrinkage cracks and reduce temperature-induced stresses.
- Higher Fatigue Resistance: FRC is more resilient under repeated loading cycles, enhancing durability in bridges, industrial floors, and pavements.
- Extended Service Life: Reduced permeability and enhanced crack resistance improve durability and minimize long-term maintenance.

1.4 Durability Properties of Fiber-Reinforced Concrete

Durability is equally vital in concrete performance, as structures are continuously exposed to aggressive environmental conditions such as chloride ingress, sulfate attack, freeze–thaw cycles, abrasion, and thermal variations. Fiber reinforcement reduces permeability and hinders the ingress of harmful agents, thereby minimizing reinforcement corrosion and improving durability. Polypropylene fibers perform exceptionally well in mitigating freeze–thaw damage, glass and basalt fibers enhance chemical durability, and steel and synthetic fibers improve abrasion and impact resistance, making FRC highly suitable for industrial floors, pavements, and other heavy-duty applications.

The durability advantages of FRC include:

- Resistance to Freeze–Thaw Damage: Polypropylene fibers improve resistance by controlling cracking and minimizing moisture-induced expansion during cycles.
- Chemical Resistance: Glass and basalt fibers reduce the penetration of aggressive chemicals, thereby protecting embedded steel reinforcement from corrosion.
- Lower Permeability: Fibers reduce porosity and water ingress, enhancing impermeability and preventing long-term degradation.
- Improved Abrasion and Impact Resistance: Steel and synthetic fibers make concrete more suitable for high-traffic and industrial applications.

1.5 Types of Fiber Used in Concrete

A wide variety of fibers are employed depending on structural and environmental requirements :

- Steel Fibers: Provide excellent strength, crack resistance, and toughness, making them suitable for pavements, precast elements, and structural members.
- Polypropylene Fibers: Prevent shrinkage cracks during curing and improve freeze–thaw durability.
- Glass Fibers: Offer enhanced chemical resistance, reduced permeability, and improved surface finish, especially in aggressive environments.
- Natural Fibers: Bamboo, jute, and hemp are sustainable alternatives that provide moderate improvements in crack resistance while contributing to eco-friendly construction.
- Basalt Fibers: Emerging as a promising option due to their high tensile strength and resistance to chemical and thermal deterioration.



Fig- Steel Fiber



Fig- Propylene Fiber



Fig- Glass Fiber



Fig- Bamboo Fiber



Fig- Synthetic Fiber

1.6 Particular Goals

To investigate the effects of different fiber kinds on concrete's structural properties.

- In order to improve crack resistance and general stability, this purpose focuses on investigating how various fiber materials—such as steel, glass, synthetic, and natural fibers—affect concrete's compressive, tensile, and flexural strengths. to assess fiber-reinforced concrete's long-term durability.
- By taking into account elements including resistance to fatigue, shrinkage, chemical attack, freeze-thaw cycles, and exposure to the environment, the study seeks to assess how fiber-reinforced concrete performs over an extended service life, guaranteeing improved structural longevity, lower maintenance costs, and improved performance. to investigate how fiber content and distribution affect concrete performance .
- This goal examines how workability, strength, fracture toughness, energy absorption, and the overall mechanical performance of fiber-reinforced concrete for both structural and non-structural applications are impacted by uniform distribution, appropriate orientation, and the ideal dosage of fibers.
- To look into the fiber-reinforced concrete's microstructural behavior. Through microstructural techniques like SEM, the research aims to examine fiber-matrix interfacial bonding, crack bridging, pore structure, and vacuum formation, emphasizing how these tiny interactions control the macroscopic strength and durability of concrete.
- Focuses on investigating how various fiber materials—such as steel, glass, synthetic, and natural fibers—affect concrete's compressive, tensile, and flexural strengths.

2. Literature Review

A thorough review of the literature on bamboo mesh-reinforced glass fiber reinforced concrete (GFRC) wall panels with advanced mesh variations has been conducted. This review covers important topics like advanced mesh configurations, sustainability considerations, the function of bamboo as reinforcement, and the basic characteristics of GFRC.

1. Md. Shahjalal, Kamrul Islam, Farnaz Batool, Mohammad Tiznobaik, F.M. Zahid Hossain (2023): Using fiber reinforcement, crumb rubber, and recycled aggregates, this paper "Fiber-reinforced recycled aggregate concrete with crumb rubber: 2023" examines the performance of concrete. The goal of the project is to improve mechanical qualities including strength, hardness, and durability as well as sustainability. The concrete exhibits enhanced ductility, impact resistance, and crack resistance due to the addition of recycled materials and crumb rubber. According to experimental findings, this composite material shows promise as an eco-friendly building material, providing a workable way to cut waste without sacrificing functionality. The study emphasizes the possibility of employing waste -derived materials in sustainable construction methods.
2. A.R. Shaterian, A. S. Ghasemi, et al. (2022): When it comes to structural applications, the publication "Performance of Hybrid Fiber-Reinforced Concrete in Structural Applications" examines how well HFRC works. In order to improve concrete's mechanical qualities, such as its durability, flexural strength, and compressive strength, the study looks at the combination of steel and polymer fibers. The results show that employing hybrid fibers enhances concrete's performance more than using only one kind of fiber. With improved toughness, crack resistance, and overall structural reliability, HFRC may prove to be a promising building material for demanding engineering applications, according to the research.

3. N. S. Mahapatra, L. G. Khan, et al. (2022): A study titled "Evaluation of the Impact of Steel, Synthetic, and Natural Fiber Reinforcements on Concrete Under Freeze-Thaw Cycles" investigates how various fiber reinforcements affect the longevity of concrete under freeze-thaw dynamics. The study examines how well steel, synthetic, and natural fibers can improve the performance of concrete subjected to freeze-thaw cycles. The results show that fiber reinforcing greatly increases concrete's ability to withstand freeze-thaw-induced cracking and degradation. Natural fibers also demonstrated encouraging results, providing a sustainable alternative for improving concrete performance against external damage, making it more appropriate for use in challenging construction sites. Of the fibers examined, steel fibers offered the greatest improvement in durability.
4. M. A. P. Daniel, M. F. Ribeiro, et al. (2021): This study examines how polypropylene fibers affect the durability, flexural strength, and compressive strength of concrete. According to the study, polypropylene fibers greatly increase concrete's resilience to freeze-thaw and shrinkage cracking. Increased toughness and durability are further benefits of the fibers, particularly in settings with sharp temperature swings. According to the study's findings, adding polypropylene fibers to concrete can effectively increase its performance and longevity, especially in applications subjected to freeze-thaw cycles and cold climates.
5. M. R. N. K. R. Srinivasan, S. P. Ramachandran, et al. (2019): This research investigates hybrid fiber-reinforced concrete (HFRC) using a combination of synthetic and steel fibers. The study reveals that HFRC enhances the mechanical properties, including compressive and flexural strength, as well as crack resistance. Additionally, the durability of concrete is improved, particularly in terms of resistance to freeze-thaw cycles, chemical attacks, and abrasion. The findings suggest that combining synthetic and steel fibers creates a more resilient concrete that performs better under environmental stresses and load-bearing conditions, increasing the material's lifespan and overall performance.
6. S. H. Yadav, M. K. Agarwal, et al. (2021): This study examines the use of steel and synthetic fibers in hybrid fiber-reinforced concrete (HFRC). According to the study, HFRC improves the mechanical qualities, such as crack resistance and compressive and flexural strength. Concrete's durability is also increased, especially with regard to its ability to withstand abrasion, chemical attacks, and freeze-thaw cycles. According to the results, adding steel and synthetic fibers to concrete makes it more resilient to load-bearing and environmental pressures, extending the material's lifespan and improving its overall performance.
7. A. K. Gupta, N. R. Gajera, et al. (2020): The combined impact of steel and polypropylene fibers on the mechanical characteristics, freeze-thaw resistance, and water absorption of concrete is examined in this study. According to the research, the hybrid combination of these fibers improves the overall durability and crack resistance of the concrete. While polypropylene fibers lessen shrinkage and increase freeze-thaw resistance, steel fibers increase tensile strength and toughness. According to the study's findings, this hybrid fiber mix produces concrete that is stronger and more resilient, making it appropriate for uses where adverse environmental conditions are present.
8. J. L. O'Connell, J. A. D. Watson, et al. (2020): This essay examines the application of carbon fiber-reinforced concrete (CFRC) and how it affects the longevity of concrete. The research focuses on how carbon fibers improve concrete's ability to withstand chemical attacks, particularly exposure to harsh substances like sulfates and chlorides. Concrete's durability and structural integrity are enhanced by CFRC, which increases its resilience in challenging conditions. The advantages of CFRC in boosting strength, decreasing permeability, and preventing cracking are covered in the study. The authors stress how CFRC can increase the longevity of concrete structures, making it a useful component for long-term infrastructure projects subjected to harsh environments.
9. K. S. K. Sahu, V. K. Gupta, et al. (2020): This study investigates how steel and polypropylene fibers affect the durability of concrete in harsh environmental settings, especially when exposed to sulfate and chloride ions. Both fiber kinds considerably increase the concrete's resilience to deterioration brought on by these harsh environmental conditions, according to the research. Polypropylene fibers lessen the chance of shrinking and breaking, while steel fibers help to increase the tensile strength and resistance to cracking. When these fibers are combined, the concrete's overall durability is increased, which makes it more appropriate for use in regions like industrial or coastal areas that are subject to rapid deterioration.
10. G. K. Kumar, R. S. Deshmukh, et al. (2020): This study examines how the performance of the material is affected when jute and bamboo fibers are used to reinforce concrete. According to the study, adding jute and bamboo fibers to concrete improves its tensile strength, resistance to cracking, and general longevity. Because the natural fibers are renewable and biodegradable, they also have positive environmental effects. Additionally, by lessening the environmental impact of concrete, these fibers improve its sustainability. The study emphasizes how jute and bamboo can be used to make concrete more environmentally friendly.
11. Prashanth, Subbaya, Nithin and Sachhidananda (2017): In essence, axial particles placed in appropriate matrices make up fiber-reinforced composites. The main goal of fiber-reinforced composites is to produce materials with a higher elastic modulus and greater strength. However, the applied load transiting from matrix to fibers, the interfacial bonding between fiber and matrix, their relative alignment, and the type of fiber influencing the overall behaviors of the material all have an impact on the strength elevation. However, depending on the final uses, the fiber alignment can be either random or continuous. The requirements of the application also influence the selection of the fiber reinforcement and its fitting matrix. The introduction of composite technology in recent years has resulted in the creation of various fiber-reinforced composite systems using various production techniques to achieve enhanced material behaviors. In this article, we compare several types of synthetic fibers and discuss their possible use as reinforcements, with a focus on carbon fibers.

3. Materials and Method

3.1 General

Concrete must be durable for modern building, yet under stress, its tensile weakness leads to fissures. Adding fibers (steel, glass, carbon, synthetic, natural) improves strength, toughness, crack resistance, and durability, enhancing performance against thermal, chemical, and environmental stresses while extending concrete's service life. The ability of fiber-reinforced

concrete (FRC) to improve concrete's durability and mechanical qualities (compressive, tensile, and flexural strength) has drawn attention. This field of study examines how different fiber types affect the behavior of concrete, and their impact on structural performance, its resistance to cracking, and its long-term endurance.

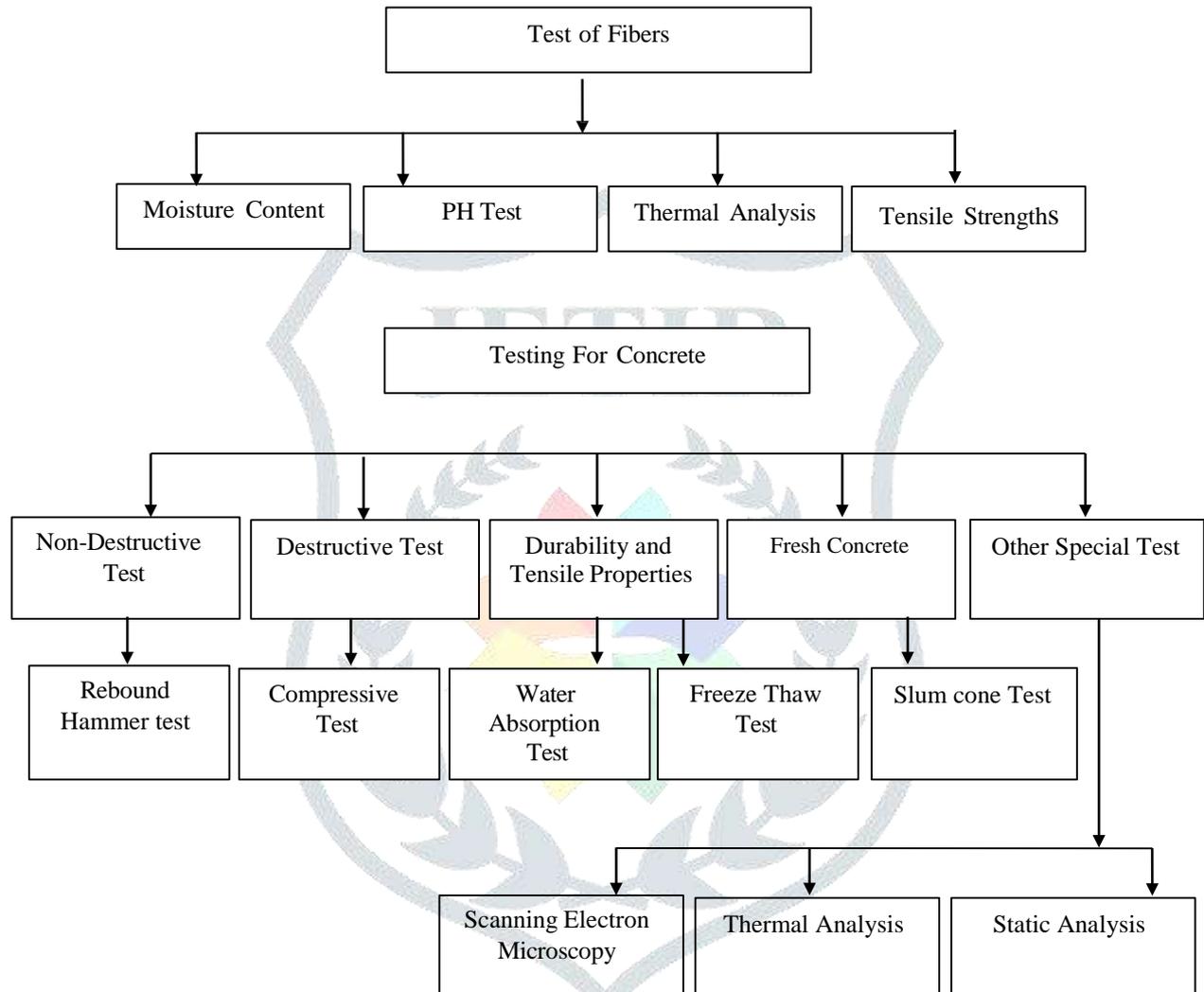


Fig. 3.1 Flow chart of Methodology

3.2 Materials

Steel Fiber - Fiber-reinforced concrete (FRC) has garnered interest due to its capacity to enhance the mechanical properties (compressive, tensile, and bending strength) and durability of concrete. This area of research looks at how various fiber types influence the physical properties of concrete, as well as how they affect the material's long-term durability, ability to resist cracking, and structural performance.

Polypropylene Fiber - Polypropylene fibers are commonly used as reinforcement in concrete due to their low cost, low weight, and chemical inertness. Especially in the early stages of concrete curing, their primary purpose is to more evenly distribute stresses throughout the matrix, hence preventing shrinkage cracking. Additionally, these fibers reduce the likelihood of surface degradation and scaling in cold climates by enhancing the concrete's resistance to freeze-thaw cycles.

Glass Fiber - Glass fibers are frequently added to concrete to increase its dimensional stability, durability, and resistance to harsh weather. They work especially well in maritime and coastal settings when concrete is subjected to harsh substances like sulfates and chlorides. By distributing stress evenly throughout the matrix, glass fibers' exceptional tensile strength and resistance to corrosion greatly increase the service life of structures by preventing microcracks from forming and spreading.

Synthetic Fiber - Because of their strength, durability, and adaptability, synthetic fibers—which are made using petrochemical processes—are extensively utilized in sectors such as construction. Fibers like polypropylene, nylon, polyester, and aramid greatly improve tensile strength, impact resistance, and fracture management when used as reinforcement in concrete. They are perfect for demanding applications including industrial floors, roads, tunnels, and pavements subjected to severe loads and hard circumstances because of their resilience to moisture, chemicals, and biological deterioration.

Bamboo Fiber - In sustainable building, natural fibers like hemp, jute, and bamboo are becoming more and more well-liked as environmentally beneficial substitutes for synthetic fibers. In addition to increasing the durability of concrete, these locally accessible, renewable, and biodegradable ingredients also lessen the overall carbon footprint associated with building. Bamboo fibers stand out among them because of their high tensile strength, lightweight nature, and good bond with the cement matrix.

Characteristic of fibers

Fibers in concrete with fiber reinforcement (FRC) improve performance by increasing toughness, strength, and durability. The aspect ratio, or length-to-diameter, is a crucial component that affects crack bridging but can also make a material less workable if it is too high. While polypropylene, which has a lower modulus, successfully reduces shrinkage and freeze-thaw

damage, steel and basalt fibers, which have strong tensile strength and elastic modulus, greatly improve tensile and flexural resistance.

Table 3.1 Different characteristics of fibers

Fiber Type	Strength	Elasticity	Durability	Workability	Unique Feature
Steel	Very High	High	Moderate	Reduces	Excellent load-carrying & crack resistance
Polypropylene	Moderate	Low	Excellent	Good	Shrinkage and fire resistance
Glass	High	Medium	Good (if AR)	Fair	Surface finish and aesthetic applications
Bamboo	Moderate	Moderate	Moderate (needs treatment)	Reduces	Eco-friendly and low-cost
Synthetic	Varies	Varies	Excellent	Good	Tailored for specific performance needs

Table 3.2 Technical Characteristics of Fibers Used in Fiber-Reinforced Concrete

Property	Steel Fiber	Polypropylene Fiber	Glass Fiber	Bamboo Fiber	Synthetic Fibers
Tensile Strength	1000–2300 MPa	350–700 MPa	1000–1700 MPa (AR Glass)	100–400 MPa (varies with treatment)	300–3000+ MPa (Carbon > Polyester > Nylon)
Modulus of Elasticity (E-Modulus)	200 GPa	3–5 GPa	70–80 GPa	10–30 GPa (varies)	Nylon: 3 GPa, Polyester: 5 GPa, Carbon: ~230–600 GPa
Fiber Length	30–60 mm	6–20 mm	6–38 mm	25–100 mm	Varies: 6–60 mm
Aspect Ratio (L/d)	40–100	100–150	30–60	50–150	30–100
Density (kg/m ³)	7850	910	2600	600–700	Nylon: ~1150, Polyester: ~1380, Carbon: ~1750
Water Absorption	None	Very Low	Low	High	Very Low
Bond with Cement Matrix	Excellent (especially hooked-end fibers)	Moderate to low (improved with surface texture)	Moderate (needs AR treatment)	Poor (unless treated chemically)	Varies (good with surface treatment)
Workability Impact on Concrete	Reduces workability; may require superplasticizer	Minor reduction	Slight reduction	Reduces (due to fiber stiffness and absorption)	Minimal (depends on type and dosage)
Durability in Concrete	Can corrode unless coated	Excellent chemical &	Good (AR glass),	Poor if untreated (decays, swells)	Excellent – inert to chemicals, moisture, and

		alkali resistance	otherwise low in alkaline		UV
Crack Control Efficiency	High	Good (for plastic shrinkage)	Moderate (surface crack resistance)	Good (short-term)	Excellent (especially carbon & aramid)
Cost (Relative)	Moderate to High	Low	Moderate	Low	Varies
Environmental Impact	High (non-renewable, energy)	Moderate (petrochemical origin)	Moderate	Low (biodegradable)	Varies (some are recyclable biodegradable)

3.3 Methodology & Sample Preparation

Fiber-reinforced concrete (FRC) is prepared through a systematic process involving material selection, mix preparation, casting, curing, and testing. Ordinary Portland cement, fine and coarse aggregates, potable water, and fibers such as steel, polypropylene, glass, basalt, or natural fibers (bamboo, jute) are used. Fibers are added gradually in the range of 0.5–5% by weight of cement to avoid clumping. After mixing dry ingredients, water or additives are introduced for workability. The fresh mix is placed into molds, cured in water for 7, 14, or 28 days, and then tested for compressive, flexural, and split tensile strength. Durability tests and SEM analysis further assess fiber–matrix bonding.

In the mix design, 5% of fibers are incorporated into M20 concrete by adjusting the standard ratios. A typical proportion following IS 10262:2019 is 1:2:3.6 (cement: sand: coarse aggregate) with 0.55 water–cement ratio plus 5% fiber. This ensures homogeneous distribution, improved strength, durability, and sustainability.

3.4 Testing of cement

The performance of fiber-reinforced concrete (FRC) is assessed through parameters such as compressive strength, flexural strength, toughness, and durability. These properties reflect how fibers influence the overall structural and long-term behavior of concrete.

pH – pH is a measure of acidity or alkalinity on a scale of 0 to 14, with 7 being neutral. Values above 7 are alkaline, while those below 7 are acidic. In concrete, pH is important because it affects chemical reactions, durability, and the stability of materials.

Moisture Content – Moisture content is the amount of water present in a material, usually expressed as a percentage of total weight. It is an essential property in materials like soil, wood, and cement composites, as it influences strength, workability, and durability. A common method of measurement is oven drying, where a sample is weighed before and after drying.

Thermal Analysis of Fibers – This evaluates how fibers behave under varying temperatures, providing insights into thermal stability and structure. Such analysis is vital for applications in composites, textiles, and insulation materials.

Tensile Strength – The tensile strength of FRC measures its resistance to direct tension and bending stresses. Factors such as fiber type, size, aspect ratio, volume percentage, distribution, and bonding with the cement matrix strongly affect performance. Excess fiber or poor mixing can reduce workability, highlighting the need for a balanced mix design.

3.5 Mix Design

Choosing the right fibers based on the particular needs of the concrete application is the first step. Different fiber types, lengths, doses, and combinations are used in the design of concrete mixtures. The control sample for comparison is a typical concrete mix devoid of fibers.

Table 3.3 Material properties with different fibers and Different Compositions

Mix Type	Cement (kg)	Water (kg)	Sand (kg)	Coarse Agg. (kg)	Fiber Type	Fiber Qty (kg)	W/C Ratio	SP Dosage (% of Cement)
Steel FRC	320	176	650	1160	Steel	16	0.55	1.0
Polypropylene FRC	320	176	655	1165	PP	6	0.55	1.2
Nylon FRC	320	176	655	1165	Nylon	10	0.55	1.2
Synthetic FRC	320	176	655	1165	Polyester/Carbon	11	0.55	1.0
Bamboo FRC	320	176	645	1155	Bamboo (treated)	7	0.55	1.5

3.6 Testing of concrete

Rebound Hammer- Concrete's surface hardness, which is connected with its compressive strength, can be measured with a non-destructive test tool called the rebound hammer, sometimes referred to as the Richter hammer. When the spring-loaded mechanism of the hammer hits the concrete's surface, the hammer's rebound is measured. The rebound value increases with concrete hardness.

Compressive Strength- Testing device that is universal is used to determine the compressive strength of concrete sample. This assesses the material's resistance to axial loads. Strength in Flexure: The material's ability to resist bending and cracking is evaluated using bending test specimens.

Permeability and Absorption of Water- To determine how fibers affect the concrete's porosity and resistance to water penetration—two factors that directly impact durability—tests including water absorption and permeability assessments are carried out.

Cycles of Freeze-Thaw- A specimen is repeatedly frozen and thawed in a controlled laboratory setting to assess its resistance to freeze-thaw damage, a crucial characteristic for concrete used in cold and variable climates. By simulating actual environmental stressors, these cycles enable researchers to evaluate the concrete's long-term performance against internal microcracking, surface scaling, and loss of mechanical strength as well as its durability and crack resistance.

3.7 Scanning Electron Microscopy (SEM)

Scanning Electron Microscopy (SEM) is a powerful tool for analyzing the microstructure of concrete, providing detailed images of the cement matrix and fiber–matrix interface. SEM analysis of fiber-reinforced concrete showed a denser, more compact microstructure than plain concrete, with reduced porosity and improved packing of hydration products. Stronger fiber–matrix bonding enhanced stress transfer and crack resistance. In specimens with synthetic fibers, the interfacial transition zone (ITZ) appeared more refined and uniform, with fewer micro-voids and continuous hydration compounds. These observations confirm that fibers improve durability, crack control, and overall mechanical performance of concrete.

3.8 Static Analysis

The effects of fiber type, length, and dosage on concrete’s mechanical and durability performance were evaluated through statistical analysis. Experimental data from strength and durability tests were analyzed using regression modeling, correlation studies, and ANOVA to determine significance and variable impact. This approach quantified fiber characteristics and helped identify optimal combinations, ensuring improved performance and application -specific suitability of fiber-reinforced concrete.

4. Result and Discussion

4.1 General

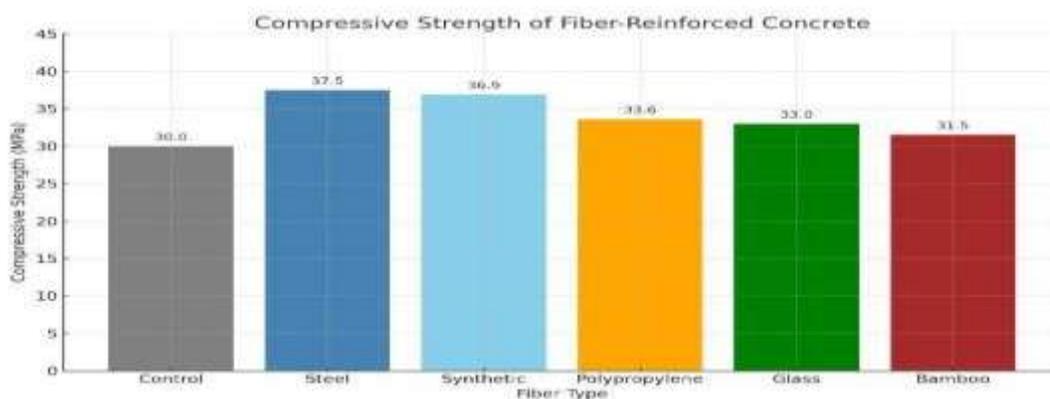
The findings of testing concrete samples reinforced with five different types of fibers—steel, polypropylene, glass, bamboo, and synthetic—at different doses (1%, 3%, and 5%) are shown and interpreted in this section. Physical (pH, moisture content, thermal characteristics), microstructural (SEM), mechanical (compressive, flexural, rebound hammer), and durability (water absorption, freeze-thaw, and chemical resistance) tests were conducted. Every test assisted in determining how the fiber type and dosage affected the performance of concrete.

Compressive Test-

The highest compressive strength was found in concrete samples that contained steel and synthetic fibers, particularly at dosages of 3% and 5%. Strength was up to 20–25% higher with steel fibers than with the control combination. Because of their superior matrix bonding and greater tensile capacity, synthetic fibers displayed comparable patterns. Fibers made of glass and polypropylene demonstrated modest gains (up to 10–15%).

Table 4.1 Features of Compressive Strength for Various Fiber-Reinforced Concretes

Fiber Type	Compressive Strength (MPa)	% Increase over Control	Rank	Remarks
Steel	37.5	25.0%	1	Highest strength, excellent reinforcement
Synthetic	36.9	23.0%	2	Comparable to steel, good alternative
Polypropylene	33.6	12.0%	3	Moderate improvement, enhances crack resistance
Glass	33.0	10.0%	4	Improves durability and reduces shrinkage cracking
Bamboo	31.5	5.0%	5	Sustainable option, lower strength but eco-friendly



Graph 4.1 Compressive Strength of FRC

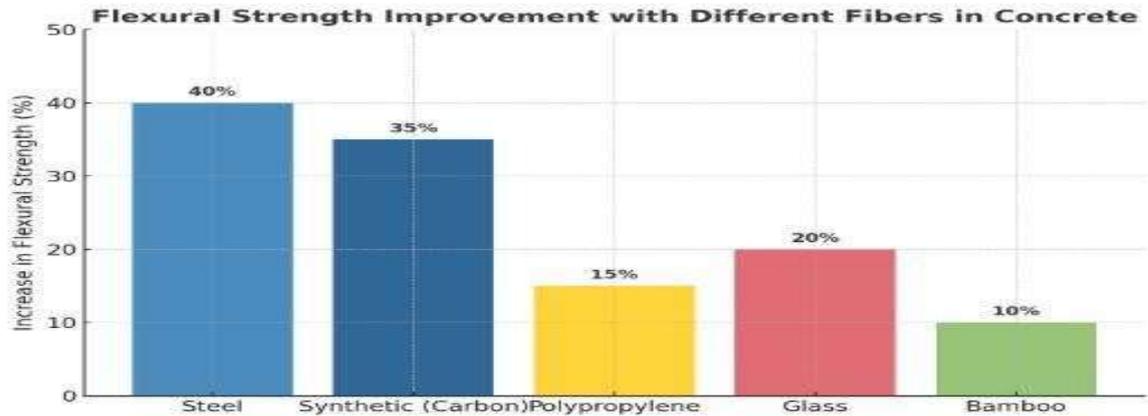
Flexural Strength

Steel and carbon-based synthetic fibers greatly increased flexural strength, indicating better crack bridging properties. Flexural capacity was found to have increased by 30–40% in samples B3 (5% steel) and A3 (5% synthetic). Early-age crack resistance was improved by polypropylene fibers, while long-term flexural gains were less pronounced. Although glass fibers increased resistance to surface tensile stresses, they were brittle after the initial crack.

Table 4.2 Features of Flexure Strength for Various Fiber-Reinforced Concretes

Fiber Type	Flexural Strength Improvement (%)	Rank	Remarks
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Steel	40%	1	Maximum flexural improvement; highly effective in resisting bending & cracking.
Synthetic (Carbon)	35%	2	Excellent improvement, lightweight, corrosion resistant, suitable for high-performance structures.
Glass	20%	3	Moderate improvement, enhances durability, often used in façade panels and thin concrete elements.
Polypropylene	15%	4	Provides crack control, economical, improves toughness but lower flexural gain compared to steel/synthetic.
Bamboo	10%	5	Eco-friendly option, sustainable reinforcement, suitable for low-cost rural applications.



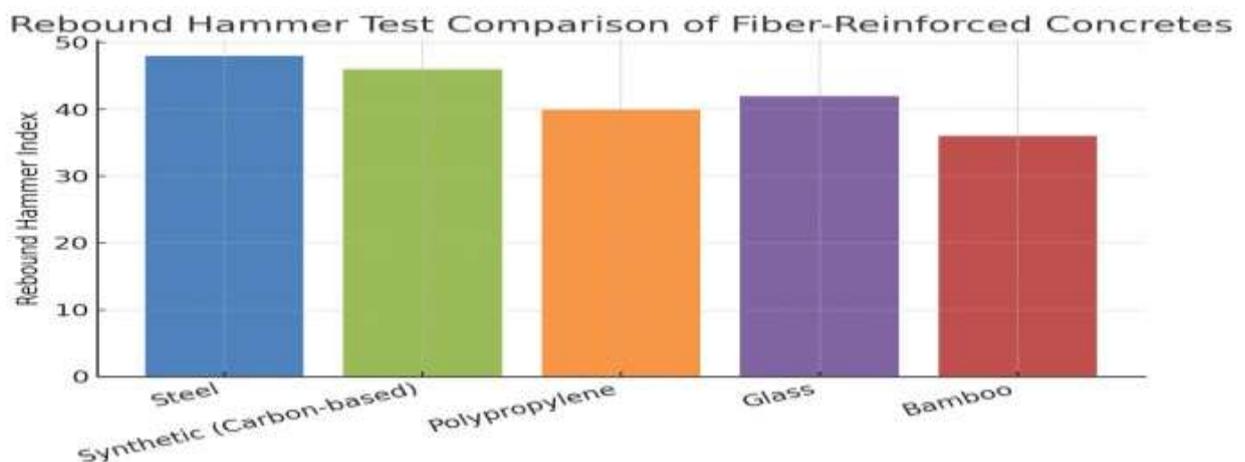
Graph 4.2 Flexure Strength of FRC

Rebound Hammer Test-

Compressive test findings showed a strong correlation with rebound values. Superior surface hardness was indicated by the highest rebound index, which was shown by steel fiber blends. The rebound values of glass and synthetic fibers were likewise high. The rebound index was lowest for bamboo fiber mixtures because of internal cavities and unequal fiber dispersion, notably at 5%.

Table 4.3 Features of Rebound Hammer test for Various Fiber-Reinforced Concretes

Fiber Type	Rebound Hammer Index	Rank	Remarks
Steel	48	1	Highest surface hardness and strength retention; ideal for heavy-duty structural applications.
Synthetic (Carbon)	46	2	Very good performance; corrosion-resistant and durable.
Glass	42	3	Moderate hardness; suitable for non-structural and decorative elements.
Polypropylene	40	4	Provides fair performance; effective for crack resistance but lower hardness.
Bamboo	36	5	Lowest hardness; eco-friendly but less durable under high loads.



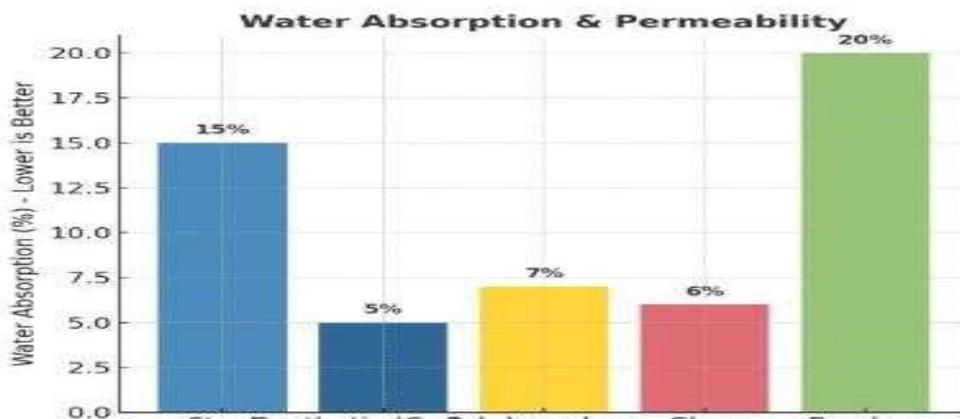
Graph 4.3 Rebound Hammer graph of FRC

Durability Performance
Water Absorption and Permeability

Alkali-resistant fibers worked well in blends of glass, polypropylene, and synthetic fibers. Due to their hygroscopic nature, untreated bamboo fibers increased absorption, which affected total porosity.

Table 4.4 Features of Water Absorption test for Various Fiber-Reinforced Concretes

Fiber Type	Water Absorption (%)	Rank	Remarks
Synthetic (Carbon)	5%	1	Lowest absorption → excellent durability, highly resistant to moisture ingress.
Glass	6%	2	Very good resistance to water penetration; suitable for durable structures.
Polypropylene	7%	3	Moderate absorption; good balance of cost and performance.
Steel	15%	4	Higher absorption may increase risk of corrosion in wet conditions.
Bamboo	20%	5	Highest absorption → vulnerable to moisture, but eco-friendly option for non-critical applications.



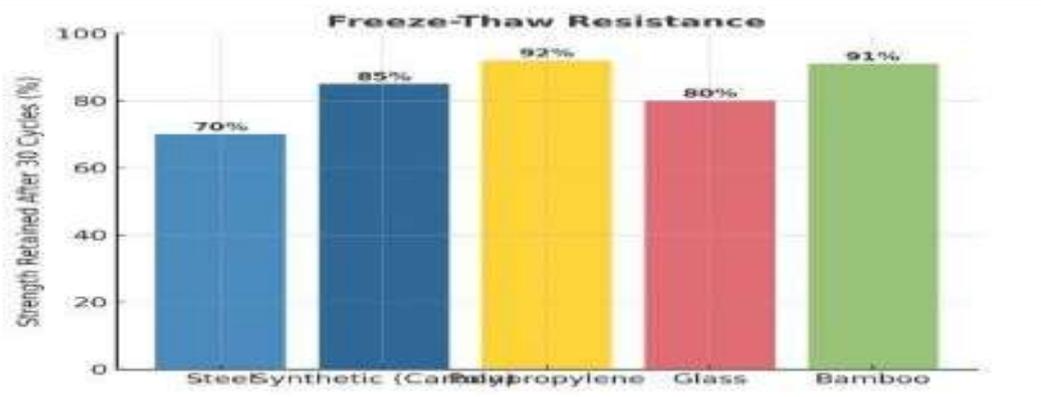
Graph 4.4 Water Absorption graph of FRC

Freeze-Thaw Resistance

Synthetic degradation is modest after 30 cycles because of the spread of microcracks at the fiber tips. Concretes made of bamboo and polypropylene fibers demonstrated exceptional resistance, maintaining over 90% of their strength. Without chemical treatment, steel fiber mixtures exhibited significant degradation, which reduced their suitability for cold climates .

Table 4.5 Features of Freez Thaw test for Various Fiber-Reinforced Concretes

Fiber Type	Strength Retained After 30 Cycles (%)	Rank	Remarks
Polypropylene	92%	1	Best freeze–thaw resistance; highly durable in cold climates.
Bamboo	91%	2	Excellent performance despite higher permeability; eco-friendly alternative.
Synthetic (Carbon)	85%	3	Very good durability; lightweight and non-corrosive.
Glass	80%	4	Moderate resistance; acceptable for non-severe environments.
Steel	70%	5	Lowest durability under freeze–thaw cycles; prone to cracking and corrosion.



Graph 4.5 Freez Thaw graph of FRC

4.3 Microstructural Analysis (SEM) –Significant variations in the fiber-matrix interaction were found by SEM analysis-

- Synthetic and steel fibers: denser matrix, restricted voids, and strong binding at interface. At the micro level, synthetic fibers improved hydration and fracture bridging.

- Glass fibers: Moderate bonding was seen on the smooth surface. In certain photos, fiber pull-out was seen.
- Polypropylene fibers: Had a moderate bond but were evenly distributed, decreasing microcracks in the plastic stage.
- Bamboo fibers: Unless treated, a rough surface, weak bond, and micro-voids surrounding the interface were visible.

4.3.1 Steel Fibers-

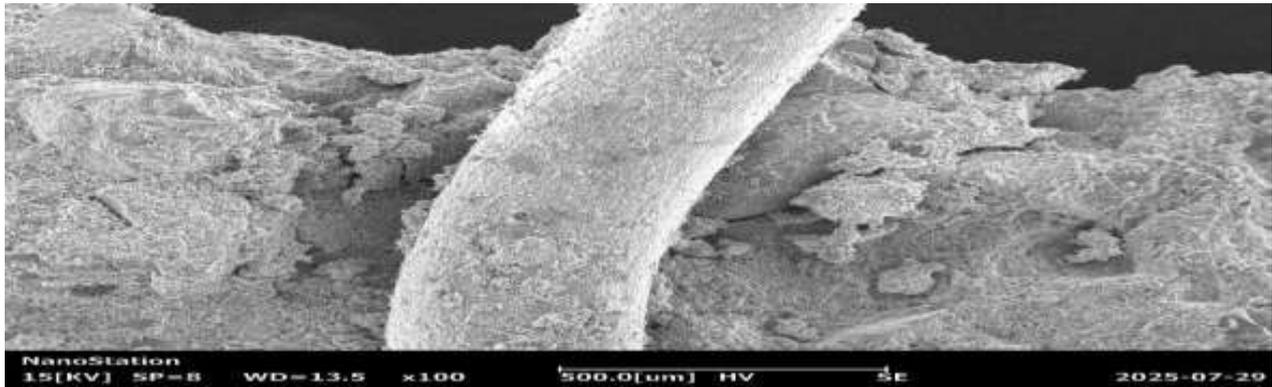


Fig. 4.1 SEM of Steel Fiber Concrete(a)

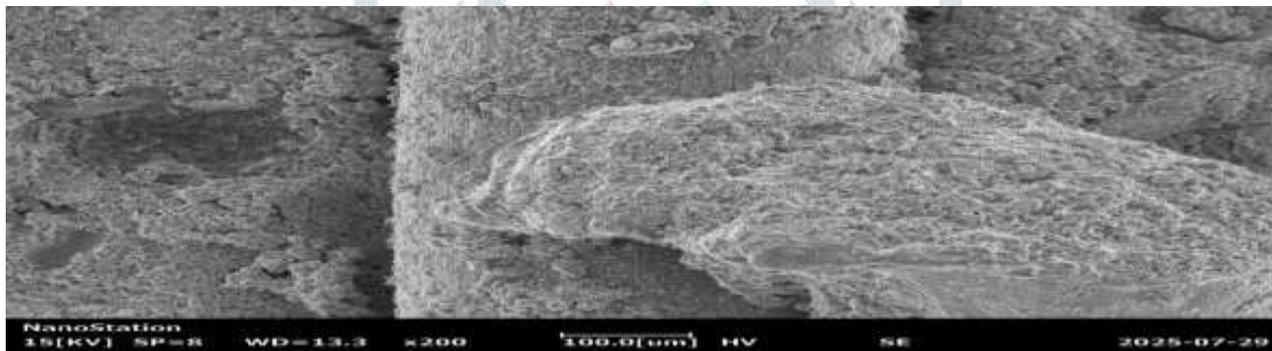


Fig. 4.2 SEM of Steel Fiber Concrete (b)

4.3.2 Synthetic Fibers-

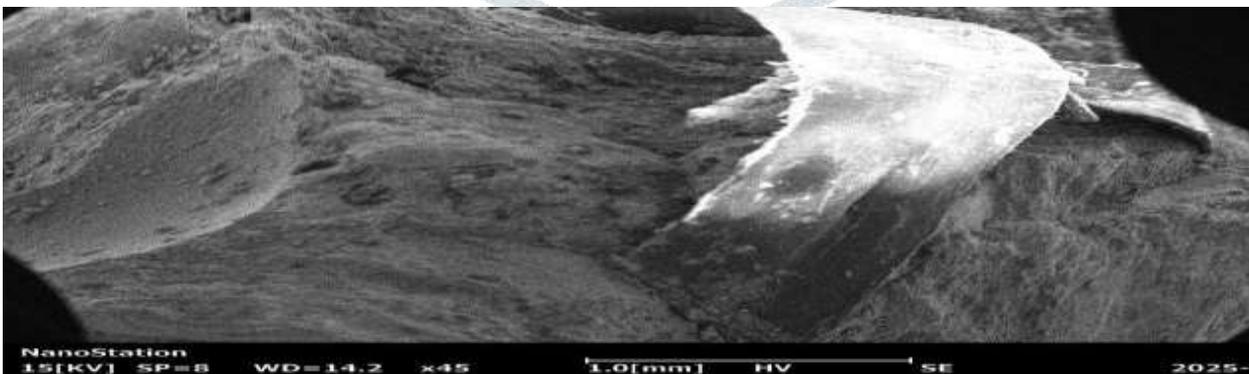


Fig. 4.3 SEM of Synthetic Fiber Concrete(a)

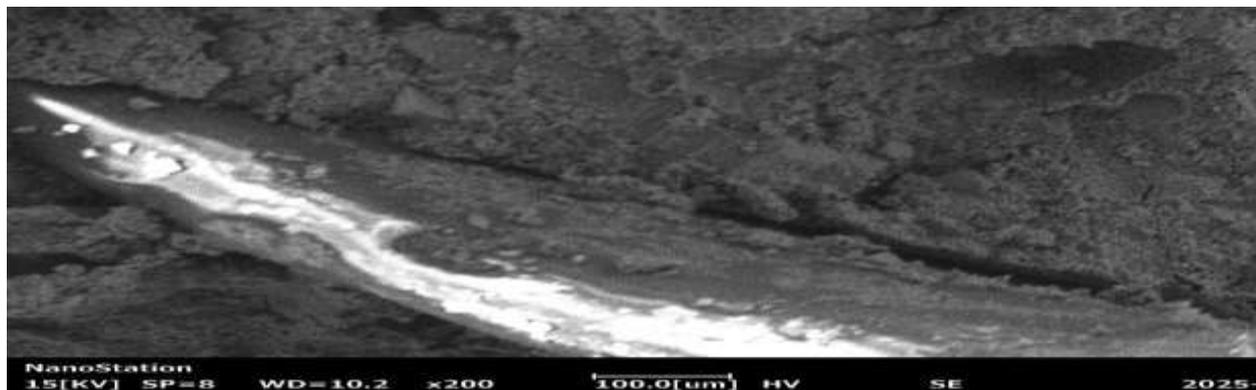


Fig. 4.4 SEM of Synthetic Fiber Concrete(b)

4.3.3 Glass Fiber

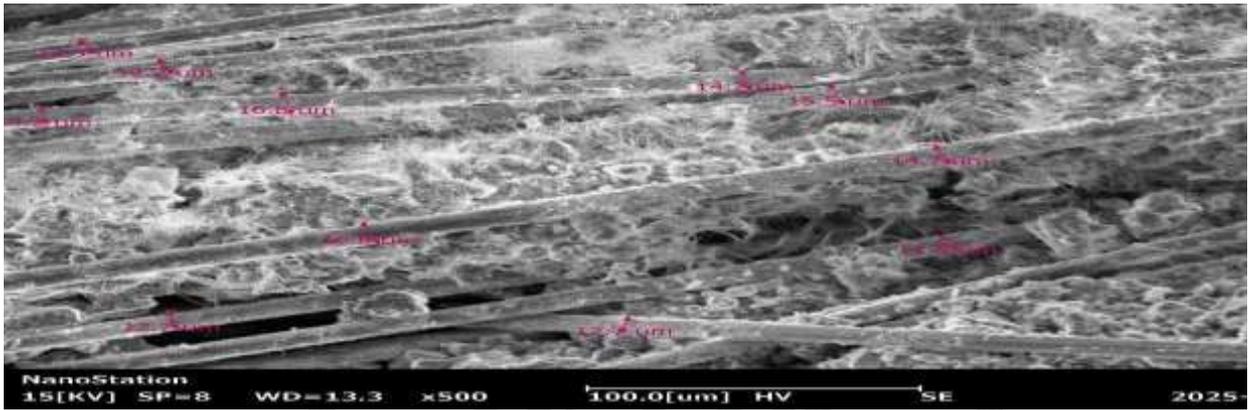


Fig. 4.7 SEM of Glass Fiber Concrete(a)

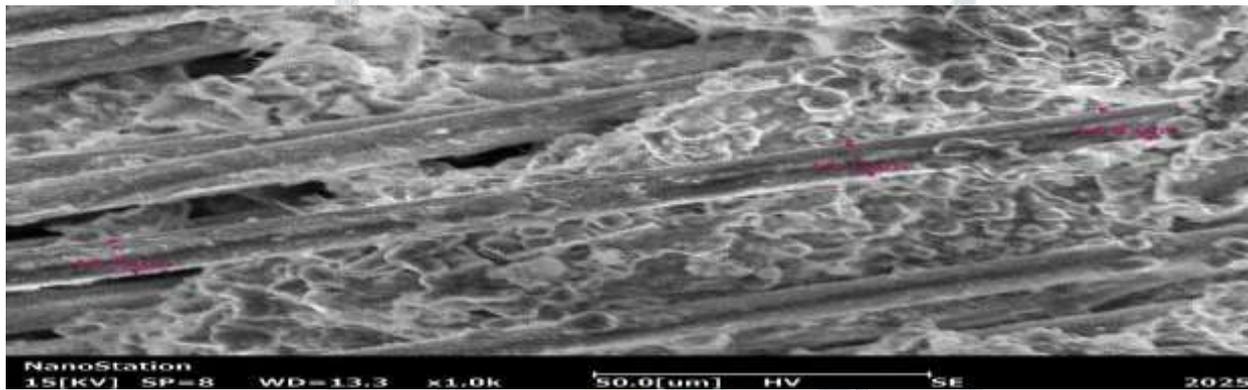


Fig. 4.8 SEM of Glass Fiber Concrete(b)

4.3.4 Bamboo Fiber

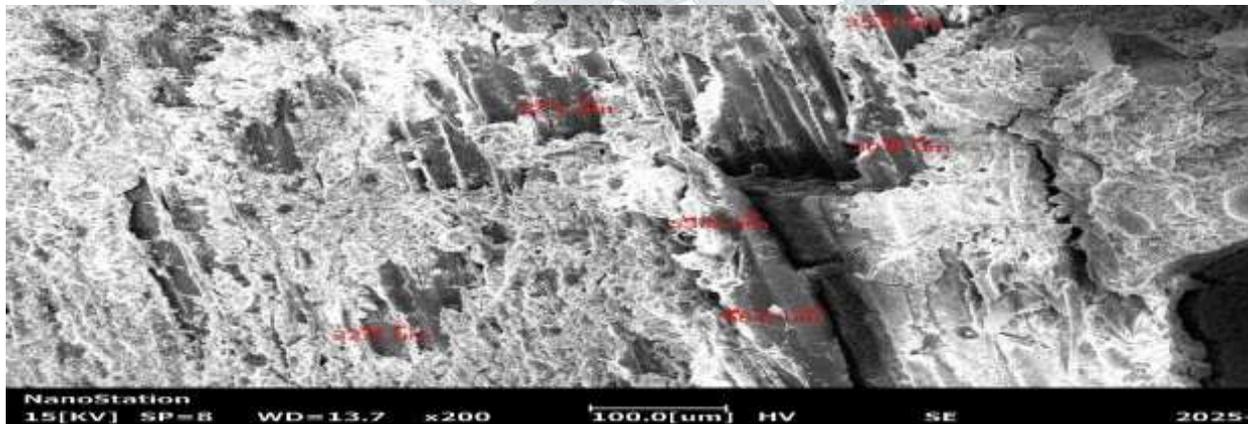


Fig. 4.9 SEM of Bamboo Fiber Concrete(a)

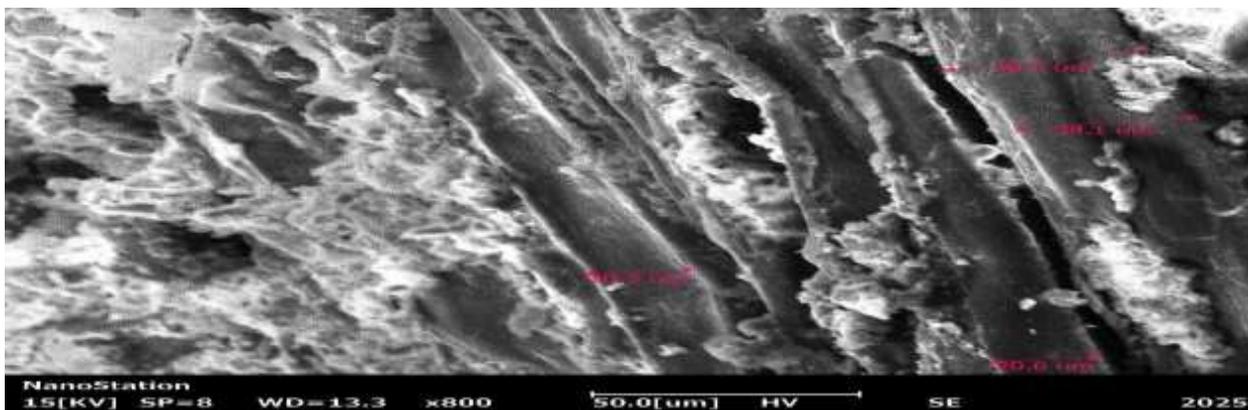


Fig. 4.10 SEM of Bamboo Fiber Concrete(b)

4.3.5 Synthetic Fiber

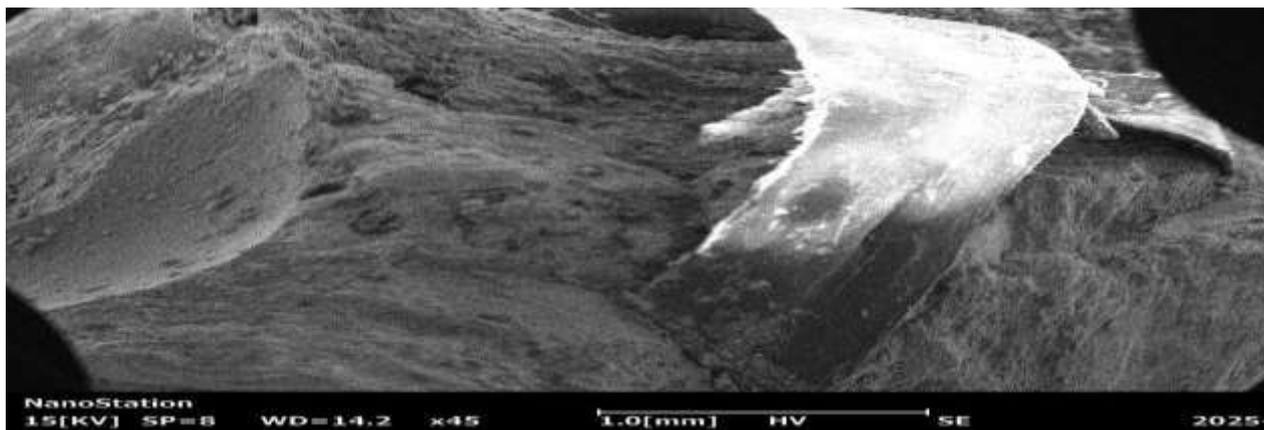


Fig. 4.3 SEM of Synthetic Fiber Concrete(a)

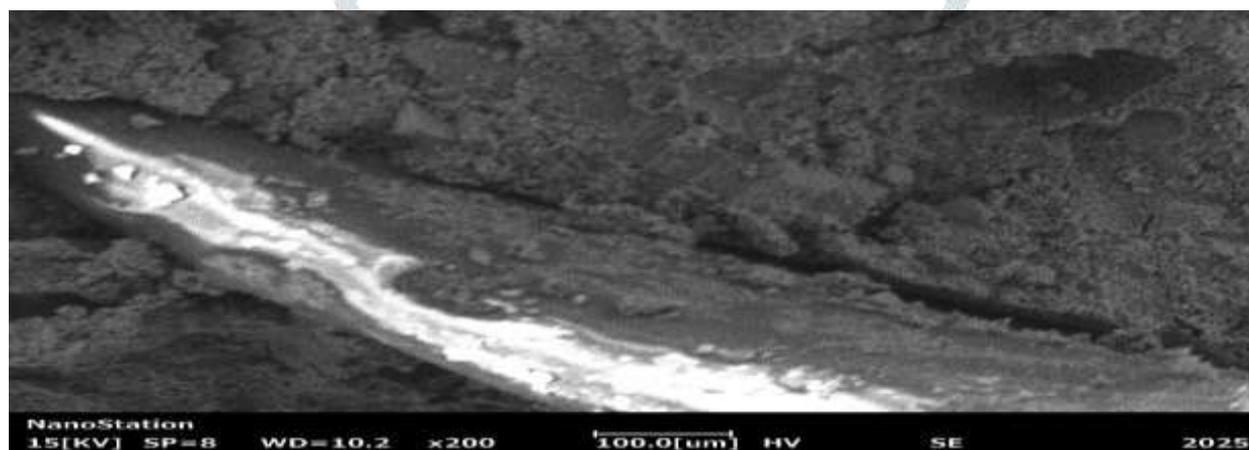


Fig. 4.4 SEM of Synthetic Fiber Concrete(b)

5. Conclusion and Future scope

5.1 Conclusion

- **Improvement of Concrete Properties:** Fibers including steel, glass, carbon, and polypropylene are incorporated into concrete to greatly improve its mechanical qualities, such as increased impact toughness, improved crack resistance, and increased tensile strength. reduction of shrinkage and decreased cracking possibility. These enhancements help to increase the concrete's overall durability, which prolongs its service life. Performance under hostile environmental circumstances.
- **Fiber-reinforced concrete (FRC),** which offers improved abrasion resistance and corrosion resistance, performs better in harsh conditions. Because of these characteristics, FRC can be used in applications that are subjected to challenging environmental conditions.
- **Synergistic Interaction with Conventional Reinforcement:** Fibre integration with traditional reinforcement, such as steel rebar, produces a synergistic effect that enhances structural performance, lengthens the service life of concrete structures, and creates a more balanced and effective composite material. decreased long-term maintenance expenses, which help make FRC applications more financially viable.
- **The impact of distribution, dosage, and fiber type:** The type of fiber used (such as steel, glass, carbon, or polypropylene), the dosage or volume percentage of fibers integrated, and other parameters all affect how successful fiber -reinforced concrete is. When choosing fibers for certain applications, it is important to take into account the different performance advantages that each type of fiber offers.
- **Effect on Cost and Workability Considerations:** The workability of the fresh concrete mix may be affected, possibly necessitating changes to the mix design, even if the addition of fibers delivers significant performance advantages.
- **The total cost of the material,** which could go up with better or more specialized fibers As a result, maximizing the concrete's mechanical and durability qualities, controlling expenses, and guaranteeing the material's suitability for the intended use all require careful balance.

5.2 Future Scope

- **Optimize Fiber Dosage:** Conduct research to find the best fiber locations and amounts for optimal strength at the lowest possible cost or workability problems.
- **Hybrid Fiber Systems:** Investigate mixing fibers (such as steel and polypropylene) to improve durability and mechanical qualities in a range of circumstances.
- **Eco-Friendly Fibers:** For structural advantages and sustainability, use renewable or recycled fibers.

- **Long-Term Durability:** Perform in-depth research on the performance of fibers exposed to actual environmental conditions.
- **Smart Fibers:** Create responsive or self-healing fibers to increase longevity and lower maintenance.
- **Cost & Scaling:** Evaluate methodologies and cost-effectiveness for large-scale, low-cost applications.

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