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Performance Evaluation of Fiber-Reinforced M30 Concrete Using Steel and E-Glass Fibers

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Abstract

Fiber-reinforced concrete (FRC), a high-performance material which has the potential of surmounting the limitations posed by regular concrete in brittleness and cracking properties, was recently innovated. By integrating discontinuous Fibers into the concrete matrix, FRC significantly improves toughness, post-cracking behavior, and overall durability. Fibers of different materials may improve different properties; for example, steel fibers increase energy absorption, flexural resistance, and tensile strength; E-glass fibers help with chemical resistance, fracture management, and decreased permeability. Additionally, their fibers aid in microstructural refinement and agent reduction in concrete. When applied in the right amounts, they provide a realistic and effective way to prolong the useful life of concrete buildings that are subjected to mechanical stress and severe weather. The study explores the enhancement of M30-grade concrete through the incorporation of steel and E-glass fibers to improve both mechanical strength and durability. By integrating fibers in varying volume fractions from 0.25% to 2.00%, the research identifies the optimal dosage range of 1.00% to 1.25% for maximum performance without compromising workability. Steel fibers significantly boosted compressive strength (up to 75.0 MPa from 65.0 MPa), split tensile strength (5.8 MPa from 4.5 MPa), and flexural strength (8.2 MPa from 6.1 MPa), while also increasing the modulus of elasticity to 30.5 GPa. E-glass fibers offered moderate strength improvements and excelled in chemical and corrosion resistance, reducing strength loss in acid environments to 10.4% compared to 15.6% in the control mix. Although higher fiber contents caused issues like poor dispersion and reduced flowability, these were managed using superplasticizers. Overall, fiber-reinforced concrete demonstrated considerable potential for use in structurally demanding and exposure-prone applications such as pavements, marine structures, and water-retaining systems. Its long-term durability and reduced maintenance make it a sustainable solution in modern construction.

Keywords: Fiber Reinforcement Concrete, Steel Fiber, E-Glass Fiber, High-Performance Fiber Reinforced Cementitious Composites, Compressive Strength, Split Tensile Strength, Flexural Strength, Modulus of Elasticity, Durability, Sustainable Construction

1. Introduction

Infra-structural systems play a predominant role in present day societal needs ranging from residential to communications and onto space travel. With urbanization gaining prominence, areas for living and transportation get more and more concentrated around metropolitan cities bringing in the need for infra-structural facilities to be denser with high-rise buildings and layered transportation forms like flyovers becomes a necessity. With this development, detrimental effects like CO2 emission and environmental decay also tends to increase bringing in a need for eco-friendly and sustainable system [1]. Sustainable building systems directly impact the betterment of livelihood conditions of communities through the choice of materials, proper design, construction and maintenance techniques. The most widely used material for construction is concrete and approximately 20 billion tons of concrete are produced every year all over the world, which is indicative of its versatility [2]. It is important that the energy and emissions related to these needs be controlled and monitored in the concrete arresting further damage to the environment. This has prompted engineers to use industrial wastes such as slag, fly ash, steel and other material Fibers, tire wastes and other chemical or organic waste products so that the resulting concrete, reduces the adverse effects on environment. Initial attempts to make concrete better was improving its tensile strength compared to its compressive strength. Addition of steel and other types of reinforcements in the tension zone and chemical additives for quick setting and other crack inhibition effects were done, but these proved to be only partly successful with high tensile steel and stainless steel for anti-corrosion, dominating the studies. With ferro cement becoming prominent, Fibers entered in making concrete with improved tensile strength due to a greater number of insignificant cracks. [3] This paved the way for a new discipline of Fiber reinforced concrete followed by addition of plasticizers enabling Ready Mix Concrete (RMC). The present thesis focusses on the studies of concrete with fly ash and different Fibers, mostly as waste materials, in an attempt to make a better concrete with an emphasis on mixing, workability/durability issues, material strength studies and structural performance of beam components and also the effect on energy and emission aspects. [4] Fiber reinforced concretes have emerged into a subject of major interest among researchers and civil engineers. Recent developments led to the appearance of high-performance Fiber reinforced cementitious composites (HPFRCC), a material which possesses the ability to generate multiple cracks due to its increase of resistance after cracking. In this dissertation the focus is on conventional SFRC, a material which presents softening response under uniaxial tension (reduction of resistance after cracking). Although the latter may be seen as the weaker gender of fiber reinforced concretes, there are several reasons that justify the interest on this material [5]. The crack-bridging capacity provided by fibers improves durability and, because minimum covers are no longer required in SFRC elements, their thicknesses can be significantly reduced. Fiber reinforcement can replace, partially or totally, conventional reinforcement (rebars or welded mesh), thus providing freedom to create daring aesthetics with curved shapes. Fibers can also be very effective on structures subjected to concentrated static or dynamic loads, applied at various places and in various directions. Despite the softening behavior observed under uniaxial tension, fibers subjected to bending stresses may provide hardening type behavior (increasing of load-carrying capacity after cracking) due to its ability to redistribute stresses within the cross-section. This research focuses on enhancing the mechanical and durability properties of M30 grade concrete through the incorporation of steel Fibers and E-glass Fibers at varying volume fractions ranging from 0.25% to 2.00%. The study includes the design of a standard M30 concrete mix, followed by systematic incorporation of Fibers to assess their influence on key mechanical properties such as compressive strength, split tensile strength, flexural strength, and modulus of elasticity at curing ages of 7, 14, and 28 days. [6] The scope further extends to evaluating the durability performance of Fiber-reinforced concrete under aggressive environmental conditions. Durability parameters include acid resistance, sulphate attack, chloride resistance, and water absorption, measured through strength loss and weight loss after chemical exposure. The study also includes an analysis of workability, mix homogeneity, and the impact of Fiber content on concrete porosity and permeability. [7] This research is limited to laboratory-scale testing using controlled materials and conditions but offers practical insights applicable to real-world construction scenarios such as pavements, marine structures, industrial flooring, water-retaining structures, and precast elements. The study identifies the optimal Fiber dosage that provides maximum benefit without compromising the mix's workability or uniformity. The findings are intended to support the development of cost-effective, durable, and sustainable Fiber-reinforced concrete suitable for modern construction demands.

2. Objectives of Research

The main goal of this research is to examine the cumulative impact of steel Fibers and E-glass Fibers on M30 grade concrete's mechanical and durability performance. The study aims to identify the optimum dosage of Fiber that ensures maximum strength and durability without negatively impacting workability or homogeneity of the mix. The research also aims to ascertain the comparative performance of both Fiber types under normal and aggressive environmental exposure. Specific research objectives are as follow:

- To analyse the influence of different dosages of steel Fiber and E-glass Fiber (0.25%–2.00% by volume) on the compressive strength of M30 concrete at various curing ages 7, 14, and 28 days.
- To examine the influence of Fiber reinforcement on the flexural strength and split tensile strength of concrete, and study the way the Fibers enhance the overall tensile performance and resistance to cracking.
- To analyse the impact of incorporation of steel Fiber and E-glass Fiber on the modulus of elasticity of M30 concrete and study how the Fiber content affects the stiffness and deformation properties of the concrete under load.
- To quantify the water absorption of various concrete mixes with varying Fiber contents and assess its impact on permeability, porosity, and long-term durability.
- To delineate the most suitable percentage of steel Fiber and E-glass Fiber singularly or combined that yields the optimum balance between mechanical performance and practical workability for structural use.

3. Scope of The Research

It is under investigation in the study because of its mechanical and durability properties of M30 grade concrete augmented with steel and E-glass fibers at varying volume fractions of 0.25 to 2.00 per cent. Some of the significant mechanical parameters which are determined in this study are compressive strength, split tensile strength, flexural strength and modulus of elasticity at 7,14 and 28 days of curing. The process begins with the formulation of a typical M30 concrete mix and is followed by the methodical addition of fibers. Testing the resilience of fiber-reinforced concrete in harsh environments is also within the purview of this investigation. Durability parameters include acid resistance, sulphate attack, chloride resistance, and water absorption, measured through strength loss and weight loss after chemical exposure. The study also includes an analysis of workability, mix homogeneity, and the impact of Fiber content on concrete porosity and permeability. This research is limited to laboratory-scale testing using controlled materials and conditions but offers practical insights applicable to real-world construction scenarios such as pavements, marine structures, industrial flooring, water-retaining structures, and precast elements. The study identifies the optimal Fiber dosage that provides maximum benefit without compromising the mix's workability or uniformity. Research like this could help pave the way for more eco-friendly, long-lasting fiber-reinforced concrete that can keep up with the demands of today's building projects.

4. Literature Review

More and Subramanian [2023] The physical, mechanical, and durability properties of different natural and synthetic fiber-infused concrete were examined. The results show that water absorption of natural fiber is more than that of artificial fiber. However, the artificial fiber is more efficient compared to natural fiber. Under acidic exposure, the weight loss of fiber concrete is higher, but the weight loss is less under an alkaline environment. Split tensile strength, ductility, and post-cracking resistance were improved [8].

Amir et al. [2022] have analyzed flexural capacity by static analysis. The result shows that compared to conventional shear reinforcement, spiral reinforcement increases flexural performance. The crack pattern, punching shear, and load displacement of slap with steel Fiber were analyzed. [9]

Ahmed et al. [2022] have reviewed the mechanical, physical, and durability of coir fiber concrete. The flexural strength of concrete with coir fiber is significantly improved compared to compressive strength, as mentioned by previous researchers. It mentioned that the optimum dosage of coir fiber was 2 to 3%. [10]

Effiong and Ede [2022] have reviewed the techniques of Near Surface Mounted (NSM) and Externally Bonded (EB) for strengthening reinforced concrete beams by using natural fiber polymer composite. In the NSM technique, synthetic fiber shows failure by flexural rupture, pull-out driven by intermediate crack, and end pull-out. However, these failure mechanisms of the concrete beam with natural fiber reinforcement still need to be explored fully. Burst cycles and break solidity of sisal fiber need to be studied mentioned that more data is needed for the design and performance of steel fiber concrete. [11]

Islam et al. [2021] have investigated the mechanical and rheological properties of concrete with nylon, iron, and coir as steel, synthetic and natural fiber. The result shows that the addition of fiber causes a significant reduction in the workability of concrete. Among these three fibers, steel fiber shows a significant increment of compressive and flexural strength. However, these three Fibers show lower compressive strength at the beginning (3-7 days) days due to weak bonding of materials. From the study, it was evident that the addition of fiber enhanced the ductility after the crack and the capacity of energy absorption. [12]

Niu et al. [2020] carried out studies on the mechanical and durability properties of basalt Fiber reinforced coral aggregate concrete. The basalt Fiber quantities used in the work were 0%, 0.05%, 0.1%, 0.15% and 0.2%. whereas the length and diameter of the Fiber were 18mm and 15mm respectively. Water-binder ratio used was 0.3. This work investigated the effect of basalt Fiber (BF) on mechanical properties, chloride content carried in coral aggregates, and water absorption of Coral Aggregate Concrete. The results indicated that with the increase in Fiber content, the mechanical properties and water absorption resistance of basalt Fiber reinforced coral aggregate concrete found to be following an increasing trend and then a decreasing trend. Further, 0.05% Basalt Fiber yielded the highest improved effect on water absorption resistance and mechanical properties at 28 days. Further, 0.05% Basalt Fiber yielded the highest improved effect on water absorption resistance and mechanical properties at 28 days. [13]

Facconi and Minelli [2020] studied the behaviour of lightly reinforced Fiber reinforced concrete panels which were under pure shear loading. In this work, Steel Fibers were added in low amount of 20 kg/m3 and 50 kg/m3 and two steel reinforcements of 0.21% and 0.74% were respectively selected to simulate lightly reinforced elements. By comparing shear strength of panels with the highest conventional reinforcement ratio, significant differences were observed for crack width values higher than 0.5 mm. By considering the crack width range 0.5 to 0.8 mm, the shear strength of the panels containing 0.25% and 0.63% of Fibers was respectively 25% and 40% higher than that achieved by reference specimen. [14]

Sadrmomtazi et al. [2020] studied residual strength and microstructure of Fiber reinforced concrete, with self-compacting property, exposed to high temperatures. This work has evaluated the effect of fly ash, steel Fibers, and curing conditions on mechanical properties, fracture energy, and microstructure of the self-compacting concrete at high temperatures. This work also evaluated physical-mechanical properties, including compressive strength, splitting tensile strength, flexural strength, fracture energy, ultrasonic pulse velocity, weight loss, and images of SEM before and after exposure at different temperatures up to 600°C. Experimental results showed the loss of compressive strength of the specimens up to 200°C, which was almost insignificant but it was 40% and 64% when the temperature was increased to 400°C and 600°C, respectively. The steel Fibers prevented the crack expansion and contributed to spalling and mechanical residual strength. As the temperature was increased, the slope of the flexural hardness of the load deflection curves and fracture energy decreased. Moreover, microstructure analysis represents a close relationship between mechanical properties and different cracks and pore structure of the Fiber's aggregates-cementitious matrix interface. The data obtained from the results of this experimental study were used to develop models, which predicted mechanical strength of Fiber reinforced self-compacting concrete. [15]

5. Materials:

5.1. Ordinary Portland Cement

Ordinary Portland cement (OPC), a mixture of calcium, silicon, and aluminum oxides with a composition of IS 1489 (part-1)-1991, is the foundation of plaster, mortar, and concrete. Portland cement and its by-products are made by heating clay and limestone to temperatures ranging from 1300 to 1400 degrees Celsius. The final product is made by grinding the resultant material, called clinker, with sulphate, often gypsum. The most common kind of Portland cement, known as ordinary Portland cement (OPC), is available in several shades of gray and is sold in shops. The majority of hardware shops also carry white Portland cement. Portland cement is very caustic and has a pH more than 13, making it a potential source of chemical burns when handled improperly. Irritation might be an unpleasant side effect of using Portland cement powder. Due to its high chromium and silica content, Portland cement is known to induce silicosis, lung cancer, asthma, and other related diseases when inhaled over an extended period of time. Air pollution from dioxin, NO2, SO2, and particles, as well as greenhouse gases like carbon dioxide, is one of the environmental challenges associated with cement usage. Other factors include the high energy costs of mining, making, and exporting Portland cement. [16] Table 1 represent the properties of cement.

Table 1: Properties of Cement

S. No.	Test	Result
1	Soundness	10 mm
2	Fineness of Cement	7.63%

3	Standard Consistency	30%
4	Setting Time - Initial	32 minutes
	Setting Time - Final	262 minutes
5	Compressive Strength (7 days)	30 N/mm²
	Compressive Strength (14 days)	41 N/mm²
	Compressive Strength (28 days)	65 N/mm²

5.2. Sand

The process of crushing hard stone results in the collection of fine aggregates, as shown in Figures and. The crushed sand is less than 4.75 millimeters. It is procured from a local source close to the Bhopal, Madhya Pradesh construction site. From 150 µm to 600 µm is the range of the fine total. [17]

5.3. Coarse Aggregates

Used in solid blends, they are filler materials of larger size. In concrete, they serve no use whatsoever. There is a discrepancy between the fine and coarse aggregate surface zones. Crushed rock or stone, dolomite totals, and the gradual erosion of rocks are major sources of coarse totals. Bhopal was the local source for the coarse aggregates used in Figures and. From 10 mm to 20 mm is the range of coarse total used. [17]

5.4. Steel Fibers in Concrete

The mechanical qualities of concrete, such as its ductility, impact resistance, tensile strength, and crack control, may be enhanced by adding steel fibers, which are small, discrete pieces of steel, to the mixture. They are available in a variety of forms, including hooked ends, crimped ends, and straight ones, and are usually constructed of galvanized steel, carbon steel, or stainless steel. Steel fibers mainly serve to improve post-cracking behavior and decrease the development of microcracks by bridging fractures that develop in concrete. Toughness and energy absorption are both greatly enhanced as a result. Floors in industrial facilities, roads, precast items, tunnel linings, and even military buildings may benefit from the exceptional performance of steel fiber reinforced concrete (SFRC) when subjected to dynamic and impact loads. The fiber concentration typically ranges from 0.5% to 2% by volume. Despite increasing the density of concrete and requiring careful mixing to avoid balling or clumping, steel Fibers offer excellent durability and are especially beneficial in structural applications where conventional reinforcement may not provide sufficient crack control. Steel Fibers shape, size diameter was confirming to ASTM A 820/ A 820M- 04. [18] [19] [23]

5.5. E-Glass Fibers in Concrete

E-glass Fibers, or electrical-grade glass Fibers, are a type of alkali-resistant glass reinforcement commonly used in Fiber-reinforced concrete (FRC) to improve mechanical performance and durability. Used in the mix were glass fibers from electrical waste that met ASTM D3517-14 standards. These Fibers are made from alumina-borosilicate glass with a low alkali content, which gives them excellent electrical insulation properties and high tensile strength. Their volumetric doses typically range from 0.5 to 2 percent, and they effectively bridge microcracks that form in the cementitious matrix and distribute stress. E-glass Fibers are lightweight, non-corrosive, and resistant to moisture, making them particularly suitable for architectural panels, precast components, tunnel linings, and surface repair works. Their low thermal conductivity and resistance to chemical attack further extend their utility in aggressive environments. However, their performance in highly alkaline cement environments can be a concern unless treated with alkali-resistant coatings. Overall, E-glass Fiber is a cost-effective and widely used synthetic Fiber that significantly raises concrete's ductility and durability over time composites. [20] [21] [22]. Table 2 represent the properties of E-glass & Steel Fiber

Table 2: properties of E-glass & Steel Fiber

Property	E-glass Fiber	Steel Fiber
Material Type	Aluminon-borosilicate glass (low alkali)	Carbon steel / Stainless steel
Density	~2.60 g/cm³	~7.85 g/cm³
Tensile Strength	1000–3500 MPa	300–2750 MPa
Young's Modulus	~72–80 GPa	~200 GPa
Elongation at Break	2.5–4.8%	1.0–3.0%
Thermal Conductivity	Low (~1.0 W/m·K)	High (~45–50 W/m·K)
Corrosion Resistance	High (non-corrosive)	Moderate to Low (corrodes without treatment)
Electrical Conductivity	Non-conductive	Conductive
Alkali Resistance	Moderate (needs surface treatment)	Poor to Moderate (may corrode in alkaline media)
Cost	Moderate	High (especially stainless-steel Fibers)
Workability Impact	Minor reduction in workability	Greater reduction in workability
Typical Use Cases	Panels, facades, repair works, tunnel linings	Industrial floors, pavements, precast segments

6. Mix Design (IS 10262:2019)

The M30 grade concrete mix was created according to IS 10262-2019, and a weight-to-cement ratio of 0.45 was employed in accordance with the regulations. A total of seventeen distinct concrete mixtures were manufactured, including a standard mix as well as variants that included varying proportions of glass fibers (GF) and steel fibers (SF) by volume. Following the M30 grade standards, the control mix (M30-C) was created using the following ingredients: 400 kg/m³ cement, 650 kg/m³ fine aggregate, 1200 kg/m³ coarse aggregate, and 180 kg/m³ water. For the Fiber-reinforced mixes, the same base proportions were maintained, and Fibers were added in incremental volume fractions ranging from 0.25% to 2.00%. Steel Fibers were added in mixes M30-SF-0.25 to M30-SF-2.00 with corresponding Fiber dosages of 20, 40, 60, 80, 100, 120, 140, and 160 kg/m³, respectively, calculated based on their higher density. Similarly, glass Fibers were introduced in mixes M30-GF-0.25 to M30-GF-2.00, with corresponding dosages of 6.5, 13.0, 19.5, 26.0, 32.5, 39.0, 45.5, and 52.0 kg/m³, accounting for their lower density. These mixes were designed to systematically study the effect of increasing Fiber volume on the mechanical performance and how well M30 grade concrete is worked. All other mix parameters were kept constant to isolate the impact of Fiber content [24]. Table 3 represent the mix design of fiber reinforcement

Table 3: Mix Design of Fiber Reinforcement

Mix ID	Volume Fraction (%)	Cement (kg/m³)	Fine Aggregate (kg/m³)	Coarse Aggregate (kg/m³)	Water (kg/m³)	Fibers (kg/m³)
M30-C	0.00	400	650	1200	180	0
M30-SF-0.25	0.25	400	650	1200	180	20
M30-SF-0.50	0.50	400	650	1200	180	40
M30-SF-0.75	0.75	400	650	1200	180	60
M30-SF-1.00	1.00	400	650	1200	180	80
M30-SF-1.25	1.25	400	650	1200	180	100
M30-SF-1.50	1.50	400	650	1200	180	120
M30-SF-1.75	1.75	400	650	1200	180	140
M30-SF-2.00	2.00	400	650	1200	180	160
M30-GF-0.25	0.25	400	650	1200	180	6.5
M30-GF-0.50	0.50	400	650	1200	180	13.0
M30-GF-0.75	0.75	400	650	1200	180	19.5
M30-GF-1.00	1.00	400	650	1200	180	26.0
M30-GF-1.25	1.25	400	650	1200	180	32.5
M30-GF-1.50	1.50	400	650	1200	180	39.0
M30-GF-1.75	1.75	400	650	1200	180	45.5
M30-GF-2.00	2.00	400	650	1200	180	52.0

7. Methodology:

In this research, we looked at how adding E-glass and steel fiber to M30 grade concrete affected its mechanical and durability characteristics. The chosen approach included meticulous forethought, careful material selection, precise mix proportioning, meticulous specimen preparation, and testing in a controlled laboratory environment. The following steps outline the experimental procedure:

Materials Used

- Cement: OPC 43 grade cement, as per IS: 8112-1989, is required.
- Fine Aggregate: 2.60 specific gravity clean river sand, which falls within Zone IV.
- Coarse Aggregate: Coarse aggregate is 20 mm in size and has a specific gravity of 2.63. It is crushed angular.

To study the impact on mechanical characteristics and crack resistance, steel fibers (SF) and glass fibers (GF) were added to the M30 grade concrete mix. Fibers were added in varying volume fractions of 0.25%, 0.50%, 0.75%, 1.0%, 1.25%, 1.50%, 1.75%, and 2.0% by volume of concrete. The required quantity of Fibers was calculated based on their densities—approximately 7850 kg/m³ for steel Fibers and 2600 kg/m³ for glass Fibers. Fibers were uniformly mixed with dry materials (cement, fine aggregates, and coarse aggregates) before adding water and superplasticizer to ensure even distribution and to avoid balling or clumping

Mix Design

The M30 grade concrete was developed in accordance with IS: 10262-2019. With the exception of variations in E-glass fiber and Steel Fiber content, all mixes maintained the same water-cement ratio, aggregate proportions, and admixture dose.

Preparation of Specimens

A pan mixer was used to mix the concrete thoroughly and evenly. For the purposes of evaluating compressive strength, split tensile strength, and flexural strength, standard cubes measuring 150 mm × 150 mm × 150 mm, cylinders measuring 150 mm × 300 mm, and beams measuring 100 mm × 100 mm × 500 mm were cast, respectively. Following a 24-hour curing period in water at 27 ± 2°C, the specimens were demolded.

Testing of Fresh & Hardened Concrete

- In the 7, 14, and 28-day curing intervals, the following tests were carried out:
- According to IS 516-1959, compressive strength
- Adaptability (IS 516-1959) for flexural strength
- According to IS 5816-1999, the split tensile strength
- Assay on Water Absorption

Data Analysis

The data was analyzed and gathered in order to determine the impact of various percentages of E-glass Fiber and Steel Fibber content. Graphs, tables, and comparative charts were used to interpret performance trends across curing periods.

8. Particle Size Distribution:

The term "gradation of sand" describes how the various particle sizes are distributed inside a certain sand sample. It has a pivotal role in establishing the strength, longevity, and quality of mortar and concrete mixtures. Properly graded sand provides better compaction, reduces voids, and ensures better packing of particles, leading to enhanced strength and workability of the mix. [25] Table 4 represent the Particle Size Distribution of sand

Table 4: particle Size Distribution

Sieve Diameter (mm)	Cumulative Passing (%) - Lower Limit	Sand (Actual)	Cumulative Passing (%) - Upper Limit
0.15	5	10	18
0.25	10	20	35
0.5	22	40	60
1.0	40	60	80
2.0	60	80	95
4.75	85	95	100
10.0	100	100	100

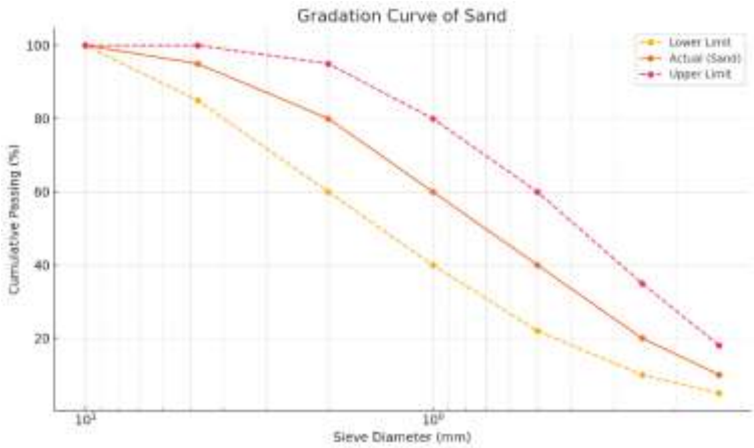

Figure 1 Particle Size Distribution of Sand

8.1. Gradation of Aggregate:

Using a typical sieve examination, we were able to assess the aggregate's gradation. The sample was found to be well-graded, with particles ranging in size from 25 mm to 4.75 mm. The 20 mm (2000 g) and 16 mm (1419 g) sieves retained most of the aggregate, suggesting that the sample is mostly composed of coarse particles. The cumulative percentage retained reached 47.08% at the 20 mm sieve and 75.46% at the 16 mm sieve, showing a balanced particle size distribution. A small amount was retained on the 25 mm (354 g) and 10 mm (900 g) sieves, while 327 g was retained on the 4.75 mm sieve. No particles passed below the 4.75 mm sieve, as the weights for the finer sieves (2.36 mm to 150 microns) were zero. This confirms that the sample consists entirely of coarse aggregate, with no contribution from fine aggregate fractions. The smooth gradation and continuous distribution of sizes are beneficial for achieving good packing density, reduced voids, and better workability in concrete. [25] Table 5 represent the gradation of aggregate.

Table 5: Gradation of Aggregate

Sieve Size	Weight Retained (g)	Cumulative Weight Retained (g)	Cumulative % Retained
25 mm	354	354	7.08
20 mm	2000	2354	47.08
16 mm	1419	3773	75.46
10 mm	900	4673	93.46
4.75 mm	327	5000	100
2.36 mm	0	5000	100
1.18 mm	0	5000	100
600 microns	0	5000	100
300 microns	0	5000	100
150 microns	0	5000	100

9. Results

This section gives the findings and explanations of the study's experimental testing. All of the components, such as cement, aggregates (both fine and coarse), steel fiber, and e-glass fiber, will be physically and mechanically analyzed to determine their durability qualities. Each test result is compared against relevant standards and guidelines to assess the quality and suitability of the materials. Furthermore, the influence of fiber on the performance of concrete is critically examined through strength, microstructural, and durability assessments. The discussion highlights the significance of observed trends, correlates the experimental findings with theoretical expectations, and supports the conclusions drawn from the study.

9.1. Workability (IS: 10262:2009):

Workable cement is the one which shows no interior friction amongst the molecules, or which has negligible frictional resistance with the protection or formwork confined in the concrete mix. The slump cone test was used to measure the consistency of the concrete. It is utilized as the sign of uniformity of concrete between one mix and the other. As per the code, IS: 10262:2009, the maximum w/c ratio adopted for M30 concrete grade is 0.30. Each trail mix had its slump measured, and its compressive strength was calculated after7,14, and 28 days of curing. [26] Table 6 represent the workability of reinforced fiber concrete with E-glass fiber and steel fiber

Table 6: workability of reinforced fiber concrete with E-glass fiber and steel fiber

Fibers Dosage (%) by Volume of Concrete	Steel Fiber Reinforced Concrete (mm)	E-Glass Fiber Reinforced Concrete (mm)
0.00	61	61
0.25	59	60
0.50	58	59
0.75	56	56
1.00	55	55
1.25	53	53
1.50	51	49
1.75	45	46
2.00	43	41

From table 6 slump tests were used to evaluate the effect of fiber dosage on the workability of three distinct kinds of fiber-reinforced concrete: E-glass, steel, and copper wire. Slump values decreased consistently across all kinds of fiber as the dose climbed from 0% to 2.0% by volume of concrete, suggesting a decline in workability. The slump for all three mixes of ordinary concrete (without fiber) was 61 mm. Fiber addition led to a progressive reduction in slump. At 1.0% dosage, the slump dropped to 55 mm for steel Fiber, 54 mm for E-copper wire Fiber, and 55 mm for E-glass Fiber. At the highest Fiber content of 2.0%, the slump values further declined to 43 mm, 45 mm, and 41 mm, respectively, for steel, E-copper, and E-glass Fibers. Slump reduction occurs when new concrete is less flowable due to the mix's increased surface area and interlocking of fibers. Among the three, E-glass Fiber showed the steepest decline in slump, indicating that it had the greatest impact on reducing workability, likely due to its fine, filamentous structure that absorbs more water and increases internal friction. Figure 2 represent the Slump value of fiber reinforcement concrete

Figure 2: Workability Test

9.2. Compressive Strength (IS 516-1959):

One of the most important ways to measure concrete's mechanical performance is by testing its compressive strength. A crucial indication of structural capacity and general material quality, it tests the concrete's potential to sustain axial loads without failure. At 7,14, and 28 days after curing, the compressive strength of concrete specimens mixed with steel and E-glass fibers varied from 0% to 2%. The goal of this experiment was to find out how fiber affects strength growth in the short- and long-term. [27] Table 7 represent the compressive strength of e-glass fiber and steel fiber

Table 7: Compressive strength test of e-glass fiber and steel fiber

Fibers Dosage (%) by Volume of Concrete	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
M30-C	30	41	65
M30-SF-0.25	32	44	68
M30-SF-0.50	34	46	70
M30-SF-0.75	35	48	72
M30-SF-1.00	36	50	74
M30-SF-1.25	36	51	75
M30-SF-1.50	35	50	73
M30-SF-1.75	34	48	71
M30-SF-2.00	32	46	69
M30-GF-0.25	31	42	66
M30-GF-0.50	32	43	67
M30-GF-0.75	33	44	68
M30-GF-1.00	33	45	69
M30-GF-1.25	32	44	68
M30-GF-1.50	31	43	67

M30-GF-1.75	30	42	66
M30-GF-2.00	29	41	65

From table 7 M30-C as the control mix, the compressive strength of concrete was measured at 7, 14, and 28 days for both SFRC and GFRC with volume fractions ranging from 0.25% to 2.00%. Glass fibers and steel fibers were utilized as reinforcements. The control mix (M30-C) showed compressive strengths of 30 MPa after 7 days, 41 MPa after 14 days, and 65 MPa after 28 days. The compressive strength significantly enhanced with the addition of steel fibers. For instance, compared to the control mix, M30-SF-1.00 significantly outperformed it after 7, 14, and 28 days, with strengths of 36 MPa, 50 MPa, and 74 MPa, respectively. The peak strength was observed at 1.25% Fiber content (M30-SF-1.25) with 36 MPa, 51 MPa, and 75 MPa, showing an increase of approximately 15% over the 28-day strength of the control. However, a slight decline in strength was noted beyond 1.25%, with M30-SF-2.00 showing 69 MPa at 28 days.

A like pattern was seen with glass fiber-reinforced concrete, albeit the strength values were somewhat lower. At a fiber volume of 1.00%, M30-GF-1.00 demonstrated strengths of 33 MPa, 45 MPa, and 69 MPa after 7, 14, and 28 days, respectively. The highest strength in the GF series was also observed at 1.00–1.25%, after which a minor decrease was noted. At the highest dosage of 2.00%, the strength returned to 65 MPa, equivalent to the control mix. These results demonstrate that Fiber incorporation enhances compressive strength up to an optimal dosage around 1.00–1.25% beyond which the benefits reduce due to possible issues in workability and uniform dispersion of Fibers. Figure 3 represent the compressive strength test of fiber reinforcement concrete.

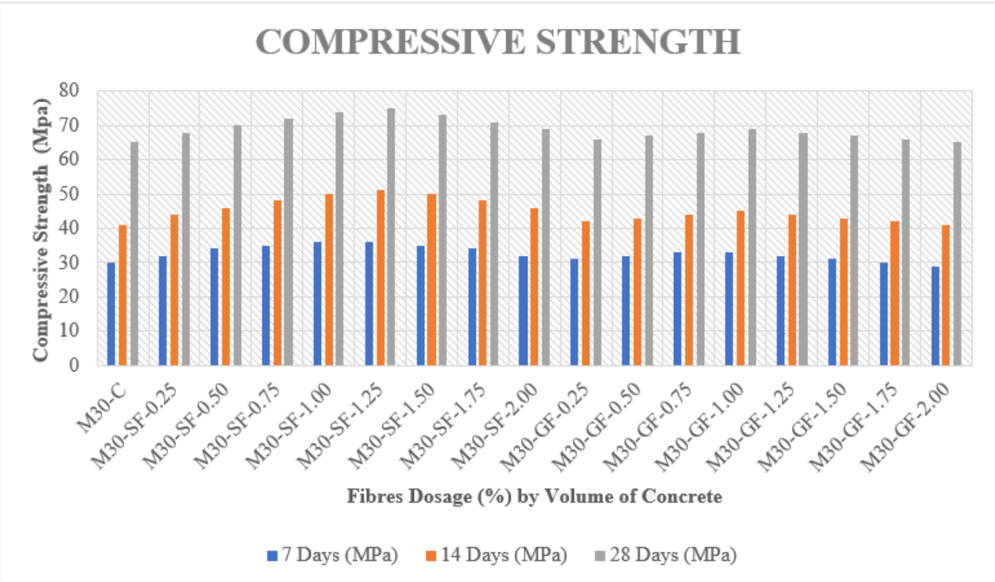

Figure 3: Compressive Strength Test

9.3. Flexural Strength (IS 516-1959):

To determine how well concrete holds its shape when bent or flexed, engineers perform a flexural strength test. This property is crucial for structural parts like pavement slabs, beams, and bridge decks that experience flexural loads, since it indicates the concrete's resistance to cracking and failure caused by bending stresses. At7,14, and 28 days, concrete specimens reinforcing steel and glass with volume fractions ranging from 0.25% to 2.00% were tested to determine the effect of reinforcement on the development of flexural strength. Due to their ability to bridge micro-cracks, improve post-crack load-carrying capacity, and increase energy absorption, fibers are anticipated to greatly increase flexural strength. Fibers made of steel have better flexural performance because of their high tensile strength and stiffness, but fibers made of glass have better toughness and fracture control. This test is essential for determining the optimal Fiber content to enhance concrete's flexural behaviour, ductility, and resistance to crack propagation under service loads. [27] Table 8 represent the flexural strength of e-glass fiber and steel fiber

Table 8: Flexural strength test of e-glass fiber and steel fiber

Fibers Dosage (%) by Volume of Concrete	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
M30-C	3.5	4.2	4.8
M30-SF-0.25	3.8	4.6	5.1
M30-SF-0.50	4.0	4.9	5.4
M30-SF-0.75	4.3	5.2	5.8
M30-SF-1.00	4.5	5.5	6.2
M30-SF-1.25	4.6	5.7	6.5
M30-SF-1.50	4.4	5.5	6.4
M30-SF-1.75	4.2	5.3	6.2
M30-SF-2.00	4.0	5.1	6.0
M30-GF-0.25	3.6	4.4	5.0
M30-GF-0.50	3.8	4.6	5.2
M30-GF-0.75	4.0	4.8	5.4
M30-GF-1.00	4.1	5.0	5.6
M30-GF-1.25	4.2	5.2	5.7
M30-GF-1.50	4.0	5.0	5.6
M30-GF-1.75	3.9	4.8	5.4
M30-GF-2.00	3.7	4.6	5.2

From table 8 We investigated concrete mixes with varying concentrations of steel (SF) and glass (GF) fibers at 7, 14, and 28 days to determine how fiber reinforcement impacts the flexural behavior of M30 grade concrete. The fiber-free control mix (M30-C) had flexural strengths of 3.5 MPa, 4.2 MPa, and 4.8 MPa at 7, 14, and 28 days, respectively. The inclusion of steel fibers greatly enhanced the flexural strength at all curing ages. At 6.5 MPa after 28 days, 4.6 MPa after 7 days, and 5.7 MPa after 14 days, for instance, M30-SF-1.25 demonstrated a 35% increase over the control mix. Blends of glass and steel fibers showed a similar trend, but with slightly less advancement. Maximum flexural strength in the GF series was attained by M30-GF-1.25 with 4.2 MPa at 7 days, 5.2 MPa at 14 days, and 5.7 MPa at 28 days. In general, the addition of steel and glass fibers to concrete greatly improved its flexural performance, especially when the recommended dose was between 1.0 and 1.25 percent by volume. At this point, however, fiber clustering, decreased workability, and inadequate dispersion during mixing probably contributed to a small drop in flexural strength. Due to their superior tensile strength, bonding with the matrix, and crack-bridging ability, steel fibers routinely outperformed glass fibers. The results show that individual fibers do a good job of strengthening fiber-reinforced concrete's flexural resistance and ductility Figure 4 represent the flexural strength test of fiber reinforcement concrete.

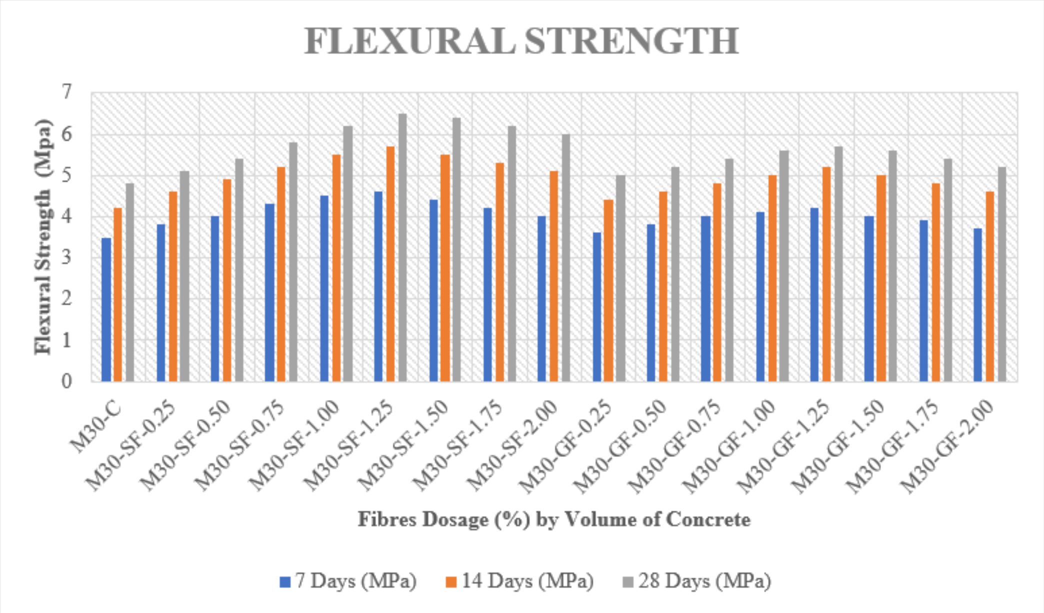

Figure 4: Flexural Strength Test

9.4. Split Tensile Strength (IS 5816:1999):

To find out how resistant concrete is to cracking and structural failure, its tensile strength a critical property is tested using the split tensile strength test. Given that concrete is naturally less strong under tension than compression, this test provides useful information about its ability to withstand indirect tensile pressures. This research examined the impact of fiber reinforcement on the development of tensile strength. At7,14, and 28 days of curing, concrete specimens with different volume percentages of fibers (ranging from 0.25% to 2.00%), including steel and glass fibers, were investigated. Cylindrical specimens are subjected to a compressive stress along their diameters until they fail in tension. Fibers are thought to increase energy absorption capacity, stress distribution, and tensile strength by bridging fissures. Contributing to the improvement of the concrete matrix's ductility and failure behavior are steel fibers, which have strong tensile qualities, and glass fibers, which have chemical stability and the capacity to arrest cracks. This test is required to assess the durability and fracture resistance of fiber-reinforced concrete in order to ascertain its structural integrity and performance over time. [28] Table 9 represent the flexural strength of e-glass fiber and steel fiber.

Table 9: Split Tensile strength test of e-glass fiber and steel fiber

Fibers Dosage (%) by Volume of Concrete	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
M30-C	2.4	2.8	3.2
M30-SF-0.25	2.6	3.1	3.6
M30-SF-0.50	2.8	3.3	3.9

M30-SF-0.75	3.0	3.6	4.2
M30-SF-1.00	3.2	3.8	4.5
M30-SF-1.25	3.3	3.9	4.6
M30-SF-1.50	3.2	3.8	4.4
M30-SF-1.75	3.1	3.6	4.2
M30-SF-2.00	2.9	3.4	4.0
M30-GF-0.25	2.5	2.9	3.4
M30-GF-0.50	2.6	3.0	3.5
M30-GF-0.75	2.7	3.2	3.7
M30-GF-1.00	2.8	3.3	3.9
M30-GF-1.25	2.9	3.4	4.0
M30-GF-1.50	2.8	3.3	3.9
M30-GF-1.75	2.7	3.2	3.8
M30-GF-2.00	2.6	3.1	3.6

From table 9 indirect tensile performance of concrete reinforced with steel and glass fibers was evaluated using split tensile strength tests. The doses of the reinforcements ranged from 0.25% to 2.00% by volume. At7,14, and 28 days, the fiber-free control mix (M30-C) reached split tensile strengths of 2.4 MPa, 2.8 MPa, and 3.2 MPa, respectively. There was a steady increase in tensile strength when fibers were added. At a fiber volume of 1.25%, the greatest results were seen; M30-SF-1.25 showed 3.3 MPa after 7 days and 4.6 MPa after 28 days, an increase of about 44% compared to the control. Enhancement was also seen in glass fiber reinforced concrete, with M30-GF-1.25 registering 2.9 MPa, 3.4 MPa, and 4.0 MPa at 7, 14, and 28 days, respectively. Because of their greater stiffness, bridging effect, and energy absorption during fracture propagation, steel fibers outperformed glass fibers in boosting tensile strength. However, at higher dosages beyond 1.25%, the strength gains diminished slightly, likely due to Fiber clustering and reduced workability. Figure 5 indirect tensile strength test of fiber reinforcement concrete.

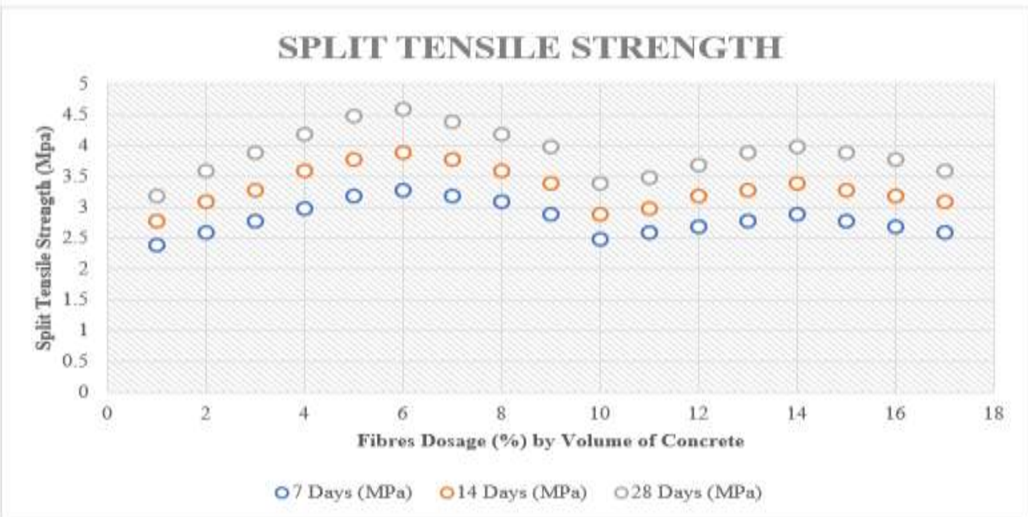

Figure 5 Split Tensile Strength Test

9.5. Modulus of Elasticity (IS 516:1959)

Due to the increasing hydration of cement, which results in matrix densification and strength gain, the modulus of elasticity of concrete shows a notable rise with the curing age. Following the usual pattern in plain concrete, the modulus of the control mix (M30-C) rose from 22.0 GPa after 7 days to 27.0 GPa after 28 days. Adding steel fibers (SF) resulted in a significant improvement at every curing age. Improved internal bonding and increased stiffness as a result of the fiber bridging effect were shown, for instance, by M30-SF-1.25's 25.3 GPa after 7 days, 28.2 GPa after 14 days, and 30.6 GPa after 28 days. Similarly, other steel Fiber mixes (e.g., SF-0.75 to SF-1.50) showed gradual increases, with peak values typically occurring at 1.00% to 1.25% Fiber dosage, after which a slight decline was noted due to possible Fiber clustering or reduced workability. In contrast, glass Fiber (GF) mixes also showed improved modulus over the control but slightly lower than steel Fiber mixes. As an example, M30-GF-1.25 achieved 24.5 GPa after 7 days, 27.0 GPa after 14 days, and 29.0 GPa after 28 days, showing that glass fibers contribute to stiffness increase, but not as much as steel does. Overall, the results confirm that both Fiber types contribute to increased modulus of elasticity, with steel Fibers offering a more pronounced effect, and curing time playing a critical role in the development of elastic properties. Table 10 represent the modulus of elasticity and figure 5 is the graphical representation of modulus of elasticity. [29]

Table 10: Comparison of Modulus of Elasticity (GPa)

Fibers Dosage (%) by Volume of Concrete	7 Days	14 Days	28 Days
M30-C	22.0	24.5	27.0
M30-SF-0.25	23.5	26.0	28.2
M30-SF-0.50	24.0	26.8	29.0
M30-SF-0.75	24.6	27.4	29.8
M30-SF-1.00	25.1	28.0	30.4
M30-SF-1.25	25.3	28.2	30.6
M30-SF-1.50	25.0	28.0	30.3
M30-SF-1.75	24.5	27.5	30.0
M30-SF-2.00	24.0	27.0	29.5
M30-GF-0.25	22.5	25.0	27.5
M30-GF-0.50	23.0	25.5	28.0
M30-GF-0.75	23.4	26.0	28.4
M30-GF-1.00	24.0	26.5	28.8
M30-GF-1.25	24.5	27.0	29.0
M30-GF-1.50	24.0	26.5	28.7
M30-GF-1.75	23.5	26.0	28.4
M30-GF-2.00	23.0	25.5	28.0

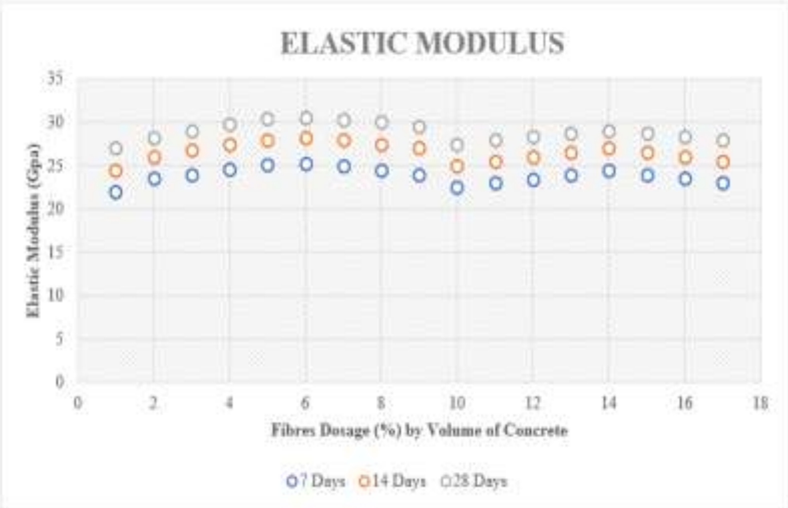

Figure 6 Modulus of Elasticity (GPa)

9.6. Water Absorption Test (IS 2386 (Part 3):1963):

In this study, water absorption was measured at 7, 14, and 28 days for plain M30 concrete, as well as mixes containing steel Fibers (SF) and E-glass Fibers (GF) at various dosages. The inclusion of Fibers generally leads to reduced absorption due to better matrix densification and crack-bridging capabilities. [30] Table 11 represent the value of water absorption

Table 11: Water Absorption

Fibers Dosage (%) by Volume of Concrete	7 Days (%)	14 Days (%)	28 Days (%)
M30-C	3.85	3.50	3.10
M30-SF-0.25	3.65	3.28	2.95
M30-SF-0.50	3.40	3.10	2.80
M30-SF-0.75	3.25	2.95	2.60
M30-SF-1.00	3.10	2.80	2.50
M30-SF-1.25	3.00	2.75	2.45
M30-SF-1.50	3.15	2.90	2.60
M30-SF-1.75	3.30	3.05	2.75
M30-SF-2.00	3.45	3.20	2.90
M30-GF-0.25	3.75	3.40	3.00
M30-GF-0.50	3.60	3.25	2.90
M30-GF-0.75	3.45	3.10	2.85
M30-GF-1.00	3.30	2.95	2.70
M30-GF-1.25	3.25	2.90	2.65
M30-GF-1.50	3.35	3.00	2.75
M30-GF-1.75	3.50	3.10	2.85
M30-GF-2.00	3.65	3.25	3.00

The water absorption test was conducted to evaluate the porosity and permeability characteristics of M30-grade concrete mixes, including control specimens and those incorporating steel Fibers (SF) and E-glass Fibers (GF) at varying volume fractions. To evaluate the time-dependent increase in the concrete's resistance to moisture intrusion, the test was conducted at 7, 14, and 28 days of curing. For every mix, the data showed a steady decline in water absorption as the curing age progressed, suggesting that the cement matrix was gradually becoming denser. The control mix (M30-C) exhibited water absorption values of 3.85% at 7 days, 3.50% at 14 days, and 3.10% at 28 days. In contrast, Fiber-reinforced mixes demonstrated notably lower absorption rates. Among steel Fiber mixes, the lowest water absorption was recorded for the M30-SF-1.25 mix, with 2.45% at 28 days, indicating enhanced permeability due to effective crack bridging and a denser matrix. Similarly, E-glass Fiber mixes showed a reduction in absorption, though slightly higher than steel Fiber mixes; for example, M30-GF-1.25 had an absorption of 2.65% at 28 days. Overall, the incorporation of Fibers, particularly steel Fibers at 1.0–1.25%, significantly improved the concrete's resistance to water penetration, which is crucial for enhancing its long-term durability and reducing the risk of moisture-induced deterioration in aggressive environments. Figure 7 graphically represent the water absorption values.

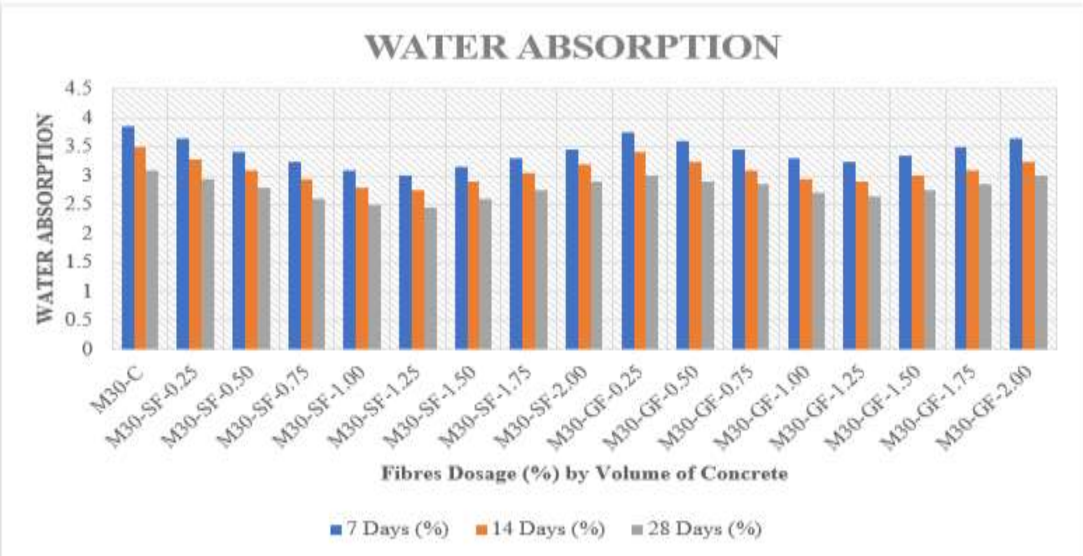

Figure 7 Water Absorption Test

10. Discussion

This experimental study aimed to evaluate the effects of steel fibers (SF) and E-glass fibers (GF) on the performance of M30 grade concrete by measuring the concrete's modulus of elasticity, compressive strength, flexural strength, split tensile strength, and durability properties like water absorption, acid resistance, sulphate resistance, and chloride resistance. At volume fractions ranging from 0.25% to 2.00%, the effects of fiber inclusion at 7, 14, and 28 days of curing were assessed.

- **Compressive Strength**

The compressive strength showed notable improvements across all Fiber-reinforced mixes. The control mix (M30-C) achieved 65 MPa at 28 days, while the optimum performance was recorded at 1.00% steel Fiber, which reached 74 MPa, reflecting a 13.8% improvement. Similarly, the E-glass Fiber mix (M30-GF-1.00) recorded 69 MPa, an increase of 6.1% over the control. The fibers' bridging effect improved the matrix's integrity and slowed the spread of cracks, which led to these benefits.

- **Flexural Strength**

Fibers significantly increased the concrete's flexural strength, which is a gauge of how resistant it is to bending. At 28 days, the flexural strength of the steel fiber mixes reached 8.2 MPa, a 34% increase, above the control mix value of 6.1 MPa. E-glass Fiber mixes also enhanced performance but to a lesser extent, with M30-GF-1.00 recording 7.4 MPa, indicating that steel Fibers were more effective in flexure due to their superior tensile strength and aspect ratio.

- **Split Tensile Strength**

Split tensile strength exhibited similar trends, confirming that Fibers significantly enhance the concrete's tensile capacity. The control mix (M30-C) achieved 4.5 MPa at 28 days, while M30-SF-1.00 reached 5.8 MPa, marking a 28.9% increase. The E-glass Fiber mix (M30-GF-1.00) achieved 5.3 MPa, reflecting an 18% improvement over the control. The findings highlight the importance of fibers in preventing the beginning and development of cracks by resisting tensile stresses.

- **Modulus of Elasticity**

The concrete's rigidity was somewhat enhanced by the fiber addition. The control mix had a modulus of 28.0 GPa, while the mix with 1.00% steel Fiber recorded 30.5 GPa, and E-glass Fiber at the same dosage recorded 29.4 GPa. These improvements reflect a denser matrix and better stress distribution under load.

- **Water Absorption:**

Fiber-reinforced concretes showed reduced water absorption. M30-C had an absorption of 4.6%, whereas M30-SF-1.00 and M30-GF-1.00 showed 3.2% and 3.4%, respectively, confirming the ability of Fibers to reduce porosity and capillary suction. It is clear from the thorough results that adding fibers greatly improves the mechanical and durability qualities of M30 concrete. The optimal dosage for both Fiber types was around 1.00% by volume, beyond which marginal improvements or even reductions in performance were observed, likely due to issues like poor workability and Fiber clustering. Among the two types, steel Fibers consistently outperformed E-glass Fibers across most parameters, especially in flexural and split tensile strength, as well as resistance to aggressive environments. Therefore, incorporating Fibers at optimized levels provides a cost-effective and sustainable solution to improve concrete performance in structural applications prone to cracking, environmental exposure, and mechanical stress.

11. Environmental Impact of Using Steel Fibers And E-Glass Fibers

- Long-term durability and environmental sustainability are greatly enhanced by the addition of fibers like steel and E-glass to concrete.
- One of the primary environmental advantages of Fiber-reinforced concrete (FRC) lies in its extended service life and reduced maintenance frequency, which lowers the overall consumption of raw materials, energy, and associated emissions throughout a structure's lifecycle.
- By improving the mechanical properties, especially crack resistance and durability under aggressive conditions (such as sulphate and chloride exposure), FRC minimizes structural deterioration and delays the need for repair or replacement, indirectly reducing construction waste generation.
- Furthermore, the use of recycled steel Fibers (when sourced sustainably) can contribute to circular economy practices, reducing the demand for virgin steel and lowering carbon footprint.
- Additionally, improved durability due to Fiber inclusion results in less water ingress and corrosion, which reduces the likelihood of environmental contamination from degraded concrete components.

- While E-glass Fibers are synthetic and energy-intensive to produce, their use in small volume fractions (<2%) offers a high strength-to-weight advantage with relatively low environmental impact when compared to traditional reinforcement methods.

Overall, the use of Fibers in concrete promotes resource efficiency, material optimization, and resilience to environmental stressors, aligning well with green building goals and sustainable construction practices.

10. Conclusion:

1. Experiments on M30 grade concrete with different amounts of steel and E-glass fibers showed that, compared to regular concrete, it had far better mechanical and durability properties.
2. The performance was assessed using durability tests, such as modulus of elasticity, flexural strength, compressive strength, split tensile strength, and resistance to water absorption,
3. Throughout the study, a 400 kg/m³, 1200 kg/m³, and 180 kg/m³ cement/fine aggregate/coarse aggregate combination was employed. Steel fibers could reach up to 160 kg/m³, while E-glass fibers could reach 52 kg/m. The volume percentage of fibers ranged from 0.25 to 2.00%.
4. To maintain the workability, particularly at greater fiber concentrations, superplasticizers were added as needed. The findings highlight the ideal fiber volume range of 1.00–1.25%, while greater contents have the tendency to diminish workability and homogeneity as a consequence of fiber clustering.
5. Adding fibers (especially steel ones) significantly decreased workability, hence superplasticizers were needed to maintain uniformity. To prevent fiber balling and guarantee appropriate dispersion, particularly at larger doses, uniform mixing was of the utmost importance.
6. Up to an ideal fiber volume of 1.25%, adding steel and E-glass fibers to concrete greatly increased its compressive strength. For instance, compared to 65 MPa (control) after 28 days, 75 MPa (with 1.25% steel fiber) was the measured increase. As a result of fiber agglomeration impacting the mix's homogeneity, a little decrease in strength was seen beyond 1.25%. Fiber inclusion significantly increased flexural strength, demonstrating greater post-cracking resistance. • The tensile strength rose by up to 20% in comparison to the control mix, peaking at 1.25% fiber volume.
7. The SF and GF mixes both achieved their maximum flexural strength at 1.25% fiber volume, which is 15-20% higher than the control concrete. The superior crack-bridging properties of steel fibers made them the superior choice over E-glass fibers.
8. The modulus increased with Fiber content up to 1.25%, reflecting a stiffer and more resilient material. At higher dosages, the stiffness began to plateau or slightly reduce due to Fiber clustering.
9. For Water Absorption the Fiber addition reduced water absorption values, indicating a denser microstructure. The best performance was seen at 1.00%–1.25% Fiber volume, with minimal water ingress over 28 days.
10. The integration of industrial waste Fibers contributes to resource conservation and promotes sustainability by reducing reliance on conventional reinforcement and minimizing CO_2 emissions related to steel production.
11. Reuse of E-glass waste and controlled steel Fiber usage provides an eco-friendly alternative in line with green construction principles.

12. In terms of practical application, the enhanced performance of Fiber-reinforced concrete makes it highly suitable for use in pavements, industrial floors, marine structures, retaining walls, precast elements, tunnel linings, and water-retaining structures such as tanks and sewage systems.
13. The improved resistance to chemical attack, reduced permeability, and increased tensile capacity ensure a longer service life and reduced maintenance needs, making it a durable and sustainable option in modern construction.
14. Moreover, the use of recycled or waste-derived Fibers can contribute positively to environmental goals by minimizing material consumption and supporting green building practices.
15. In both typical and extreme environmental circumstances, fiber-reinforced concrete has shown to be an excellent material for increasing the strength and longevity of concrete buildings.

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