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Application Of Glass Fiber Reinforced Concrete (Gfrc) For Sustainable Construction

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CHAPTER-1
INTRODUCTION

1.1 GENERAL

Cement concrete is a widely used construction material made by mixing cement, water, fine aggregates (like sand), and coarse aggregates (like gravel or crushed stone). When water is added to the cement, a chemical reaction called hydration occurs, causing the mixture to harden and gain strength over time. Concrete is known for its durability, versatility, and ability to be moulded into various shapes before setting. It's commonly used in buildings, roads, bridges, and other infrastructure projects due to its strength and long-lasting performance.

1.2 GLASS FIBRE REINFORCED CONCRETE (GFRC)

Glass Fiber Reinforced Concrete is a type of concrete that is strengthened with alkali-resistant glass Fibers instead of traditional steel reinforcement. These glass Fibers are mixed into the concrete, helping improve its tensile strength, flexibility, and impact resistance. GFRC is lightweight yet strong, making it ideal for applications where weight and durability are important— like building panels, bridge components, pavements, and architectural elements. It also resists cracking and weather damage better than regular concrete. Because it can be moulded into thin sections and complex shapes, it's commonly used in both structural and decorative applications. Plus, its long life and reduced maintenance needs make it a sustainable choice for modern construction.

1.3 PROPERTIES OF GFRC

(i) High tensile strength (1700N/mm^2).

(ii) Impact Resistance.

(iii) Water resistant.

(iv) Low thermal expansion.

(v) Less creep with increase with time.

(vi) Light weight

(vii) Resistance to cracks in concrete.

(viii)Resistance to corrosion.

Cement is a fine, powdery substance made primarily from limestone (calcium carbonate), clay, and other minerals. When mixed with water, it acts as a binder that hardens and sets through a chemical process called hydration. The most commonly used type is Ordinary Portland Cement (OPC), which forms the base of most concrete mixes.

1.4 Properties of Concrete

Concrete is a composite material made primarily of cement, water, aggregates (fine and coarse), and sometimes admixtures. Its performance is defined by its properties in two states:

Fresh concrete refers to the stage before it hardens. Its properties affect how easy it is to mix, transport, place, compact, and finish.

1.4.1 Workability

(i) Separation of constituents (cement paste from aggregates).

(ii) Causes: Excess water, improper mixing or handling.

(iii) Prevention: Segregation.

(iv) Depends on: Water-cement ratio, aggregate size and shape, temperature, admixtures.

(v) Measurement Tests: Slump Test, Compaction Factor Test, Vee-Bee Test.

1.4.2 Bleeding

(i) Water rising to the surface of fresh concrete after placing.

(ii) Impact: Causes weak surface, delays finishing, may lead to shrinkage cracks.

(iii) Control: Use finer cement, reduce water content, or use admixtures.

1.4.3 Setting Time

(i) Initial Setting Time: Time taken to start hardening.

(ii) Final Setting Time: Time taken to become completely rigid.

(iii) Typical Time: 30 minutes to 10 hours (depends on conditions and admixtures).

Concrete is foundational to modern infrastructure, critical for the construction of everything from skyscrapers to bridges and roads. Its widespread use highlights its fundamental role in global development; however, conventional concrete faces significant limitations, including brittleness and a propensity for cracking under tension. These vulnerabilities can lead to accelerated degradation under environmental and mechanical stresses, which are particularly problematic for Portland Cement Concrete (PCC) roads that bear the brunt of heavy, continuous traffic.

1.5 Use of Glass Fiber Reinforced Concrete (GFRC) across different sectors:

1.5.1 Transportation Infrastructure

(i) Bridge decks and panels – for lightweight, durable components.

(ii) Pavements and overlays – better crack resistance and durability.

(iii) Tunnel linings – for added strength in underground structures.

(iv) Sound barriers and noise walls – lightweight and weather-resistant.

1.5.2 Building Construction

(i) Cladding panels – for decorative and protective outer walls.

(ii) Architectural elements– like columns, cornices, and facades due to its moldability.

(iii) Precast components – faster installation and reduced labour.

1.5.3 Civil Engineering Structure

(i) Canopies and shelters – weather-resistant and durable in public spaces.

(ii) Retaining

1.5.4 Sustainability Projects

(i) Green buildings – due to its reduced cement content and long service life.

(ii) Lightweight panels – help in reducing structural load and material usage.

1.5.5 Renovation and Retrofitting

(i) Used to strengthen old structures without adding much weight.

(ii) Ideal for repairing concrete where access is limited or aesthetics are important.

1.6 Factor effecting properties of GFRC:

(i) Volume of fiber.

(ii) Compaction of concrete.

(iii) Mixing.

(iv) Size of coarse aggregate

(v) Water cement ratio.

1.7 Need For Study

Hence, the present study has been caried out to investigate the application of GFRC for Sustainable Construction.

Chapter-2

Literature Review

2.1 General

Studies over the last two decades have increasingly highlighted the potential of GFRC in civil and for Sustainable Construction.

The purpose of this literature review is to understand what researchers know about GFRC. Below is the list of some researchers that were helpful in this study:

2.2 Background Study

A. Qudoos, H. G. Kim, Atta-ur-Rehman, and J.-S. Ryou (Dec 2018) [1] The cement was replaced (by weight) with ash at various replacement levels up to 30% maximum and studied for different parameters. The effect of mechanical processing on the pozzolanic efficiency of ashes was investigated via compressive strength test.

M. Abed and R. Nemes (Jan 2019) [2] The mechanical properties of the 21 concrete mixes are determined after one, three and nine months of curing. Results of compressive strength, splitting tensile strength, flexural strength and modulus of elasticity are presented. Findings indicate that incorporating waste materials can be valuable in SCHSC, thereby potentially leading to an increasingly green environment and paving the way for advancements in sustainable construction.

H. Dilbas and Ö. Çakır (Sep 2020) [3] This paper investigates the effect of the treatment methods on the physical and the mechanical properties of recycled aggregate concrete (RAC). The physical and the mechanical tests were conducted on concrete specimens at the age of 28 days. According to the test results, although the physical properties were negatively affected by the incorporation of RA and TRA with/without BF in concrete.

J. Ahmad, F. Aslam, O. Zaid, R. Alyousef, H. Alabduljabbar, and A. Manan (Jan 2021) [4] This study aims to examine the performance of polypropylene fiber reinforced concrete through different tests. PPFs were added into concrete blends in a percentage of 1.0%, 2.0%, 3.0%, and 4.0% by weight of cement to offset its objectionable brittle nature and improve its tensile capacity. The fresh property was evaluated through slump cone test and while mechanical strength was evaluated through compressive strength, split tensile strength flexure strength, and flexure cracking behaviours after 7-, 14-, and 28-days curing.

R. Prakash, R. Thenmozhi, S. N. Raman, C. Subramanian, and N. Divyah (Jun 2021) [5] To enhance the weak mechanical characteristics of lightweight concrete, various contents of sisal fibre at 1%, 2%, 3% and 4% have been added on the basis of the binder's weight. Mechanical properties, such as compressive strength, split tensile strength, flexural strength, elastic modulus and impact resistance, were examined. Results showed that the compressive strength increased by up to 6% when 3% fibre was added.

J. Ahmad, F. Aslam, O. Zaid, R. Alyousef, and H. Alabduljabbar (2021) [6] When studying the behaviour of concrete after cracking, it is important to analyse the fracture energy (Gf), which is the energy required to fracture the test specimen, and the fracture toughness (KIC), defined as the ability of the test specimen to resist brittle decay or crack expansion [17]. The fracture energy increased by 40%, 46%, and 64% for samples with 0.50%, 0.75%, and 1.00% glass fiber content, respectively, compared to plain concrete.

To improve the strength and flexibility of GFRC over time, enhancements have been made in two directions: the use of alkaline-resistant (AR) fibers with a high zirconium oxide content and the modification of the Portland cement-based matrix with various additives such as silica micro-particles, slag, fly ash, metakaolin, acrylic polymer, or Sulfo aluminate. The purpose of these additives is to reduce alkalinity and remove CH (calcium hydroxide) around the filaments.

J. Ahmad et al. (Jan 2021) [7] Response surface methodology (statistical models) is used to optimize the combined dosage of wheat straw ash and bentonite clay and is verified through experimental tests. It can also be suggested that bentonite and wheat straw ash are successfully neutralized in concrete instead of cement.

O. Zaid, J. Ahmad, M. S. Siddique, F. Aslam, H. Alabduljabbar, and K. M. Khedher (Jun 2021) [8] The volume ratios of glass fibers utilized in this study were 0.5%, 1.0%, 1.5% and 2.0%. Adding glass fibers increases concrete density to some extent and then marginally reduces the density of coconut shell concrete. When the percentage of glass fibers increases, the compressive, flexural and split tensile strength of coconut shell concrete also increases.

R. Prakash, R. Thenmozhi, S. N. Raman, C. Subramanian, and N. Divyah (2021) [9] This research investigates untreated Coconut Shell Particles (CSP) incorporated with coconut shell ash (CSA) to improve the durability properties at elevated temperatures and in sulphuric acid. Initially, the physical and mechanical properties of cube and cylinder specimens after 7, 28, 56, and 90 days of moist curing were studied. Moreover, the reduction in the compressive strength after exposure to the elevated temperature of 500 °C for 1 hr. was still much less by an average of 75.38% compared to other waste materials blended into the concrete by previous works.

Ch. Devi, D. S. Vijayan, R. Nagalingam, and S. Arvindan (Jan 2022) [10] The article's primary objective is to educate the public about new, practical, and cost-effective technology. The article's primary objective is to inform readers about emerging low-cost technologies. Additionally, the paper discusses current GFRC applications.

P. P. kumar and B. K. Chaitanya (Mar 2022) [11] Fiber-reinforced concrete has various applications in structural components. Some of the fibers like glass, carbon, polypropylene, and aramid fibers give an improvement in generous properties like hardened, durability, stiffness, toughness, shrinkage. The purpose of this research is to investigate the properties of glass fiber reinforced high- performance concrete (GFRHC) for arriving high-performance trail mixes are prepared with cement replacement with silica fume (SF) ranging from 0% to 25%. An optimum mix is chosen in that constant 1.15 % cement is replicate with nano-silica. For that optimized mix along with nano-silica, glass fibers are induced at 1%, 2%, 3%, and 4% by weight of cement.

J. Blazy, R. Blazy, and Ł. Drobiec(Apr 2022) [12] The article highlights that glass fiber reinforced concretes (GFRC) can meet the requirements of Smart City better than ordinary concretes. The comprehensive discussion on GFRC composition is presented together with the review of glass fibers' influence on various concrete properties. the article also describes the GFRC application fields and emphasizes the possibility of the creation of not only structural elements mainly intended for load transferring but also elements accompanying the building process, as well as elements of small architecture that make public spaces more attractive, durable, and safer. Owing to greater design and shaping freedom, GFRC can also better fulfill the needs of habitants of Smart City.

M. Anas, M. Khan, H. Bilal, S. Jadoon, and M. N. Khan (2022) [13] This paper reviews the effects of fibers inclusion on the performance of concrete. Generally, the addition of fibers improves tensile strength, flexural strength, and durability performance. Moreover, incorporating fibers reduces the shrinkage cracks of concrete. However, incorporating fibers in concrete has some negative effects like low workability.

K. K. Annamaneni and K. Pedarla (Jan 2023) [14] This research investigates the characteristics of glass fibres reinforced concrete (GFRC) after 7 and 28 days of curing, such that GFRC may be employed in construction. Concrete containing short alkali-resistant glass fibres of 36 mm in length and 1% volume fraction (VF) was developed for this purpose. The testing findings revealed that the average compressive strength of GFRC after 28 days of curing was 72.06 MPa. The flexural properties of GFRC are determined, and the 7-day and 28-day average bending strengths of GFRC concrete samples are 6.46 MPa and 7.94 MPa, respectively, indicating that GFRC responds well under loading conditions.

T. A. Kinjawadekar, S. Patil, and G. Nayak (Jun 2023) [15] To assess the mechanical qualities of GFRP bars, the research includes mix design, casting, and extensive testing, such as flexural and tensile tests. Furthermore, a comprehensive study of GFRP-integrated reinforced concrete building sections is carried out, looking at factors like primary stresses, bending stresses, shear stresses, and deflection.

2.3 References from Literature Review:

2.3.1 Glass Fiber Reinforcement:

Use of alkali-resistant glass fibers within concrete to enhance tensile and flexural strength.

2.3.2 Composite Behavior:

Interaction between the concrete matrix and dispersed fibers, leading to better performance under load.

2.3.4 Crack Bridging:

Fibers arrest crack growth, improving durability and reducing maintenance.

2.3.5 Lightweight Construction:

GFRC's low density helps in reducing structural weight—ideal for precast transport infrastructure.

2.3.6 Sustainability Metrics:

Long service life, reduced material usage, and potential for recycled content align GFRC with green building goals.

2.4 Aim of Work

(i) To design controlled mix of M20 grade.

(ii) To design GFRC concrete with different %age of GFRC.

(iii) To determine properties of optimized GFRC mix.

(iv) To determine durability properties of GFRC for enhancing sustainable construction.

2.5 Overview of Work

(i) This study aims to explore and analyze the application of GFRC for sustainable construction, focusing on:

(ii) How GFRC improves durability and mechanical performance in real-world applications.

(iii) Evaluation of sustainability benefits, including life-cycle performance.

(iv) Identifying challenges, such as cost, production complexity, and long-term behavior.

Chapter-4
Results and Discussions

OPC 53 grade is used throughout the investigation. The cement is tested for its various properties as per IS: 4031 – 1988 and found to be confirming to the requirements as per IS: 1489-1999 Part . The results of tests concluded on cement are as follows.

All the tests are performed in Quality Control Lab PWD (B&R) Karnal using M20 Grade of Concrete and OPC 53 Grade of cement, Aggregates are of size 20mm, natural river sand was used through out the testing, CTM was also used for compressive and flexural strength test.

4.1 Compressive Strength Test on Concrete

The compressive strength test is fundamental in assessing the quality and durability of concrete used in construction. It measures the concrete's ability to withstand axial loads, ensuring that structures can safely support the intended loads.

Sample Cube Test Readings and Compressive Strength of Concrete

Sr. No.	Age Days	Load (KN)	Compressive Strength after 7 days N/mm^2	GFRC added (%)	Strength 7 days after adding GFRC N/mm^2	Load (KN)	Compressive Strength (MPA) after 28 days N/mm^2	Load (KN)	Compressive Strength (MPA) after 28 days (GFRC)
1	7	159.75	7.10	0.5	11.10	444.37	19.75	609.75	27.10
2	7	252	6.92	1	11.20	430.87	19.15	651.6	28.96
3	7	284	6.98	2	9.97	447.75	19.90	604.8	26.88
4	7	230.6	7.05	3	10.25	421.875	18.75	587.47	26.11

Table 4.1 Sample Cube Test Readings and Compressive Strength of Concrete

Using M 20 Grade of concrete the strength of concrete after 7 days in N/mm^2 =11.20 N/mm^2 (Average Strength)

Total Aggregates= 25.8 kg Coarse aggregates and 12.86kg Fine aggregates with (0.5, 1, 2, 3) GFRC by weight of cement and Water/Cement Ratio = 0.45

Compressive Strength = LOAD/AREA = 7.10X150X150/1000=159.75KN and so on.

S.NO.	M20+GLASSFIBRE	COMPRESSIVE STRENGTH (N/mm^2) (7DAYS)	(28DAYS)
1.	0.5%	11.10	27.10
2.	1%	11.20	28.96
3.	2%	9.97	26.88
4.	3%	10.25	26.11

TABLE 4.2 Compressive Strength of Concrete in 7 and 28 Days (N/mm^2)

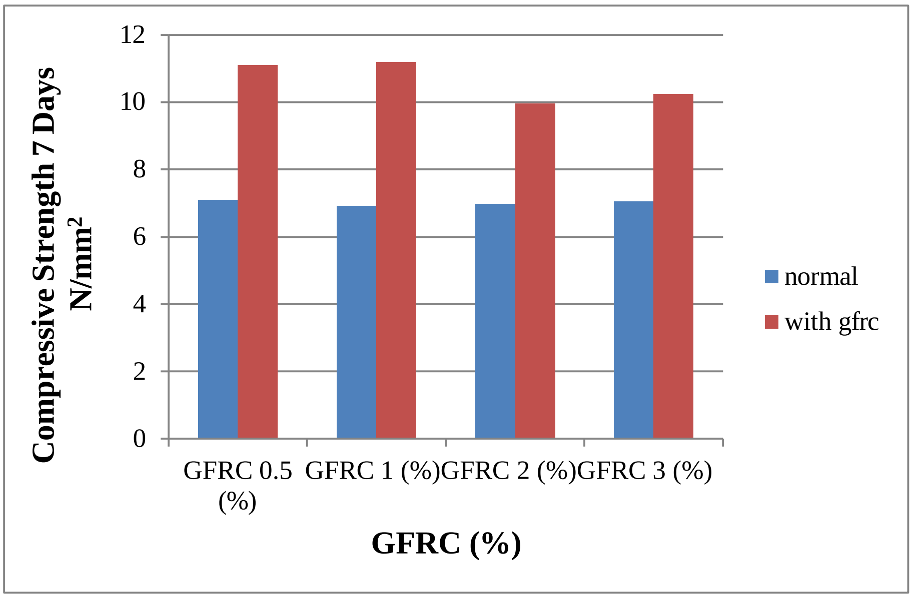

Fig. 4.1 Compressive Strength of Concrete 7 days

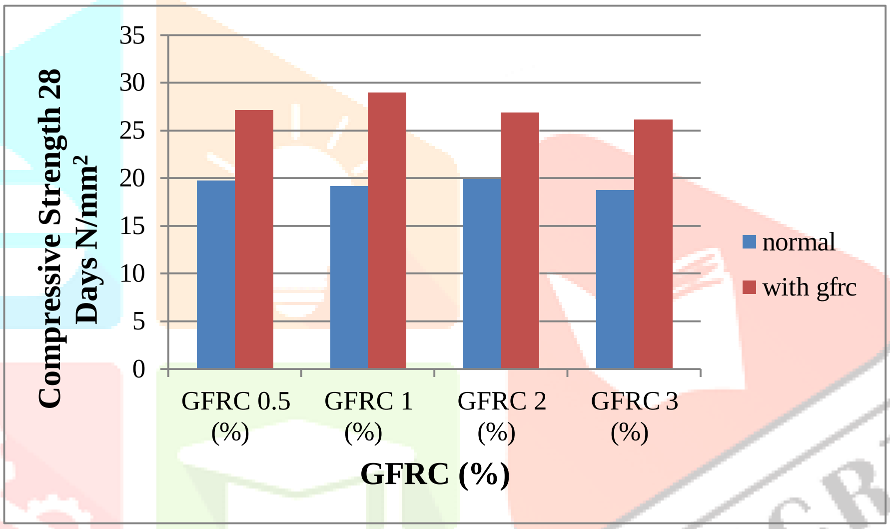

Fig.4.2 Compressive Strength of Concrete 28days

We are mixing glass fiber used in concrete 0.5% to 3% of the weight of cement.

4.1.1 Conclusion

The compressive strength test is a crucial quality control measure in concrete construction, ensuring that the concrete used meets the required strength criteria for structural safety and durability.

As we conclude from the above table that on adding GFRC, the strength of concrete increases.

4.2 Split Tensile Strength Test

The Split Tensile Strength Test determines the tensile strength of cylindrical concrete specimens by applying a compressive load along their length until failure occurs. This method is particularly useful for assessing the performance of materials like Glass Fiber Reinforced Concrete (GFRC).

These results indicate that Specimen B has a higher tensile strength than Specimen A.

S.NO.	M20+GLASSFIBRE	SPLIT TENSILE STRENGTH (N/mm^2) (7 DAYS)	(28 DAYS)
1.	0.5%	1.41	3.40
2.	1%	2.83	3.92
3.	2%	2.62	3.57
4.	3%	2.43	3.42

Table 4.3 Split Tensile Strength

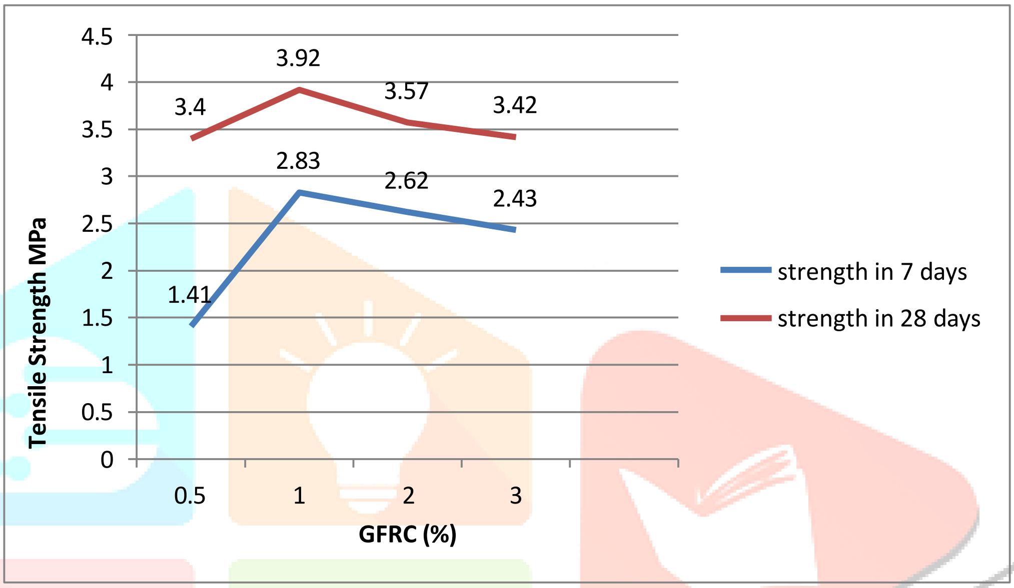

Fig. 4.3Tensile Strength Chart 7and 28 Days With GFRC

At 1% GFRC Tensile Strength is increased and then decreased.

4.2.1 Conclusion

The Split Tensile Strength Test (ASTM C496) is essential for evaluating the tensile properties of GFRC, providing insights into its suitability for various structural applications. By analysing the maximum load at failure and calculating the tensile strength, engineers can make informed decisions about material selection and structural design.

Sample ID	Load at Failure (KN)	Diameter (mm)	Length (mm)
T1	130	150	300
T2	180	150	300

Table 4.4 Split Tensile Strength Test Results

CHAPTER-5

CONCLUSIONS AND FUTURE SCOPE

5.1 Conclusion

After conducting compressive strength**,** split tensile strength**,** and flexural strength and comparing findings with conventional concrete and existing literature, the following conclusions are drawn:

5.1.1 Compressive Strength:

GFRC shows a moderate increase (6–10%) in compressive strength. While not its primary advantage, the inclusion of glass fibers improves crack resistance under axial loads.

5.1.2 Split Tensile Strength:

A significant increase (25–30%) was observed, indicating enhanced resistance to cracking and tensile failure. This makes GFRC highly suitable for infrastructure components prone to tension, such as pavements, curbs, and thin panels.

5.1.3 Flexural Strength:

The most prominent improvement was seen in flexural behavior, with a 30–35% gain over plain concrete. GFRC demonstrated excellent post-crack behaviour, making it ideal for bridge decks, road pavements, and airport slabs.

Property	**Improvement in GFRC**	**Discussion Point**
Compressive Strength	10-15 % ↑	increase; SIGHTY impact from fibers
Split Tensile Strength	25–30% ↑	Significant; due to fiber bridging
Flexural Strength	30–35% ↑	Major improvement; excellent for pavements and decks
Durability	High	Crack control leads to less maintenance and longer service
Sustainability	Moderate to High	Reduced lifecycle costs and material savings
WORKABILITY	DECRESE	DECRESE DUE TO ADD IN GRFC

TABLE 5.1 SUMMARY OF KEY FINDINGS

5.2 Limitation and Recommendations

(i) Some variability in test results was observed, possibly due to:

(ii) Uneven fiber dispersion

(iii) Manual casting/mixing techniques

(iv) Variations in curing conditions

5.3 Final Conclusions

GFRC can be used wherever a light, strong, weather resistant, attractive, fire retardant, impermeable material is required. It is characterized by many useful properties. Glass Fiber Reinforced Concrete (GFRC) proves to be a highly effective material in enhancing the mechanical performance, durability, and sustainability of concrete used for Sustainable Construction. Its improved tensile and flexural properties make it a smart solution for modern, long-lasting, and eco- friendly construction.