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Evaluation of Mechanical Properties of Glass Fiber Reinforced Concrete (GFRC) for Sustainable Construction

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ABSTRACT

Aim of the Study: Conventional concrete, though widely used, is brittle and prone to cracking due to its low tensile strength. Glass Fiber Reinforced Concrete (GFRC) offers a promising alternative because of its high tensile capacity, crack resistance, and corrosion-free behavior.

Methods: This study investigated the effect of adding alkali-resistant glass fibers (0.1%–1.0% by weight of cement) to Ordinary Portland Cement (OPC, 43 grade). Cube specimens (150 × 150 × 150 mm) were prepared, cured for 7, 14, and 28 days, and tested for compressive strength using a Universal Testing Machine (UTM). Workability was evaluated with a slump test, and durability was assessed through water absorption. Conventional concrete served as the control.

Results: The addition of glass fibers improved compressive strength by up to 12% compared to control samples after 28 days (25.1 MPa vs. 22.4 MPa). GFRC also exhibited better crack resistance and lower water absorption (8.2 kg at 28 days vs. 7.1 kg in the control). However, higher fiber contents reduced workability.

Conclusion: Results confirm that glass fibers act as micro-reinforcements, bridging cracks and redistributing stresses effectively. Optimal performance was observed at around 1.0% fiber content, while higher dosages caused mixing difficulties. GFRC demonstrates strong potential for prefabricated elements, pavements, and repair applications, contributing to sustainable construction by utilizing glass waste. Future research on hybrid fibers and long-term durability is recommended.

Keywords: Glass Fiber Reinforced Concrete (GFRC); Compressive Strength; Workability; Crack Resistance; Sustainable Construction.

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1. INTRODUCTION

The construction industry is one of the fastest-growing sectors worldwide and plays a central role in socio-economic development. At the heart of this industry lies concrete, a material that remains indispensable in modern construction due to its versatility, compressive strength, and cost-effectiveness (Bondok et al., 2023). When new, concrete is a mouldable and workable mix. When it hardens, it becomes a strong and stiff building material. Its versatility and inexpensive cost make it the most used building material in the world (Asif et al., 2025; Yahiaoui et al., 2022).

But even with these benefits, regular concrete has some built-in issues. It is naturally hefty, not very strong against tension and impact, and can break and become brittle when stressed (Gerengi et al., 2024). These flaws have led academics and professionals to seek changes and improvements that can address these issues and extend the lifespan of concrete constructions. Concrete's weakness in terms of tension was eliminated by using reinforced concrete, in which steel bars or meshes are incorporated into the concrete. However, their drawbacks are that steel reinforcement is rusty and prone to rust, it is expensive, and the process creates a high consumption of energy when made (Aladdin, 2024).

Fibre reinforcement is another recent advancement in boosting the strength of concrete during the last few decades. The incorporation of fibres into the Cementitious matrix will lead to the production of Fibre Reinforced Concrete (FRC) that is highly resistant to tension forces and will resist the effects of impacts and crack control (Tibebu et al., 2022). Fibres serve as micro-reinforcements, connecting cracks and preventing them from spreading while under mechanical stress. They also make concrete more ductile and able to absorb energy, changing it from a brittle material to a quasi-ductile composite (Chen et al., 2022).

Glass fibres have gotten a lot of attention among the other types of fibres studied, such as steel, polymer, basalt, and natural fibres. Glass fibres have a high elastic modulus, high tensile strength, low density, and minimal water absorption, which makes them great for use in structures (Dai et al., 2023). Additionally, glass fibres don't rust like steel, which makes reinforced constructions last longer, especially in harsh environments such as maritime applications (Manikandan et al.).

Using glass fibres in building is not a new idea. Glass fibres were first used in mortar and concrete mixes in 1931 to strengthen them (Blazy et al., 2022). These fibres are made by heating molten glass and drawing it through small holes to produce strands of glass, which are then cut into short lengths and are used to reinforce concrete. Also over the years, people have taken to glass fibers as well. This is due to the reasons that they are hardy and long-lasting and because they lend themselves well to considerations for sustainability objectives. Glass fibre waste as a result of the industrial production process is produced in massive quantities and, being dumped in landfills, exerts a negative impact on the environment, therefore a method for using this waste is taking glass fibre in concrete (Demir, 2024).

The application of GFRC (Glass Fibre Reinforced Concrete) has grown dramatically in the last few years in the construction industry. Studies have highlighted its ability to improve toughness, ductility and crack resistance under tensile and flexural loads (Rahman et al., 2022). GFRC - widely used in architectural panels, precast parts, facade systems, and repairs for its lighter weight and improved performance over that of regular concrete (Annamaneni & Pedarla). GFRC is not only used to build stronger buildings, but also to construct sustainable buildings as, without having the steel reinforcement, it requires less energy consumption which reduces the carbon footprint of concrete, industrial waste can be reused (Awaji & Akita, 2024).

Traditional reinforced concrete structures, however, are steel reinforced and difficult to excess cost, provide durability and be eco-friendly. Steel production is extremely energy intensive and contributes significantly to greenhouse gas emissions (Zendaoui et al., 2024). Moreover, reinforced concrete buildings can also have the issue of the corrosion of the steel within them, making their construction less strong and costing more to maintain (Väisänen et al., 2024). Fibre reinforcement, especially using glass fibres, can help solve these problems by making concrete less dependent on steel while keeping or even improving its structural performance.

Sustainability is now a key consideration in the construction of buildings. Using glass fibers in concrete aligns with many of the goals of green construction worldwide. First, it reduces the need for steel, which is a significant source of carbon emissions. Second, it effectively utilizes industrial glass waste, contributing to improved waste management and supporting the concept of a circular economy (Hany et al., 2022). Third, GFRC is more environmentally friendly because it is light, which makes it cheaper to ship and requires less energy. Additionally, GFRC structures often require less maintenance due to their greater resistance to cracking and longer lifespan, which ultimately saves money and resources over time (Lan et al., 2025).

2. LITERATURE REVIEW

The integration of fibres into cementitious composites has been extensively researched as a method to mitigate the intrinsic brittleness of traditional concrete. Multiple studies have examined the impact of various fibres, including glass, steel, polypropylene, coconut, and basalt, on the mechanical and durability characteristics of concrete. Yahiaoui et al. (Yahiaoui et al., 2022) investigated the integration of coconut fibres into earth cement blocks, noting substantial enhancements in post-peak residual strength, ductility, and toughness. Studies by Gerengi et al. (Gerengi et al., 2024) and Väisänen et al. (Väisänen et al., 2024) similarly emphasised the superior performance of glass fibres compared to polymer fibres, indicating that glass fibres, owing to their elevated elastic modulus and tensile strength, typically surpass polypropylene fibres in improving mechanical properties and minimising water absorption. Furthermore, Demir (Demir, 2024) and Annamaneni & Pedarla (Annamaneni & Pedarla) highlighted the preeminence of GFRC in terms of flexural and compressive strength, illustrating its capability to substitute for traditional reinforcement in various structural applications. These studies demonstrate that fibre reinforcing, especially using glass fibres, significantly enhances concrete's tensile properties, crack resistance, and longevity.

Despite these promising findings, consensus in the literature also reveals key challenges. Multiple studies, including those by Tibebu et al. (Tibebu et al., 2022) and Rath et al. (Rath et al., 2017), observed that higher fiber dosages (beyond 1.5–2.0% by weight of cement) tend to reduce the workability of fresh concrete, often leading to clumping and difficulties in compaction. This reduction in workability directly impacts concrete quality if not addressed through admixtures or optimized mix designs. Additionally, several review studies (Zendaoui et al., 2024) consolidated the scattered findings on fiber-reinforced concrete but pointed out inconsistencies in determining the optimum dosage of glass fibers. Some experimental works, such as those of Hany et al. (Hany et al., 2022), found that only 0.10% fiber content improved compressive strength, whereas others reported performance peaks closer to 1.0–1.5%. These differences highlight the influence of material sources, mix proportions, and testing conditions. Further, most published research was carried out under controlled laboratory settings. As highlighted by Yıldırım and Özhan (Yıldırım & Özhan, 2023), such ideal conditions do not fully replicate field realities, where variables such as environmental exposure, uneven mixing, and large-scale batching can significantly alter GFRC behavior. This creates a gap between laboratory evidence and practical application that must be bridged through region-specific studies.

Recent research in sustainable construction highlights the use of alternative binders and waste by-products to reduce environmental impacts while maintaining structural performance. Biochar derived from rice husk has been shown to produce low-carbon concrete blocks (Javed et al., 2025), while palm oil ash has demonstrated potential as a green cement replacement (Asif et al., 2025). Similarly, wastewater-integrated concrete pavers analyzed with machine learning confirm both performance efficiency and sustainability (Blouch, Kazmi, Metwaly, et al., 2025). Other works on green concrete emphasize improved strength workability balance (Akram et al., 2025), whereas low-grade clay minerals in LC3 composites and locally available resources in concrete design have been validated as cost-effective options (Blouch et al., 2025). Agro-industrial wastes such as bagasse ash and silica fume (Muneer et al., 2025) and hybrid mixes of fly ash and hemp (Arshad et al., 2025) further expand eco-friendly solutions. Beyond materials, renewable energy applications in construction (Ullah et al.) and green finance initiatives (Akrama et al., 2023) are advancing sustainable practices. Together, these studies demonstrate strong progress toward greener construction but also highlight the need for further exploration of fiber-reinforced systems like GFRC, which specifically target strength, crack resistance, and durability improvements within sustainable frameworks.

The reviewed literature also emphasizes the sustainability dimension of fiber reinforcement. Scholars such as Blazy et al. (Blazy et al., 2022) and Lan et al. (Lan et al., 2025) have underlined the potential of utilizing glass fiber waste from industrial processes as a means of reducing landfill disposal and minimizing the carbon footprint of the construction sector. Incorporating waste glass fibers into concrete not only improves mechanical properties but also contributes to the circular economy by reusing materials that would otherwise become environmental liabilities. However, limited research has contextualized this practice in developing countries like Pakistan, where construction industries are expanding rapidly and face challenges of both durability and sustainability. Most studies have been conducted in Europe, East Asia, and North America, where material properties and field conditions differ considerably. Hence, the applicability of global findings to local contexts remains uncertain.

Building upon this literature, the present study identifies three key gaps. First, there is insufficient clarity on the optimum dosage of glass fibers in locally sourced concrete mixes that balances improvements in compressive strength, durability, and crack resistance with acceptable workability. Second, there is limited empirical evidence on the performance of GFRC using Pakistani aggregates, cement types, and curing practices**,** which may differ from results reported internationally. Third, although sustainability has been highlighted in prior works, few studies have systematically examined the dual benefit of mechanical enhancement and waste reduction when glass fibers are used as reinforcement.

To address these gaps, the research pursues the following objectives: (i) to investigate the effect of varying percentages of alkali-resistant glass fibers (0.1%–1.0% by weight of cement) on the compressive strength, durability, and workability of concrete; (ii) to compare the performance of GFRC with conventional concrete through standardized tests such as slump, water absorption, and compressive strength; (iii) to establish the optimal dosage of glass fibers for balancing mechanical performance with fresh concrete workability; and (iv) to highlight the role of GFRC in sustainable construction by utilizing industrial glass waste.

The significance of this research lies in both its scientific and practical contributions. Scientifically, the study expands the understanding of fiber–matrix interactions in a local context, validating whether global findings on GFRC hold true under Pakistan's construction conditions. It also contributes to composite material science by pinpointing the saturation point at which fiber addition ceases to deliver proportional benefits. Practically, the study offers the construction industry a viable pathway to reduce dependence on steel reinforcement, extend the lifespan of infrastructure, and lower maintenance costs through improved crack resistance. From a sustainability perspective, the research promotes green building practices by repurposing industrial waste, lowering carbon emissions associated with steel production, and enabling lightweight prefabricated systems that reduce transportation energy. GFRC's adaptability also makes it suitable for modular construction, pavements, seismic applications, and repair works, all of which are highly relevant to Pakistan's growing infrastructure demands.

In summary, the literature establishes that glass fibers improve the mechanical and durability properties of concrete, but it also highlights unresolved challenges concerning optimum dosage, workability trade-offs, and contextual applicability. This research builds on global insights while addressing localized needs, providing valuable evidence for both academia and industry. By systematically investigating the effects of glass fibers on compressive strength, durability, and workability in Pakistani conditions, the study not only contributes to material science but also supports sustainable construction practices that are vital for future infrastructure development.

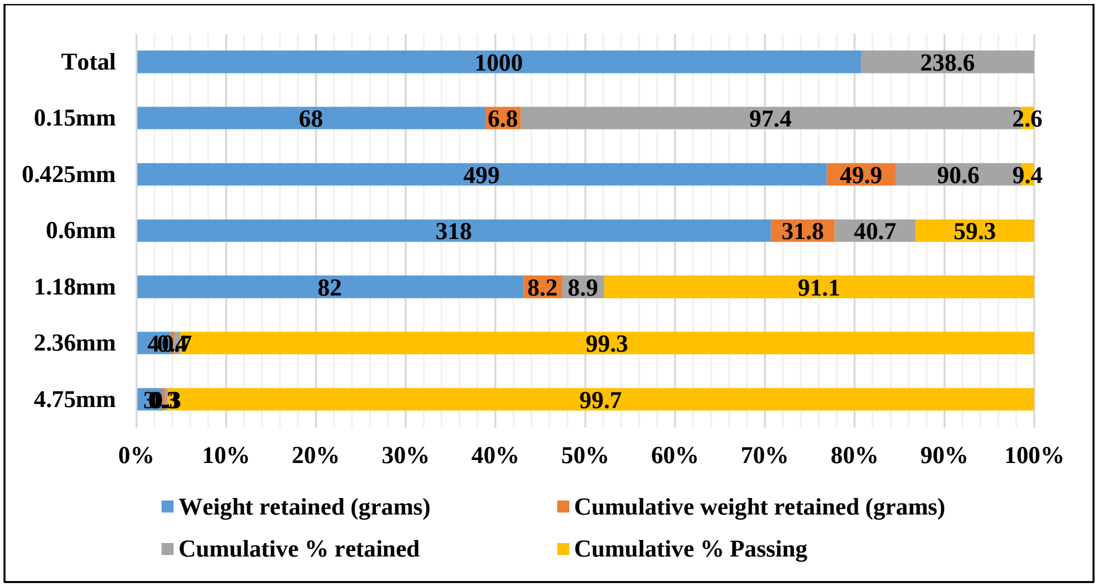
3. MATERIALS & METHODOLOGY

The goal of the experimental program was to investigate the effect of glass fibres on the strength and durability of concrete. The process consists of four key steps: selecting the raw ingredients, mixing them, curing the mixture, and verifying the hardened samples. To ensure that the results could be replicated and were reliable, each stage was conducted according to conventional procedures.

3.1 Materials

Cement: The primary binder used in this investigation was Ordinary Portland Cement (OPC) 43 grade. This grade is commonly used in Pakistan for building purposes because it is strong enough and readily available. The cement met the standards set by ASTM C150 and was tested for fineness, standard consistency, and initial and final setting times to ensure it met the specified parameters.

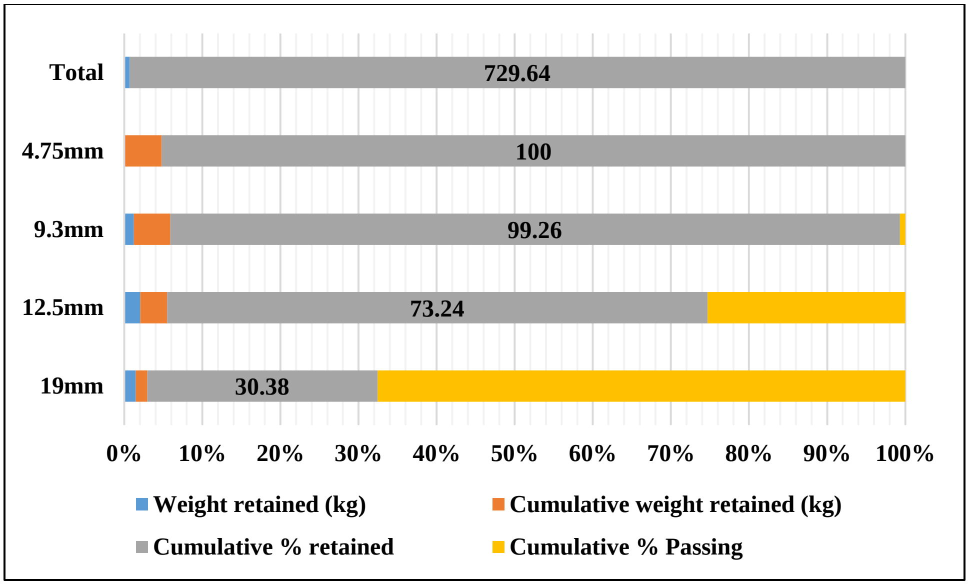
Fine Aggregates: River sand passing through a 4.75 mm sieve was used as fine aggregate. The sand was washed, dried, and tested for fineness modulus, bulk density, and specific gravity in accordance with ASTM C136. The calculated fineness modulus of fine aggregate was 2.38 (Figure 1), which falls within the acceptable range for producing workable concrete.



Fineness modulus of Fine aggregate = 238.6/100 = 2.384

Figure 1. *Sieve Analysis of Fine Aggregate*

Coarse Aggregates: Crushed granite aggregates with nominal sizes of 20 mm and 10 mm were employed in a 60:40 ratio to ensure a dense and well-graded mix. The fineness modulus of coarse aggregate was determined as 7.30 (Figure 2). These aggregates conformed to ASTM C33 requirements, and tests for specific gravity, water absorption, and impact value were conducted before use.



Fineness modulus of Coarse aggregate = 729.64/100 = 7.30

Figure 2. *Sieve Analysis of Coarse Aggregate*

Water: Potable water with a pH of 6.5–7.5 was used for both mixing and curing. Clean water free from impurities is essential for achieving proper hydration of cement and ensuring that no deleterious reactions compromise the concrete's properties.

Glass Fibers: Alkali-resistant (AR) chopped strand E-glass fibers with an average length of 12 mm were used as reinforcement (Figure 3). The physical and mechanical properties of the fibers are presented in Table 1. The fibers were incorporated in dosages ranging from 0.1% to 1.0% by weight of cement.

Figure 3. *Shredded Glass Fibers*

Table 1. *Properties of Alkali-Resistant Glass Fibers*

Property	Value
Tensile Strength	1000–3500 MPa
Elastic Modulus	70–80 GPa
Density	~2.6 g/cm^3
Fiber Length	12 m

3.2 Mix Proportioning & Procedure

The concrete mix was designed following the nominal proportion of 1:2:4 (cement: sand: coarse aggregate) by weight, which is commonly used in structural applications. The water-to-cement ratio was maintained at 0.50 to achieve a balance between workability and strength. Glass fibers were added as a partial replacement for cement by weight, at varying dosages of 0.1%, 0.25%, 0.50%, 0.75%, and 1.0% (Figure 4). Control specimens without fibers were also prepared for comparison. To ensure uniformity in experimentation, all materials were weighed accurately before mixing. The batching process followed ASTM C192, which specifies procedures for making and curing concrete test specimens in the laboratory. The mixing process plays a crucial role in ensuring that fibers are evenly distributed within the concrete matrix. A tilting drum mechanical mixer was used to prepare the batches.

Figure 4. *Dry Mixing of Material*

1. **Dry Mixing:** Cement, fine aggregate, and coarse aggregate were first dry mixed for one minute to achieve uniform distribution.
2. **Fiber Addition:** Glass fibers were then introduced gradually into the dry mix to avoid clumping. The mix was rotated for 2–3 minutes to ensure proper dispersion of fibers throughout the matrix.
3. **Water Addition:** Potable water was added gradually while mixing continued for another 2–3 minutes. A superplasticizer was introduced in small quantities where necessary to enhance workability, as fibers tend to reduce slump.
4. **Final Mixing:** Mixing continued until a homogeneous and workable mix was obtained. Care was taken to avoid overmixing, which may lead to fiber breakage, or undermixing, which could result in poor dispersion and weak bonding.

Figure 5 presents the flow of the mixing procedure.

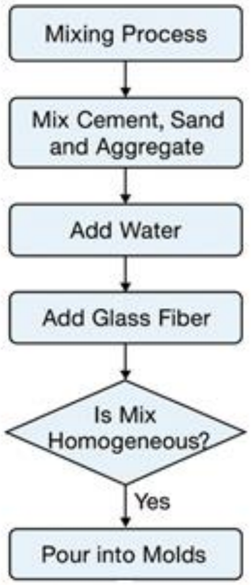


Figure 5. *Schematic diagram of the GFRC mixing process*

3.3 Curing Process

Curing plays a vital role in the development of concrete strength and durability. Specimens were carefully demolded after 24 hours and immediately placed in a water-curing tank maintained at 27 ± 2°C, in accordance with ASTM C511. The curing durations selected were 7, 14, and 28 days, allowing for assessment of strength development over time. Proper curing was especially critical in GFRC, as inadequate hydration could weaken the fiber–matrix bond and reduce the overall effectiveness of the reinforcement. **Figure 6** shows the specimens stored in curing tanks.

Figure 6. *Curing of GFRC cube specimens in a water tank*

3.4 Testing

Three types of tests were conducted to assess the performance of GFRC relative to conventional concrete:

1. Compressive Strength Test

Compressive strength was determined using a Universal Testing Machine (UTM) in accordance with ASTM C39. The cube specimens were tested at 7, 14, and 28 days. The ultimate load recorded by the

UTM was divided by the cross-sectional area of the specimen to calculate compressive strength. Representative results are provided in Section 4.

2. Workability (Slump Test)

Workability was assessed using the slump cone test as per ASTM C143. Fresh concrete was placed into a truncated cone in three layers, tamped 25 times per layer, and the cone was then lifted vertically. The difference between the original height of the cone and the subsided height of the concrete was recorded as the slump. This test provided insight into the effect of fiber addition on fresh concrete properties.

3. Water Absorption Test

Durability was evaluated through water absorption tests. The dry weight of specimens was recorded, after which they were immersed in water for 7, 14, and 28 days. At each curing interval, the specimens were weighed again to measure the increase in mass due to water absorption. This test followed ASTM C642, which specifies methods for measuring water absorption of hardened concrete. Table 2 presents the observed water absorption values.

Table 2. *Water Absorption Results*

Curing Duration	Average Weight (kg)
Without curing	7.1
7 days	7.6
14 days	7.8
28 days	8.2

The experimental program was structured to ensure comparability and reliability. For each fiber percentage, at least three specimens were prepared and tested, and the average values were reported. Control specimens were included in every batch to serve as benchmarks. The experimental framework is summarized in Figure 7.

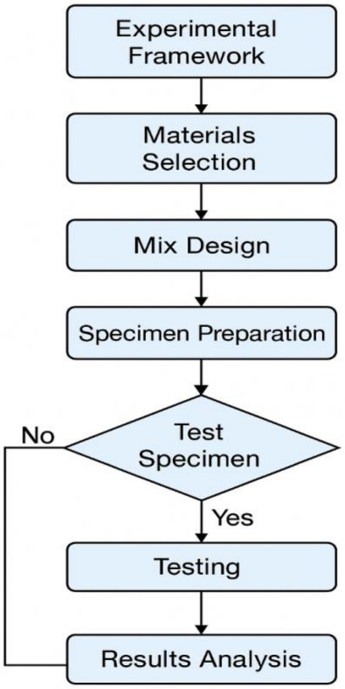


Figure 7. *Flowchart of the experimental framework for the GFRC study*

To ensure the reliability and accuracy of the experimental results, the study employed several quality control measures. We used calibrated digital scales for weighing and batching ingredients to ensure accurate mix proportions. The mixing and casting processes took place in a controlled laboratory environment to minimize outside factors and ensure that all specimens were uniform. Additionally, all testing devices were set up according to the manufacturer's instructions, ensuring that the recorded data was accurate and consistent. To further minimize the risk of random error, each test was performed at least three times, and the average of these readings was used for analysis. These steps, taken together, strengthened the experimental program and made the results more credible.

4. RESULTS

The experimental program collected data on the compressive strength, workability, and water absorption of Glass Fibre Reinforced Concrete (GFRC) in comparison to conventional concrete. This section presents the results, followed by a detailed discussion of their implications, limitations, and connections to previous studies.

4.1 Compressive Strength

After 7, 14, and 28 days of curing, the compressive strength of the cube specimens was measured. The control mix (without fibres) reached an average strength of 22.4 MPa after 28 days. The GFRC specimens, on the other hand, showed incremental improvements as the fibre concentration rose to 1.0%. The best compressive strength was achieved at a 1.0% fibre dose, with an average of 25.1 MPa, which is 12% higher than the control (Figure 8).

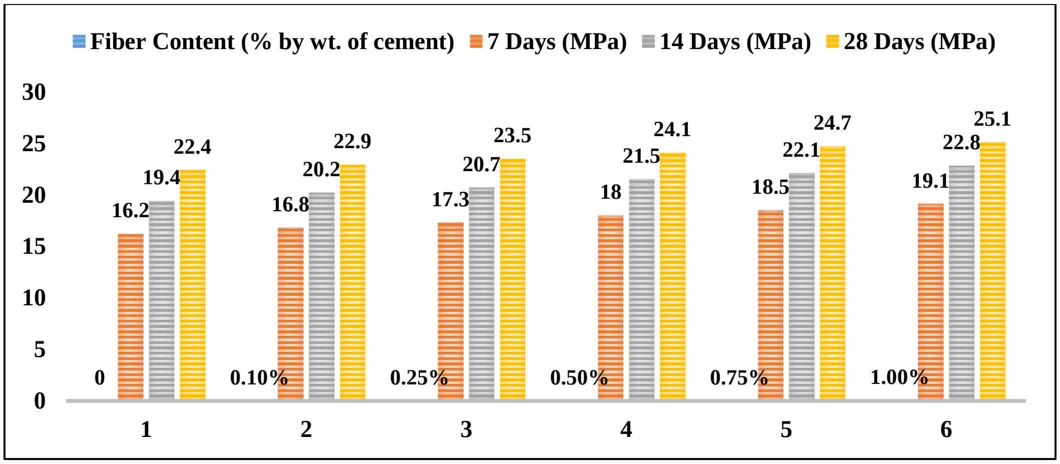


Figure 8. *Compressive Strength Results of GFRC vs. Control*

The results indicate that compressive strength increased with fiber content up to 1.0%. Beyond this dosage, as observed in related studies (Rath et al., 2017; Tibebu et al., 2022), workability problems often occur, which may offset strength gains. The improvement in compressive strength can be attributed to the micro-reinforcement effect of glass fibers, which bridge micro-cracks and prevent their propagation during loading (Wu et al., 2022).

These findings are consistent with prior research by Hany et al. (Hany et al., 2022), who observed optimum compressive strength improvements at low fiber contents (0.10–1.0%). Similarly, Wu et al. (Wu et al., 2022) reported that glass fibers enhance microstructural bonding, leading to improved load redistribution and delayed crack formation. However, unlike steel fibers, which tend to enhance compressive strength more significantly at higher dosages, glass fibers show a saturation point beyond which additional fibers may negatively impact mix homogeneity (Rath et al., 2017).

4.2 *Workability (Slump Test)*

The workability of fresh GFRC was assessed using the slump test. Results demonstrated a clear decline in slump values as fiber content increased (Figure 9).

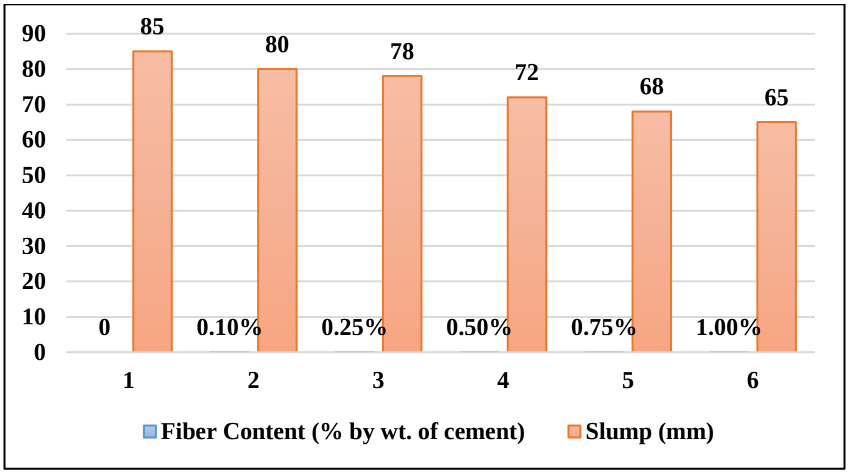


Figure 9. *Slump Test Results*

The control mix exhibited a slump of 85 mm, while the slump of GFRC decreased to 65 mm at 1.0% fiber content. The decline in workability is primarily due to the fibrous network created within the mix, which hinders the free flow of particles and increases internal friction (Tibebu et al., 2022). Fibers also increase the surface area of solids in the mix, demanding more paste for lubrication, thereby reducing overall workability (Devi et al., 2022).

This trend aligns with the observations of Tibebu et al. (Tibebu et al., 2022) and Rath et al. (Rath et al., 2017), who also reported that increasing fiber dosage reduces slump values significantly. In practical applications, reduced workability can pose challenges for placement and compaction, especially in congested reinforcement areas. The use of superplasticizers may be necessary to restore workability without increasing water-to-cement ratio, which otherwise compromises strength.

4.3 *Water Absorption*

Durability was assessed using water absorption tests. Results are summarized in Figure 10.

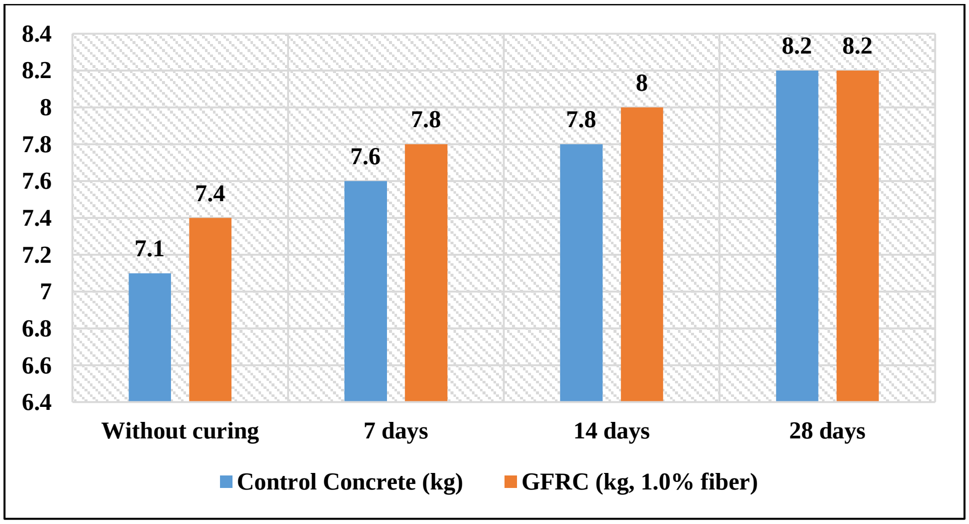


Figure 10. *Water Absorption Results of GFRC Specimens*

GFRC specimens absorbed slightly more water than control specimens during the early stages, likely due to increased porosity at higher fiber contents. However, at 28 days, both control and GFRC showed similar absorption values (8.2 kg). This indicates that, while fibers may initially create additional voids in the mix, adequate curing enables the cementitious matrix to fill these voids, improving long-term durability.

These findings are in partial agreement with Gerengi et al. (Gerengi et al., 2024), who noted that glass fibers, when properly dispersed, reduce water absorption due to improved crack control. However, if fibers clump or are unevenly distributed, localized weak zones may form, slightly increasing permeability (Yıldırım & Özhan, 2023).

5. DISCUSSION

The experimental program aimed to assess the impact of glass fibres on the mechanical and durability characteristics of standard concrete. The outcomes derived from testing of compressive strength, workability, and water absorption indicate significant patterns and consequences for the performance of Glass Fibre Reinforced Concrete (GFRC). A thorough analysis of these data is conducted to determine the advantages, constraints, and prospective applications of this material, as well as a comparison with prior discoveries documented in the literature.

The results for compressive strength show that adding glass fibres made a noticeable difference compared to control specimens that didn't have fibres. The control mix had a strength of 22.4 MPa after 28 days, whereas the mix with 1.0% fibre dosage had a strength of 25.1 MPa, which is about 12% stronger. This gradual increase was observed for curing ages of 7 and 14 days, indicating that fibres contribute to strength development in both the short and long term. The increased compressive strength is mainly due to the fibres acting as micro-reinforcements that fill in the cracks forming in the cementitious matrix. By resisting crack initiation and propagation, the fibers allow for a more uniform redistribution of stresses, thereby improving load-carrying capacity. These observations are supported by earlier studies such as Wu et al. (Wu et al., 2022), who highlighted the ability of glass fibers to enhance microstructural bonding, and by Hany et al. (Hany et al., 2022), who confirmed that even low fiber dosages improve compressive strength, though with variations depending on local materials.

Although the observed improvement in compressive strength was significant, it remained relatively modest compared to the enhancements reported for tensile and flexural strengths in similar studies (Wu et al., 2022). This outcome reflects the intrinsic behavior of glass fibers, which are more effective in tension than in compression. Their ability to arrest microcracks directly translates into better tensile and flexural resistance, whereas the impact on compressive behavior is less dramatic. Nonetheless, a 12% increase in compressive capacity still represents a meaningful improvement, particularly for structural applications where even small strength gains can reduce material consumption or improve safety margins. Importantly, the optimum dosage was found at 1.0%, beyond which strength gains are unlikely due to potential issues of fiber clumping and workability loss, a limitation also highlighted by Rath et al. (Rath et al., 2017).

Workability, as measured by the slump test, showed a consistent decline with increasing fiber content. The control mix recorded a slump of 85 mm, while the mix with 1.0% fibers achieved only 65 mm. This decline is expected, as fibers introduce a network within the mix that hinders flowability and increases internal friction. The fibrous reinforcement also increases the overall surface area that must be coated by the cement paste, thus reducing the mobility of fresh concrete. Tibebu et al. (Tibebu et al., 2022) similarly reported that fiber addition reduces slump significantly, particularly at higher dosages. This reduction in workability presents practical challenges during mixing, placement, and compaction, particularly in heavily reinforced or complex structural forms where adequate flowability is critical. Unless addressed through the use of superplasticizers or optimized mix designs, reduced workability may lead to honeycombing, poor compaction, and eventual reductions in mechanical performance. This finding emphasizes the trade-off between mechanical improvements and practical constructability, a theme repeatedly noted in GFRC research (Devi et al., 2022; Patil & Burile, 2015)

Durability was assessed through water absorption testing. Results revealed that GFRC specimens exhibited slightly higher absorption values than control specimens during early curing stages but converged to similar values after 28 days. At 7 days, GFRC with 1.0% fibers absorbed 7.8 kg of water compared to 7.6 kg in the control, while at 28 days, both reached approximately 8.2 kg. This convergence suggests that although the inclusion of fibers may initially create additional voids or microchannels that increase absorption, proper hydration over time fills these voids, mitigating the effect. This interpretation aligns with Gerengi et al. (Gerengi et al., 2024), who found that well-dispersed fibers reduce water penetration by controlling crack formation, but poorly distributed fibers can create localized weaknesses that increase permeability. In the present study, careful mixing and curing appear to have balanced these effects, resulting in durability performance comparable to conventional concrete at 28 days.

The discussion of results highlights both strengths and weaknesses of GFRC. On one hand, the inclusion of fibers improves compressive strength, enhances crack resistance, and provides comparable durability to conventional concrete when cured properly. On the other hand, the reduction in workability presents a significant drawback, especially for field applications without access to chemical admixtures. The balance between strength enhancement and practical constructability becomes crucial when determining fiber dosage. The optimum identified in this study, around 1.0% by weight of cement, corresponds closely with findings by Wu et al. (Wu et al., 2022) and Rath et al. (Rath et al., 2017), though variations in reported values emphasize the importance of local experimentation.

In broader terms, the results confirm the fundamental mechanism of fiber reinforcement. Fibers act as micro-scale bridges that delay crack initiation and inhibit crack propagation, thereby improving ductility and toughness (Guérin et al., 2018). Even though the compressive strength increase was modest, the qualitative change in failure mode from brittle to quasi-ductile is highly significant. This transformation allows concrete to absorb more energy before failure, which is especially valuable in seismic zones or applications where impact resistance is required. The findings also suggest that GFRC is particularly suited for thin or lightly loaded structural elements such as façade panels, cladding, and overlays, where crack resistance is more critical than high compressive capacity.

The water absorption results further highlight the durability benefits of fibers in crack-sensitive environments. Even though initial absorption was slightly higher, long-term results show that GFRC can resist water ingress as effectively as conventional concrete. This property is critical in environments where moisture-related deterioration, such as corrosion of embedded steel, is a concern. Since glass fibers are non-corrosive, their inclusion further enhances durability in marine or chemically aggressive conditions, where steel-reinforced concrete often suffers premature degradation (Aydın et al., 2021).

Comparing these results with the literature reveals both consistency and divergence. The optimum dosage observed here is similar to that reported by Wu et al. (Wu et al., 2022) and Rath et al. (Rath et al., 2017), who emphasized that beyond 1.0–1.5%, additional fibers provide diminishing returns or even negative effects due to poor workability. However, the modest improvement in compressive strength contrasts with Hany et al. (Hany et al., 2022), who reported notable gains at very low dosages (0.10%). These discrepancies highlight the influence of local materials, aggregate characteristics, and mixing practices. For instance, differences in cement composition, aggregate texture, and curing conditions between Pakistan and other regions may explain variations in fiber performance. This reinforces the argument that local research is necessary to establish reliable guidelines for GFRC application in specific contexts.

The practical implications of these findings are significant. For construction engineers, the modest increase in compressive strength coupled with substantial improvements in crack resistance makes GFRC an attractive material for prefabricated components, pavements, and overlays. Its lightweight nature reduces transportation costs, while its corrosion resistance enhances service life in marine and coastal applications. For policymakers and industry stakeholders, GFRC offers a pathway toward sustainability by reducing reliance on steel reinforcement and utilizing waste glass fibers from industrial processes. This aligns with global efforts to reduce carbon emissions, promote circular economy practices, and extend the lifespan of infrastructure (Blazy et al., 2022; Lan et al., 2025).

Nevertheless, limitations of the study must be acknowledged. The experimental program only investigated fiber dosages up to 1.0% due to expected workability challenges beyond this threshold. Tensile and flexural strength tests, which are critical for fully characterizing GFRC behavior, were not included, limiting the scope of mechanical evaluation. Moreover, the study was conducted under controlled laboratory conditions with small-scale specimens, which do not fully replicate the variability of field construction. Long-term durability under real environmental exposures such as freeze–thaw cycles, chloride penetration, and sulfate attack remains unexplored. Addressing these gaps will require further research.

Looking ahead, several directions for future research are evident. Hybrid reinforcement systems that combine glass fibers with steel, polypropylene, or basalt fibers could yield synergistic benefits, enhancing both tensile and compressive performance while mitigating workability issues. Similarly, integrating supplementary cementitious materials such as fly ash, silica fume, or nano-silica could improve workability and sustainability while reducing cement consumption. Long-term field trials are also essential to validate laboratory findings under real conditions, particularly in regions like Pakistan, where temperature extremes, variable curing practices, and construction methods may significantly affect performance. Furthermore, GFRC’s potential for advanced applications such as 3D printing and modular construction deserves attention, as its lightweight, crack-resistant, and ductile characteristics align well with emerging construction technologies (Ahmadi et al., 2023; Su et al., 2022).

In conclusion, the discussion of results demonstrates that GFRC is not merely a marginal improvement over conventional concrete but a material with transformative potential. By enhancing strength, improving crack resistance, and offering sustainable advantages, GFRC addresses both technical and environmental challenges in the construction industry. While limitations related to workability and large-scale application remain, these can be overcome through optimized mix designs, admixture use, and hybrid approaches. The present study confirms that GFRC, at an optimum dosage of around 1.0%, is a viable and sustainable alternative for Pakistan’s construction sector, with significant implications for both infrastructure performance and environmental sustainability.

6. CONCLUSION

This study investigated the effect of incorporating alkali-resistant glass fibers into conventional concrete, with emphasis on compressive strength, workability, and durability. The results confirm that glass fibers enhance mechanical performance while also contributing to sustainable construction practices.

At 28 days of curing, the control concrete achieved 22.4 MPa, while the mix with 1.0% fibers attained 25.1 MPa, representing a 12% improvement in compressive strength. The improvement was attributed to fibers acting as micro-reinforcements that bridge cracks and redistribute stresses, thereby delaying failure and enhancing ductility. Although the increase in compressive capacity was modest compared to tensile or flexural benefits reported in literature, the results demonstrate the potential of GFRC for structural applications requiring crack resistance and energy absorption. Workability declined steadily with increasing fiber dosage, with slump values reducing from 85 mm in control concrete to 65 mm at 1.0% fiber content. This reduction reflects the fibrous network restricting flow and increasing internal friction. Without the use of admixtures, such loss of workability poses practical challenges during placement and compaction. Durability, assessed through water absorption, showed comparable results between GFRC and control specimens at 28 days. Although initial absorption was slightly higher in GFRC, proper curing reduced the differences, indicating that glass fibers do not compromise long-term resistance to water ingress.

Overall, GFRC offers improved strength, enhanced crack resistance, and satisfactory durability, making it suitable for prefabricated elements, pavements, overlays, and repair works. Its use also aligns with sustainable construction by utilizing industrial glass waste and reducing reliance on steel reinforcement.

7. LIMITATIONS & FUTURE RESEARCH DIRECTIONS

This study was limited to assessing the effects of glass fiber addition on compressive strength, workability, and water absorption, with fiber content restricted to 1.0% due to anticipated mixing and placement difficulties at higher dosages. Beyond 0.5%, the mix became increasingly difficult to handle, exhibiting reduced flowability and uneven dispersion of fibers, which may compromise uniformity and overall quality. Moreover, while early-age performance was encouraging, the long-term durability of GFRC under real environmental conditions remains uncertain and was not addressed within the scope of this work. Scaling up from laboratory-scale mixes to field applications also poses challenges in achieving consistent fiber distribution.

Future investigations should therefore focus on extending the range of fiber dosages and exploring hybrid reinforcement systems that combine glass fibers with steel or polypropylene to optimize strength and ductility. Research on pre-treatment of fibers to improve bonding with the cementitious matrix, as well as the inclusion of supplementary materials such as nano-silica, fly ash, or silica fume, may further enhance both performance and sustainability. Large-scale field trials and long-term durability studies are essential to validate laboratory findings under actual service conditions. Additionally, the development of pre-packed GFRC mixes could provide a practical pathway for improving quality control and facilitating efficient on-site construction.

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