Experimental Analysis of Compressive Strength and Cost Efficiency of Steel and Glass Fiber Reinforced M20 Concrete

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ABSTRACT

This study examines the impact of steel and glass fibers on the compressive strength of M20-grade concrete. Conventional concrete, while widely used, exhibits inherent brittleness and poor tensile performance, often resulting in premature cracking. To enhance its mechanical behavior, two fiber-reinforced concrete mixes were prepared—one incorporating 6% steel fibers and the other 4% glass fibers by weight of

cement. Standard concrete cubes were cast for each mix and subjected to curing periods of 7, 14, and 28 days. Compressive strength was evaluated using a calibrated compression testing machine. The results demonstrated that both steel and glass fibers significantly improved compressive strength compared to the control mix, with steel fibers showing superior performance. These findings offer valuable insights for selecting the appropriate fiber types in concrete applications that require enhanced strength and crack resistance.

INTRODUCTION

The evolving demands of civil infrastructure have encouraged the adaptation of advanced materials to overcome the limitations of traditional concrete. Although conventional concrete is structurally dependable in compression, its poor tensile characteristics and inherent brittleness often result in the development of microcracks, leading to early-age deterioration and reduced service life. These drawbacks can compromise the durability and long-term stability of concrete structures, especially when exposed to fluctuating loads, environmental changes, or shrinkage stresses.

To improve mechanical performance and crack resistance, researchers have explored the integration of discrete reinforcing fibers into the concrete matrix, a method that transforms the brittle nature of concrete into a more ductile, energy-absorbing composite. Known as Fiber-Reinforced Concrete (FRC), this approach enhances the material's resistance to cracking, increases load-carrying capacity after initial failure, and extends the structure's service life under dynamic and static conditions. The effectiveness of fiber reinforcement depends on several factors, including the type, geometry, dosage, and dispersion of the fibers within the mix. Among various fiber types, steel and glass fibers have been recognized for their distinct and complementary contributions to concrete performance. Steel fibers exhibit high tensile strength and excellent bonding characteristics with the cement matrix, significantly improving post-cracking behavior and energy dissipation. In contrast, glass fibers are lighter, chemically inert, and particularly efficient in minimizing shrinkage-related surface cracking due to their high aspect ratio and corrosion resistance. Both fibers offer structural benefits, yet their individual effects on compressive strength in regular-strength concrete—particularly M20 grade—remain a subject worthy of further investigation.

In this experimental study, the focus was placed on evaluating the compressive strength of M20 grade concrete with the independent addition of steel and glass fibers. Two modified mix designs were developed: one incorporating 6% crimped steel fibers and the other 4% alkali-resistant chopped glass fibers, each calculated by the weight of cement. To promote better fiber distribution and improve the density of the cementitious matrix, the volume of 20 mm coarse aggregate was deliberately reduced by 50% in all mixes, including the control. This reduction was aimed at improving the bonding between paste and fibers, thereby enhancing strength development.

Concrete cubes measuring 150 mm × 150 mm × 150 mm were cast for each type of mix—conventional, steel fiber-reinforced, and glass fiber-reinforced. The specimens were cured in water for 7, 14, and 28 days to study strength development over time. The compressive strength of each sample was then evaluated using a calibrated compression testing machine as per IS 516:1959. The results indicated noticeable improvements in compressive strength for both fiber-reinforced mixes compared to the conventional concrete, with the steel fiber mix showing superior performance, particularly at 28 days of curing.

This study contributes to a better understanding of how individual fiber types influence strength properties in medium-grade concrete and highlights the potential of fiber inclusion as a practical method for structural enhancement. Additionally, the modified aggregate content approach presents a promising direction for optimizing mix design to improve fiber dispersion and mechanical performance. These findings may aid engineers and practitioners in selecting appropriate materials and proportions for durable and high-strength concrete in real-world applications.

LITERATURE REVIEW

The integration of fibers into concrete has gained significant attention in the last few decades as a reliable method to enhance the structural performance of cement-based composites. While traditional concrete offers good compressive strength, it often fails under tension and exhibits brittle failure modes. Fiber-reinforced concrete (FRC) has emerged as a practical solution to overcome these limitations by improving ductility, crack resistance, and overall mechanical behavior. Among various types of fibers investigated, steel and glass fibers have shown consistent effectiveness in modifying the performance of concrete and have become the most researched options in structural and infrastructural applications[1], [3].

Steel fibers are widely used in concrete reinforcement due to their high tensile strength, toughness, and bonding capabilities with the cement matrix. Their inclusion enhances energy absorption capacity and residual strength after cracking. Banthia and Trottier (1995) demonstrated that steel fiber-reinforced concrete exhibits superior post-crack load-bearing capacity, largely due to the mechanical interlock and bond provided by deformed steel fibers. Similarly, Sivakumar and Santhanam (2007) found that steel fibers added in the range of 1% to 3% by volume significantly improved not only compressive strength but also toughness and impact resistance in high-strength concrete [10], [11], [12].

Glass fibers, in contrast, are primarily valued for their lightweight nature, resistance to corrosion, and ability to mitigate shrinkage-induced surface cracks. Their chemical stability and insulating properties make them suitable for architectural applications and environments with high moisture exposure. Zollo (1997) reported that adding glass fibers up to 1.5% by volume can lead to noticeable improvements in flexural and tensile strength without adversely affecting the workability of concrete. Bentur and Mindess (2007) further emphasized that alkali-resistant (AR) glass fibers are effective in improving early-age crack resistance due to plastic shrinkage, making them ideal for overlays and thin-section concrete elements [8], [9].

While most studies have independently assessed the impact of steel and glass fibers, hybrid fiber systems have also been explored. These combinations aim to utilize the distinct advantages of each fiber type, providing synergistic benefits in terms of both micro- and macro-crack control. For instance, Jagtap et al. (2019) investigated a hybrid mix containing steel and glass fibers in M30 grade concrete and observed a 25% increase in compressive strength over the conventional mix. However, in contrast to such hybrid studies, the current investigation isolates the effects of each fiber type to offer clearer insight into their individual contributions to M20 grade concrete—an area where fewer studies exist[17].

Some researchers have specifically focused on the structural implications of fiber-reinforced concrete under different curing durations. Song and Hwang (2004) studied the development of mechanical properties over time in steel fiber-reinforced concrete and found significant strength gains between 7 and 28 days of curing, indicating enhanced long-term durability. Likewise, Panda and Balasubramanian (2017) evaluated the durability performance of both steel and glass fiber concretes and highlighted that the long-term resistance to water penetration and chloride attack was significantly better than conventional concrete, especially when fiber dispersion was uniform[12], [22].

Another essential aspect in fiber-reinforced mix design is the distribution and orientation of fibers, which greatly affects the mechanical response. According to Afroughsabet and Ozbakkaloglu (2015), uniform fiber distribution plays a critical role in crack bridging efficiency and energy dissipation during load application. In many experimental setups, including the present study, adjustments to mix design—such as reducing the volume of coarse aggregates—can improve fiber dispersion. Reducing the size or quantity of coarse aggregates allows for a more homogeneous cement matrix, which facilitates better bonding between fibers and cement paste. This approach aligns with findings from Li (2003), who demonstrated that matrix refinement enhances the fiber-matrix interaction and improves strength characteristics[13], [18].

The compressive strength of concrete, being a fundamental property for structural design, is frequently used as a benchmark for evaluating the effectiveness of fiber reinforcement. Nataraja et al. (1999) concluded that the addition of steel fibers increased the peak and post-peak compressive stress levels, particularly in medium-strength concrete. Glass fibers, while not as effective as steel fibers in increasing compressive strength, provide superior surface integrity and early crack resistance (Daniel et al., 2018). The distinct behavior of these two fiber types reinforces the need to evaluate them independently, especially in common grades like M20, which are extensively used in general construction [15], [27], [9].

Despite the benefits, practical implementation of fiber-reinforced concrete still faces challenges in terms of workability, fiber clumping, and cost. As noted by Rajak et al. (2019), the dosage and type of fiber must be optimized based on the intended structural function, cost constraints, and environmental conditions. The present study contributes to this ongoing discourse by experimentally assessing the compressive strength performance of M20 grade concrete with separately incorporated steel and glass fibers. Through controlled curing and mix adjustments, such as a 50% reduction in 20 mm coarse aggregate content, the research aims to offer applicable insights into how each fiber type influences compressive behavior over short- and medium-term durations [25], [17], [13].

RESEARCH OBJECTIVES

1. To evaluate the individual effects of **steel and glass fibers** on the **compressive strength** of M20 grade concrete.
2. To design and prepare **fiber-reinforced concrete mixes** using 6% steel fibers and 4% glass fibers by the weight of cement.
3. To investigate the **strength development** of concrete specimens cured for **7, 14, and 28 days**.
4. To analyze how the **reduction of coarse aggregate** (by 50%) influences **fiber dispersion** and overall strength performance.
5. To compare the performance of **steel fiber** and **glass fiber** concrete mixes with **conventional (control) concrete**.
6. To study the behavior of fiber-reinforced concrete in terms of **crack control and matrix density** resulting from different fiber types.
7. To provide practical insights on the **suitability of steel and glass fibers** for construction applications requiring improved strength and durability.
8. To compare the cost of steel fiber–reinforced and glass fiber–reinforced concrete by evaluating the total material cost per cubic meter and determining the cost–benefit ratio relative to compressive strength improvement.

Methodology

1. This experimental study was undertaken to investigate the influence of steel and glass fibers on the compressive strength of M20 grade concrete. The materials used included Ordinary Portland Cement (OPC) of 43 grade, natural river sand as fine aggregate, 20 mm nominal size crushed coarse aggregate, potable water for mixing and curing, and two types of discrete fibers—crimped steel fibers and chopped alkali-resistant glass fibers.
2. Three distinct concrete mixes were prepared:
3. **Control mix (conventional concrete)** – without any fibers
4. **Steel Fiber-Reinforced Concrete (SFRC)** – containing 6% steel fibers by weight of cement
5. **Glass Fiber-Reinforced Concrete (GFRC)** – containing 4% glass fibers by weight of cement
6. The mix design was based on IS 10262:2019 guidelines, targeting M20 grade concrete with a water–cement ratio of 0.50. To ensure optimal dispersion of fibers and improve matrix density, a deliberate adjustment was made to the aggregate proportions: the quantity of 20 mm coarse aggregate was reduced by 50% across all mixes. This modification was aimed at enhancing paste content and achieving a more uniform distribution of fibers within the cementitious matrix.
7. All materials were measured by weight and mixed using a mechanical mixer to ensure consistency and homogeneity. For each mix type, a total of **nine standard cubes** were cast using steel molds, each having dimensions of 150 mm × 150 mm × 150 mm. The mixing procedure involved first blending dry materials (cement, sand, aggregates, and fibers) followed by the gradual addition of water to achieve the desired workability.
8. After casting, the concrete cubes were demolded after 24 hours and transferred to a curing tank containing clean water maintained at room temperature. Three cubes from each mix were designated for testing at each of the following curing intervals: **7 days, 14 days, and 28 days**. This curing schedule allowed for the assessment of both early-age and later-age compressive strength development.
9. The compressive strength of each specimen was evaluated using a calibrated **Compression Testing Machine (CTM)** in accordance with **IS 516:1959**. The load was applied gradually and uniformly until failure, and the maximum load at failure was recorded for each specimen. The average compressive strength for each mix and curing duration was calculated based on the results of three tested cubes.
10. Throughout the casting and curing process, standard procedures were followed to avoid segregation, ensure proper compaction, and minimize errors due to external variables. Special care was taken during the incorporation of fibers to avoid clumping and to maintain uniform distribution across all specimens.
11. This methodology was designed to isolate the effect of fiber type on concrete performance while keeping all other parameters constant. By introducing a controlled reduction in aggregate content and carefully regulating curing conditions, the study aimed to produce reliable and comparable data that could highlight the effectiveness of steel and glass fibers in improving the compressive strength of concrete.

COST ANALYSIS OF FIBER-REINFORCED CONCRETE

This section presents a comparative cost analysis of conventional concrete, steel fiber–reinforced concrete (SFRC), and glass fiber–reinforced concrete (GFRC). Market rates were considered based on bulk-order prices commonly available in the Nagpur and Maharashtra region to provide realistic and economical cost estimates.

The cost of concrete production per cubic meter was calculated using the material quantities derived from the M20 mix proportion and the fiber dosages used in this study. A 50% reduction in 20 mm coarse aggregate was consistently applied across all mixes, as adopted in the experimental design. Material rates used for this cost evaluation are as follows:

- Cement (OPC 43 grade): ₹ 320 per bag (₹ 6.4 per kg)

- Fine Aggregate (River Sand): ₹ 850 per tonne
- Coarse Aggregate (20 mm): ₹ 700 per tonne
- Steel Fibers (crimped): ₹ 65 per kg (bulk rate)
- Glass Fibers (alkali-resistant): ₹ 120 per kg (bulk rate)

Cement content for M20 concrete was taken as approximately 400 kg per m³, resulting in a steel fiber dosage of 24 kg (6% by weight of cement) and a glass fiber dosage of 16 kg (4% by weight of cement).

A detailed cost comparison for each mix is shown in Table .

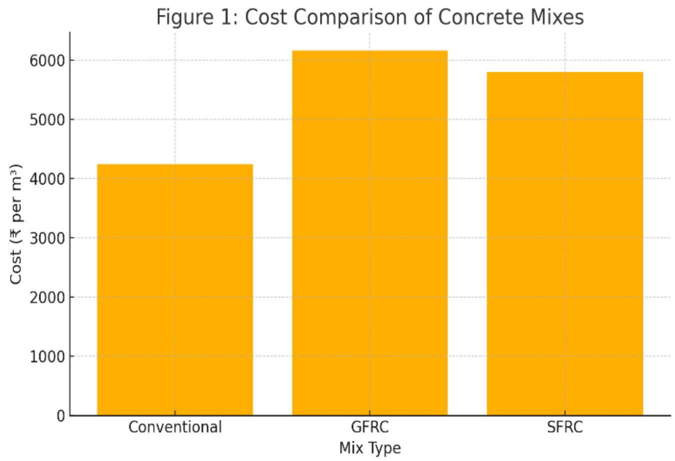


Table : Cost Comparison of Concrete Mixes (Per m³)

Mix Type	Cement Cost (₹)	Sand Cost (₹)	Coarse Aggregate Cost (₹)	Fiber Cost (₹)	Total Cost (₹ / m³)
Conventional Concrete	2,560	1,190	490	—	**4,240**
Glass Fiber Concrete (GFRC)	2,560	1,190	490	1,920	**6,160**
Steel Fiber Concrete (SFRC)	2,560	1,190	490	1,560	**5,800**

Interpretation

- The addition of fibers increases the overall cost per cubic meter compared to conventional concrete.
- Steel fibers have lower material cost than glass fibers, making SFRC more economical despite higher strength gains.
- GFRC, while costlier than SFRC, provides improved crack resistance and surface durability.
- SFRC provides the best cost-to-strength ratio, as its 25.6% improvement in compressive strength comes at a modest cost increase.

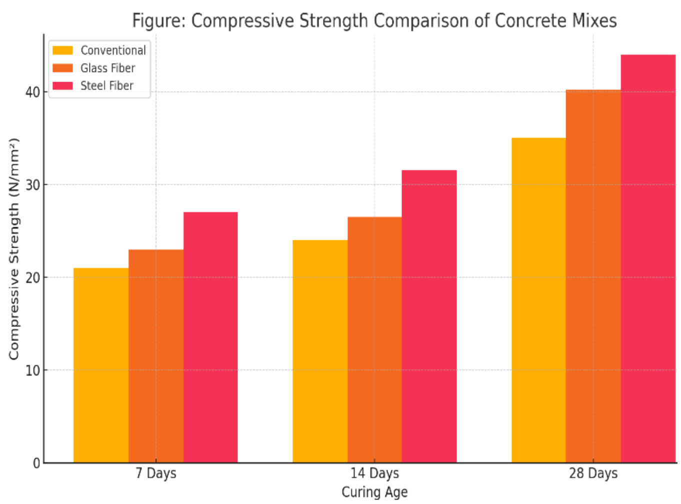
RESULTS

The experimental results of the compressive strength tests for conventional concrete, steel fiber-reinforced concrete (SFRC), and glass fiber-reinforced concrete (GFRC) at different curing ages are presented in Table 1 and illustrated in Figure 1. A total of 27 cubes were tested, with three specimens per mix type evaluated at each curing period (7, 14, and 28 days).

Compressive Strength Comparison of Concrete Mixes

Mix Type	7 Days	14 Days	28 Days
Conventional Concrete	**21.00**	**24.00**	**35.00**
Glass Fiber Concrete	**23.00**	**26.50**	**40.24**
Steel Fiber Concrete	**27.00**	**31.50**	**43.98**

Each value represents the average of three cube samples tested using a Compression Testing Machine (CTM) in accordance with IS 516:1959.



DISCUSSIONS :

The experimental findings demonstrate a clear enhancement in compressive strength for both steel and glass fiber-reinforced concrete (SFRC and GFRC) compared to conventional concrete. The results validate the hypothesis that the inclusion of fibers, particularly steel fibers, significantly improves the mechanical behavior of concrete under compression. The strength development was monitored over three curing periods—7, 14, and 28 days—and the results consistently favored the fiber-reinforced mixes.

At 7 days, SFRC achieved a compressive strength of 27 N/mm², indicating a 28.5% increase over the conventional mix, which recorded 21 N/mm². GFRC also demonstrated improved performance, reaching 23 N/mm², approximately 9.5% higher than the control mix. These early-age strength gains are largely attributed to the fiber-matrix interaction, where fibers bridge micro-cracks and inhibit their propagation, resulting in better load transfer within the matrix. The performance of SFRC at early ages is particularly noteworthy, suggesting enhanced matrix integrity and crack resistance even before complete hydration has occurred.

At the 14-day mark, the trends observed at 7 days were further reinforced. SFRC attained a strength of 31.50 N/mm², compared to 24.00 N/mm² in the control mix—reflecting a strength gain of nearly 31.25%. GFRC reached 26.50 N/mm², also showing a significant increase of around 10.4% from the control. The ongoing hydration process likely contributed to improved fiber-matrix bonding, while the uniform fiber distribution aided in better crack control and stiffness. The reduction in 20 mm coarse aggregate by 50% across all mixes also played a crucial role. This reduction increased paste volume, promoted better fiber dispersion, and minimized voids, all of which contributed to a denser and more homogeneous concrete matrix.

At 28 days, the differences in compressive performance became even more prominent. The control mix reached 35.00 N/mm², GFRC achieved 40.24 N/mm², and SFRC attained the highest value of 43.98 N/mm². These results translate to a 14.9% strength gain for GFRC and a 25.6% gain for SFRC over the conventional mix. The considerable increase in strength in SFRC at 28 days is due to the superior mechanical properties of steel fibers, such as high tensile strength, stiffness, and strong mechanical anchorage. These properties enable the fibers to absorb more energy and resist both initiation and widening of cracks under compressive loading.

Glass fibers, although not as mechanically strong as steel fibers, still contributed positively to the overall compressive behavior of the concrete. Their contribution is more prominent in terms of reducing surface micro-cracks, controlling plastic shrinkage, and improving early-age performance. Their chemical resistance and lightweight nature make them more suitable for applications where corrosion and weight are critical considerations.

The improved performance of the fiber-reinforced mixes also suggests a better stress distribution and post-cracking behavior, which conventional concrete lacks. Moreover, the tailored mix design, especially the reduction of larger aggregate particles, likely enhanced the interaction between the cement paste and fibers. This allowed for more uniform stress flow and less stress concentration around coarse aggregates, which is a common issue in traditional mixes.

It is important to note that although fiber addition improved strength, it may also influence workability. The increase in fiber content and paste volume can lead to stiff mixes, potentially requiring superplasticizers or adjustments to maintain desired workability in field applications.

Overall, the experimental results confirm that steel fibers are more effective in improving compressive strength than glass fibers for M20 grade concrete. However, both types of fibers offer structural and durability benefits. These findings can inform practical decisions on material selection in civil infrastructure, particularly where improved strength and crack resistance are required. The study also provides useful insights for optimizing mix designs that include fibers without compromising concrete performance or constructability.

Cost–Benefit Discussion

The cost analysis reveals that steel fiber–reinforced concrete is more economical compared to glass fiber–reinforced concrete when evaluated on a cost-per-strength-gain basis. While GFRC shows a 14.9% increase in compressive strength over the control mix, SFRC achieves a significantly higher 25.6% improvement. Despite both mixes exhibiting higher material costs than conventional concrete, the increase in cost is moderate when considered against the improvement in mechanical performance. SFRC offers the highest value, providing superior strength enhancement at a lower fiber cost, whereas GFRC remains advantageous for applications requiring enhanced crack control and surface durability.

Conclusion:

This experimental investigation evaluated the impact of steel and glass fibers on the compressive strength of M20 grade concrete. By incorporating 6% steel fibers and 4% glass fibers (by weight of cement) into separate mixes, and curing specimens over 7, 14, and 28 days, a comprehensive comparison was achieved. Additionally, a 50% reduction in 20 mm coarse aggregate content was introduced across all mixes to enhance fiber dispersion and matrix uniformity.

The results confirmed that both fiber types significantly enhanced the compressive strength of concrete compared to the conventional control mix. Steel fiber-reinforced concrete exhibited the highest strength gain, with a 28-day compressive strength improvement of approximately 25.6%, attributed to the high tensile resistance and bridging capacity of crimped steel fibers. Glass fibers also demonstrated a notable 14.9% improvement, contributing positively to early-age crack resistance and durability, particularly under moisture-sensitive conditions.

The study confirms that while steel fibers are more effective in enhancing compressive strength, glass fibers offer a lightweight, corrosion-resistant alternative with moderate strength benefits. This insight is especially valuable for infrastructure applications where specific mechanical performance, durability, or cost considerations dictate material choices.

Furthermore, the study highlights the practical advantages of modifying mix proportions—particularly reducing larger aggregates—to improve fiber distribution and mechanical behavior in fiber-reinforced composites. The clear differentiation between steel and glass fiber performance in a standard M20 concrete mix under uniform curing conditions adds novel value to existing research, especially in the context of general-purpose construction in developing regions.

Future research may expand on this foundation by incorporating other mechanical properties such as flexural and tensile strength, examining the durability under aggressive environmental conditions, or exploring hybrid fiber combinations. Additionally, life-cycle cost analysis and scalability for field implementation would further enhance the practical relevance of fiber-reinforced concrete in structural applications.

Cost Comparison Conclusion

The cost evaluation confirmed that steel fiber–reinforced concrete is the most economical option, offering the highest compressive strength gain at a relatively lower fiber cost. Although glass fiber–reinforced concrete is slightly more expensive, it provides valuable benefits in terms of crack resistance and durability. Overall, the cost–benefit analysis supports the use of steel fibers for strength-critical applications and glass fibers for durability-focused applications.

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