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An Experimental Study on Determining the Strength Properties of FRC with Numerous Mix Proportions

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Abstract— **Extensive research is being conducted globally on incorporating fibres into concrete to enhance its mechanical properties. This study aims to evaluate the strength characteristics of fibre-reinforced concrete (FRC) with varying mix proportions. 18 concrete samples of M-25 grade were prepared, incorporating different percentages of steel and glass fibers. Six samples contained glass fibres (GF) at 5%, 10%, and 15% by weight of cement, and six contained steel fibres (SF) at the same percentages. Additionally, two samples were prepared with a combination of 5% glass fibres and 10% steel fibres and two samples with 10% glass fibres and 5% steel fibres. These were compared to a control sample without fibre reinforcement. The compressive strength of the FRC was assessed at 7 and 28 days. The findings indicate that higher percentages of glass fibers had a notably negative impact on compressive strength, while the inclusion of steel fibers had a comparatively lesser effect. The maximum compressive strength was observed by including 5% steel fibres at 28 days. However, increasing the fiber content beyond this percentage resulted in a reduction in compressive strength. The lowest compressive strength was recorded in samples containing 15% glass fibers at 28 days.**

Index Terms— **Concrete, Glass fibres, Steel fibers, Compressive strength, Fiber Reinforced Concrete (FRC)**

I. Introduction

Concrete's inherent brittleness and low tensile strength necessitates reinforcement to enhance its mechanical properties, particularly compressive strength. Fiber reinforcement has emerged as a crucial method to address these limitations, with various fibers being employed to improve performance. Steel fibers are widely used due to their ability to increase compressive strength by up to 20%, making them ideal for structural applications [1-5]. On the other hand, Polypropylene fibers, while offering moderate improvements, are valued for their resistance to cracking and shrinkage [6-8]. Conversely, Glass fibers, though limited by brittleness, contribute to moderate strength improvements and are often used in non-structural applications [9-10]. There has also been a surge recently in use of natural fibers in the production of concrete, such as bamboo and sisal, with an aim to provide a sustainable alternative, enhancing strength when optimally added however due to excessive water retention issue, strength properties outputs are very unreliable [11]. The table 1 below shows the current state of knowledge regarding the use of different types of fibers in concrete.

TABLE I
State of the Art Regarding Fiber Usage in Concrete Production

Fiber Type	Compressive Strength Improvement	Challenges
Steel	Up to 20%	Increased weight, cost
Polypropylene	Up to 6.92%	Environmental concerns
Natural (Bamboo, Sisal)	Optimal at 1.5% addition	Lower workability
Glass	Moderate improvement	Brittle, limited structural use

Steel fibers have gained significant popularity in recent years due to their numerous advantages, leading to their widespread use in various applications as both primary and secondary reinforcement in concrete. Common applications include slab tracks, slabs on grade, heavy pavements, precast elements, and shotcrete linings. The uniform distribution of steel fibers throughout the concrete matrix enhances the material's shear strength, impact resistance, fatigue strength, and flexural properties, as evidenced by several studies [12-16].

Since the first documented used in Russia [17], Glass fibers have gained prominence as a reinforcing material in cementitious composites due to their distinctive properties. Plain concrete, characterized by its brittle nature, low tensile strength, and limited ductility, is prone to cracking under tensile stress [18]. The introduction of glass fibers into concrete matrices has been shown to improve its tensile performance and mitigate shrinkage-induced cracking significantly. In addition to enhancing the mechanical properties of concrete, glass fibers offer several practical advantages. They are alkali-resistant, lightweight, and exhibit substantial tensile strength, positioning them as a favorable alternative to traditional steel reinforcement in specific applications as longitudinal bars [19]. Glass fibers have also found widespread use in architectural and ornamental concrete applications, where their lightweight nature, combined with considerable strength, allows for the development of structurally sound and aesthetically versatile elements [20].

This study focuses on the combined effects of use of locally available steel and glass fibers on the compressive strength of concrete, addressing a significant gap in current research. By integrating these fibers, the research aims to enhance compressive strength, leveraging the high tensile properties of steel and the lightweight nature of glass. This synergy could lead to more robust concrete formulations, offering improved performance for structural applications. The findings are expected to provide valuable insights into optimizing fiber-reinforced concrete, contributing to advancements in construction materials. This study also underscores the potential of multi-fiber strategies to revolutionize concrete technology.

II. Materials

Pioneer cement OPC of grade 53 was utilized in this study, with its physical properties conforming to ASTM C192 [21], as detailed in Table 2. Fine aggregate in the form of sand, with a specific gravity of 2.65 and passing through a 4.75 mm sieve, was employed for the concrete mix. Potable water with a pH of 6.5 and a hardness of 120 mg/L was used in the preparation of the concrete, while coarse aggregate with a nominal size of 19 mm was incorporated.

TABLE 2
Physical properties of cement

Test	Test Results	ASTM Specification
Normal Consistency	29.5%	25-35%
Initial setting time	90 minutes	>30 minutes
Final setting time	320 minutes	<600 minutes
Specific Gravity	3.15	3.1-3.15

A. Glass Fiber (GF)

Glass fibers are produced through the homogeneous melting of various raw materials under high temperatures, as illustrated in Figure 1. For this experimental research, glass fibers with a length of 40 mm and a diameter of 0.016 mm were utilized. These fibers are characterized by high flexibility and strength. The incorporation of glass fibers in concrete has been shown to reduce bleeding in the concrete mix, thereby improving its overall workability and performance.

B. Steel Fiber

Various types of steel fibers are commercially available, including round and rectangular steel fibers, with round fibers being the most commonly used. These fibers typically have a diameter starting from 0.25 mm. In this experimental study, steel fibers with a length of 40 mm were employed. These small metal reinforcements, as depicted in Figure 2, are added to concrete to enhance its mechanical properties, including strength, durability, and crack resistance.

Fig. 1. Glass Fibers

Fig. 2. Steel Fibers

III. Experimental investigation

A. Concrete Mix Design

The mixing of concrete is a critical stage in the production process, influencing the overall quality and performance of the final product. In this study, an M-25 grade concrete mix was prepared following the guidelines outlined in ACI 211.1 [22]. The components—cement, sand, water, coarse aggregates, and fibers—were combined thoroughly until the mixture achieved a uniform consistency, as illustrated in Figure 3. A powered mixer was utilized to ensure comprehensive and consistent blending of the materials. Water was incrementally introduced to attain the desired workability and consistency of the concrete mix.

Fig. 3. Concrete Mix Preparation

B. Cylinder Casting

Cylinders for the experimental work were cast using 150x300 mm molds, as depicted in Figure 4. The molds were securely sealed on all sides to prevent any leakage. The mixed materials were carefully poured into the molds in three distinct layers to ensure uniform filling throughout the entire depth. Each layer was thoroughly compacted to achieve optimal density and to minimize air voids, thereby enhancing the quality and reliability of the concrete specimens.

Fig. 4. Cylinder Casting

C. Curing of Concrete

Curing is a critical step in the concrete process, as it ensures the development of adequate strength and durability. Without proper curing, concrete may fail to achieve its intended strength and may be prone to cracking due to insufficient moisture. After 24 hours of casting, the concrete specimens were placed in a curing tank, as illustrated in Figure 5. Proper curing was maintained for a standard duration of 7-28 days to ensure that the specimens remained adequately hydrated and to facilitate optimal strength development.

Fig. 5. Cylinder Curing

D. Compressive Strength:

Compression tests were conducted using a Compression Testing Machine (CTM), as depicted in Figure 6, on concrete samples of 150x300 mm cylinders with varying ratios of steel and glass fibers. The tests were performed at 7 and 28 days of curing, in accordance with ASTM C39/C39M-21 [23]. The CTM was operated at a loading rate of 0.25 MPa/s ± 0.05 MPa/s, ensuring a continuous and shock-free application of load, as specified by the standard. The ultimate load carried by each specimen during the test was recorded, and the compressive strength was calculated using the appropriate formula provided by ASTM C39/C39M-21 [23]. Table 3, 4 and 5 demonstrate the results obtained from the tests performed.

$$f_{cm} = \frac{4000P_{max}}{\pi D^2} \tag{1}$$

Whereas,

f_{cm} = Compressive strength, MPa

P_{max} = Maximum load, kN

D = Average measured diameter, mm

Fig. 6. Compression Testing Machine

TABLE 3
COMPRESSIVE STRENGTH OF CONCRETE WITH STEEL FIBERS (SF)

Sr#	% of SF	7 days Compressive strength in MPa	28 days Compressive strength in MPa
1	0	16.31	27.87
2	5	19.67	30.27
3	10	17.82	28.93
4	15	17.07	26.68

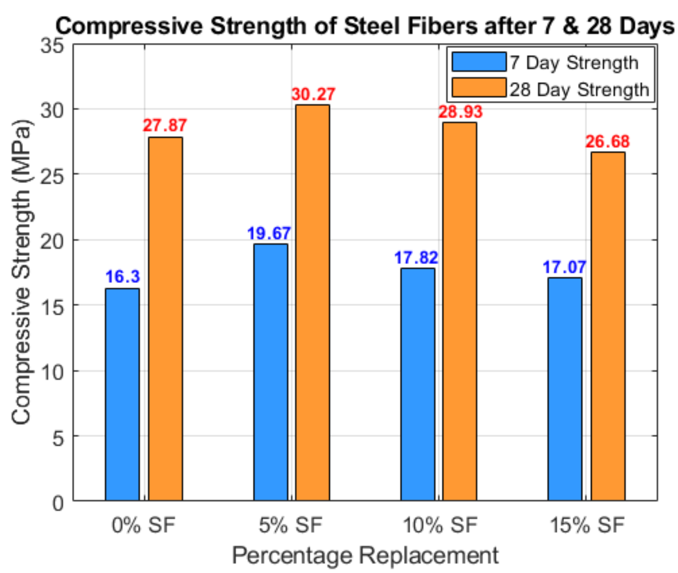

Fig. 7. Compressive strength of steel fibers after 7 & 28 days

Figure 7 illustrates that the compressive strength of steel fiber-reinforced concrete decreases with increasing percentages of steel fiber content after 7 and 28 days of curing. This decline may be attributed to the potential for fiber congestion at higher concentrations, which can lead to phenomena such as fiber balling and inadequate bonding with the cement matrix. Concrete samples containing 5%, 10%, and 15% steel fibers demonstrate greater strength compared to the control sample (0% steel fibers), likely due to the enhanced resistance of steel fibers to cracking. As per literature, compressive strength generally increases with the addition of steel fibers up to 3-5%, beyond which a further increase in fiber content tends to reduce the compressive strength. This research also showed similar outcomes with the optimal compressive strength being observed at a 5% steel fiber content. Specifically, the compressive strength of the control sample at 28 days of curing was 27.87 MPa, which is higher than that of the sample containing 15% steel fibers. The reduction in strength at higher fiber percentages is likely due to the detrimental effects of excessive steel fibers on the overall bonding and structural integrity of the concrete mix.in specimen.

TABLE 4
COMPRESSIVE STRENGTH OF CONCRETE WITH GLASS FIBERS (GF)

S. No	% of GF	7 days Compressive strength in MPa	28 days Compressive strength in MPa
1	0	16.30	27.87
2	5	18.47	29.32
3	10	16.83	27.13
4	15	13.47	24.01

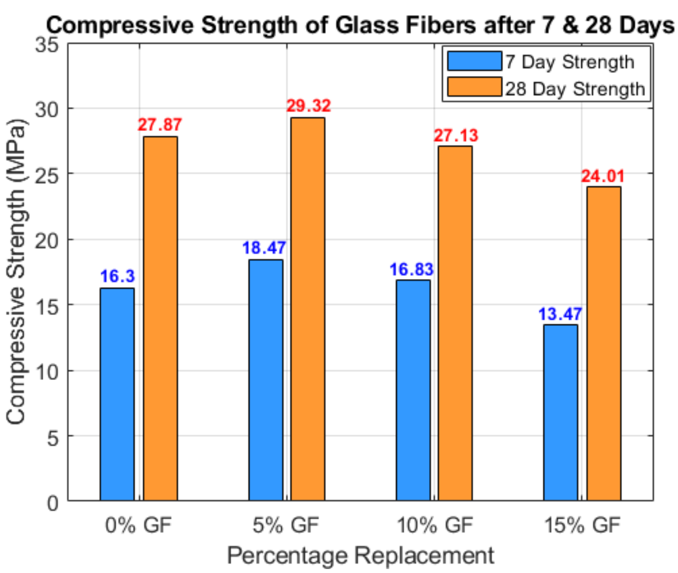

Fig. 8. Compressive strength of steel fibers after 7 & 28 days

Figure 8 illustrates that the compressive strength of glass fiber-reinforced concrete (GFRC) decreases with increasing percentages of glass fibers after 7 and 28 days of curing. This reduction in compressive strength is likely due to the non-uniform dispersion of glass fibers during the mixing process, which can result in inadequate bonding and distribution within the concrete matrix.

According to Ahmad et al. (2021) [18], the inclusion of glass fibers beyond 6% adversely affects the compressive strength of concrete. Our study supports this finding, showing a decline in compressive strength with glass fiber contents exceeding 5%. Specifically, the control sample (0% glass fibers) had a compressive strength of 16.3 MPa. The highest compressive strength observed in our study was with 5% glass fibers. At 28 days, the trend persisted, with the compressive strength of GFRC decreasing as the percentage of glass fibers increased. Notably, the control sample (0% glass fibers) exhibited higher compressive strength compared to samples with 10% and 15% glass fibers, although it was lower than the compressive strength achieved with 5% glass fibers.

TABLE 5
COMPRESSIVE STRENGTH OF CONCRETE WITH HYBRID FIBERS (STEEL & GLASS FIBERS)

S. No	% of Fiber	7 days Compressive strength in MPa	28 days Compressive strength in MPa
1	0	16.30	27.87
2	5% SF & 10% GF	14.89	24.59
3	10% SF & 5% GF	17.02	26.19

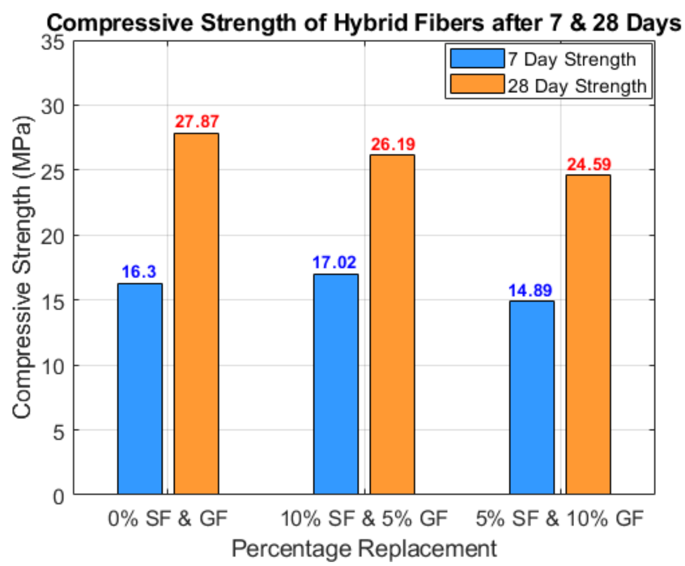

Fig. 9. Compressive strength of hybrid fibers after 7 & 28 days

Figure 9 demonstrates that the concrete sample with dual fiber content, specifically 10% steel fibers and 5% glass fibers, exhibits greater compressive strength compared to the sample with 5% steel fibers and 10% glass fibers. This observation indicates that steel fibers contribute more significantly to the compressive strength of concrete than glass fibers. Supporting this, Ganta et al. [20] observed that steel fibers possess a higher elastic modulus and stiffness compared to other commonly used fibers, making them more effective in enhancing the mechanical properties of concrete. In our study, the control sample (0% fibers) exhibited greater strength than the sample with 5% steel fibers and 10% glass fibers, but it showed lower compressive strength compared to the sample with 10% steel fibers and 5% glass fibers.

The optimum compressive strength of 26.19 MPa was achieved with the 10% steel fibers and 5% glass fibers combination. The results also highlight that a higher proportion of steel fibers increases compressive strength.

IV. Conclusions

The concrete reinforcement using steel and glass fibers modifies its properties, transforming it from a brittle to a more ductile material, thereby enhancing its resistance to cracking. Based on the results, the following conclusions can be drawn:

1. The incorporation of steel fibers significantly enhances the compressive strength of concrete. Specifically, a 5% volume fraction of steel fibers achieved the maximum compressive strength of 30.27 MPa. A 5% volume fraction of glass fibers resulted in a maximum compressive strength of 29.32 MPa.
2. The compressive strength of concrete containing glass fibers decreases as the fiber content increases. Notably, the highest compressive strength was observed with 5% glass fibers. Beyond this percentage, the compressive strength continually decreases with higher glass fiber content. Conversely, concrete with 5% steel fibers showed superior compressive strength compared to higher percentages of steel fibers.
3. An increase in the quantity of fibers, whether steel or glass, adversely affects both the workability and compressive strength of concrete. Excessive fiber content can lead to complications in mixing and placement, ultimately reducing the effectiveness of the reinforcement.

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