STUDY ON MECHANICAL STRENGTH CHARACTERISTICS OF STEEL FIBER REINFORCED CONCRETE

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ABSTRACT

Steel Fiber Reinforced Concrete (SFRC) is a composite material in which discrete steel fibers are uniformly distributed within the concrete matrix to enhance its mechanical performance. This study investigates the mechanical strength characteristics of SFRC with emphasis on compressive strength, split tensile strength, and flexural strength. Concrete mixes were prepared with varying volume fractions of steel fibers while maintaining a constant mix design. Standard specimens were cast and cured, and experimental tests were conducted in accordance with relevant codes of practice. The results indicate that the inclusion of steel fibers significantly improves tensile and flexural strength due to effective crack-bridging action, enhanced ductility, and improved post-cracking behavior. A marginal improvement in compressive strength was also observed with increasing fiber content. The study concludes that SFRC exhibits superior mechanical performance compared to conventional concrete, making it suitable for applications requiring improved load-carrying capacity, crack resistance, and durability such as industrial floors, pavements, and structural elements.

1.INTRODUCTION

1. Steel fibre Reinforced concrete

One variety of Portland cement concrete that incorporates tiny steel fibres at random intervals is called Steel Fibre Reinforced Concrete (SFRC). These fibres boost the concrete's toughness, tensile strength, and resistance to cracking due to plastic shrinkage, drying shrinkage, and applied loads by acting as internal reinforcement. In comparison to regular concrete, SFRC is more durable and performs better in the face of impacts, frost, and abrasion.

Aspect ratio, the ratio of a steel fiber's length to its diameter, is a typical way to define the fiber's cross-sectional shape, which might be round, triangular, or flat. A number of parameters affect the performance of steel fibre reinforced concrete (SFRC). These include the mechanical properties of the steel fibres, how well they connect with the cement matrix, and the amount and consistency of the fibre distribution inside the concrete. Achieving optimal structural performance relies on the proper selection and distribution of fibres.

In some cases, SFRC can replace conventional rebar since it is more cost-effective and has other advantages, like better crack management and resilience to dynamic or impact stresses. It finds extensive application in industrial flooring, roadways, tunnel linings, precast components, and buildings subjected to severe weather.

The addition of steel fibres to regular concrete makes SFRC a stronger, more ductile, and longer-lasting material that can endure complicated stresses and increase the useful life of concrete buildings. It is becoming more and more common in modern civil engineering and building projects due to its adaptability and performance benefits.

2. Effects of Steel fibers in Concrete

The addition of steel fibres to concrete improves its overall performance, especially when it comes to minimising cracking. Plastic shrinkage, which happens when concrete is still wet, and drying shrinkage, which happens when concrete dries out and becomes harder, are two causes of concrete cracks. Incorporating steel fibres into concrete improves its structural stability and aids in controlling both types of cracking.

In addition to controlling cracks, steel fibres inhibit water passage through concrete by reducing its permeability. Bleeding, the upward migration of water during setting that might weaken the surface of the concrete, is also reduced by this decrease in permeability. The use of steel fibres makes concrete endure longer by mitigating these impacts.

For high-stress uses like industrial floors, pavements, and structures exposed to dynamic loads, concrete with certain kinds of steel fibres added increases its resistance to impact, abrasion, and breaking. Steel fibres help concrete resist stresses by improving its tensile strength, which in turn distributes stress throughout the material and makes it less likely to crack or break suddenly.

By incorporating steel fibres into regular concrete, a composite material is created that is more resistant to cracking, water seepage, surface wear, and structural stresses. This is why steel fibre reinforced concrete is becoming more and more common in today's construction, especially in areas that require resistance to extreme weather, longevity, and durability.

2 LITERATURE SURVEY

2.1 Literature

There is a precise definition of literature when used in a research setting. Novels, poetry, and other forms of written expression are not the only ones it can encompass. As an alternative, it encompasses all the literature on a certain subject.

2.1.1 Literature Review

To conduct research on a specific issue, one must first compile and analyse all of the relevant literature, which includes studies, reports, and hypotheses. This is more than just a bibliography; it synthesises and critically evaluates the prior work in the topic.

2.1.2 Steel Fibre Reinforcement in Concrete

A type of reinforced concrete known as steel fibre reinforced concrete (SFRC) improves the material's mechanical and durability qualities by evenly dispersing discrete steel fibres throughout the matrix. Steel fibres serve as micro-reinforcement in SFRC, bridging fractures as they form and preventing them from expanding, in contrast to traditional reinforced concrete that mostly utilises steel bars. This process enhances the material's resistance to impact, ductility, post-cracking toughness, flexural and tensile strengths, and flexibility.

Different types of steel fibres have different lengths, diameters, shapes, and volume fractions. The most common kinds of fibres are straight, crimped, hooked-end, and twisted fibres; their diameters range from 0.3 to 1 mm, and their lengths are 25 to 60 mm. The percentage of fibre in concrete can vary from 0.25 to 2 percent by volume, depending on the use. Small amounts of fibre can have a big impact on concrete's performance, according to the experiments. When compared to plain concrete, beams and prisms, for instance, exhibit flexural strengths 20–70% higher and tensile strengths 15–50% higher. Your impact resistance might get up to three times higher, and your post-cracking toughness could go up 1.5-3 times higher.

The dosage, orientation, length, and shape of the fibres determine how well SFRC works. In comparison to straight fibres, hooked fibres are superior for post-cracking performance and anchoring, while longer fibres are better for energy absorption and crack bridging. While high fibre quantities can impair workability, necessitating careful mixing and positioning, uniform fibre distribution guarantees consistent mechanical behaviour throughout the construction.

When crack control, strong tensile and flexural performance, and blast resistance are paramount, SFRC finds widespread application in industrial floors, airport pavements, tunnels, and precast components. Reduced water penetration and corrosion of embedded reinforcement are two ways in which fibres increase durability by limiting crack widths. Studies conducted over longer periods of time have also shown that SFRC retains superior toughness and residual strengths even when subjected to repeated loading and environmental stresses.

Overall, concrete's performance is much enhanced by steel fibre reinforcement, particularly when it comes to tension, bending, impact resistance, and longevity. A versatile and useful material in modern construction, SFRC mixes can be designed by engineers to satisfy specific structural and durability requirements by optimising fibre type, length, and volume.

2.2 Novelty of the Study

The potential of steel fibre reinforced concrete (SFRC) to improve tensile, flexural, impact, and post-cracking performance has been the subject of much research. Before the advent of modern cement mortars, Porter and Alfsen (1918) conducted experiments using 50 mm long steel fibres reinforcing concrete prisms with volume fractions lower than 1%. Crack patterns were finer and more spread, and flexural and tensile tests showed strength gains of 10-20%, proving that the fibres were successful in reducing brittle failure.

Romualdi conducted tests on 150×150×700 mm concrete beams in the 1960s using volumes of 0.5%, 1%, and 1.5% along with short steel fibres (25-50 mm length, 0.5 mm diameter). Direct tensile testing demonstrated post-cracking load retention of 15-25%, while three-point bending tests demonstrated flexural strength gains of 25-35%. Likewise, Ramey examined 150×150×600 mm beams that were filled with hooked steel fibres (30-45 mm, 0.6 mm diameter, 0.5-1.5% volume). Both static and dynamic loading tests showed that the maximum load increased by 30-50% and that energy absorption under impact increased by 2-3 times, highlighting the significance of fibre geometry in toughness.

Over 150 SFRC studies were examined by Sabir Khan, Saiful Islam, and Zarghaam Rizvi (2013) from the 1980s to the 2010s. Utilised fibres ranged from 0.5% to 2% by volume and included hooked, crimped, and straight varieties. There was a rise of 20–70% in flexural strength, 15–50% in tensile strength, a tripling in impact resistance, and an average of 70–85% in residual flexural strength following cracking. In their analysis of worldwide experimental data, Muhammad Nasir Amin et al. (2022) confirmed that SFRC with 0.5-2% steel fibres improved post-cracking toughness by 1.5-3× and compressive strength by 5-15%.

These findings were subsequently corroborated by research involving self-compacting and high-performance concrete. The 100×100×500 mm SCC beams reinforced with hooked steel fibres (30-50 mm, 0.6 mm diameter, 0.5-1.5% volume) were examined by Jawad Ahmad et al. (2023). Toughness improved by 2-2.5×, flexural strength by 35-50%, and tensile strength by 20-35%. However, workability was significantly hindered by the higher fibre content. In their 2014 study, Abdul Ghaffar et al. examined 150 mm cubes, 150×300 mm cylinders, and 100×100×500 mm beams that contained 0.5-1.5% steel fibres. There was an increase of 25-50% in flexural strength, 20-40% in tensile strength, and 5-15% in compressive strength.

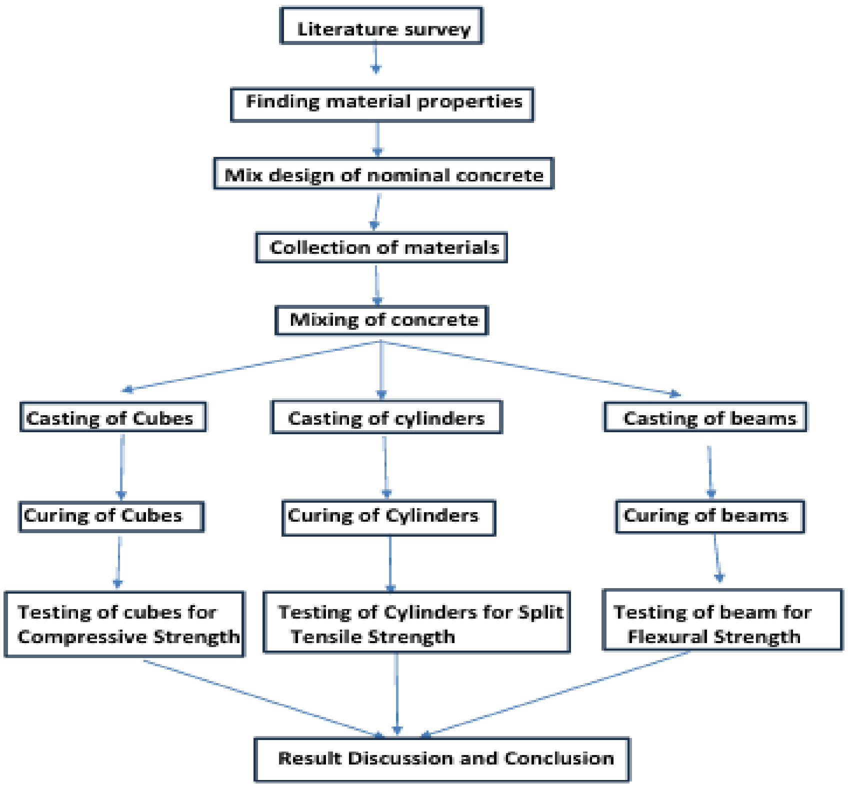
Beams exhibiting 30–50% increased flexural strength and 20–40% enhanced tensile strength at 0.5–1.5% fibre volume were reported by K. Sree Sandhya et al. (2019), who also noted comparable tendencies.

The greater energy absorption of SFRC was demonstrated in dynamic and fatigue experiments. The beams and slabs subjected to repeated impact and fatigue loading that Nemkumar Banthia examined had an impact resistance 1.5-2.5 times greater, a fatigue life 2-3 times longer, and crack widths 15-20% narrower than the control samples. Using hooked and twisted fibres (0.5-2% volume), Naaman performed pull-out and flexural hardness tests, resulting in 60-80% post-cracking load retention and 1.5-2× greater energy absorption. Researchers Mohammed A. Mujalli et al. (2018–2020) found that beams and prisms reinforced with 30–60 mm roughened fibres had increased post-cracking toughness and residual tensile strength improvements of 20–40%.

The effects of deflection-hardening, repeated cracking, and fibre orientation have been researched at length. R. Bentur showed that the orientation of the fibres has a 10-30% effect on fracture breadth and toughness. M. P. Collins demonstrated a 30-60% increase in flexural toughness in beam bending tests using 0.5-2% fibres. Beams subjected to serial breaking were studied by V. C. Li, who found that hooked fibres exhibited the most remarkable deflection-hardening and post-cracking energy absorption. S. Mindess reported enhanced durability, greater post-cracking load retention, and a 20-30% reduction in fracture width by a combination of microstructural and mechanical studies.

3. MATERIALS AND METHODOLOGY

3.1Flowchart of project work



3.1.2Mix design of nominal concrete

a. Concrete mix design refers to the process of choosing appropriate elements and optimising their proportions to create a mix that meets the required standards for workability, durability, and strength while keeping costs low. The performance requirements of both the flexible and hardened stages of concrete dictate the proportioning of constituents.
b. Mix design requires the following:
c. Reaching the structural performance-critical minimum compressive strength.
d. Incorporating all available equipment to achieve full compaction by guaranteeing sufficient workability.
e. Adapting the water-cement ratio and/or cement content to meet the needs of the site in terms of durability.
f. Making mass concrete with a lower cement concentration to avoid shrinkage cracking caused by temperature changes.
g. The mix design of the nominal concrete must be executed in accordance with the Indian Standard codes IS 10262:2009 (Guidelines for Concrete Mix Proportioning) and IS 456:2000 (Code of Practice for Plain and Reinforced Concrete). The proportions of cement, aggregates, and water to achieve the appropriate strengths, workability, and durability of concrete can be found in these codes, which also give standard processes for these tasks..

3.1.3Collection of materials

To improve the project's performance, traditional concrete components were partially replaced with silica fume and fly ash.

The manufacturing processes for silicon and ferrosilicon alloys produce ultrafine powders known as silica fume. Its high silica content and small particle size make it more reactive, which in turn makes concrete stronger, lasts longer, and has less water seepage. An easily accessible material, silica fume is frequently utilised to improve the functionality of high-strength and fiber-reinforced concrete.

3.1.4Mixing of concrete

A homogeneous concrete mix is formed by completely mixing the chosen constituents, which include water, fine aggregate, coarse aggregate, silica fume, and cement. To make sure the specimens can be easily removed after curing, the freshly mixed concrete is then poured into greased moulds. Uniform material distribution and desired workability are directly impacted by proper mixing and moulding, which in turn influences the concrete's strength and durability.

3.1.5 Casting of concrete in moulds

- **Sampling**: While pouring concrete, take random samples to check for consistency.
- **Filling Cubes**:
  - Apply three coats of concrete to cube moulds.
  - Use a tamping rod to compact each layer for 25 strokes.
  - Use a trowel to smooth up the top surface after compacting the last layer..
- **Demoulding:**
  - Once the 24-hour period has passed, carefully remove the specimens from the moulds, being cautious not to crack the edges.

- **Curing:**
  - Cure the samples according to the established protocols.
  - to determine the change in strength over time, test three specimens for seven, fourteen, and twenty-eight days.
- **Cylinder Specimens:**
  - o Before pouring into cylinder moulds, make sure to use a tamping rod to crush each of the three layers.
- **Beam Specimens**:
  - Fill three layers of beam moulds, pressing down with 25 strokes per layer.
  - Accurate compacting guarantees consistent density, reduces empty spaces, and enhances the concrete specimens' resilience and longevity.Table 3.1 Size of Moulds

S.no	Moulds	Size	Specimen casted for
1	Cube	150mm X 150mm X 150mm	Compressive Strength
2	Cylinder	300mm X 150mm	Module of Elasticity
3	Cylinder	300mm X 150mm	Split tensile Strength

Fig 3.1 Casting of cubes

1. Testing of specimen

The cubes, cylinders, and beams of concrete undergo testing to ascertain their mechanical qualities following seven, fourteen, and twenty-eight day curing times, respectively:

1. **Cubes:** Tested for compressive strength.
2. **Cylinders:** Tested for split tensile strength.
3. **Beams**: Undergone flexural strength testing.

Each test's measured data are meticulously documented for further study. The results of these tests are crucial for determining how well and how long the concrete mix performs when cured at various times.

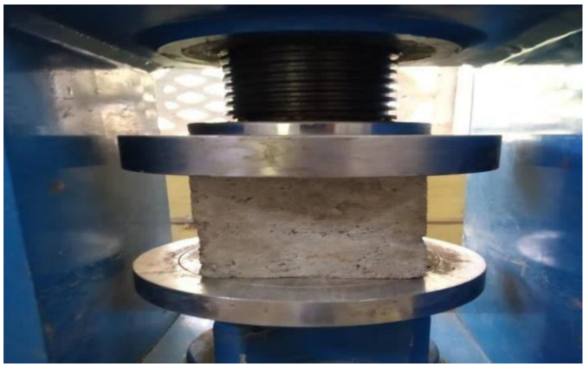


Fig 3.2 Testing of concrete cube in compressive strength testing machine

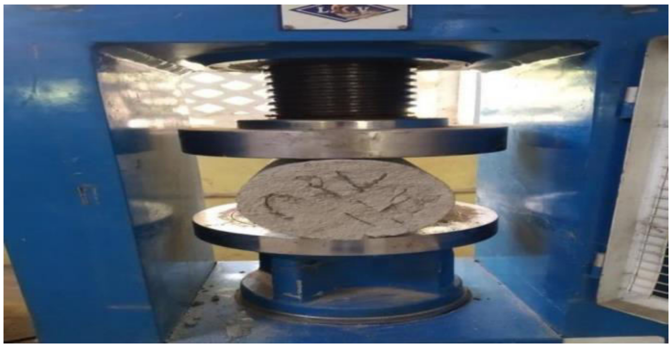


Fig 3.3 Testing of concrete cylinder in Split tensile strength testing machine

Fig 3.4 Testing of concrete prism in flexural testing machine

4.MATERIALS AND TESTING

According to relevant criteria, the physical and chemical characteristics of various materials are ascertained.

4.1 **Cement**

As a binder—a substance that can set, harden, and adhere to other materials—cement is an essential building ingredient because it allows other materials to be bound together into a solid mass. In and of itself, cement is not often utilised in building. It is more commonly used in the production of concrete or mortar for masonry projects when mixed with fine aggregates (sand) and coarse aggregates (gravel or crushed stone). In terms of worldwide consumption, concrete is second only to water among all construction materials. Buildings, roads, bridges, and other civil engineering projects rely on it due to its adaptability, strength, and longevity.

Cement from Portland

On a global scale, Portland cement (OPC) is the cement of choice. As opposed to just drying, the chemical reactions that occur when this cement is combined with water cause it to harden, making it a hydraulic cement.

Limestone (calcium carbonate) and clay are heated in a rotating kiln to around 1450 °C during the manufacturing process. Calcination is a high-temperature process that breaks down limestone, producing quicklime and carbon dioxide (CO_2). The primary binding components of cement, calcium silicates and other cementitious compounds, are formed when the calcium oxide combines with the clay's silica, alumina, and iron oxides.

After the process is complete, the clinker—which are tiny cementitious nodules—are combined with a small amount of gypsum and pulverised into a fine powder. Gypsum slows the setting time of cement, ensuring that it does not harden too soon after mixing. Concrete technology relies on the end product, ordinary Portland cement, which is utilised extensively in both commercial and residential construction.

Uses and Characteristics

Concrete, mortar, and grout cannot be made without Portland cement. A mixture of cement, water, fine and coarse aggregates, and OPC forms the composite material known as concrete. Here are some of its benefits:

Almost any shape may be cast from it, making it very versatile.

Construction projects including buildings, bridges, dams, or pavements rely on this material for its structural strength.

• Longevity: Shows no signs of deterioration regardless of exposure to chemicals, weather, or mechanical stressors.

• Modifiability: fly ash, silica fume, and slag are admixtures and supplemental cementitious elements that can be used to improve the material's overall performance.

The raw materials and manufacturing technique determine whether Portland cement is grey or white. White cement is typically reserved for decorative and architectural uses, while grey cement is more generally used in general building.

Engineers and researchers can create concrete mixes with the desired strength, workability, and durability by studying the composition, qualities, and applications of Portland cement. This makes Portland cement one of the most flexible and essential materials in modern building.

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Fig 4.1 Cement

We used ordinary Portland cement of 43 grade, which is in accordance with IS:8112-1989 and was sourced from Ultra Tech Cement. Cement was evaluated in accordance with IS 4031-1986. Table 4.1 displays the cement test results.

The chosen materials are measured and proportioned in accordance with the computed quantities after the mix design is finished. The procedure consists of the following steps:

1. **Preparation of Cubes**
    1. Moulds that are commonly used are cubes with dimensions of 150 mm × 150 mm × 150 mm.
    2. 2. In order to achieve a flat top surface, the concrete mix is crushed after being layered into the moulds.
2. **Curing of Cubes**
    1. One, for a whole month, the cubes are immersed in water to promote strength growth and correct hydration.
3. **Compressive Strength Testing**
    1. The cubes are taken out of the water bath and any excess water is cleaned off after the curing period.
    2. A compression testing machine is used to assess the cubes' compressive strength after 28 days.
    3. Third, to reach the desired mean strength, we average the strengths of three cubes.
4. **Preparation of Beams**
    1. If the cubes achieve the target mean strength, the same mix proportions are used to prepare concrete beams of the required size for flexural testing or other structural tests

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5.RESULT &DISCUSSION

Table 5.1 Compressive strength

Type of concrete	% of GGbs	% of Steel fibers	Cube	Average strength(MPa)
PLAIN	0.0	0.0	3	49.11
	10	0.0	3	51.33
	15	0.0	3	56.44
SFRC	0.0	0.5	3	50.89
	0.0	1	3	52.22
	10	0.5	3	54.66
	10	1	3	55.99
	15	0.5	3	58.21
	10	1	3	58.21

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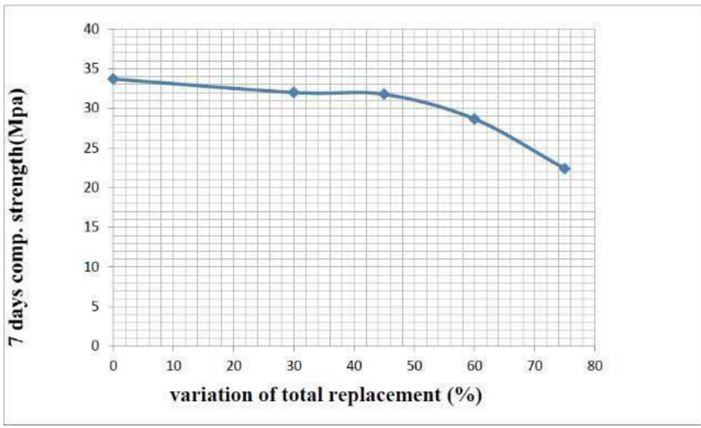
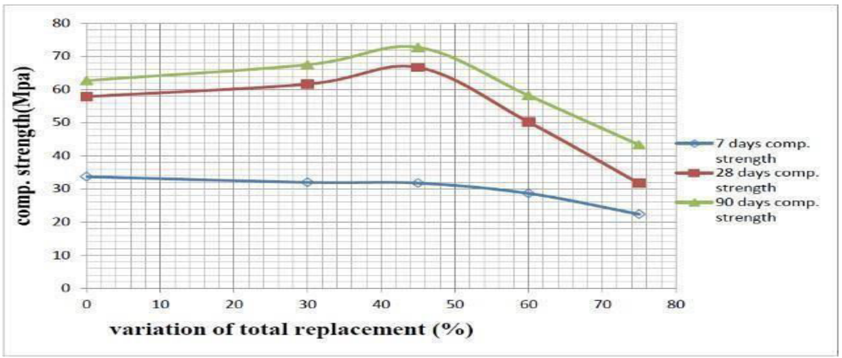


Graph 5.1 variation of 7-day compressive strength

Graph 5.2 variation of 28-day compressive strength



Graph 5.3 Comparison of compressive strength at 7, 28, and 90days of curing

6.CONCLUSIONS AND FUTURE SCOPE

6.1 CONCLUSIONS

The following findings are derived from the practical study of Steel Fibre Reinforced Concrete (SFRC) that partially substitutes cement with GGBS:

1. Flexural Strength

- You can boost the flexural strength of beams by about 5.18% by partially replacing cement with 15% GGBS.
- Flexural strength can be increased by as much as 15.3% when 1% steel fibres by weight are added to concrete.
- The flexural strength can be increased to 21.13% by combining 1% steel fibres with 15% GGBS replacement.
- The amount of fibres has an effect on the most common location for flexural cracks, which are in the centre one-third (L/3) of the beam.
- Ductile failure occurs at critical loads, with fractures pointing towards the loading point, and SFRC beams exhibit more deflection than plain concrete beams.

2. Compressive Strength

- The compressive strength is increased by around 14.91% when 15% GGBS is partially substituted for cement.
- A 7% boost in compressive strength is achieved with the addition of 1% steel fibres.
- The compressive strength is increased by 21% when 1% steel fibres are mixed with 15% GGBS.
- Concrete's overall strength qualities are greatly enhanced when GGBS and steel fibres are combined.

3. Workability

- The mineral additive effect makes the mixture more workable when 15% GGBS is used in place of cement.
- With increasing fibre content and aspect ratio, workability is diminished by the addition of steel fibres.
- Balling during mixing can occur with high aspect ratio fibres, which can make putting and compacting the concrete a real pain.

4. Economic Considerations

- Cost-effective partial replacement is possible with GGBS since it is less expensive than cement. Optimal percentages of GGBS and steel fibres improve strength, ductility, and longevity without breaking the bank.

5. Overall Conclusion

- The experimental study found that SFRC with GGBS partially replacing cement had better ductility, reduced crack propagation, and increased flexural and compressive strength.
- The best mechanical performance and cost efficiency are achieved when 1% steel fibres are mixed with 15% GGBS.

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SCOPE FOR FUTURE WORK

To go deeper into the concrete qualities covered in this project, one can take into account the following parameters::

1. Crack Control and Durability

1. Fractures in concrete components tend to spread unchecked until they reach the reinforcement bars. To prolong the useful life of buildings, research into crack arresting techniques is essential.

2. Silica Fume Content

1. To improve strength, durability, and crack resistance, one can experiment with varying amounts of silica fume as a partial cement substitute.

3. Cement Grade Variations

1. First, the rate of strength growth, workability, and long-term durability can be affected by using different grades of cement, such as 33 grade and 53 grade.

4. Recycled Aggregate

Sustainability, mechanical qualities, and economic benefits can be explored by examining the usage of recycled aggregates in concrete.

5. Fiber-Reinforced Concrete

1. High-performance structural applications can benefit from fiber-reinforced concrete, which can be made with steel, glass, polypropylene, or hybrid fibres, instead of plain concrete. This type of concrete improves ductility, flexural strength, and fracture resistance.

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