Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 45 No. 2 (2024)

Experimental Study on Structural Behaviour of Fiber Reinforced Concrete Beam Using Hybrid Fibers

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Abstract: - This study investigates the effect of the addition of steel and glass fibers in concrete and thus evaluate its performance under compression, tension and flexural type of loading based on IS code method of mix design. Mix design is carried out for M20 and M25 grade of concrete. The samples were prepared by varying the percentage volume of fraction of steel and glass fibers w.r.t concrete. Steel fibers are used in the range of 0% to1.5% & glass fibers are used in the range of 0% to 0.3% by volume of concrete. The mentioned fraction is used in various combinations for concreting & to get the results of 7 days & 28 days of samples to decide the optimum mix. The three numbers of beams are casted as a conventional concreting and the 3 no of beams are casted with optimum hybrid mix of steel fiber and glass fibers. The casted beams are cured for 28 days then this beam tested for flexural strength. The cubes and cylinders are casted and tested for compression and tensile strength of M20 and M25 grade concrete with and without hybrid fiber mix respectively. Simply supported beam with two equal point load acting at top surface of beam will be tested, up to failure in the well-equipped heavy structural laboratory. The behaviour of beam studied in concern with crack and ultimate load.

Key words: - *crimped steel fiber, glass fiber, HFRC beam, deflection, flexural strength, compressive strength*

1 Introduction

Fiber-reinforced concrete (FRC) is a type of concrete that incorporates fibers to enhance its structural and durability properties. These fibers are typically made of materials such as steel, glass, synthetic polymers, or natural fibers like basalt or jute. The addition of fibers to concrete imparts improved mechanical and durability characteristics, making it a popular choice in construction and civil engineering applications. The primary objectives of using fiber reinforcement in concrete are to enhance tensile strength, control cracking, and improve the overall performance of the material. Traditional concrete is strong in compression but relatively weak in tension, which can lead to cracking under certain conditions. Fiber reinforcement helps in addressing this weakness by providing additional support and preventing cracks from propagating. Hybrid Fiber Reinforced Concrete (HFRC) is a specialized form of concrete that incorporates a combination of different types of fibers to enhance its mechanical and durability properties. Traditional concrete is known for its strength in compression but is relatively weak in tension. Adding various types of fibers addresses these limitations by improving tensile strength, flexural strength, toughness, and durability. Hybrid Fiber Reinforced Concrete represents an advanced material that combines the benefits of various types of fibers to overcome the limitations of traditional concrete. Its application is well-suited for projects where enhanced strength, durability, and crack resistance are critical. As with any concrete technology, it's essential to tailor the mix design to the specific requirements of the project and consider factors such as environmental conditions, loading, and construction methods. Hybrid Fiber Reinforced Concrete is a valuable material for structural purposes, offering enhanced strength, durability, crack resistance, and seismic performance. Its application is particularly relevant in high-performance structures where the long-term integrity and reliability of the concrete are critical considerations. Glass fiber is a low-cost, corrosionresistant fiber. Understanding the basic properties of glass fiber-reinforced concrete under tensile, compressive, bending, and shear pressures provides the foundation for designing the material. It also helps determine how the material would behave under secondary effects of loading such as creep, heat response, and moisture migration.

Experimental work

A. Materials and Properties

Below are the materials' qualities and how they were used for the experimental investigation.

1) **Crimped steel fiber**

For concrete to be strengthened and perform better in a variety of applications, steel fibers are essential. Choosing and adding steel fibers to the concrete mix properly can improve its strength, longevity, and capacity to withstand dynamic loads and cracking. crimped steel fibers offer enhanced bonding and pull-out resistance in comparison to straight fibers, making them suitable for various applications where improved reinforcement properties are required. Proper mix design, quality control, and adherence to industry standards are crucial for the successful use of crimped steel fibers in concrete. The fibers have a wavy or crimped configuration along their length. This design helps in achieving better mechanical interlocking with the concrete matrix.

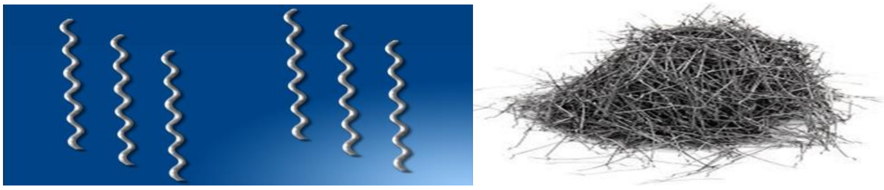

Fig1 crimped steel fiber

Following table shows physical properties of crimped steel fiber

Table 1. Properties of steel fiber

Property	Crimped Steel fiber
Density in kg/m^3	7850 kg/m^3
Length in mm	50 mm
Diameter in mm	1 mm
Aspect Ratio	50

2) **A R Glass Fiber**

Alkali-resistant glass fiber, or AR glass fiber, is a specialized type of glass fiber designed to resist degradation when exposed to alkalis. It is commonly used to reinforce cement-based materials like concrete in construction projects. By incorporating AR glass fibers into concrete mixes, structures gain improved durability, crack resistance, and mechanical strength, particularly in environments with high alkaline content. These fibers are treated with coatings or sizing agents during manufacturing to enhance their resistance to alkalis. AR glass fibers find applications in reinforced concrete, shotcrete, GRC panels, and FRP composites, offering enhanced performance and longevity in various construction projects. If it concerns situations where resistance to alkaline conditions is crucial, AR glass fibers are a great way to improve the mechanical qualities and longevity of concrete.

Fig 2 A.R. glass fiber

Following table shows physical properties of A.R. glass fibers

Table 2. Properties of A.R. glass fiber

Property	Glass Fiber
Density in kg/m^3	2700 kg/m^3
Length in mm	12 mm
Diameter in mm	0.014 mm (14μ)
Aspect Ratio	857.14

3) Cement

OPC 53 Grade cement is known for its high compressive strength and is commonly used in the construction of structures where superior strength properties are required. It is important to follow proper mix design and construction practices to optimize its performance in various applications. OPC (Ordinary Portland Cement) 53 Grade is a type of cement that conforms to the Indian standard IS 12269. It is commonly used in construction projects in India and other regions where the IS 12269 standard is adopted. The "53 Grade" designation indicates the compressive strength of the cement at 28 days, measured in megapascals (MPa). Here are key features and characteristics of OPC 53 Grade cement. Following table shows physical properties of cement

Table 3: Properties of cement

Properties	Values
Grade of cement	Opc53
Specific gravity	range of 3.10 to 3.20.
Fineness of cement	2%.
Consistency	33.5%.
Initial setting time	98 minutes.
Final setting time	212 minutes.

4) Fine aggregate

Fine aggregate is one of the essential components of concrete, along with coarse aggregate, cement, and water. It is typically composed of natural sand or crushed stone with particle sizes smaller than 4.75 millimeters. Fine aggregate plays a crucial role in concrete mixtures, contributing to the workability, strength, and durability of the finished product. Fine aggregate improves the workability of concrete by providing a smooth surface for the cement paste to coat and reducing the friction between particles. It contributes to the overall strength of concrete by filling voids between coarse aggregate particles and improving the packing density. Fine aggregate is often sourced from natural deposits of sand, which can be river sand, pit sand, or sea sand. Crushed stone, such as granite or basalt, can also be used as fine aggregate. Following table shows physical properties of fine aggregate

Table 4. Properties of fine aggregate

Properties	Value
Specific gravity	2.922
Water absorption	1.83%
Fineness modulus	3.2
Silt Content of F.A.	4 %
Bulk density 1) Loose weight 2) Compacted weight	1.853 kg/lit 2.113 kg/lit

5) Coarse aggregate

Coarse aggregate is an essential component of concrete, alongside fine aggregate, cement, and water. It consists of larger particles, typically ranging in size from 4.75 millimetres (0.187 inches) to 37.5 millimeters (1.5 inches) in diameter. Coarse aggregate plays a critical role in providing strength, volume stability, and durability to concrete mixtures. Crushed angular stones, such as granite, basalt, or limestone, are commonly used as coarse aggregate. Coarse aggregate contributes significantly to the compressive strength of concrete by providing a framework for the cement paste to surround. The surface texture of coarse aggregate influences the bond between the aggregate and the cement paste. A rough surface provides better adhesion. coarse aggregate is a vital component of concrete, providing strength, volume stability, and durability to the material. The selection and quality control of coarse aggregate are critical aspects of concrete mix design, ensuring that the resulting concrete meets the desired performance requirements for a given application. Following table shows physical properties of course aggregate.

Table 5: Properties of coarse aggregate

Properties	Value
Specific gravity	2.9
Water absorption	1.6%
Fineness modulus	4.931
Bulk density 1) Loose weight	1.56 kg/lit
2) Compacted weight	1.795 kg/lit

6) Water

Water is a crucial component in the process of making and curing concrete. It plays several important roles in the production and performance of concrete mixtures. Here are the key ways in which water is used for concreting. Water is added to the mix of cement, fine aggregate (sand), and coarse aggregate to form a plastic and workable consistency. The water-to-cement ratio (w/c ratio) is a critical parameter that influences the strength and durability of the resulting concrete. The chemical composition of water, particularly its pH level, should be within acceptable limits. Highly acidic or alkaline water can affect the stability of the concrete and may lead to corrosion of reinforcing steel. High chloride content in water can lead to corrosion of reinforcing steel in concrete. Therefore, the chloride content of water should be within permissible limits to ensure the durability of the structure. The consistency and quantity of water in the mix are critical. The water-to-cement ratio should be carefully controlled to achieve the desired workability without compromising the strength and durability of the concrete. Whenever possible, potable (drinkable) water is recommended for concrete mixing and curing to ensure that the water does not introduce harmful substances into the concrete.

B Hybradation of fibers proportion

Hybrid fiber in the context of concrete refers to the use of a combination of different types of fibers to reinforce the concrete matrix. These fibers can be synthetic or natural and are added to concrete mixes to improve various properties, such as tensile strength, flexural strength, toughness, and durability. The combination of different fibers is known as a hybrid fiber system, and it aims to leverage the unique benefits of each type of fiber. Here are some key aspects of hybrid fiber reinforcement in concrete. The combination of steel and glass fibers in concrete aims to create a high-performance hybrid system that addresses various structural and durability requirements. Proper mix design, testing, and quality control are crucial for the successful implementation of this hybrid fiber-reinforced concrete in construction projects. Following table shows combination of S.F. & G.F.

Table 6: combination of S.F& G.F.

<table>
<tr><th>Sr no</th><th>Mix</th><th>S.F.</th><th>G.F.</th></tr>
<tr><td>1</td><td>H1</td><td>0.25</td><td rowspan="6">0.1</td></tr>
<tr><td>2</td><td>H2</td><td>0.50</td></tr>
<tr><td>3</td><td>H3</td><td>0.75</td></tr>
<tr><td>4</td><td>H4</td><td>1</td></tr>
<tr><td>5</td><td>H5</td><td>1.25</td></tr>
<tr><td>6</td><td>H6</td><td>1.5</td></tr>
<tr><td>7</td><td>H7</td><td>0.25</td><td></td></tr>
</table>

8	H8	0.50	0.2
9	H9	0.75	
10	H10	1	
11	H11	1.25	
12	H12	1.5	
13	H13	0.25	0.3
14	H14	0.50	
15	H15	0.75	
16	H16	1	
17	H17	1.25	
18	H18	1.5	

C. Casting of specimens

Casting concrete testing specimens is a crucial step in the process of assessing the properties and strength of concrete. These specimens are typically cast and cured in accordance with specific standards such as I.S. (Indian standard) or other relevant codes. The most common types of concrete specimens for testing include cubes, cylinders, and beam. Use a mix design that represents the concrete to be tested. This includes the selection of appropriate cement, aggregates, water-cement ratio, and any additives. Used a concrete mixer to ensure uniform mixing of the concrete constituents. Mix the concrete according to the approved mix design. Pour the concrete into the moulds in layers. Compact each layer thoroughly to eliminate air voids Compact the concrete in the moulds using a vibrating table.

Fig 3 Mixing of HFRC (Hybrid fiber reinforced concrete)

D Testing of specimen

1 Compressive test of concrete

Compressive strength testing is one of the most common and important tests performed on concrete. The compressive strength of concrete is a measure of its ability to withstand axial loads or forces that tend to squeeze or crush the material. The test provides valuable information about the quality of the concrete mix and its ability to meet design requirements. For the purpose of casting test specimens, steel moulds measuring 150mm x 150mm x 150 mm are employed. Between 0% and 1.5% of the total weight of the materials went into filling the moulds with steel fibers and between 0% and 0.3% with alkali-resistant glass fibers . To prevent the specimen and mould from bonding, all of the moulds' base plates and sidewalls were greased prior to casting. The specimen was then left undisturbed for a whole day at a temperature between 8 and 22 degrees Celsius and a relative humidity of at least 90% (IS 516-1959). Subsequently, the samples are taken out of the moulds and put inside the curing tank. The specimens are evaluated using a compression instrument after 7 days and 28 days after cure. The load must be applied without any shock and imposed continuously at an estimated rate of 140 Kg/sqcm/min until the specimen breaks down and no additional force can be resisted, according to IS516-1959. The maximum load is recorded. Figure 1 depicts the compression testing of a cube.

Fig 4:- Compression testing of concrete

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2 Split tensile test of concrete

Splitting tensile strength, also known as indirect tensile strength or Brazilian tensile strength, is a measure of the tensile strength of concrete. It is determined by applying a tensile force to a cylindrical or disk-shaped concrete specimen that is diametrically loaded. The test is particularly useful for assessing the tensile strength of concrete, which is important in applications where concrete is subjected to tensile forces, such as pavements and concrete pipes. Here's a step-by-step guide on how to conduct a split tensile strength test. To determine the tensile strength of a concrete specimen, split tensile strength is used. For the split tensile strength test, cylindrical specimens with dimensions of 150 mm diameter and 300 mm length were casted. After 24 hours, the specimens were removed from the moulds and placed in the curing tank for 28 days to cure. A cylindrical specimen was put horizontally between the machine's loading surface and a load was given without any shock and raised continuously at a normal rate within the range of 1.2 N/mm^2 to 2.4 N/mm^2 /min until specimen failure along the vertical diameter occurred. Three cylinders are examined for each % of fibers, and the average figure is recorded.

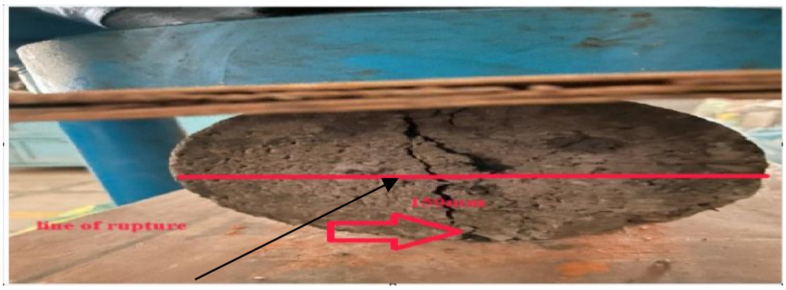


Fig 5 Spilite tensile test of concrete

3 Flexural strength test

The flexural test, also known as the modulus of rupture test or the bending test, is conducted to determine the flexural or bending strength of a material, such as concrete. This test is important for assessing the behaviour of materials under flexural stress, which is crucial in the design of structural elements like beams and slabs. Here's a step-by-step guide on how to conduct a flexural test on concrete Beam specimens with dimensions of 100x100x500 mm are casted for flexural strength tests. After 24 hours after casting, the specimens are removed from the moulds and stored in a curing tank for 28 days. Flexural strength specimens are evaluated on a flexural strength testing equipment under two-point loading in accordance with I.S. 516-1959 across a load effective span of 400 mm. The load and accompanying deflections are recorded until the specimen fails. Three beams are tested for each % of fiber content, and the average value is recorded.

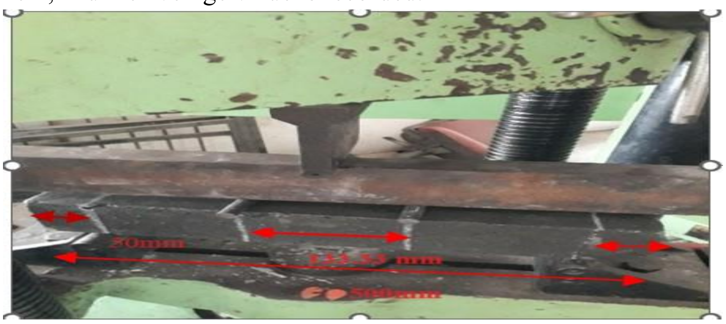
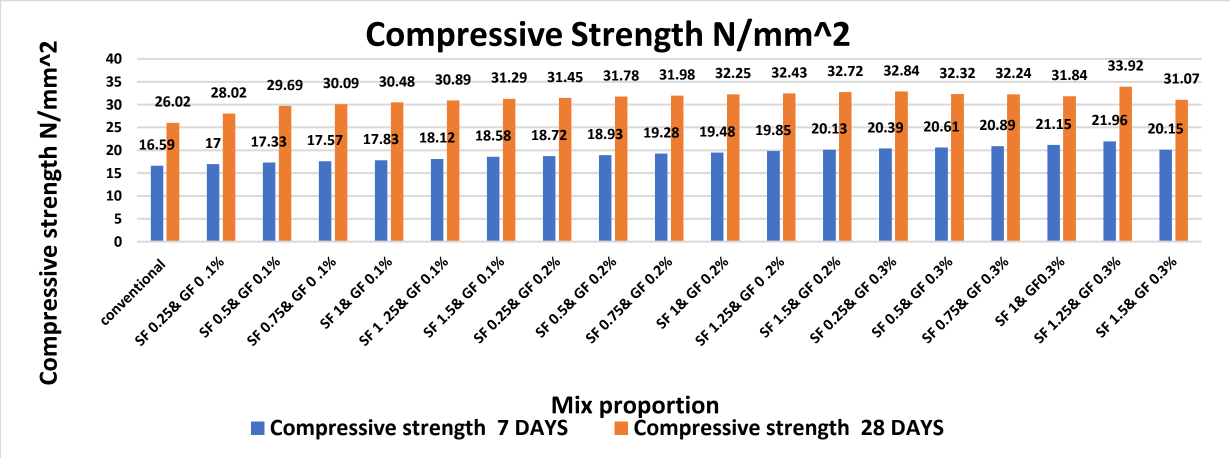


Fig 6 Flexural strength test of concrete

Results and discussions

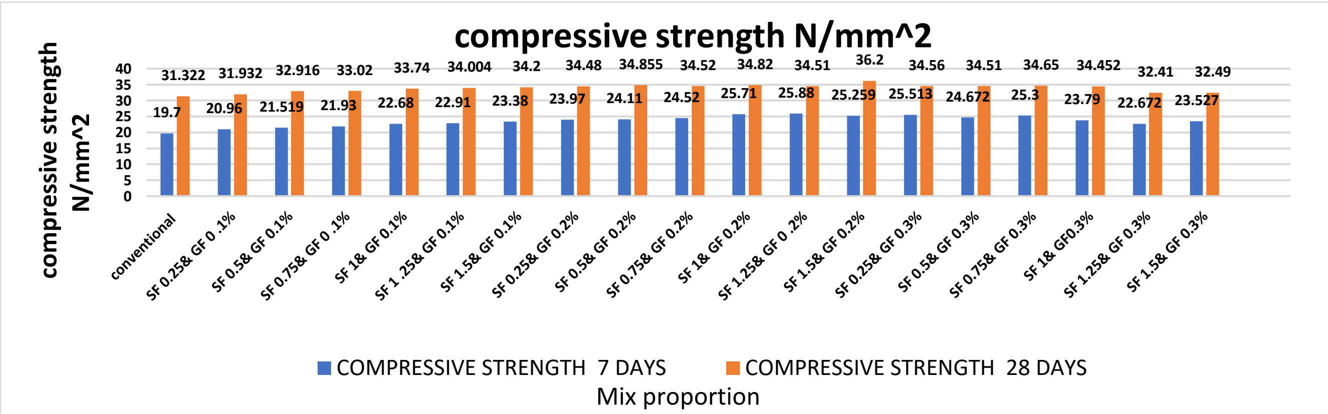
1. Compressive strength test results on HFRC after 7 and 28days curing is graphically represented in Fig given below

Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 45 No. 2 (2024)



Graph 1 Compressive strength result M20

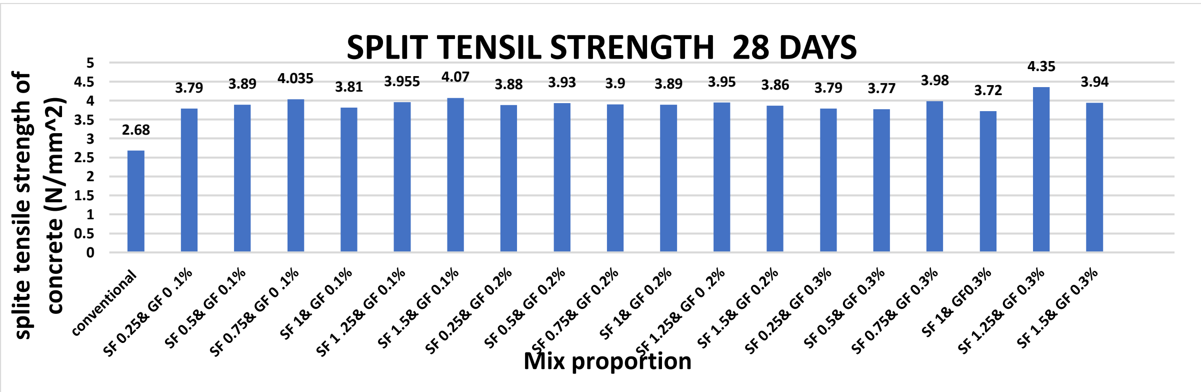
It is observed that, for the optimum mix of hybrid fiber in concrete mix shows 23.29% increase in compressive strength after 28 days, as compared with conventional concrete. The optimum mix is found to be M20 concrete is 1.25% steel fiber and 0.3% glass fiber.



Graph 2 compressive strength result M25

It is observed that, for the optimum mix of hybrid fiber in concrete mix shows 13.47% increase in compressive strength after 28 days, as compared with conventional concrete. The optimum mix is found to be M25 concrete is 1.5% steel fiber and 0.2% glass fiber.

2 Split tensile strength test results on HFRC after 28days curing is given in the figure given below.



Graph 3 Split tensile strength result M20

Comparing the conventional concrete having optimum mix hybrid fibers with conventional concrete, it is observed that the split tensile strength is increased by 38.39%, which indicates tremendous improvement in tensile strength of concrete.

Tuijin Jishu/Journal of Propulsion Technology
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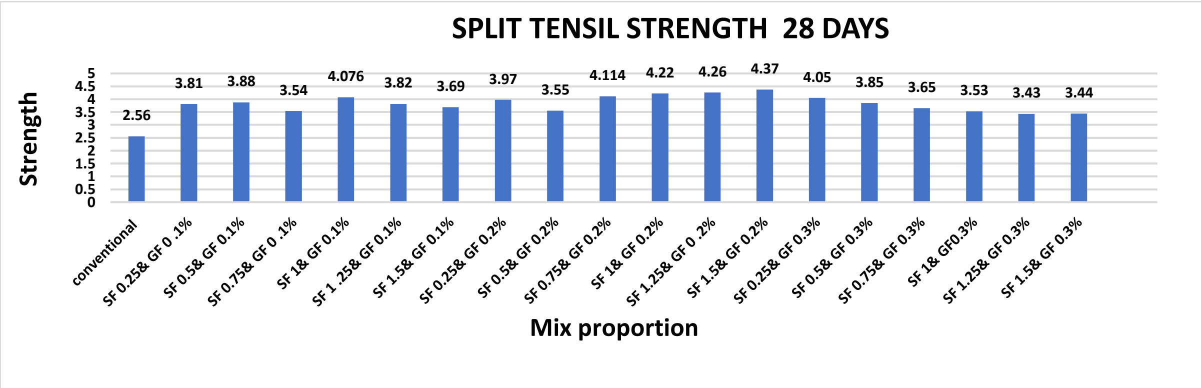
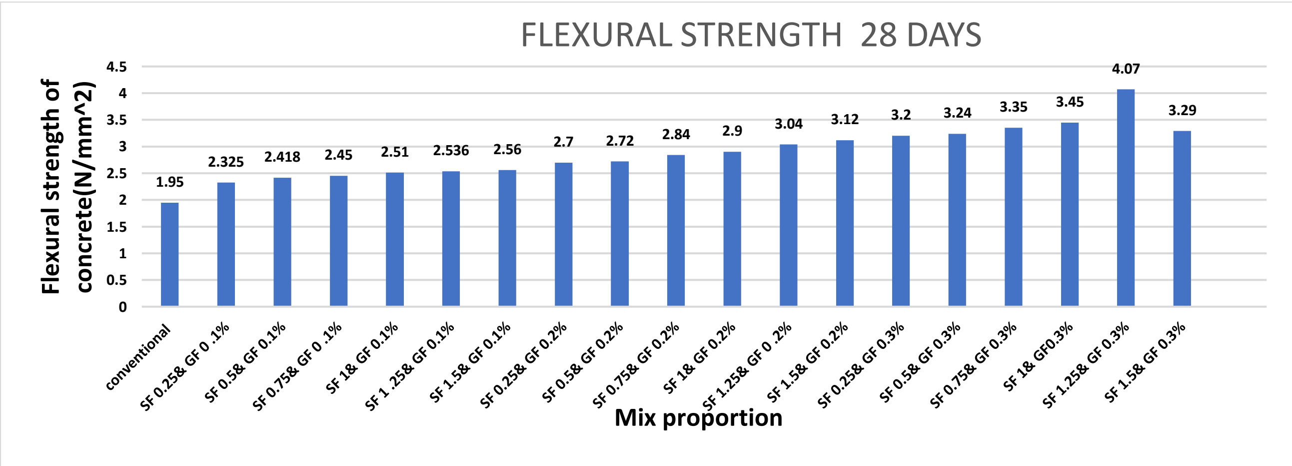


Graph 4 split tensile strength result M25

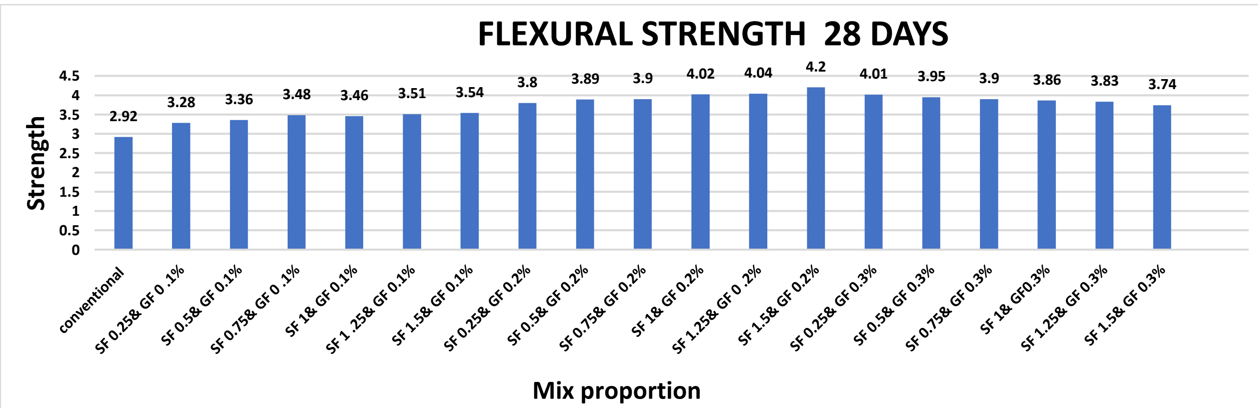
Comparing the conventional concrete having optimum mix hybrid fibers with conventional concrete, it is observed that the split tensile strength is increased by 41.41%, which indicates tremendous improvement in tensile strength of concrete.

3 Flexural strength test results on HFRC after28 days curing is given in the figure given below



Graph 5 Flexural strength result M20

If compared to normal concrete, the optimum combination of hybrid fiber in concrete shows a 52.08% increase in flexural strength after 28 days.

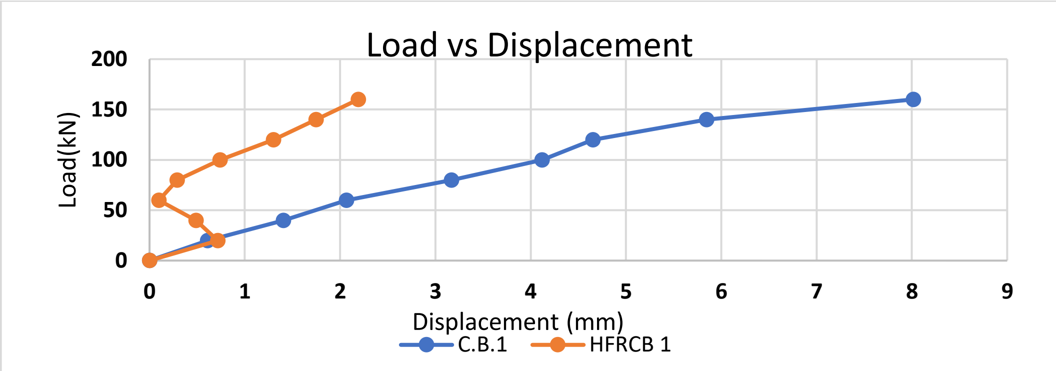


Graph 6 Flexural strength result M25

If compared to normal concrete, the optimum combination of hybrid fiber in concrete shows a 30.47% increase in flexural strength after 28 days.

Hybrid fiber reinforced concrete beam

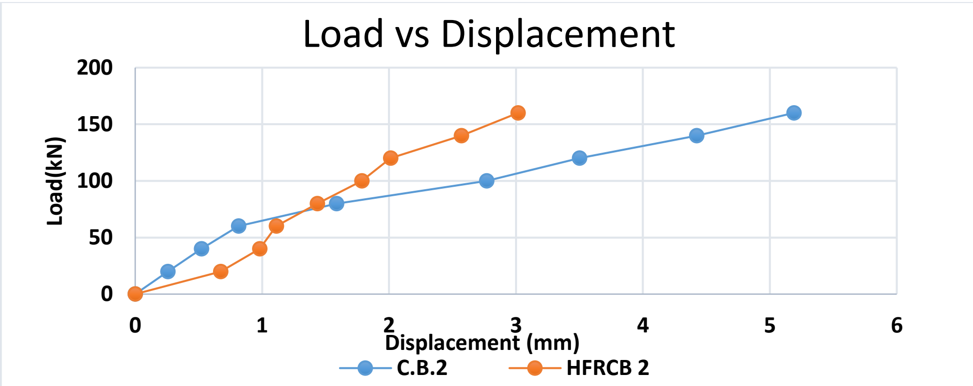
For M20 R.C.C. conventional beam 1vs Hybrid fiber reinforced concrete beam 1, graph represents the variation in displacement as shown below.



Graph 7 C.B. 1 vs HFRCB.1 result M20

The maximum deflection of a standard beam under two-point loading that's simply supported conditions was measured to be 8.01 mm at 160kN static load. Under two-point loading that's simply supported conditions, the maximum deflection of a hybrid fiber concrete beam was found to be 2.19 mm, with a static load of 160 kN. It was observed that the percentage decreases in deflection considering value of deflection of hybrid fiber concrete beam w.r.t conventional concrete beam was found to be 72.65%.

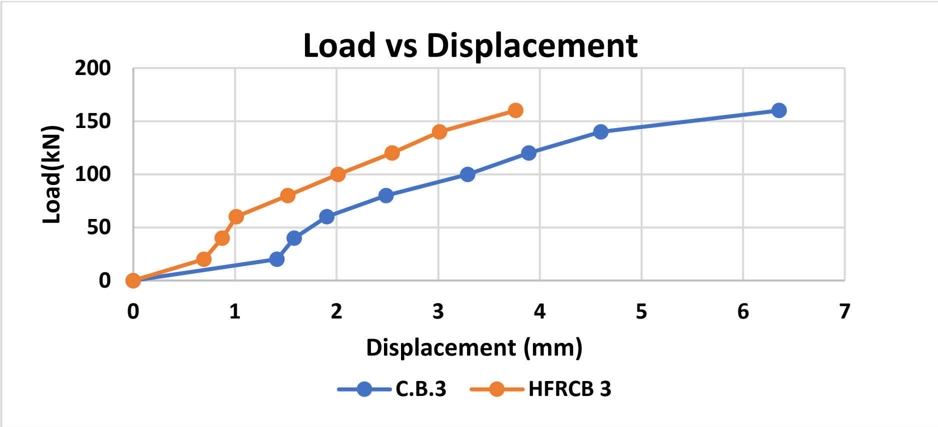
For M20 R.C.C. conventional beam 2vs Hybrid fiber reinforced concrete beam 2, graph represents the variation in displacement as shown below.



Graph 8 C.B. 2 vs HFRCB 2 result M20

The maximum deflection of a conventional beam under two-point loading that's simply supported conditions was measured to be 5.18 mm at 160KN static load. under two-point loading that's simply supported conditions, the maximum deflection of a hybrid fiber concrete beam was found to be 3.01 mm, with a static load of 160 kN. the percentage decreases in deflection considering value of deflection of hybrid fiber concrete beam w.r.t conventional concrete beam was found to be 41.88%.

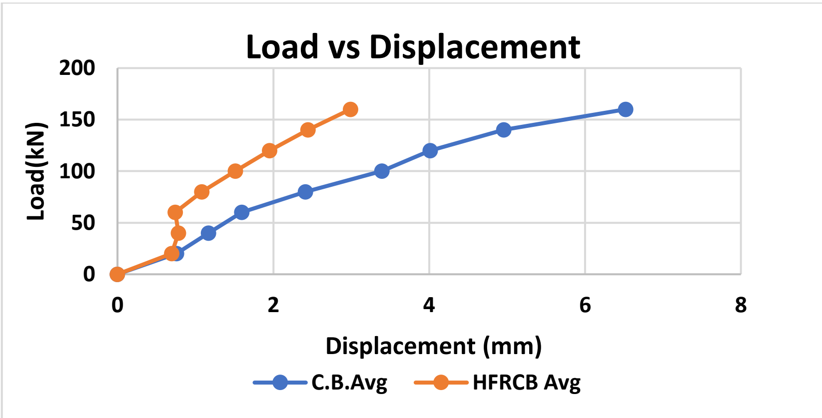
For M20 R.C.C. conventional beam 3vs Hybrid fiber reinforced concrete beam 3, graph represents the variation in displacement as shown below.



Graph 9 C.B. 3 vs HFRCB.3 result M20

The maximum deflection of a conventional beam under two-point loading that's simply supported conditions was measured to be 6.35 mm at 160kN static load. Under two-point loading that's simply supported conditions, the maximum deflection of a hybrid fiber concrete beam was found to be 3.76 mm, with a static load of 160 kN. the percentage decreases in deflection considering value of deflection of hybrid fiber concrete beam w.r.t conventional concrete beam was found to be 40.81%.

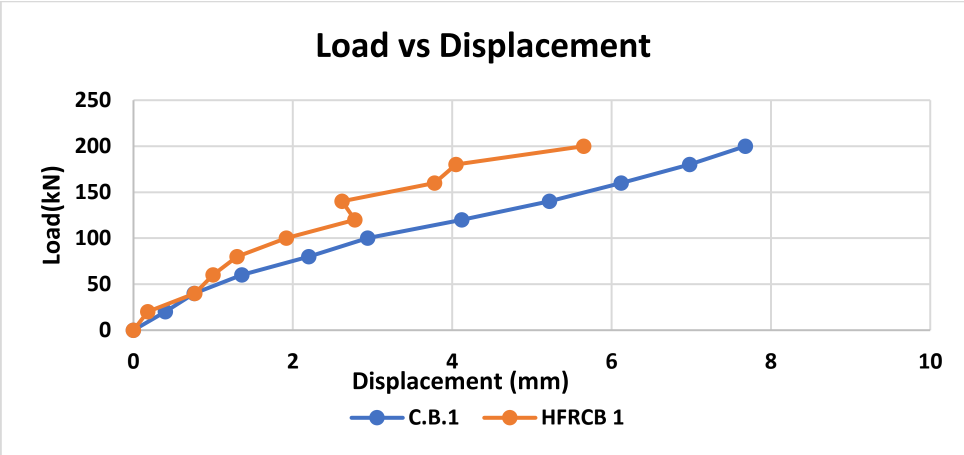
For M20 R.C.C. conventional beam avg vs Hybrid fiber reinforced concrete beam avg, graph represents the variation in displacement as shown below.



Graph 10 C.B. avg vs HFRCB. avg result M20

The maximum deflection of a standard beam under two-point loading that's simply supported conditions was measured to be 6.51 mm at 160KN static load. Under two-point loading that's simply supported conditions, the maximum deflection of a hybrid fiber concrete beam was found to be 2.98 mm, with a static load of 160 kN. The percentage decreases in deflection considering average value of deflection of hybrid fiber concrete beam w.r.t conventional concrete beam was found to be 54.15%.The HFRC beam's averaged displacement of 2.98 mm was found to correspond to a load of 160 kN, which is the same displacement as the conventional beam's corresponding load of 91.57 kN.

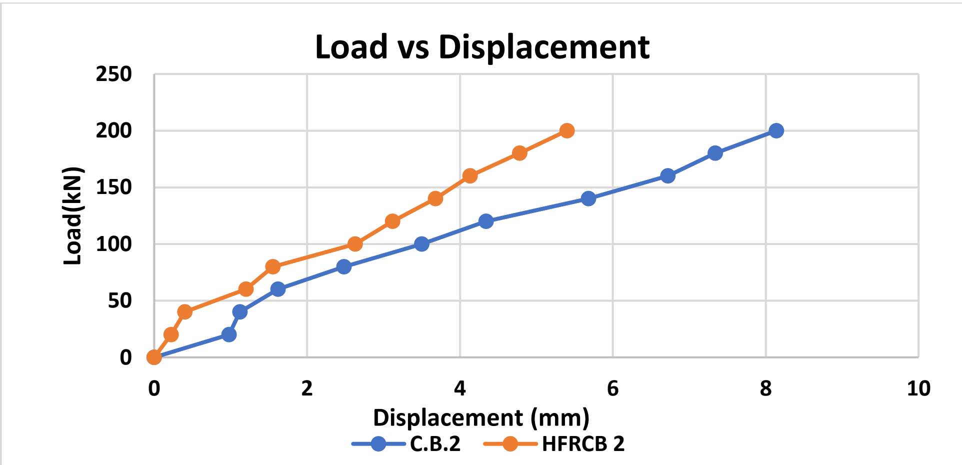
For M25 R.C.C. conventional beam 1vs Hybrid fiber reinforced concrete beam 1, graph represents the variation in displacement as shown below.



Graph 11 C.B. 1 vs HFRCB.1 result M25

The maximum deflection of a conventional beam under two-point loading that's simply supported conditions was measured to be 7.68 mm at 200KN static load. Under two-point loading that's simply supported conditions, the maximum deflection of a hybrid fiber concrete beam was found to be 5.65 mm, with a static load of 200 kN. the percentage decreases in deflection considering value of deflection of hybrid fiber concrete beam w.r.t conventional concrete beam was found to be 26.00%.

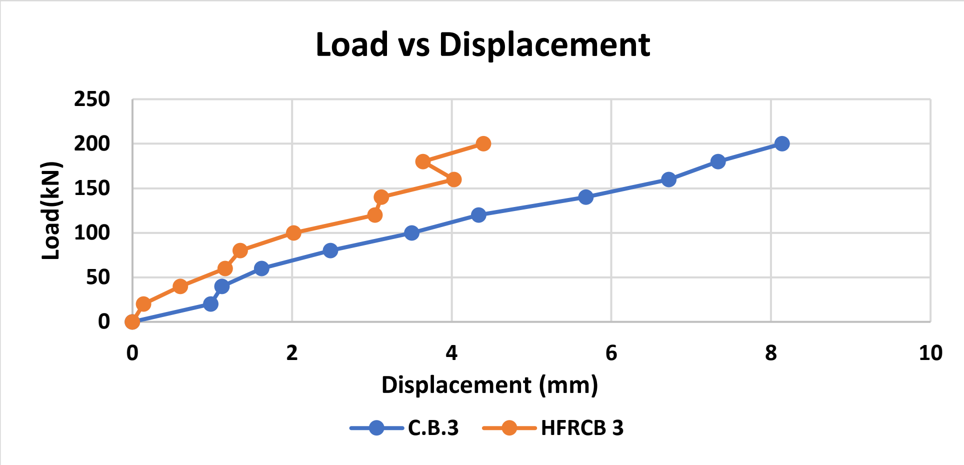
For M25 R.C.C. conventional beam 2vs Hybrid fiber reinforced concrete beam 2, graph represents the variation in displacement as shown below.



Graph 12 C.B. 2 vs HFRCB.2 result M25

The maximum deflection of a conventional beam conditions was measured to be 8.14 mm at 200KN static load. Under two-point loading that's simply supported conditions, the maximum deflection of a hybrid fiber concrete beam was found to be 5.4 mm, with a static load of 200 kN. the percentage decreases in deflection considering value of deflection of hybrid fiber concrete beam w.r.t conventional concrete beam was found to be 34.00%.

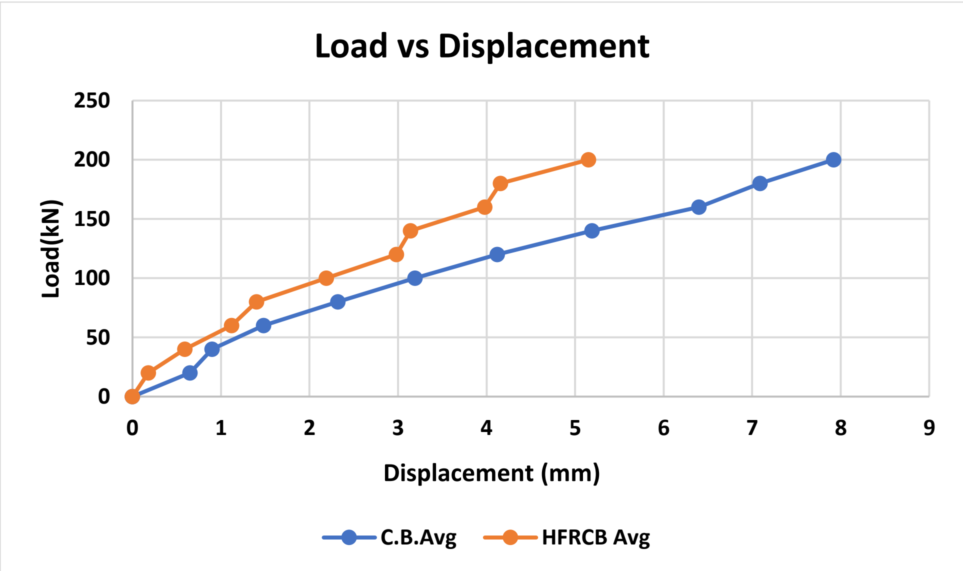
For M25 R.C.C. conventional beam 3vs Hybrid fiber reinforced concrete beam 3, graph represents the variation in displacement as shown below.



Graph13 C.B. 3 vs HFRCB.3 result M25

The maximum deflection of a conventional beam under two-point loading that's simply supported conditions was measured to be 8.14 mm at 200KN static load. Under two-point loading that's simply supported conditions, the maximum deflection of a hybrid fiber concrete beam was found to be 4.4 mm, with a static load of 200 kN. the percentage decreases in deflection considering value of deflection of hybrid fiber concrete beam w.r.t conventional concrete beam was found to be 46.00%.

For M25 R.C.C. conventional beam avg vs Hybrid fiber reinforced concrete beam avg, graph represents the variation in displacement as shown below.



Graph 14 C.B. avg vs HFRCB. avg result M25

The maximum deflection of a standard beam under two-point loading that's simply supported conditions was measured to be7.92 mm at 200KN static load. Under two-point loading that's simply supported conditions, the maximum deflection of a hybrid fiber concrete beam was found to be 5.15 mm, with a static load of 200kN.the percentage decreases in deflection considering average value of deflection of hybrid fiber concrete beam w.r.t conventional concrete beam was found to be 35.00%.The HFRC beam's averaged displacement of 4.95 mm was found to correspond to a load of 200 kN, which is the same displacement as the conventional beam's corresponding load of 135.51 kN.

Conclusion

The results obtained show the addition of small quantities of steel and glass fibers gradually improves the a compressive, splitting tensile, and flexural strengths. For hybrid fiber reinforced concrete, the compressive, split, and flexural strengths are all significantly greater.

- The optimum hybrid fiber percentage to use in the M20 concrete mixes is 0.3% glass fiber and 1.25% steel fiber and M25 concrete mixes is 0.2% glass fiber and 1.5% steel fiber.
- For M20 the percentage decreases in deflection of R.C Beam considering average value of deflection of hybrid fiber concrete beam w.r.t conventional concrete beam was found to be 54.15%.
- For M20 the HFRC beam experiences a 75% increase in load at displacement 2.98 mm compared to the conventional beam.
- For M25 the percentage decreases in deflection considering average value of deflection of hybrid fiber concrete beam w.r.t conventional concrete beam was found to be 35.00%.
- For M25 The HFRC beam experiences a 48% increase in load at displacement 4.95 mm compared to the conventional beam.

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