Experimental Study of Steel and Polypropylene Fiber Reinforced Concrete

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Abstract

Fiber-reinforced concrete (FRC) is a composite material incorporating cement, sand, coarse aggregates, and fibers. FRC use both natural and artificial fibers as reinforcement to improve the mechanical properties. This study investigated the effects of two types of artificial fiberssteel and polypropylene—on concrete properties. Steel fiber reinforced concrete (SFRC) with 2% fiber by volume and polypropylene fiber reinforced concrete (PFRC) with 1.5% fiber by volume were prepared. A total of eighteen specimens were made using M20 grade concrete: six cubes, six cylinders, and six beams for each type of fiber. Mechanical properties were tested under compression, including compressive strength, split-tensile strength, and flexural strength. Results showed that PFRC with 1.5% polypropylene fiber exhibited a 23.4% increase in compressive strength, a 32.2% increase in split-tensile strength, and a 20% increase in flexural strength compared to conventional concrete. SFRC with 2% steel fiber demonstrated a 27.2% increase in compressive strength, a 42.7% increase in split-tensile strength, and a 35.8% increase in flexural strength compared to conventional concrete.

Keywords: Compressive strength, Fiber Reinforced Concrete (FRC), Flexural strength, Polypropylene reinforced concrete (PFRC), Split-tensile strength, Steel fiber reinforced concrete (SFRC).

1. Introduction:

Fiber-Reinforced Concrete (FRC) is mixture of cement, sand, aggregate and fibers. The FRC is prepared to enhance the strength of mechanical properties of concrete. The fibers used in concrete could be either artificial fiber such as glass, polypropylene, steel, or natural fibers such as jute, coir, coconut hair. Concrete has the disadvantages of low tensile strength, weak deformation resistance, and poor crack resistance. The addition of fiber improves its ability to withstand cracking, lateral force, increases load-deflection rate, increases in tensile strength and increase in cyclic load, and increases its flexural strength and ductility (Anas et al., 2022),(Bagherzadeh et al., 2012).

The utilization of FRC has grown in relevance recently due to its enhanced mechanical qualities over normal concrete (F. M. D. S. More & Subramanian, 2022). The use of FRC in the construction industry has been increasing over the past three decades, and the most used is Steel Fibre Reinforced Concrete (SFRC). Field applications of FRC includes airport runways, tunnel linings, bridge structures, and protective structures, to name a few. Using short, randomly distributed fibres in concrete has been shown to increase the flexural strength and toughness of the material and contribute to better crack control (Elsanadedy et al., 2012).

Various enhancements in such properties were achieved depending on the properties of the concrete matrix, fibre and fibre/matrix interface. In a flexural-loaded FRC beam, such enhancements are mainly influenced by the fibre-bridging stress distribution acting across the first crack that develops on the tensile face of the beam (Köksal et al., 2008).

The effectiveness of FRC in improving various mechanical properties of concrete largely depends on the fiber dosage, fiber aspect ratio, percentage of longitudinal steel, tensile strength of fibers, and concrete compressive strength (Behbahani et al., 2011) (D. F. More & Selvan, 2021). The strength of concrete increases with the increase in fiber aspect ratio and volume fraction (Yoo et al., 2017),(Sahoo et al., 2015). In the other hand, Polypropylene fibre (PPF) is a synthetic fibre obtained from propylene polymerization having advantages such as light weight, high strength, high toughness, and corrosion resistance. Concrete reinforced with PPF, the toughness and durability of concrete can be enhanced along with increment in strength to resist crack formation and growth in concrete (Karzad et al., 2023),(Liu & Zhang, 2014). This research work aims to perform comparative experimental analysis to determine mechanical strength of SFRC and PFRC concrete with optimal fiber ratio of 1.5 % by volume for PFRC and 2% by volume for SFRC.

2. Methodology

The methodology of the research is shown in fig. 1. The work begins with the determination of optimal fiber ratio from literature review which is followed by acquiring the Steel and Polypropylene fiber along with other material. Then, six different samples were made which were then subjected to mechanical tests to determine compressive, split tensile and flexural strength.

The experimental study in a laboratory setting, where SFRC and PFRC samples were prepared and subjected to test. The experimental study involved preparing six numbers of FRC samples with steel 2% and polypropylene 1.5% fiber to each sample and the samples were undertaken to compressive, split tensile and flexural strength test. In this experiment, steel fiber with hooked ends measuring 50 mm in length and 0.60mm in diameter and polypropylene fiber with 50mm length and 1mm in width were used as shown in Fig. 2.

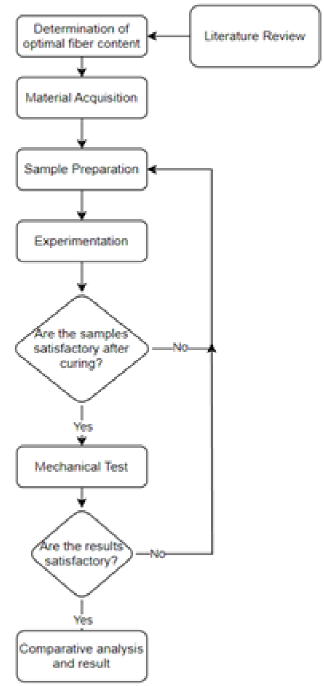

Fig. 1: Methodology Flowchart

i. Cement:

OPC 43 cement of 3.18 specific gravity was adopted in this experiment, conforming to IS12269-2013.

ii. Fine Aggregates:

River sand, which was available nearby, were chosen in this experimental program. The maximum size of fine aggregate were 4.75 mm, satisfying to zone II with reference to Indian Standard 2386–1963. Adopted river sand has a specific gravity of 2.56.

iii. Coarse Aggregates:

Graded crumbled stone of 20 mm and 12.5 mm size were adopted as coarse aggregate confirming to Indian Standard 2386–1963. The crushed stone aggregate adopted was with the specific gravity of 2.69.

iv. Design Mix:

The mix proportions for M20 grade were taken as 1:1.5:3 ratio.

In this experiment, specimens were cured in water for 28 days at room temperature.

1. Results and Discussion

After the preparation of six different samples for tests of SFRC and PFRC, mechanical tests i.e. compressive test, split tensile test and flexure test were performed. The results obtained from the tests is discussed in this section.

3.1 Compressive Strength

Compressive strength of PFRC with 1.5 % fiber ratio and SFRC with 2 % fiber ratio was obtained by subjecting the sample block to Compressive Testing Machine (CTM) shown in Fig 3, once the sample was properly cured for 28 days.

Both samples were prepared simultaneously and then compressive test was performed. The results of the test can be seen in Table 1 which is compared to that of regular M20 concrete. All samples were subjected to compression test after curing samples for 28 days. The block dimension was 150 mm x 150 mm x 150 mm. The results showed that the use of polypropylene and steel fiber as reinforcement in concrete increase the compressive strength of concrete. For fiber ratio of 1.5 %, using polypropylene fiber reinforcement in concrete, the compressive strength is increased by 23.4 %. Using steel fiber reinforcement for fiber ratio of 2 % in concrete, the compressive strength is increased by 27.2 %.


(a) (b)

Fig 2: (a) Polypropylene fiber (b) Steel fiber

Table 1: Results of compressive strength test for PFRC and SFRC

Sample	Fiber Ratio	Test Method	Maximum Compressive Load	Compressive Strength of Sample	Compressive strength of M20 Conventional Sample
PFRC	1.5%	IS 516:2018	555.4 kN	24.68 MPa	20 MPa
SFRC	2 %	IS 516:2018	572.6 kN	25.44 MPa	20 MPa

The results shown in Table 1 are evident to conclude that the use of polypropylene and steel fiber as reinforcement in concrete increase the compressive strength of concrete. For fiber ratio of 1.5 %, using polypropylene fiber reinforcement in concrete, the compressive strength is increased by 23.4 %. Using steel fiber reinforcement for fiber ratio of 2 % in concrete, the compressive strength is increased by 27.2 %.

Fig. 3: Compressive strength test of block

3.2 Split tensile strength

Split tensile strength of PFRC and SFRC with 1.5 % fiber ratio was obtained by subjecting the cylindrical samples to Compressive Testing Machine (CTM) as shown in Fig. 4, once the samples were properly cured for 28 days. Both samples were prepared simultaneously and then split tensile test was performed.

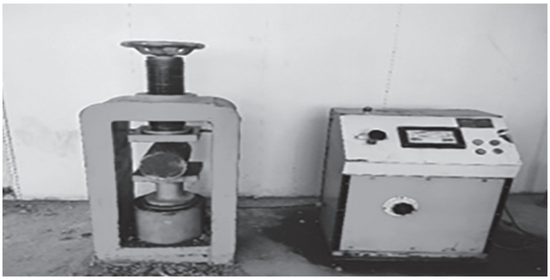

Fig. 4: Split tensile strength test of sample

The results of the test can be seen in Table 2 which is compared to that of regular M20 concrete. The rate of loading was 0.25 kN/s, length of the cylindrical sample (l) was 300 mm and the diameter of the cylindrical sample (d) was 150 mm.

Table 2: Results of split tensile strength test for PFRC and SFRC

Sample	Fiber Ratio	Test Method	Maximum Load	Split Tensile Strength of sample	Split Tensile strength of control sample
PFRC	1.5%	IS 516:2018	278.7 kN	3.90 MPa	2.95
SFRC	2 %	IS 516:2018	297.5 kN	4.21 MPa	2.95

The results shown in table 2 are evident to conclude that the use of polypropylene and steel fiber as reinforcement in concrete increase the split tensile strength of concrete. For fiber ratio of 1.5 %, using polypropylene fiber reinforcement in concrete, the split tensile strength is increased by 32.2 %. Using steel fiber reinforcement for fiber ratio of 2 % in concrete, the split tensile strength is increased by 42.7 %.

3.3 Flexural Strength

Flexure strength of PFRC with 1.5 % fiber ration and SFRC with 2 % fiber ratio was obtained by subjecting the beam samples to Flexure Testing Machine as shown in Fig. 5, once the sample was properly cured for 28 days. Both samples were prepared simultaneously and then flexure test was performed. The results of the test can be seen in Table 3 which is compared to that of regular M20 concrete. The width and depth of the beam was 150 mm and the length of the sample was 700 mm whereas the equivalent length was 600 mm.

The results shown in table 3 are evident to conclude that the use of polypropylene and steel fiber as reinforcement in concrete increase the compressive strength of concrete. For fiber ratio of 1.5 %, using polypropylene fiber reinforcement in concrete, the compressive strength is increased by 20 %. Using steel fiber reinforcement for fiber ratio of 2 % in concrete, the compressive strength is increased by 35.8 %.

Table 3: Results of flexure strength test for PFRC and SFRC

Sample	Fiber ratio	Test Method	Maximum Load	Flexure Strength of sample	Flexure strength of M20 concrete
PFRC	1.5%	IS 516:2018	20.94 kN	3.72 MPa	3.1 MPa
SFRC	2 %	IS 516:2018	23.72 kN	4.21 MPa	3.1 MPa

Comparative analysis of PFRC and SFRC shows that when concrete is reinforced with steel fiber at optimal fiber ratio of 2 % all three mechanical properties namely, compressive strength, tensile strength and flexure strength is better than when it is reinforced with polypropylene fiber at optimal fiber ratio of 1.5 %.

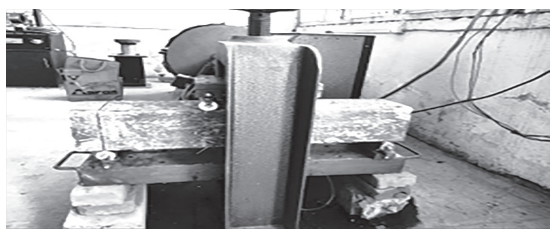

Fig. 5: Flexure strength test of beam

4. Conclusion

The study investigated the effect of steel fibre and polypropylene fibre on the strength of concrete, when it is added to the conventional concrete. The M20 design mix, six different samples with 1.5 % fiber ratio for polypropylene and 2 % fiber ratio for steel fiber were made to determine the compressive strength, split tensile strength and flexural strength. The mechanical properties (compressive strength, split-tensile and flexural strength) of the fiber reinforced concrete were compared with conventional concrete.

The obtained results showed that the compressive strength of polypropylene fiber reinforced blocks is 27.2 % higher than conventional concrete blocks and that of steel fiber reinforced block is 23.4 % higher than conventional concrete block. Also, the split tensile strength of polypropylene fiber reinforced blocks is 32.2 % higher than conventional concrete blocks and that of steel fiber reinforced block is 42.7 % higher than conventional concrete block.

Moreover, the flexural strength of polypropylene fiber reinforced beams is 20 % higher and steel fiber reinforced beams is 35.8 % higher than conventional concrete block. The compressive strength of PFRC is 3.07 % greater than that of SFRC, split tensile strength of SFRC is 7.94 % greater than that of PFRC and flexural strength of SFRC is 13.17 % greater than that of PFRC.

Additionally, the mode of failure of fiber (both polypropylene and steel) reinforced samples was found to be less brittle in comparison to traditional concrete. Also, the fiber reinforced concrete samples showed greater resistance to crack generation and propagation in comparison to conventional concrete samples. The experimental results can be validated using the numerical analysis of the samples for further enhancement of the results.

Data Availability Statement:

The data that support the findings of this study are available to the main author, upon reasonable request.

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