

# An Investigation on Mechanical Properties of Hybrid Fiber Reinforced Concrete

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**Abstract:** A composite can be termed as hybrid, if two or more types of fibers are rationally combined in a common matrix to produce a composite that derives benefits from each of the individual fibers. The aim is to study the mechanical properties i.e. split-tensile strength and compressive strength on hybrid effect between steel fiber (SF) and chopped carbon fiber (CF). The test on Hybrid Fiber Reinforced Concrete (HFRC) is to be explored at steel fiber volume fraction 0.5%, 1%, 1.5% and carbon fiber 0.1%, 0.2%, 0.3% by the volume of cement with reinforcement and without reinforcement. For this study, 60 cubes of 150mm, 60 cylinders of 150mm diameter and 300mm height of different combination of SF and CF will be casted of M25 grade of concrete. After testing, effect of different combination and the optimized composition will be concluded. The testing results shows that the optimum of hybrid combination 0.3% CF and 1% SF gives the optimised response in terms of Split-Tensile Strength while hybrid combination of 0.3% CF and 1.5% SF gives the optimised response in terms of Compressive Strength.

**Keywords:** Chopped Carbon Fibers, Concrete, Hybrid Composite, Mechanical Properties, Steel Fibers.

## 1. INTRODUCTION

Cementitious materials are characterized by low tensile strength, low strain capacity and low fracture toughness: they are brittle materials. Reinforcement in the form of continuous steel bars and stirrups is used to resist imposed tensile and shear stresses in reinforced concrete which renders it a usable structural material. In the last five decades, another kind of reinforcement has been used to overcome the brittleness, namely discontinuous and randomly distributed fibers, producing a new structural material known as fiber reinforced concrete with improved strength, ductility and durability. The term Fiber Reinforced Concrete (FRC) is defined as concrete made of hydraulic cements containing fine and coarse aggregates and discontinuous discrete fibers. It is important to recognize that, in general, fiber reinforcement is not a substitute for conventional reinforcement. The role of these two types of reinforcement is different in concrete; continuous steel bars are used to increase the tensile and shear capacities of concrete while the primary reason for addition of discontinuous fibers to the concrete matrix is to improve the post cracking response by controlling the crack opening and propagation.

A composite can be termed as hybrid, if two or more types of fibers are rationally combined in a common matrix to produce a composite that derives benefits from each of the individual fibers and exhibits a synergetic response. According to Bentur and Mindess [A. Bentur and S. Mindess, 2005] the advantages of hybrid fiber systems can be listed as follows;

- To provide hybrid reinforcement in which one type of fiber is smaller, so that it bridges the micro cracks of which growth can be controlled. This leads to a higher tensile strength of the composite. The second type of fiber is larger, so that it arrests the propagating macro cracks and can substantially improve the toughness of the composite.
- To provide a system in which one type of fiber, which is stronger and stiffer, improves the first crack stress and the ultimate strength, and the second type of fiber, which is more flexible, and ductile leads to improved toughness and strain in the post-cracking zone.
- To provide a hybrid reinforcement, in which the durability of fiber types is different. The presence of the durable fiber can increase the strength and/or toughness relation after age while the other type is to guarantee the short-term performance during transportation and installation of the composite elements.

In well-designed hybrid composites, there is positive interaction between the fibers and the resulting hybrid performance exceeds the sum of individual fiber performance. This phenomenon is often termed as synergy. "Synergy is the phenomenon where acting of two or more subjects together leads to a better result than the sum of action of the same subjects independently of each other. That means when applied to hybrid fiber concrete one could suppose that the synergy of short and long fibers leads to an improved tensile response of the hybrid fiber concrete, compared to the arithmetic sum of tensile responses of two concretes, one of which contains only long and the other only short fibers in the same dosage as the hybrid fiber concrete"

Hsie Machine et al [1] investigates the mechanical properties of polypropylene hybrid fiber reinforced concrete. There are two forms of polypropylene fibers including coarse monofilament, and staple fibers. The content of the coarse monofilament fiber is at

3 kg/m<sup>3</sup>, 6 kg/m<sup>3</sup>, and 9 kg/m<sup>3</sup>, and the content of the staple fiber is at 0.6 kg/m<sup>3</sup>. Wu Yao et al [2] studies on the mechanical properties of hybrid fiber reinforced concrete at low fiber volume fraction was carried out. Concretes containing steel, carbon and polypropylene (PP) fibers in hybrid form at the same volume fraction (0.5%). The carbon and PP fibers were smooth and straight, while the steel fibers were hooked end. Jyothis Jose Oommen and Mr. Tom George [3] presents an experimental study on the effect of hybrid fiber addition to M40 concrete mix using the steel-nylon hybrid fiber reinforced system. Four different volume fractions of fiber content i.e., 0.5%, 1.0%, 1.5% and 2.0% were studied for both fibers. N. Banthia and R. Gupta [4] investigates the effect of using different fiber types such as macro and micro-fibers of steel, polypropylene and carbon for a very high strength matrix of an average compressive strength of 85 MPa. Control, single, two-fiber and three fiber hybrid composites were cast using different fiber types. Volume fraction of fibers used in various mixes were 0.5%, 0.75%, 1% and 1.3% Flexural toughness tests were performed. M. K. Yew et al [5] investigates the effect of hybrid nylon-steel fiber-reinforced concrete were investigated in comparison to that of polypropylene-steel fiber-reinforced concrete, at the same volume fraction (0.5%). The content of macro steel fibers is at 0.4% volume fraction, and the content of micro nylon and polypropylene-fibers is at 0.1% volume fraction.

## 2. EXPERIMENTAL PROGRAM

### 2.1. Materials

The materials used for the control concrete mixture consisted of the normal Type I Portland cement, the gravel having a maximum size 2 cm, and the river sand having a fineness modulus of 2.186. The additives are Steel Fibers and Chopped Carbon Fibers, and they are showed in Fig. 1. The diameter of Steel fibers is 1.25mm, the length is 50mm, and the Tensile Strength is 1500 MPa. The Chopped Carbon Fiber having length of 6mm, diameter of 7  $\mu$ m and tensile strength is 2000MPa.



Fig. 1: Steel Fibers and Chopped Carbon Fiber

Table 1: Properties of Carbon and Steel Fibers

Material	Carbon	Steel
Length (mm)	6	50
Diameter ( $\mu$ m)	7	1250
Geometry	Straight	Crimped
Tensile strength (MPa)	2000	1500

### 2.2. Mixing and Curing

The mixing process started with the dry mixing of the coarse and fine aggregates for 1 min. The cement and Fibers were added; then dry mixing kept for another 1min, then added water and the mixture was mixed for 3min to ensure that the fibers can evenly disperse throughout the concrete. The fresh concrete was filled in 150mm $\times$ 300mm cylinder moulds and 150mm $\times$ 150mm $\times$ 150mm Cube molds. The former is for the tests of split tensile strengths, and the latter is for compressive strength. Both molds were removed after 24 h, and the specimens were allowed to cure in a water tank at 23 $\pm$ 1  $^{\circ}$ C. Property tests were performed after the samples had cured for 28 days.

2.3. Mix Design

Table 2: Mix Proportion

Material	Cement	Water	Fine Aggregates	Coarse Aggregates
Mass (kg/m <sup>3</sup> )	383.16	207.07	670.66	1277.19
Mass (kg)	50	27.02	87.52	166.66
Proportion	1	0.5	1.73	3.3

2.4. Specimen Codes

Table 3: Specimen Codes

Specimen codes	Fiber volume fraction (%)	
	Carbon	Steel
N	0	0
A-1	0.1	0.5
A-2	0.2	0.5
A-3	0.3	0.5
B-1	0.1	1
B-2	0.2	1
B-3	0.3	1
C-1	0.1	1.5
C-2	0.2	1.5
C-3	0.3	1.5

3. RESULTS AND DISCUSSION

3.1. Compressive strength



Fig. 2: 7-Days Compressive Strength

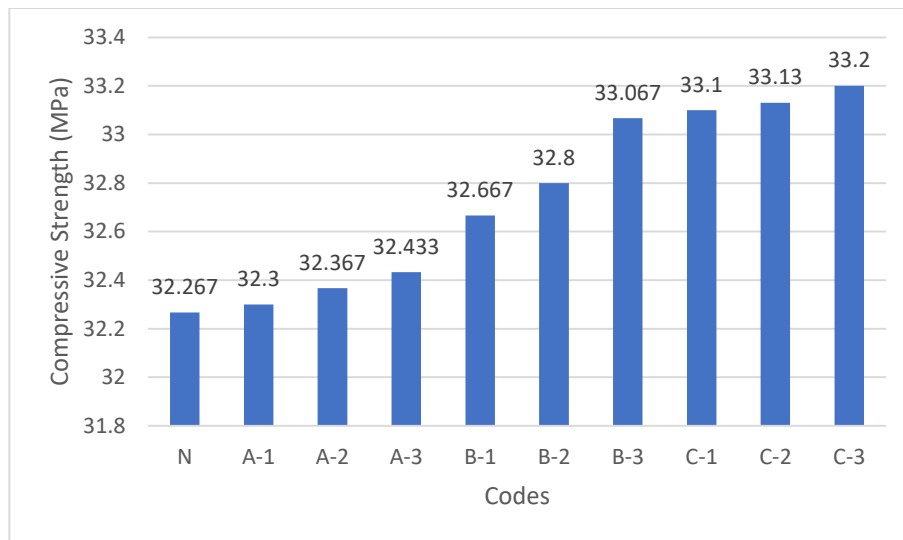


Fig. 3: 28-Days Compressive Strength

The Compressive Strength of the concrete keeps on increasing as the fiber contents of the concrete increases. The maximum Compressive strength was for 0.3% Chopped Carbon Fiber and 1.5% Steel Fiber, volume fraction is by the weight of the cement. The increase in compressive strength for A batch was from 0.1% to 0.5%, for B batch was from 1.24% to 2.48% and for C batch was from 2.58% to 2.89% as compared to conventional concrete.

### 3.2. Split-tensile strength



Fig. 4: 7-Days Split-Tensile Strength

The Split-tensile strength for 7-days and 28-days was maximum in B-3 which is 0.3% Chopped Carbon Fiber and 1% Steel Fiber, volume fraction is by the weight of the cement. The increase in split-tensile strength for A batch was from 1.28% to 3.89%, for B batch was from 6.46% to 12.97% and for C batch was from 9.08% to 5.81% as compared to conventional concrete.



Fig. 5: 28-Days Split-Tensile Strength

#### 4. CONCLUSION

Following conclusions are drawn from the experimental investigations conducted to assess the influence of fibers on the mechanical response of the concrete

- The combination of SF-1% and CF-0.3% gives the optimum response of the concrete in terms of split tensile strength.
- The Split tensile strength was increased by 12.97% compared to conventional concrete for the optimum response combination.
- While the compressive strength of the concrete keeps on increasing as the percentage of fibers are increased in the concrete.
- The Compressive Strength was increased by 2.48% compared to conventional concrete for the optimum response combination.

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