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Study the Mechanical Properties of Hybrid Fiber Reinforced Concrete

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***Abstract*—There is increase in fiber use in concrete from last few decades. There is demand of providing cost effective technique with this innovative material while offering improved structural properties. The fibers can be used to replace the conventional bars partially or fully. This paper presents the mechanical properties of Hybrid Fiber Reinforced concrete (Steel and Polypropylene). The combined volume fractions of steel and polypropylene used were 1.25% and 1.75%. The hooked end steel fibers with fibrillated polypropylene were used in this study. The compressive strength and flexural strength of the HyFRC was determined in this study. The concrete of M20 grade concrete was used in this study. The significant improvement in compressive and flexural strength was observed in this study. There improvement in failure strain is observed in this study.**

***Index Terms*— Steel fiber; Fibrillated polypropylene fiber; Aspect ratio; Concrete.**

I. INTRODUCTION

The concrete has the advantage that it has capacity to withstand large compressive forces. But the draw back with concrete is that it is weak in tension. The concrete is not capable of resisting large strain value. The concrete as such is brittle material and has low ductility. Concrete has low impact strength. The concrete has limited fatigue life. The concrete has low tensile strength due to this cracks are formed on the tensile face of the member. The cracks slowly start progressing to the compression end of the member and finally, the member breaks. Drying shrinkage also causes the concrete to crack. With time crack opening gradually increases and try to fail the concrete.

The concrete becomes weak due to formation of internal micro cracks, these cracks are responsible for failure of plain concrete. The fibers helps to arrest cracks and prevent the breeding of the cracks. The fibers basically bridge the cracks and stop propagation of crack. Fiber reinforced concrete is an established product now being widely used for applications such as industrial floors, roads, pavements, tunneling, composite construction, walls, precast systems and more. To find the benefits of adding fibers into concrete leading to an extension of the possible areas of application in structural and civil engineering. The main cause for adding fibers to concrete is to boost the post-cracking behavior of the concrete, i.e., to raise its energy absorption potential and apparent ductility, and to stop crack breeding. Also, it helps to maintain the concrete integrity.

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II. FIBER MECHANISM

Fiber mechanism basically works in two forms: the positioning mechanism and the crack arresting mechanism. The positioning mechanism needs a great number of fibers regularly scattered inside the concrete medium to capture any existing micro crack that can grow and create a rigorous crack. The fibers along the developed stress are more effective in arresting the cracks than the fibers that are perpendicular to the developed stress in concrete.

The later mechanism called crack bridging needs larger straight forward fibers with satisfactory link to concrete. When the crack start to form the fibers along the stress developed become effective and try to capture the crack by developing tensile strength in it. Fibers along the developed stress are more effective in crack bridging.

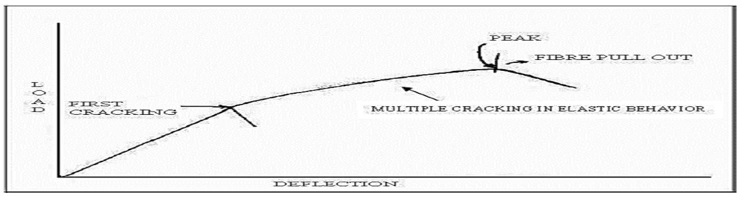

Fig 1 Load deflection curve for fiber mechanism

A. Bridging Action

Withdrawal resistance of fibers (dowel action) is essential for efficiency. Withdrawal strength of fibers knowingly improves the post-cracking tensile stress. As an FRC beam or other Structural portion is loaded, fibers bridge the cracks. Due to fiber bridging action the FRC sample provide greater final tensile strength, larger toughness and better energy absorption.

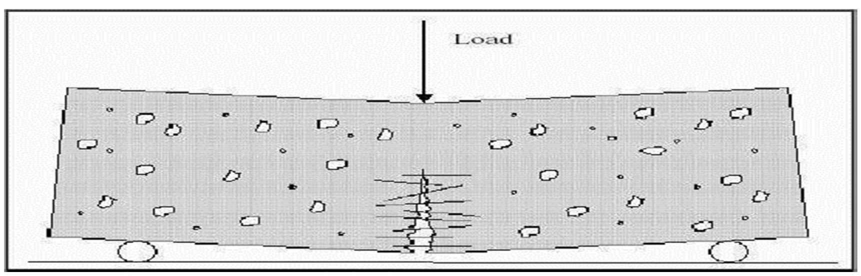

Fig 2 fiber bridging action

B. Fiber Reinforced Concrete

Fiber Reinforced Concrete is a concrete consisting of mixtures of cements, mortar or concrete and discontinuous discrete uniformly dispersed suitable fibers ([ACI Committee 544,1997]. Presently for reinforcing concrete, 300000 metric tons of fiber used. The fiber material can be steel, cellulose, carbon, polypropylene, glass, nylon and polyester. The steel fibers are mostly used fibers around (50% of total tonnage used).

C. Hybrid Fiber Reinforced Concrete

A compound can be named as hybrid, when two or more kind of fibers are reasonably used in a same medium to develop a compound that obtain aids from individually fibers and shows a synergetic reaction [A. Bentur and S. Mindess, 2005]. Following are the advantages of hybrid fiber systems:

- To provide different types of fibers one is strong and stiffer and other is flexible, the stronger fiber improves the ultimate strength and first crack stress. The strain and toughness are improved due to flexible fibers in post cracking zone.
- To provide different types of fiber lengths like one is smaller and the other type of fiber is longer. The micro cracks are controlled by smaller fibers and provide higher tensile strength to the compound. Larger fiber controls breeding of macro cracks and improve toughness of composite.

In this study I have made efforts towards mechanical properties of concrete that later can be used to develop flexural model for HyFRC for its structural application. The hybrid fibers are used in various combinations in four sets. Compressive and flexural strength tests have been performed on samples containing unlike volume fractions of SF and PF. The tests were performed per Indian standards.

D. Materials Used

Cement: For making the concrete the cement is used as binding material. It has pozzolanic properties. It is in fine powder form. It is produced by crushing of clinkers. The Portland pozzolanic cement was used in this work. It was tested as per the provisions laid down in IS1489 code and results are given in tabular form.

TABLE I. CEMENT PROPERTIES

Sr. No.	Cement property	Value Obtained	Limits As Per IS 1489
1	Standard Consistency (using vicat Apparatus),%	28	-
2	Setting TimeInitial, Min.	67	>30min
3	Setting Time Final, Min.	450	s<10Hrs
4	Specific Gravity (using specific gravity bottle)	3	3-3.15
5	7 days Compressive strength (N/mm^2)	26.3	22
6	28 days Compressive strength (N/mm^2)	39.6	33

E. Fine and Coarse Aggregates

In the present study, Local coarse sand obtained from river bed was used. The 10mm coarse aggregate have been used in this study. The aggregates type used here are crushed angular in shape.
Fineness modulus of fine aggregates = 2.91
Grading zone = 2
Fine aggregates Specific gravity = 2.64
Coarse aggregates Specific gravity = 2.68

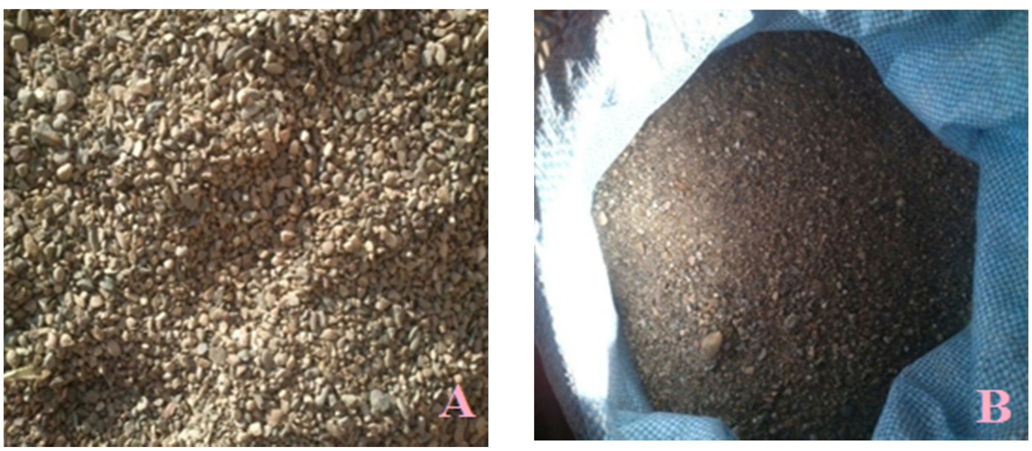

Fig 3Picture of Coarse aggregates (A) and Fine aggregates(B)

F. Fibers

Steel Fibers:The fibers that I have used in this study are hooked end SF. This shape is probably the most popular and successfully used in earlier structure. Steel fibers are available in various types. The proper details regarding fibers used in the work are given below. These are mixed in concrete as per proportions given in experimental program.

TABLEII. STEEL FIBER PROPERTIES

Property	Value
Diameter of Steel fiber (d)	0.80mm
Fiber Length (L)	60mm
Aspect Ratio (L/d)	75
Fiber tensile strength N/mm^2	1250

Fig 4Steel fibers 60mm length hooked end with aspect ratio 75

Fig 5 Fibrillated Polypropylene Fiber of 20mm Length

G. Polypropylene Fibers

Different volume fractions of fibrillated polypropylene fibers (PPF) with length 20 mm are used. The fibers and their specifications are provided by *NINA Concrete Systems Pvt. Ltd*. The fibers meet the terms with ASTM C 1116 Type 3 4.1.3. They are manufactured from film sheets which are cross connected by adequate fiber lengthwise.. PPF properties are shown below in tabular form.

TABLE III. PHYSICAL PROPERTIES OF PPF

Sr. No.	Property	Values
1	Fiber Length	20mm
2	Type of fiber	Fibrillated/ mesh type
3	Specific gravity	0.91
4	Tensile strength N/mm^2	570
5	Alkali resistance	Alkali proof

H. Mix Design for M20 Grade concrete

M20 grade concrete was used in this study. The proportion of mix design is given in the table 4.4. This has been obtained as per provisions of IS 10262 and based upon properties of the materials explained above. While designing mix concrete our purpose is to select the ingredients in such a way to obtain strength and durability. The purpose is to select the ingredient in economical manner and to achieve desired strength.

TABLE IV. FINAL MIX PROPORTION

Cement	FA	CA	w/c
1	1.78	2.95	0.50

I. Mixing, Casting and curing of specimen

Mixing

Materials were mixed in a linear – cross flow mixer type 'o'. It have a power driven rotating pan and paddle. This mixer is sturdy enough for fibrous mixes and a good uniformity of fiber distribution is achieved. Firstly the sand, cement and aggregates were mixed in dry state and then mixed for 3-5 minutes after adding water. Then water 1/3 of total amount is added and then fibers are added then after 2-3 minutes rest of the water is added.

Fig 6Drum type mixer (A) and freshly prepared HyFRC (B)

J. Casting

All cubes and prismatic beams were cast in metallic molds on vibrating table respectively. The molds should be cleaned from dust particles. Before the concrete is poured into the molds mineral oil should be applied on all sides. The Fresh HyFRC concrete is poured into the cubes and beam molds. The molds are filled in three layers of equal height with simultaneous tamping. After this for the small duration mound is kept on table vibrator. Trowel is used to remove excess concrete from molds. At last top surface is well finished and molds are placed on safe place.

III. Testing of Specimens

Two tests were performed to find the response of HyFRC to compression and tension as per IS 516. Which are as follows.

1. Compression test
2. Flexure test

Three point bending test for flexural characterization was used.

IV. Results

A. Compression test values of M20 grade hybrid fiber concrete at 28 days curing

For evaluating the compressive strength behavior of HyFRC, compressive strength test is considered to be the most favorable method. The results of compressive strength and stress and strain curves of various sets of HyFRC are shown below in table.

B. Flexural Test values of M20 grade HyFRC at 28 days curing

Results of three point bending test for various volume fractions (1.25% and 1.75%) of HyFRC with different proportions of SF and PPF are shown in the tabular form. The load deflection results are also expressed in the tabular form. These results are used for the development of analytical model and calculation of fiber index for hybrid fiber reinforced concrete. The load deflection curves are plotted for all the four set of combination.

TABLE V. AVERAGE VALUE OF STRESS IN (MPA)

Set Type	Combined Volume(V_F) with PPF variation	Sample one Load (kN)	Sample two Load (kN)	Sample three Load (kN)	Average load (kN)	Compressive strength (MPa)
Set-0	0%	600	640	624	621.33	27.61
Set-1(1.50%SF&0.25%PPF)	1.75% (0.15%)	794	815	839	816	36.26
Set-2 (1%SF&0.25%PPF)	1.25% (0.20%)	766	785	760	770	34.22
Set-3(1.25%SF&0.50%PPF)	1.75% (0.30%)	656	664	675	665	29.55
Set-4(0.75%SF&0.50%PPF)	1.25 % (0.40%)	556	546	575	559	24.84

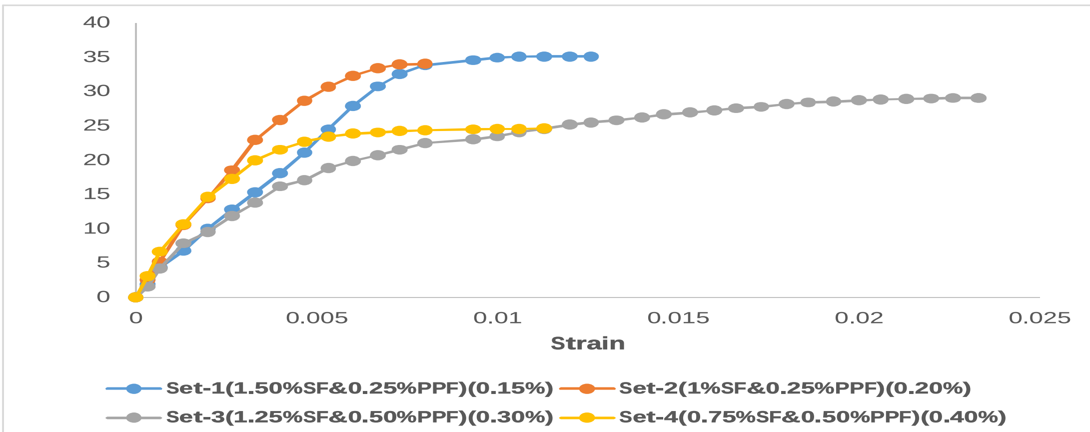

Fig 7 Stress Strain curves for various sets of hybrid fiber reinforced concrete

TABLE VI. ULTIMATE LOAD (THREE POINT LOADING) FOR HYBRID FIBER REINFORCED CONCRETE FOR VARIOUS SETS

Set Type	Combined volume fraction (with PPF Volume content to combined)	Sample1 Load (kN)	Sample 2 Load(kN)	Sample 3 Load(kN)
Set-0 (Conventional)	0%	4.5	5	5
Set-1(1.50%SF&0.25%PPF)	1.75% (0.15%)	15	14.7	15
Set-2(1%SF&0.25%PPF)	1.25% (0.20%)	11	10.5	10.5
Set-3(1.25%SF&0.50%PPF)	1.75% (0.30%)	14.5	14.2	14.5
Set-4(0.75%SF&0.50%PPF)	1.25% (0.40%)	7.5	7.3	7.5

V. CONCLUSIONS

- HyFRC can sustain large strain value before failure.
- Strain value increases as the fiber content increases.
- There is increase in compressive strength around 30%.
- There is increase in flexural strength around 100%.
- The replacement of SF with 0.30% polypropylene (with respect to combined volume fraction) fiber gives the same ultimate load carrying capacity as given by that volume fraction of steel fiber alone.
- It was observed that polypropylene fiber content up to 0.30% gives good result but decrease in flexural and compressive strength was noted when the content was increased.

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