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EXPERIMENTAL STUDY OF STRENGTH PARAMETERS OF HYBRID FIBRE REINFORCED CONCRETE

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ABSTRACT: *Conventional concrete is weak in tension which results in low tensile strength and brittle failure of concrete elements. In order to overcome this weakness of concrete, use of combination of different types of suitable fibers is practiced these days. This is called Hybrid Fiber Reinforced Concrete (HFRC). This paper presents experimental test results of M20 Gr. concrete mix by inclusion of polypropylene and hooked end steel fibers in it. Fibers were added in predefined proportions in concrete. Hooked end steel fibers from 0.5% to 2% by volume of concrete were used in the investigation. Also for each percentage of steel fiber, polypropylene fiber (PP) from 0.1% to 0.3% was added in concrete. For 1.1% & higher steel fiber percentages, super plasticizers were used in order to improve the workability of concrete. Test results show that combination of these fibers boosts the impact strength, split tensile strength and pull out strength of fibers. Only marginal improvement was found in case of compressive strength. For mixes without any superplasticizers, concrete mix with 0.8% steel fiber and 0.3% polypropylene fiber was observed to be optimum mix from workability and strength point of view. For mixes with superplasticizers, concrete mix with 1.4% steel fiber and 0.3% PP fiber was observed to be optimum mix.*

Key words: Fiber reinforced concrete, steel fibers, polypropylene fibers, workability, strength

I] Introduction

Conventional Concrete is characterized by brittle failure, nearly complete loss of loading capacity occures, once failure is initiated[8]. To improve such type of weakness numerous studies on fiber reinforced concrete have been performed. The fiber can make the failure mode more ductile by increasing the tensile strength of concrete. Hybrid Fiber reinforced concrete (HFRC) can be defined as a composite material consisting of mixture of cement mortar or concrete and discontinuous, discrete, uniformly dispersed suitable fibers of two or more than two types[2]. Fiber reinforced concrete is thus a relatively new material in which steel or other fibers are introduced as micro reinforcements. When fibers are added to concrete, it becomes homogeneous, isotropic and transforms it to a ductile material. These fibers will act as secondary reinforcement in concrete and reduce crack formation and propagation.

Steel fiber reinforced concrete（SFRC） has the ability of excellent tensile strength, shock resistance, fatigue resistance, ductility and crack arrest. Therefore, it has been applied in various professional fields of construction, irrigation works and architecture. Steel fiber remains the most used fiber of all followed by polypropylene, glass and other fibers.[7]

To identify the usage of fibers in concrete, in these last four decades, most of the research was done on mechanical behavior of fiber reinforced concrete and the fibers itself.
Balaguru, P.,[3] found that addition of polypropylene fibers up to a volume fraction of 0.1% does not affect the compressive strength. Also it is observed that addition of steel fibers shows improvements in flexure, impact strength. Song, P. S., & Hwang, S.[5] studied the effect of fiber on compressive strength of concrete in terms of fiber reinforcing parameter. They have marked that brittleness with low tensile strength and strain capacities of high strength concrete can be overcome by addition of steel fibers. M. Tamil Selvi et al[10] concluded that the fibers interaction play a vital role in improvement of mechanical properties caused by the introduction of fibers. The test results show that the addition of steel and polypropylene fibers to concrete exhibit better performance. Rai, A., & Joshi Y. P.[11] studied applications and properties of fibre reinforced concrete. Their study revealed that fiber addition improves ductility of concrete and its post-cracking load-carrying capacity.

II] Objective of study

The objective of the study is to investigate the improvement in strength parameters of HFRC such as compressive strength, split tensile strength, impact strength & bond strength, compare the same with conventional concrete and arrive at suitable optimum mix of HFRC.

III] Experimental program

A. Materials used for casting

i] Casting of conventional concrete: 43 grade ordinary Portland cement conforming to IS 8112:1989, natural sand with specific gravity 2.65 and fineness modulus 2.25 conforming to zone II of IS 383:1997 and coarse aggregate with specific gravity 2.6 of size 20 mm.

ii] Casting of HFRC concrete: For casting of HFRC specimens, all the materials used were same. In addition to them fibers were added. They are: a) Steel fibres of aspect ratio 80, diameter 0.75 mm and length 60 mm having tensile strength of 1110 MPa. The density of steel fibers is 7850 Kg/m^3 b) Fibrillated polypropylene fibers of tensile strength 453 MPa. The density of polypropylene fibers is 946 Kg/m^3.

iii] Super plasticizers: In order to improve the workability of concrete, super plasticizers were used for mixes with steel fiber content more than 1.1% up to 2%.

B. Mix Proportions

Design mix of M20 grade concrete was carried out according to IS 10262:2009. Mix proportion obtained was 1:1.95:2.20 (by weight) with water cement ratio of 0.51. Slump of mix was measured and casting of specimens was done. After 24 hours demoulding was done and specimens were kept for curing in a curing basin for 28 days.

C. Methodology

i) Workability:

Workability test was carried out according to IS 1199:1959. Slump was checked to measure consistency of concrete. Fig. 1 shows the slump cone test of the wet concrete.

Fig. 1: Slump Cone test

ii) Compressive strength of concrete :

Compressive strength of cubes was carried as per I.S. 516-1959. Cube specimens of standard dimensions 150 x 150 x 150 mm were cast. After 24 hours the specimens were demoulded and transferred to curing tank for 28 days. Fig. 2 shows the compressive strength test of cubes being performed on compression testing machine.

Fig. 2: Compressive test on CTM

iii) Pull out strength on concrete:

According to IS 2770(Part I)- 1967 pull out test was carried out to determine bond strength of fiber reinforced concrete. Pull out test is carried to determine in-situ compressive strength of concrete. The test specimen was mounted in Universal Testing Machine (UTM) such that the bar is pulled axially from the cube as shown in Fig. 3. The loading was applied until the bond between surface of the embedded bar in cube and concrete is failed and this system is unable to take load. The bond stress is calculated by dividing the load at failure by surface area of embedded bar length.

Bond Stress = Load at Failure / Surface area of embedded length

$$= P / \pi D L$$

Where,
P = Load at failure
D = Diameter of bar
L = Embedded length

Fig. 3 shows the pull strength of cubes testing on UTM

Fig. 3: Pull out test on UTM

iv) Split tensile strength on concrete:

The split tensile test was conducted as per IS 5816:1999. Specimens were cast using standard size of cylinder with 300 mm length & 150 mm diameter. The specimens were kept for curing for 28 days. The test was carried out by placing the specimen in between upper platen & lower platen of a compression testing machine and the load was applied until failure of the cylinder along the vertical diameter.

Split tensile strength is calculated using the following equation;
Split tensile strength = $2P/ (\pi DL)$
Where :
P=split tensile load, D=diameter of the cylinder, L=length of cylinder
Fig. 4 shows Split tensile strength test being performed on standard cylinders on compression testing machine(CTM)

Fig. 4: Split tensile test on CTM

v) Impact strength :

The impact strength of the HFRC specimens was determined according to ACI committee 544.2R-89. The impact test was conducted on concrete cylindrical disc of size 150 mm diameters & 60mm thickness. Stainless steel ball of 100 mm dia. weighing 5.450 kgs was used. The height of fall of the spherical ball is kept constant for all the experiments i.e 1.2 m. The number of drops (blows) required for first cracking of the disc is noted. Procedure is continued until there are visible cracks on the specimen and is stopped when failure is observed. Impact strength is calculated by using following equation;
Impact strength=N.m.g.h.

Where:
N=Number of blows, m=mass of steel ball, g=acceleration due to gravity, h=ht. of drop
Fig. 5 shows the impact strength on concrete disc

Fig. 5: Impact strength

IV] Test Results and Discussions

i) **Workability & Compressive strength test:** Table 1 below shows Workability & Compressive strength test results

Table 1. Variation in slump & compressive strength of concrete due to addition of fibers

Type of Concrete (M20 Grade)	% steel fiber	%PP fiber	Slump (mm)	Permissible slump in mm for medium workability mm (as per IS 456-2000)	% drop of slump	Compressive strength of cubes (Mpa)	% increase in comp. Strength compared to conventional concrete
Conventional	--	--	98	75-100	--	26.6	0
Hybrid Fiber reinforced	05	0.1	95		3.15	27.96	5.10
		0.2	96		2.08	28.41	6.80
		0.3	97		1.03	28.57	7.40
	0.8	0.1	90		8.16	28.76	8.12
		0.2	92		6.52	28.84	8.42
		0.3	93		5.37	29.10	9.39
	1.1	0.1	83		15.30	29.37	10.41
		0.2	85		16.66	29.54	11.05
		0.3	87		15.29	29.71	11.69
	1.4	0.1	76		28.94	29.80	12.03
		0.2	78		25.64	30.12	13.23
		0.3	79		24.05	30.24	13.68
	1.7	0.1	61		60.65	30.18	13.45
		0.2	63		58.06	29.82	12.10
		0.3	65		55.55	29.66	11.50
	2.0	0.1	50		96.01	28.71	7.90
		0.2	51		92.15	28.51	7.18
		0.3	53		88.46	28.32	6.46

Based on the present experimental program and the analysis of test results, it is observed that as the percentage of steel fibre increases the workability of FRC decreases. This is due to the fact that the added fibre will obstruct the flow and hence affect the workability of concrete. In comparison with conventional concrete, there was a slump drop of 3.15% for combined 0.5% steel and 0.1% PP fibre content. For the same steel fibre content of 0.5%, when PP fibre content was increased to 0.2 % & 0.3 %, slump drop was observed to be of 2.08 % & 1.03% respectively as compared to conventional concrete. This shows that workability of concrete increases due to addition of fibrillated PP fiber in it. This is due to good mixability of PP fibre. A mix with steel fiber content of 1.4% and PP fiber content of 0.3% , shows slump drop of 24.05%. in comparison with conventional concrete. It was observed that as the percentage of steel fiber is increased, there is decrease in workability of the concrete. Fig. 5 shows variation in the slump values with different percentages of steel and polypropylene fibers

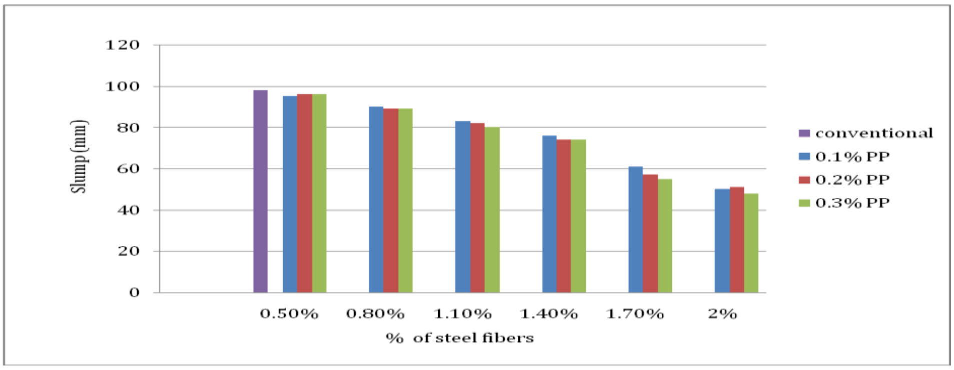

Fig. 5: Variation in Slump of concrete with different percentages of steel & PP fibers

It was seen that even after addition of superplasticizer, workability of mix with steel fiber percentage beyond 1.4%, the slump value recorded do not satisfy the minimum requirement of 75 mm as per I.S. 456-2000. Hence, mixes with steel fiber content 1.7% and 2.0% were found to be not workable.

Optimum mix from workability considerations:

A mix with 0.8% steel fiber and 0.3% PP fiber shows slump of 93 mm. From workability point of view this mix can be considered to be an optimum mix (without addition of superplasticizer). Mix with 1.4% steel fiber and 0.3% PP fiber shows slump of 79 mm which is within acceptable range as per IS 456. Hence, from workability point of view this mix can be considered to be an optimum mix with addition of superplasticizer.

ii) Compressive strength :

From table no. 1, it can be observed that, in comparison with conventional concrete. Compressive strength of HFRC increased by 5.10% with addition of combined 0.5% steel and 0.1% PP fiber. When PP fiber content was increased to 0.2% & 0.3% for the same steel fiber content, the increase in compressive strength observed was by 6.80% and 7.40% respectively. This shows that, with increase in percentage of PP fibers, there is slight increase in compressive strength. By addition of 0.8% steel and 0.3% PP fibers compressive strength of HFRC increased by 9.39% in comparison with conventional concrete. This shows that there is only marginal increase in compressive strength of concrete due to addition of steel fibers.

iii) Pull out strength :

Results of pull out test are presented in table 2 below.

Table 2. Variation in pull out strength of concrete due to addition of fibers.

Pull out strength (MPa)							
% of Steel Fiber → / % of PP Fiber ↓	0%	0.50%	0.80%	1.10%	1.40%	1.70%	2%
Conventional	3.22						
0.1% PP		5.48	6.45	7.48	7.61	7.39	7.26
0.2% PP		5.92	6.62	7.55	7.63	7.33	7.27
0.3% PP		6.08	6.97	7.58	7.67	7.31	7.23
Percent increase in comparison with Conventional concrete	0	88.81	116.46	135.40	138.19	127.02	125.53

From table no. 2, it is found that pull out strength of concrete increases with increase on steel & PP fiber content. Due to addition of 0.5% steel and 0.3% PP fibers, the increase in pull out strength was observed to be 88.81% when compared with the conventional concrete. For optimum mix of 0.8% steel fiber & 0.3% PP fiber, improvement in pull out strength is 116.46% as compared to conventional concrete. Whereas, for optimum mix with 1.4% steel & 0.3% PP fiber pull out strength was observed to be 138.19%. This shows that there is tremendous increase in the pull out strength of concrete due to addition of steel fibers.

Fig. 6 shows variation in pull out strength of concrete with different percentages of steel and polypropylene fibers

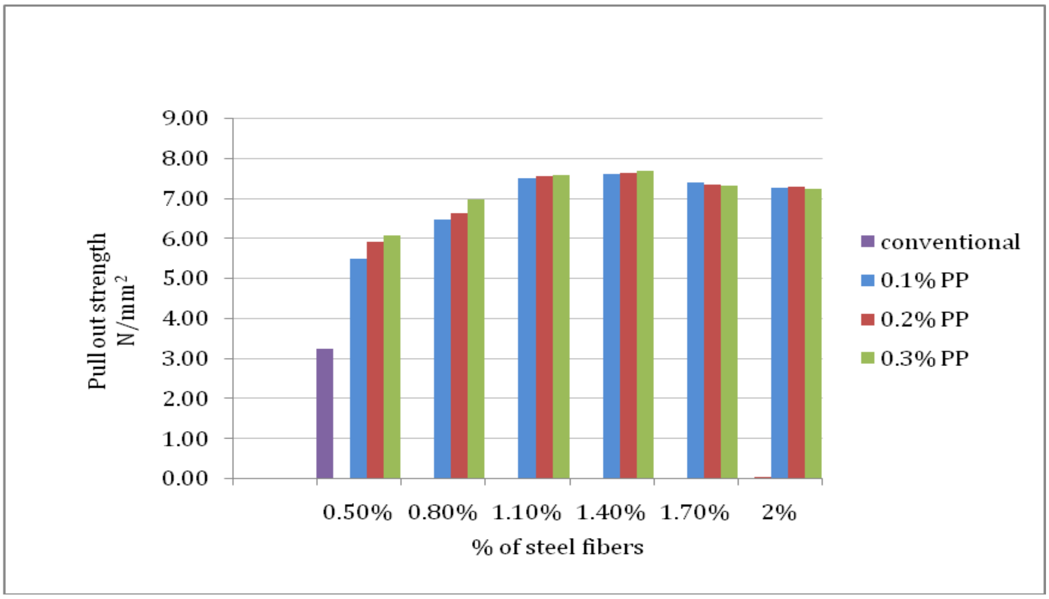

Fig.6: Variation in pull out strength of concrete with varying % of steel & PP fibers

iv) Split Tensile strength :

Table No. 3 below shows results of split tensile test on HFRC.

Table 3. Variation in split tensile strength of concrete due to addition of fibers

Split tensile strength (MPa)							
% of Steel Fiber → / % of PP Fiber ↓	0%	0.50%	0.80%	1.10%	1.40%	1.70%	2%
conventional	2.16						
0.1% PP		3.96	4.32	4.50	4.64	4.38	4.28
0.2% PP		4.08	4.36	4.54	4.69	4.34	4.26
0.3% PP		4.17	4.40	4.57	4.72	4.31	4.23
Percent increase in comparison with Conventional concrete	0	93.06	103.70	111.57	118.51	99.54	95.83

From table no. 3, it is found that split tensile strength of concrete increases with increase in steel & PP fiber content. Due to addition of 0.5% steel and 0.3% PP fibers, the increase in split tensile strength was observed to be 93.06% when compared with the conventional concrete. For optimum mix of 0.8% steel fiber & 0.3% PP fiber, improvement in split tensile strength is 103.73% as compared to conventional concrete. Whereas, for optimum mix with superplasticizer & 1.4% steel with 0.3% PP fiber split tensile strength was observed to be 118.51%. This shows that there is very good improvement in the split tensile strength of concrete due to addition of steel & PP fibers.

Fig.7 shows variation in split tensile strength of concrete with varying % of steel &PP fibers

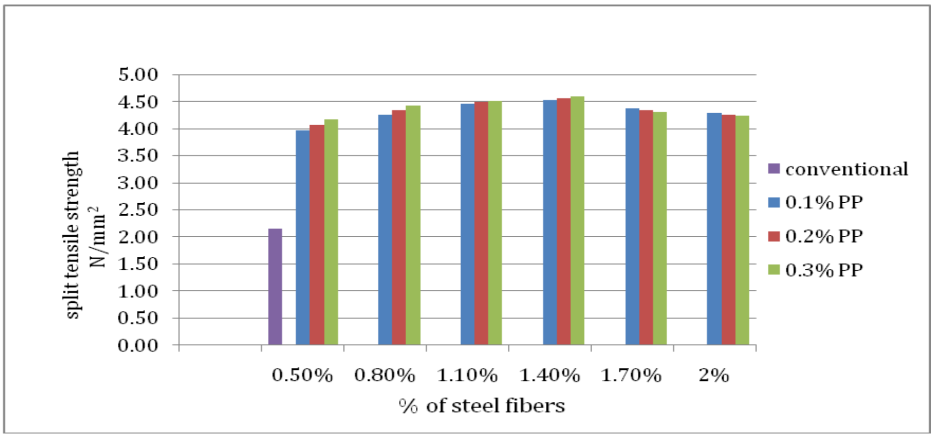

Fig.7 : Variation in split tensile strength of concrete with varying % of steel &PP fibers

v) Impact strength:

Results of impact strength are presented in table 4 below.

Table 4. Variation in impact strength due to addition of fibers

Impact strength (N-m)							
% of Steel Fiber → / % of PP Fiber ↓	0%	0.50%	0.80%	1.10%	1.40%	1.70%	2%
conventional	32.7						
0.1% PP		98.10	915.60	1275.30	1661.16	1964.0	2236.68
0.2% PP		300.84	1072.56	1438.80	1785.42	2053.56	2295.54
0.3% PP		431.64	1190.28	1530.36	1876.98	2151.66	2374.02
Percent increase in comparison with Conventional concrete	0	1220	3540	4580	5640	6480	7160

From table no. 4 it is clear that due to addition of 0.5% steel and 0.3% PP fibers, the increase in impact strength was observed to be 1220% when compared with the conventional concrete. For optimum mix of 0.8% steel fiber & 0.3% PP fiber, improvement in impact strength is 3540% as compared to conventional concrete. Hence, it can be concluded that there is tremendous improvement in impact strength of concrete due to addition of steel & PP fibers.

Fig. 8 shows variation in impact strength of concrete with varying % of steel & PP fibers

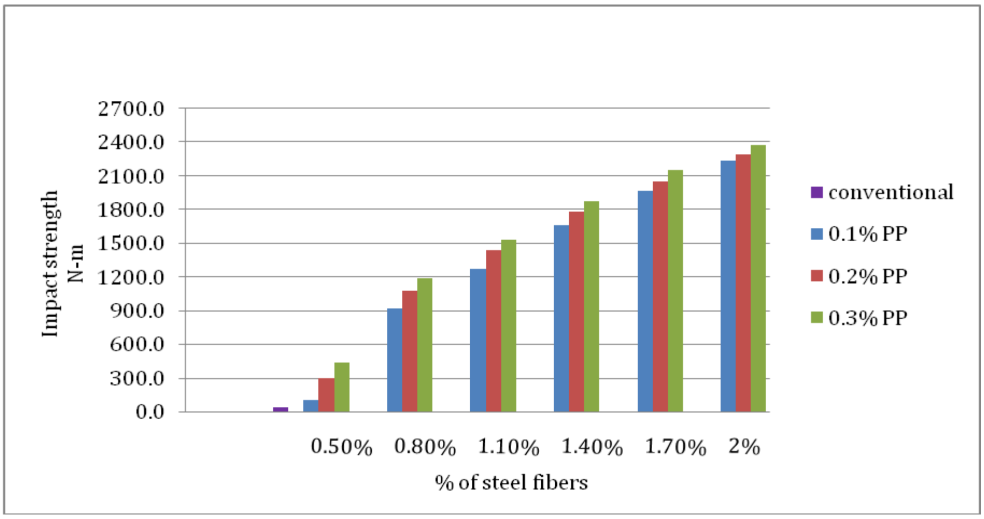

Fig. 8 :Variation in impact strength of concrete with varying % of steel & PP fibers

V] Conclusion

Based on the experimental results, following conclusions are drawn;

- The optimum mix of HFRC from workability and strength point of view, without superplasticizer is 0.8% steel and 0.3% PP fiber content. For mixes with superplasticizer, optimum mix is 1.4 % steel and 0.3% PP fiber.
- Workability of concrete decreases as the percentage of steel fibers increases. Whereas with increase in percentage of fibrillated PP fibers, workability of concrete mix increases.
- There is only marginal increase in compressive strength of concrete due to addition of fibers. For optimum mix of 0.8% steel fiber & 0.3% PP fiber, improvement in compressive strength is 9.39% as compared to conventional concrete.
- There is tremendous increase in the pull out strength of concrete due to addition of steel & PP fibers. For optimum mix of 0.8% steel & 0.3% PP fiber pull out strength increased up to 116.46% as compared to conventional concrete.
- There is very good improvement in the split tensile strength of concrete due to addition of steel & PP fibers. For optimum mix 0.8% steel & 0.3% PP fiber split tensile strength increased up to 103.73% as compared to conventional concrete.
- There is tremendous improvement in impact strength of concrete due to addition of steel & PP fibers. For optimum mix of 0.8% steel fiber & 0.3% PP fiber, improvement in impact strength is 3540% as compared to conventional concrete.
- Optimum mixes found in this investigation using Hooked end steel fibers & fibrillated PP fibers can make concrete strong, ductile & durable.

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