A Study on Mechanical Properties of Concrete Reinforced with Hybrid Fibers at a Low Fiber Volume Fractions

Srikanth Koniki, D Ravi Prasad

Abstract*: This study is aimed to investigate the effect of fiber hybridization on basic mechanical properties of 30 MPa concrete. Fibers used in the study are Hooked-end steel, polyester and polypropylene. Hybridization was done in two stages, the first stage of the investigation was to develop and study the effect of polyester-polypropylene (Non–metallic) HFRC at a total fiber volume fraction of 0.15%. Further, the investigation was carried out to develop a hybrid fiber reinforced concrete made with metallic (hooked-end Steel) and non-metallic fibers at a total fiber volume fraction of 0.5%. Mechanical properties, namely compressive strength, direct tensile strength and flexural strength were investigated. The results obtained were compared with mono-fiber reinforced concrete and conventional concrete. Significant improvement in direct tensile strength and flexural strength observed with the with the fiber hybridization compared to mono-fiber reinforced concrete and control mix. This may be due to synergic response of different fibers at different scales of cracking at different stress levels in concrete. Superior results were observed at metallic – non-metallic hybridization due to exhibition of synergetic response of fibers by inhibition of crack growth and propagation, at different scales of cracking at different stress levels in concrete.

Keywords : Fiber hybridization, concrete. Fibers, compressive strength

I. INTRODUCTION

Concrete is widely used construction material but its brittleness, low strain capacity and poor resistance to crack growth are the major shortcomings [1]. Imparting sufficient ductility to the concrete is need of the hour. Utilization of short random discrete fibers is known to improve the properties of concrete by inhibiting the crack growth and propagation, commonly known as fiber reinforced concrete (FRC) [2]. Many kinds of fibers like metallic and non-metallic fibers are widely used in construction industry, but fracture in concrete is a gradual and multi-scale process which varies with different stress levels [3], FRC improves theproperties of concrete up to limited ranges of strains and crack openings [4]. To arrest the multi-scale cracks produced at different stress levels and to reduce the shortcomings of concrete, fiber hybridization is an alternative solution. The synergy of fibers is well Explained for HFRC [5]. HFRC can be developed in any of the ways, by varying lengths of the fiber [6], varying diameters of the fiber [7] and by varying Young's modulus of the fiber [8].

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Srikanth Koniki, Research Scholar, Department of Civil Engineering, NIT Warangal, Telangana, India

D. Ravi Prasad, Assistant Professor, Department of Civil Engineering, NIT Warangal, Telangana, India

Development of HFRC by varying Young's modulus of fiber is the most effective and widely used method. Fiber effect on the concrete depends on properties of the fibers such as aspect ratio, Young's modulus, tensile strength and fiber to matrix interaction. Low modulus and short fibers like polypropylene, polyester, nylon, etc., improves the properties of concrete at an earlier stages by reinforcing the plastic shrinkage cracks and cracks at low stress levels [9]. High modulus and long fibers like steel, carbon, asbestos fibers etc., bridge the propagation of macro-cracks [10]. Polyester (PO) and polypropylene (PP) fibers used in this study are Recron-3s, these fibers are triangular in cross-section, engineered and specially designed to act as secondary reinforcement. High modulus Steel fibers are well known to improve the mechanical properties of concrete but these fibers are only effective in higher dosages. Higher dosages of steel fibers increases the cost of construction which also leads to low workability and improper compaction. Moreover, steel fibers doesn't affect the cracks forming at early stages of concrete [11]. To avoid the potential problems associated with higher dosage steel fibers and to improve the performance of concrete at fresh and hardened state of concrete this research proposes a new hybrid system that consist of steel fibers (metallic) and polyester and polypropylene fibers (non-metallic) at low fiber volume fraction of 0.5%.

II. EXPERIMENTAL PROGRAMME

Materials and Mix Proportions

Ordinary Portland cement (OPC) of 53 grade confirming to IS: 12269-1987 [12]. Class F Flyash conforming toIS 3812-2003 [13] used in the investigation. Locally available River sand and well graded crushed granite conforming to IS 383-1970 used for the production of concrete and the mix proportions are presented in table 1. To get the desired workability Conplast SP430 of FOSROC Chemicals was used for all mixes as per IS 9103 -1999Hooked-end steel, Polyester and Polypropylene fibers. The properties of the fibers are shown in Table 2.

Cement (kg/m^3)	Fly ash (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Water
283	100	650	1180	180

Table 1 Mix proportions of 30 MPa concrete per cubic meter

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Property	Hooked-end Steel fiber (HS)	Polyester (PO)	Polypropylene (PP)
Length (mm)	25	12	6
Diameter (mm)	0.4	0.043	0.033
Aspect ratio	62.5	279	181
Specific gravity	78.4	1.34	0.91
Elastic modulus (GPa)	210	9.5	4.5
Tensile strength (MPa)	1100	875	560

Table 2 Properties of the fiber used for the study

Mixing and Curing

Firstly, fine aggregate and coarse aggregate were mixed in a pan mixture of 100kg capacity and dry mixed for 1min. Then, cement and mineral admixtures were mixed separately until a uniform coloured binding material was obtained and then it was transferred into the pan mixer and mixed for 1min, then potable water was slowly added and mixed for 2min. after fibers was added and mixed for 3min. Super-plasticizer was added to get required workability according to IS 456-2000 [15].

The concrete specimens were prepared using moulds of 150x150x150 mm cubes to measure compressive strength, 500x100x100 mm prisms to measure flexural strength and; specially designed dog-bone shaped specimens for direct tensile strength. Table vibrator was used for compacting the concrete in moulds.

Fiber Hybridization Technique

The hybridization of fibers was carried out in three stages. In first stage, optimization of fiber dosage was done for PP and PO fibers individually. Fiber dosages for PP and PO were varied from 0.05%, 0.1%, 0.15% and 0.2%., and hooked-end steel (HS) at a fiber volume fraction of 0.5%.

In second stage, the aim is to develop polyester polypropylene HFRC (Non-metallic). Even though both fibers young's modulus are nearer, length of the polyester fiber is 12mm and polypropylene is 6mm (combination of short graded fiber) moreover tensile strength of the PP and PO fibers are 875 and 560 respectively. So there is need to study the hybridization effect. Total fiber volume fraction is 0.15% (optimum dosage of mono PP and PO fibers).

Third stage of the study is to develop HFRC using metallic–non-metallic fibers. To develop metallic–non-metallic HFRC, obtained optimum percentage of hybrid combinations from the non-metallic HFRC are systematically added to the metallic fibers at a total fiber dosages of 0.5%. Example for the hybridization is illustrated in fig. 1

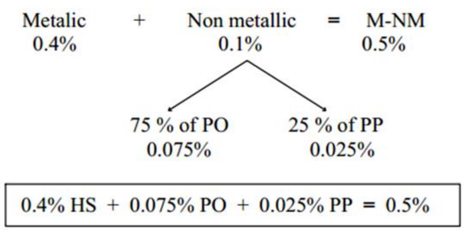

Fig1: Metallic – Non-metallic hybrid combinations at 0.5% fiber dosage

Test Methods

The compressive strength and flexural strength of concrete is obtained as per (IS 516, 2004) Tinius-Olsen of 3000 kN capacity was used. The uniaxial tensile test was performed on dog bone shaped specimens, size of the specimens and experimental set-up are shown in fig. 2 and 3. Experimentation was done on UTM of 40kN capacity (displacement control) at a strain rate of 0.01 mm/s. twenty-eight days strengths of specimens were calculated from the average of three.

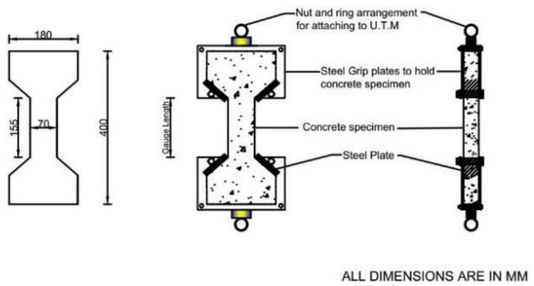

Fig 2: Direct tensile test specimen and grip details

Fig 3: Testing of dog-bone shaped specimen under uni-axial tension

III. RESULTS DISCUSSION

Optimization of mono fibers

Optimization of mono-fiber is done to know the effect of fiber and its optimum dosages on concrete.

Optimization of PP and PO fiber:

Compressive, direct tensile and flexural strengths of concrete were studied for different dosages of PP and PO fiber: 0.05%, 0.1%, 0.15% and 0.2%. Optimum dosage of PP fiber was achieved at 0.15%. The percentage strength increase of PP-FRC and PO-FRC compared to the

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conventional concrete is presented in table 3.It is observed that there is no significant improvement in compressive strength of concrete with the addition of fibers. Whereas fiber effect on direct tensile strength and flexure is more as compared with the compressive strength. Strength improvement of PP-FRCand PO-FRC under uniaxial tension at an optimum dosage of 0.15% is 8.6% and 12.5%. Percentage strength increase in flexure is 12.7% and 15.3% respectively. This strength increment is understood that fibers bridge and delay the formation of cracks in concrete. Percentage increase of direct tensile strength and flexural strength is slightly more when compared with the PP FRC. This is due to PO fiber tensile strength is more as compared with the PP fiber.

Mechanical behaviour of SFRC:

Percentage increase of metallic fiber (hooked-end steel) is more as compared to non-metallic fiber. This is mainly because steel fibers have higher modulus of elasticity and higher tensile strength than non-metallic fibers; and also presence of hooks at the end of steel fiber improves fiber-matrix bond thereby, improving the direct tensile strength, flexural strength and compressive strength. Percentage increase in strength of HS FRC are presented in Table 4. It is observed that, there is a marginal improvement in compressive strength of steel fiber reinforced concrete (SFRC) observed i.e. 3.9%. Percentage strength improvement for direct tensile strength and flexural strength for HS-FRC at a fiber volume fraction of 0.5% is 9.6and 12.3 %.

Mix ID	Compressive Strength		Direct tensile strength		Flexure Strength	
	MPa	% Strength Improvement	MPa	% Strength Improvement	MPa	% Strength Improvement
Control mix	36.21	-	3.18		4.10	
PP 0.05	36.43	0.60%	3.30	1.56%	4.29	4.63%
PP 0.1	36.72	1.40%	3.33	4.56%	4.49	9.39%
PP 0.15	**37.09**	**2.40%**	**3.45**	**8.56%**	**4.62**	**12.74%**
PP 0.2	36.64	1.20%	3.40	2.95%	4.32	5.36%
PO 0.05	36.46	0.70%	3.33	4.66%	4.39	6.96%
PO 0.1	36.68	1.30%	3.46	8.66%	4.57	11.37%
PO 0.15	**37.07**	**2.40%**	**3.58**	**12.45%**	**4.73**	**15.37%**
PO 0.2	36.83	1.20%	3.48	3.25%	4.44	8.36%

Table 3 Strength properties of PP and PO FRC

Mix ID	Compressive Strength		Direct tensile strength		Flexure Strength	
	MPa	% Strength Improvement	MPa	% Strength Improvement	MPa	% Strength Improvement
Control mix	36.21	-	3.18		4.10	
HS 0.5	37.6	3.9%	3.49	9.6%	4.6	12.3%

Table 4 Strength properties of HS – FRC

Synergy between polypropylene and polyester (Non-metallic HFRC):

Hybridization of polypropylene and polyester were studied, and the results were compared with mono FRC and conventional concrete. 3 types of hybrid combinations

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considered for hybridization i.e. 75% of PO + 25% of PP, 50% of PO + 50% PP, 25% of PO + 75% of PP at a total fiber volume fraction of 0.15% which is optimum dosage for mono PP and PO FRC. Strength effectiveness of non-metallic HFRC Table 5.Improvement in mechanical properties was observed in fiber hybridization when compared with mono FRC. Optimum hybrid combination of non-metallic HFRC was achieved at 75% of PO combined with 25% of PP (NM 0.15 (3)). Strength improvement of compressive strength for non-metallic HFRC is not significant even with the fiber hybridization. And the percentage strength improvement for direct tensile strength and flexural strength of non-metallic HFRC at an optimum dosage of 0.15% is 15.2 and 20.5%. Strength effectiveness of non-metallic HFRC is more as compared with mono fibers because small and low Young's modulus fibers arrest plastic shrinkage cracks at fresh state of concrete long and high modulus fibers control the propagation of micro-cracks at hardened state of concrete. Due to this synergy between PO and PP fibers, overall performance of non-metallic HFRC has improved

Mechanical properties of Metallic–Non-metallic HFRC:

The optimum dosages Obtained from non-metallic hybrid fibers i.e., 75% of PO combined with 25% of PP (75% PO + 25% PP) were combined to hooked-end steel fibers as explained in fig.1 to develop a HFRC incorporated with metallic and non-metallic hybrid fibers to achieve superior performance at different scales of cracks at varied stress levels in concrete. Fiber volume fractions and hybrid combination and mechanical properties of metallic–non-metallic HFRC are presented in table 6. Compressive strength has marginally increased due to addition of metallic - non-metallic fibers. The maximum strength increment observed at 0.4% metallic + 0.1% non-metallic fibers i.e. 9.3%. The percentage strength improvement in tensile strength and flexure strength is maximum at a hybrid combination of 0.4% of metallic with 0.1% of non-metallic fibers (M-NM 0.5 (2)) is 26.4% and 32.0% respectively. This strength increment may be understood that more availability of non-metallic fiber which arrest the formation and propagation of cracks at low stress levels. Later metallic fibers came into picture and control the propagation of macro cracks at higher stress levels in the concrete.

Flexure Strength	% Strength Improvement	-	12.7%	15.3%	16.75	17.1%	**20.5%**
	MPa	4.10	4.62	4.73	4.74	4.81	**4.92**
Direct tensile strength	% Strength Improvement	-	8.5%	12.4%	12.1%	14.4%	**15.2%**
	MPa	3.18	3.45	3.58	3.57	3.63	**3.65**
Compressive Strength	% Strength Improvement	-	2.4%	2.4%	2.0%	2.1%	**2.4%**
	MPa	36.21	37.09	37.07	36.92	36.97	**37.07**
Total Fiber Dosage (%)		-	0.15%				
Fiber dosage	PO	-		0.15%	0.037 (25%)	0.07 (50%)	**0.01 (75%)**
	PP	-	0.15%		0.11 (75%)	0.07 (50%)	**0.037(25 %)**
Mix ID		Control mix	PP 0.15	PO 0.15	NM 0.15 (1)	NM 0.15 (2)	**NM 0.15 (3)**

Table 5 Mechanical properties and its strength effectiveness of non-metallic HFRC

Flexure Strength	% Strength Improvement	-	12.2%	26.7%	**32.0 %**
	MPa	4.10	4.60	5.17	**5.37**
Direct tensile Strength	% Strength Improvement	-	10.1%	21.2%	**26.4 %**
	MPa	3.18	3.49	3.86	**4.00**
Compressive Strength	% Strength Improvement	-	3.9%	4.1%	**7.1%**
	MPa	36.21	37.62	37.70	**38.78**
Fiber Dosage (%)	75% PO+25% PP	-	0	0.05	**0.10**
	HS	-	0.5	0.45	**0.4**
Total fiber dosage (%)		-	0.5		
Mix ID		Control Mix	HS 0.5%	M-NM 0.5 (1)	**M 0.5**

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M-NM 0.5 (3)		0.35	0.15	38.42	6.1%	3.96	25.3%	5.34	30.1%
M-NM 0.5 (4)		0.3	0.20	37.01	2.2%	3.76	18.7%	4.85	18.1%

Table 6 Mechanical properties and its strength effectiveness of Metallic and non-metallic HFRC

IV. CONCLUSION

Following conclusions are drawn from the present experimental investigation.

1. Optimum dosage of PO and PP Fiber achieved at 0.15% volume fraction.
2. Effect of fiber on compressive strength is not significant whereas improvement in tensile properties of concrete is more with addition of fiber. Strength improvement in FRC using metallic fiber is more compared to non-metallic fiber HFRC.
3. Concrete with hybrid combinations 75% of PO + 25% of PP shown better performance.
4. Optimum dosage of metallic – non-metallic HFRC at 0.5% volume fraction is achieved at a hybrid combination of 0.4% M + 0.1% NM
5. Synergy effect was found to be good with the metallic and non-metallic fiber hybridization due to inhibition of crack control at all stress levels.

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