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Behaviour of High Performance Concrete Using Steel FIBER

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ABSTRACT

In this investigation a series of compression tests were conducted on 150mm cube, 150mm x 300mm, cylindrical specimens gave the complete split tensile strength and 100mm x 100 x 500mm beam for flexural strength using silica fume, fly ash and steel fiber of volume fraction 0, 0.5, 1.0 and 1.5 of diameter 1mm of aspect ratio 30 on Portland pozzolana cement using M-25 grade concrete. As a result the incorporation of steel fibers, silica fume, fly ash and cement has produced a strong composite with superior crack resistance, improved ductility and strength behaviour prior to failure. Addition of fibers provided better performance for the cement-based composites, while silica fume in the composites may adjust the fiber dispersion and strength losses caused by fibers, and improve strength and bond between fiber and matrix with dense calcium-silicates-hydrate gel. The results predicated by mathematically modelled expressions are in excellent agreement with experimental results. On the basis of analysis of large number of experimental results, the statistical model has been developed. On the examining the validity of the proposed model, there exists a good correlation between the predicated values and the experimental values as showed in figures. The variation in compressive strength, split tensile strength and flexural strength with respect to changes in the fiber content can be observed. From the results obtained, it is clear that compressive and split tensile strength and flexural strength of concrete is maximum when the fiber content is 1.5 % of the concrete.

Keywords: FRC, HPC, Steel Fibers, Compressive, Flexural and Split Tensile Strength of Concrete.

I. INTRODUCTION

The word concrete comes from Latin word "concretus" (meaning compact or condensed) Concrete is a composite material of cement, fine aggregates, coarse aggregates, and water. The mixture when placed in forms and allowed to cure, hardens into a rock-like mass known as concrete. The hardening is caused by chemical reaction between water and cement and it continues for a long time, consequently the concrete grows stronger with age. Concrete is strong in compression but weak in tension. This weakness in concrete leads to cracking. These cracks are basically micro cracks. The presence of micro cracks is responsible for the inherent weakness of concrete. The weakness can be removed by inclusion of fibers in the mix. Such a concrete is called fiber-reinforced concrete.

The fiber-reinforced concrete is a composite material essentially consisting of conventional concrete reinforced by fine fibers. Concrete is strong in compression but very weak in tension. This weakness in the concrete makes it to crack under small loads, at the tensile end. These cracks gradually propagate to the compression end of the member and finally, the member breaks. The formation of cracks in the concrete may also occur due to the drying shrinkage. These cracks are basically micro cracks. These cracks increase in size and magnitude as the time elapses and the finally makes the concrete to fail. The formation of cracks is the main reason for the failure of the concrete. To increase the tensile strength of concrete many attempts have been made. One of the successful and most commonly used method is providing steel reinforcement. Steel bars, however, reinforce concrete against local tension only. Cracks in reinforced concrete members extend freely until encountering are bar. Thus need for multidirectional and closely spaced steel reinforcement arises. That cannot be practically possible. Fiber reinforcement gives the solution for this problem. So to increase the tensile strength of concrete a technique of introduction of fibers in concrete is being used. These fibers act as crack arrestors and prevent the propagation of the cracks. These fibers are uniformly distributed and randomly arranged. This concrete is named as fiber reinforced concrete.

American Concrete Institute (ACI) defines High Performance Concrete "A concrete which meets special performance and uniformity requirements that cannot always be achieved routinely by using only conventional materials and normal mixing, placing and curing practices". The requirements may involve enhancements of characteristics such as placement and compaction without segregation, long-term mechanical properties, and early age strength or service life in severe environments. Concretes possessing many of these characteristics often achieve High Strength, but High Strength concrete may not necessarily be of High Performance.

MATERIALS AND METHODS

Sample In order to study the interaction of Steel fibers (hooked end) with concrete under compression, flexure, and split tension, 36 cubes, 36 beams and 36 cylinders were casted respectively. The experimental program was divided into four groups. Each group consists of 9 cubes, 9 cylinders and 9 beams.

- The first group is the control (Plain) concrete with 0% fiber (PCC).
- The second group consisted of 0.5% of Steel fiber (hooked end), with aspect ratio 35, by volume.
- The third group consisted of 1.0% of Steel fiber (hooked end), with aspect ratio 35, by volume.
- The fourth group consisted of 1.5% of Steel fiber (hooked end), with aspect ratio 35, by volume.

MATERIALS

Cement

In the present study Ordinary Portland Cement (43 grade) conforming to IS: 8112 was used. cement was tested in accordance to test methods specified in IS: 4031 and results obtained are shown in Table 1.

Table 1: Test Results of Cement Sample

Sr. No	Characteristics	Experimental value	Specified value as per IS:8112-1989
1	Consistency of cement (%)	32.5	----
2	Specific gravity	3.12	3.15
3	Initial setting time (minutes)	41	>30
4	Final setting time (minutes)	347	<600
5	Compressive strength (N/mm^2) (i) 3 days (ii) 7 days (iii)28days	 24.10 34.56 47.92	 >23 >33 >43
6	Soundness (mm)	1.00	10
7	Fineness of Cement (gm)	0.50	10

FINE AGGREGATE

The fine aggregate was locally available river sand which is passed through 4.75mm sieve. Result of sieve analysis is given in Table 2.

Table 2: Test Results of Fine Aggregate

S. No.	Sieve Size	Weight Retained (gm)	Weight Retained (%)	Weight Passing (%)	Cumulative Weight % passing
1	4.75 mm	52	5.2	94.8	5.2
2	2.36 mm	30	3.0	91.8	8.2
3	1.18 mm	110	11.0	80.8	19.2
4	600 µ	100	10.0	70.8	29.2
5	300 µ	346	34.6	36.2	63.8
6	150 µ	330	33.0	3.2	96.8
7	Pan	32	3.2	0	100
					Total=252.4

Fineness Modulus = 252.4/100 = 2.52

COARSE AGGREGATE

The coarse aggregate was locally available quarry having two different sizes, one fraction is passing through 20mm sieve and another fraction passing through 10mm sieve. Result of sieve analysis is given in Table 3.and 4.

Table 3: – Sieve analysis for coarse aggregate of 10mm size

S. No.	Sieve Size	Weight Retained (gm)	Weight Retained (%)	Weight Passing (%)	Cumulative Weight % passing
1	20 mm	-	-	-	-
2	10 mm	3.146	31.46	68.54	31.46
3	4.75 mm	6.368	63.68	4.86	97.14
4	2.36 mm	0.252	2.52	2.34	97.66
5	1.18 mm	0.234	2.34	0	100
6	600 µ	0	0	0	100
7	300 µ	0	0	0	100
8	150 µ	0	0	0	100
					Total 624.26

Fineness Modulus = 624.26/100=6.24

Table 4: - Sieve analysis for coarse aggregate of 20mm size

S. No.	Sieve Size	Weight Retained (gm)	Weight Retained (%)	Weight Passing (%)	Cumulative Weight % passing
1	40 mm	0	0	0	0
2	20 mm	1.46	14.60	85.40	14.60
3	10 mm	8.306	83.06	2.34	97.66
4	4.75 mm	0.190	1.90	0.44	99.56
5	2.36 mm	0.044	0.44	0	100
6	1.18 mm	0	0	0	100
7	600 µ	0	0	0	100
8	300 µ	0	0	0	100
9	150 µ	0	0	0	100
					Total 711.82

Fineness Modulus = 711.82/100=7.11

Fibers

The various types of fibers like carbon, glass, synthetic, steel etc. can be used in reinforcing concrete. In the present study, steel fibers have been incorporated in concrete. 0.5 to1.5% of steel fibers were added of total concrete mass. Physical properties of steel fibers used are shown in Table 5.

Table 5: Physical properties of steel fibers

Particulars	Properties
Shape	Cylindrical
Type	Hooked
Length, mm	30
Diameter, mm	1
Aspect Ratio	35

Silica Fume

The silica fume used was obtained from Orkla India (Pvt) Ltd (Brand name: Elkem Microsilica 920-D), Navi Mumbai. Physical and chemical properties of silica fume are shown in Table:

Table 6: Physical Properties of Silica Fume (Source: Test Report)

Physical Properties	Test Results
Color	Light Grey
Specific Gravity	2.26

Table 7: Chemical properties of Silica Fume

Chemical properties	Percentage by weight
Calcium oxide(CaO)	0.426
Silica(SiO_2)	93.80
Alumina(Al_2O_3)	0.206
Iron oxide(Fe_2O_3)	0.096
Magnesium oxide(MgO)	0.222
Sodium oxide (Na_2O)	0.107
Potassium oxide(K_2O)	0.337

FLY ASH

Fly ash usually refers to ash produced during combustion of coal. Physical properties and chemical properties of fly ash are given in table 3.8 and 3.9 respectively.

Table 8: – Physical of fly ash.

Physical Properties	Fly Ash
Specific gravity	2.30
Mean grain size (μm)	20
Specific area (cm^2/gm)	2680
Colour	Grey to black

Table 9: Chemical Properties of Fly Ash

Fly Ash	Chemical Composition (%)
Silicon dioxide (SiO2)+ Aluminium oxide (Al2O3) + Iron Oxide (Fe2O3)	95.5
Silicon dioxide (SiO2)	60.5
Sulphur trioxide (SO3)	0.2
Reactive Silica (SiO2)	33.4
Chlorides (C1)	0.01
Magnesium oxide (MgO)	0.6

Loss on Ignition	1.1
Sodium oxide (Na2O)	0.1
Insoluble Residue	-

Super Plasticizer

Super plasticizer **STRUCTURO 100(M)** (Fosroc chemicals) was used as admixture. Structuro 100(M) combines the properties of water reduction and workability retention. Specifications of super plasticizer are shown in Table 3.10

Table 10: Specifications of Super plasticizer (Source : Fosroc Chemicals)

Particulars	Properties
Appearance	Light yellow
Basis	Aqueous solution of Carboxylic ether polymer
pH	6.5
Density	1.06 kg/litre
Chloride content	Nil to IS:456
Alkali content	Less than 1.5g Na_2O equivalent per litre of admixture
Optimum dosage	0.5 to 3.0 litres per 100kg of cementitious material

Mixing of Specimens

Hand mixing is adopted throughout the experimental work. First the materials cement, fine aggregate, coarse aggregate, steel (hooked end) fibers weighed accurately as per the above mentioned calculations. The sand is laid in a layer of approximately 10cm thick. Then cement is added to the sand and mixed thoroughly to get a uniform colour. The coarse aggregate is spread on the ground and then the cement-sand mixture is mixed with it to get a uniform matrix. The steel (hooked end) fibers of 30mm lengths are dispersed in the water. The water along with the fiber is added to the mixture and mixed thoroughly to get a uniform mass in colour and consistency.

Table 11: For mixes

Sr. No.	Mix Designation	Ingredients
1	M1	M25 grade concrete
2	M2	M25 grade concrete with replacement of 10% fly ash, 5% silica flume with 0.5 % steel fiber
3	M3	M25 grade concrete with replacement of 10% fly ash, 5% silica flume with 1 % steel fiber
4	M4	M25 grade concrete with replacement of 10% fly ash, 5% silica flume with 1.5 % steel fiber

METHODOLOGY

Compressive Strength Test

For compressive strength test, cube specimens of dimensions 150 x 150 x 150 mm were cast for M-25 grade of concrete. The moulds were filled with 0%, 0.5% 1.0% and 1.5% steel fibres. Vibration was given to the moulds using table vibrator. The top surface of the specimen was levelled and finished. After 24 hours the specimens were demoulded and were transferred to curing tank where in they were allowed to cure. At the end of curing period, the specimens were tested in a compressive testing machine as per procedure laid in : IS 516-1989. Compressive strength test is initial step of testing concrete because the concrete is primarily meant to withstand compressive stresses. The failure load was noted. In each category three cubes were tested and their average value is reported. The compressive strength was calculated as follows.

Compressive strength (MPa) = Failure load / cross sectional area.

Split Tensile Strength Test

For Split tensile strength test, cylinder specimens of dimension 150 mm diameter and 300 mm length were cast. The specimens were demoulded after 24 hours of casting and were transferred to curing tank where in they were allowed to cure for 28 days. These specimens were tested under compression testing machine. In each category three cylinders were tested and their average value is reported.

Split Tensile strength was calculated as follows:

Split Tensile strength (MPa) = 2P / π DL, Where, P = failure load, D = diameter of cylinder, L = length of cylinder

Flexural strength test

For flexural strength test beam specimens of dimension 100x100x500 mm were cast. The specimens were demoulded after 24 hours of casting and were transferred to curing tank where in they were allowed to cure. These flexural strength specimens were tested under two point loading as per I.S. 516-1959, over an effective span of 400 mm on Flexural testing machine. Load and corresponding deflections were noted up to failure. In each category three beams were tested and their average value is reported. The flexural strength was calculated as follows.

Flexural strength (MPa) = (P x L) / (b x d2),

Where, P = Failure load, L = Centre to centre distance between the support = 400 mm, b = width of specimen=100 mm, d = depth of specimen= 100 mm.

RESULTS

Tests Results

Compression Strength Test Results

The mix M1 was used as control mix i.e. fiber content as 0% and compressive strength at 56 days was 29.40 N/mm2. The compressive strength of M2, M3, and M4 was found to increased by 9%, 13% and 20% at 56 days, respectively, when compared to M1.

Table 12: Compression Test Results

Sr. No.	Percentage of Fiber %	Percentage of Fly Ash %	Percentage of Silica Fume %	Average Compressive Strength (N/mm2)		
				7 days	28 days	56 days
M1	0	0	0	18.50	27.60	29.40
M2	0.5	10	5	21.70	29.80	32.20

M3	1	10	5	23.90	31.50	33.50
M4	1.5	10	5	25.80	34.20	35.40

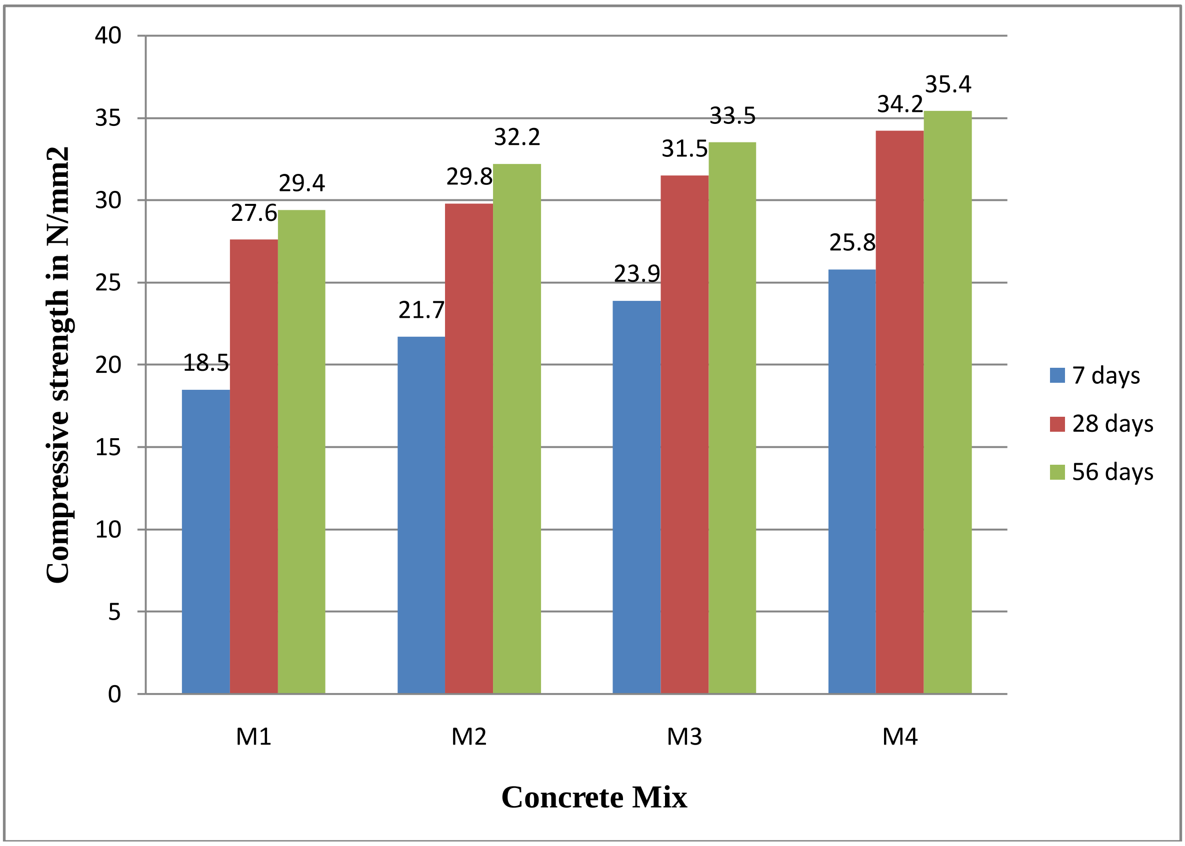

Fig. 1: Comparison of Compressive Strength

Split Tensile Strength Test Results

The split tensile strength of mix M1 at 56 days was 4.40 N/mm2. The Split tensile strength of mix M2, M3, and M4 was found to increased by 6%, 32% and 51%, at 56 days, respectively, when compared to M1.

Table 13: Split Tensile Strength Test Results

Sr. No.	Percentage of Fiber %	Percentage of Fly Ash %	Percentage of Silica Flume %	Average Split Tensile Strength (N/mm2)		
				7 days	28 days	56 days
M1	0	0	0	2.45	3.85	4.40
M2	0.5	10	5	3.68	4.50	4.70
M3	1	10	5	4.51	5.50	5.85
M4	1.5	10	5	5.05	6.35	6.67

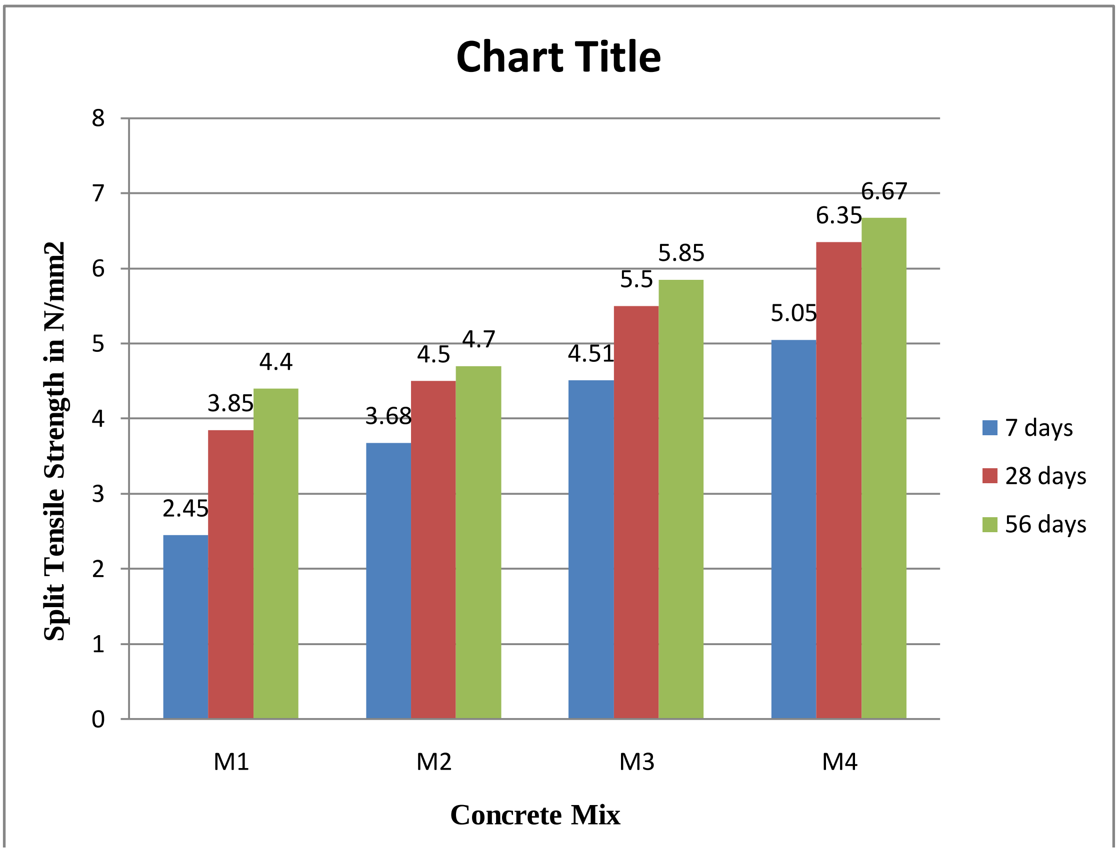

Fig. 2: Comparison of Split Tensile Strength

Flexural Strength Test Results

The Flexural Strength of mix M1 at 56 days was 4.05 N/mm2. The Flexural Strength of mix M2, M3, and M4 was found to increased by 6%, 19% and 45%, at 56 days, respectively, when compared to M1.

Table 14:- Flexural Strength Test Results

Sr. No.	Percentage of Fiber %	Percentage of Fly Ash %	Percentage of Silica Flume %	Average Split Tensile Strength (N/mm2)		
				7 days	28 days	56 days
M1	0	0	0	2.50	3.15	4.05
M2	0.5	10	5	3.25	4.20	4.30
M3	1	10	5	4.65	5.05	4.85
M4	1.5	10	5	4.95	5.95	5.90

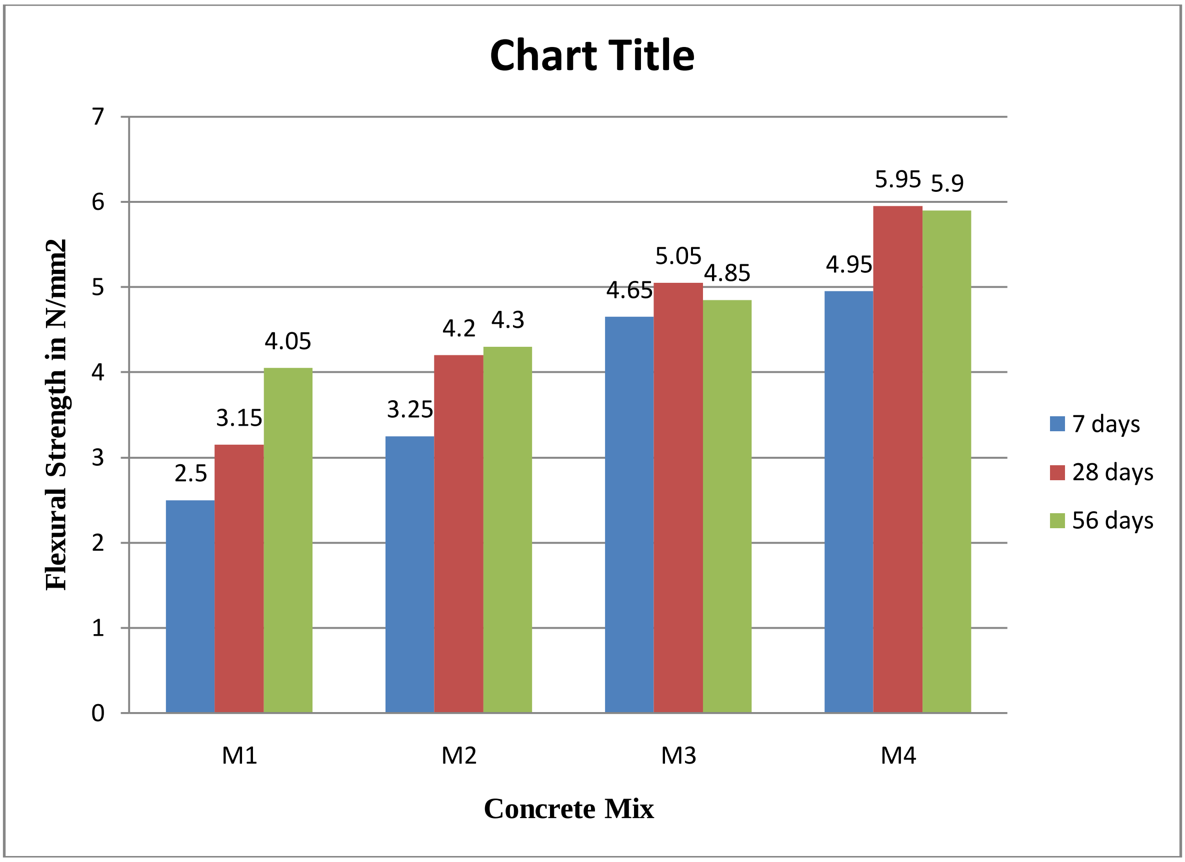

Fig. 3: Comparison of Flexural Strength

CONCLUSION

The variation in the compressive stress and split tensile stress with respect to changes in the fiber content can be observed. From the results obtained, it is clear that the compressive and split tensile strength of concrete is maximum when the fiber content is 1.5% of the concrete.

1. The 56-day compressive strength of HPC mixes with fiber content of 0.5%, 1.0% and 1.5%, were found to be increased by 9%, 13% and 20%, when compared to strength at 0% fiber content.
2. The 56-day split tensile strength of HPC mixes with fiber content of 0.5%, 1.0% and 1.5%, were found to be increased by 6%, 32% and 51%, when compared to strength at 0% fiber content.
3. The 56-day flexural strength of HPC mixes with fiber content of 0.5%, 1.0% and 1.5%, were found to be increased by 6%, 19% and 45%, when compared to strength at 0% fiber content.

The Steel fiber (hooked end) used in this project has shown considerable improvement in all the properties of concrete when compared to conventional concrete like,

- Compressive strength by 20% for 1.5% of steel fiber.
- Split Tensile strength by 51% for 1.5% of steel fiber.
- Flexural strength (Modulus of Rupture) by 45% for 1.5% of steel fiber.

Scope for Future Study

1. Further study can be made by increasing the percentage of fiber content.
2. Different types of fibers like synthetic fiber, carbon fibers, or glass fibers may be used for future investigation.
3. In durability properties, HPC mixes containing fiber exposed to freezing and thawing cycles, can be investigated.
4. Further study can be done on HPC mixes containing fiber subjected to elevated temperatures.
5. Further study can be done for determining the deflections and durability of concrete.
6. Further study on the seepage characteristics of the steel fiber.
7. As the failure of SFRC is ductile, further studies on retrofitting of damaged structures constructed of this concrete can be undertaken.

8. The study can be done using different types of fibers such as polyproplyne, carbon, GI, HDPE (high density poly ethylene) fibers in ternary blended combinations when subjected to different sustained elevated temperatures.
9. Effect of sudden cooling, gradual cooling and intermittent cooling on the properties of steel fiber reinforced ternary blended concrete when subjected to sustained elevated temperatures.
10. Effect of grade of concrete on the properties of steel fiber reinforced ternary blended concrete when subjected to sustained elevated temperatures.

REFERENCES

[1]. ACI (1999), Building Code Requirements for Structural Concrete (ACI 318-99) and Commentary, ACI-318R-99, American Concrete Institute, Detroit, Michigan.

[2]. Adanagouda1, Dr.H.M.Somasekharaiah2, Shashi kumar.B3 (2015)“ Experimental Investigation on Strength Characteristics of Fly Ash Based High Performance Concrete with Steel Fiber and Polypropylene Fiber” International Journal of Innovative Reasearch In Science, Engineering and Technology (IJIRSET) ISSN (Online) :2319-8753, ISSN (Print) : 2347-6710, Vol. 4, Issue 9, September 2015.

[3]. Konda Rushi Kesava Reddy1, Dr. K. Chandrasekhar Reddy2 (2013)“Flexural Behavior of Steel Fibre Reinforced High Strength Concrete Beams” International Journal of Science and Research (IJSR) ISSN (Online): 2319-7064

[4]. Elavarasi.D1, and Saravana Raja Mohan.K1 “Structural behaviour of High Strength Steel Fibre Reinforced Concrete (HS-SFRC) block pavement” International Journal of ChemTech Research ISSN: 0974-4290, Vol.7, No.4, pp 1790-1794, (2015)

[5]. K.R.Venkatesan, P.N.Raghunath, K.Suguna (2015) “ Flexural Behavior of High Strength Steel Fibre Reinforced Concrete Beams” International Journal of Engineering Science and Innovative Technology (IJESIT) Volume 4, Issue 1, January 2015

[6]. 1K.Saravanan, 2S.Arul Vignesh, 3R.Santhosh, 4K.Alagusankareswari “Experimental Study on Concrete using Steel Fibre” International Journal of Mechanical Civil and Control Engineering, ISSN (Online): 2394-8868, Vol. 1, Issue. 2, April, 2015

[7]. S. Eswari (2015) “ Experimental Investigation on Flexural Performance of Hybrid Fibre Reinforced Concrete” International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056 Volume: 02 Issue: 03 | June-2015

[8]. Abdul Ghaffar (2014) “Steel Fibre Reinforced Concrete” International Journal of Engineering Trends and Technology (IJETT) – Volume 9 Number 15 - Mar 2014.

[9]. Mr.V.D.Sabale,Dr. Y.M. Ghugal“ Experimental Study of Fresh Concrete Properties of Fibre Reinforced Concrete with Metakoalin” International Journal of Emerging Engineering Research and Technology, ISSN 2349-4395 (Print) & ISSN 2349-4409 (Online),Volume 2, Issue 4, July 2014.

[10]. R. Madheswaran, 2S. Arun Singh, 3K.S. Sathyanarayanan“ Experimental study on hardened concrete by using steel fibers with mineral admixture” International Journal of Civil Engineering and Technology (IJCIET) ISSN 0976 – 6308 (Print) ISSN 0976 – 6316(Online) Volume 5, Issue 5, May (2014)

[11]. Nikhil A. Gadge1, Prof. S. S. Vidhale (2013) “ Mix Design of Fiber Reinforced Concrete (FRC) Using Slag & Steel Fiber” International Journal of Modern Engineering Research (IJMER) www.ijmer.com Vol. 3, Issue. 6, Nov - Dec. 2013 pp-3863-3871 ISSN: 2249-6645

[12]. P. Ramadoss1, K. Nagamani2“ Impact characteristics of high-performance steel fiber reinforced concrete under repeated dynamic loading” International Journal of Civil Engineering, December 2013

[13]. Khadake S.N.*, Konapure C.G. (2013) “An Experimental Study of Steel Fiber Reinforced Concrete with Fly Ash for M35 Grade” International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com Vol. 3, Issue 1, January -February 2013, pp.950-953

[14]. A.M. Shende1, A.M. Pande2, M. Gulfam Pathan (2012) “Experimental Study on Steel Fiber Reinforced Concrete for M-40 Grade” International Refereed Journal of Engineering and Science (IRJES) ISSN (Online) 2319-183X, (Print) 2319-1821 Volume 1, Issue 1 (September 2012), PP. 043-048

[15]. Milind V. Mohod (2012) “Performance of Steel Fiber Reinforced Concrete” RESEARCH INVENTY: International Journal of Engineering and Science ISSN: 2278-4721, Vol. 1, Issue 12 (December 2012), PP 01-04

[16]. Falah A. Almottiri (2011) “Physical Properties of Steel Fiber Reinforced Cement Composites Made with Fly Ash” Jordan Journal of Civil Engineering, Volume 5, No. 2, 2011

[17]. B.W. Xu *, H.S. Shi (2009) “Correlations among mechanical properties of steel fiber reinforced concrete” Construction and Building Materials 23 (2009) 3468–3474

[18]. ChoteSorankom and BarzinMobasher(2009), “Flexural Design of Fiber-Reinforced Concrete”, ACI Materials Journal / September- October.

[19]. GuerriniGL (2000), “Application Of High Performance Fiber-reinforced Cement-Based composites”. Applied Composite Materials 7, pp 195-207

[20]. Girish M.G. at al (2010) Flexural Fatigue Analysis of Steel Fibre Reinforced Concrete CAFET-INNOVA TECHNICAL SOCIETY. ISSN 0974-5904, Volume 05, No. 05 (01)

[21]. K. Holschemacher, T. Mueller, Y. Ribakov (2009) “Effect of steel fibres on mechanical properties of high-strength concrete” Materials and Design 31 (2010) 2604–2615

[22]. Naaman, A.E., (1987). “High Performance Fibre Reinforced Cement Composites”. Concrete Structures for the Future, IABSE Symposium, Paris-Versailles, 371-376.

[23]. Naaman, A.E., and Hammoud, H. (1998), “Fatigue characteristics of high performance fibre-reinforced concrete”, Journal of cement and concrete composites, 20, 353-363.

[24]. Parra-Montesinos,Gustavo J. ,Reinhardt, Hans W., Naaman A.E.,(2011), “High Performance Fiber Reinforced Cement Composites”,RILEM BookSeries, Vol.2.pp.550

[25]. Prashant Y.Pawade,1 Nagarnaik P.B.2, Pande A.M.(2011) " Performance of steel fiber on standard strength concrete in compression" INTERNATIONAL JOURNAL OF CIVIL AND STRUCTURAL ENGINEERING Volume 2, No 2, 2011
[26]. S.P. Singh a,*, S.K. Kaushik (2003) "Fatigue strength of steel fibre reinforced concrete in flexure" Cement & Concrete Composites 25 (2003) 779–786
[27]. Saravana Raja Mohan. K, Parthiban. K (2011) " Strength and behaviour of Fly Ash based Steel Fibre Reinforced Concrete Composite" INTERNATIONAL JOURNAL OF CIVIL AND STRUCTURAL ENGINEERING Volume 2, No 1, 2011
[28]. Vikrant S. Vairagade, Kavita S. Kene (2012) " Introduction to Steel Fiber Reinforced Concrete on Engineering Performance of Concrete" International Journal of Scientific & Technology Research Volume 1, Issue 4, May 2012
[29]. Balaguru P and Najm H (2004), "High-performance fibre reinforced concrete mixture proportion with high fibre volume fractions", Material Journal, volume 101, issue 4, July 1, 2004 pp281-286
[30]. Madan S. K., Rajeshkumar G., and Sign S.P., "Steel Fibers as Replacement to Web Reinforcement for RCC Deep Beam in Shear", Asian journal of Civil Engineering Building and Housing), Vol. 8, No. 5 (2007), pp 479-489