Experimental Study on High Performance Steel Fibre Reinforced Concrete using Metakaolin

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***Abstract*- The current paper presents the result and discussion of an experimental study on HSFRC using Metakaolin (MK). The effects of these fiber and Metakaolin on workability, density, and on various strengths of M60 grade concrete are studied. Fiber content varies from 2.5% to 10 % by weight of cement and Metakaolin content varies from 5% to 20% by weight of cement. The various strengths considered for investigation are compressive strength, flexural strength, split tensile strength, and shear strength. Cubes of 150mm for compressive strength, cylinders of size 150mm diameter x 300mm length for split tensile strength, beams of 100 x100 x 500 mm for flexural strength, push-off specimens of size 150 x 150 x 450 mm for shear strength were cast. The prepared specimens were water cured and tested for variety of properties up to certain period of the time.**

Keywords*— *HSFRC, Metakaolin, Mechanical Properties, Density, M60 grade Concrete.

I. INTRODUCTION

As we know, brittle failure is the inherent property of the plain concrete, i.e. it has very low tensile strength and low strain capacity at fractures. These shortcomings of plain concrete are overcome by adding reinforcement bars or prestressing steel. The main drawback of the reinforcing steel is corrosion due to the ingress of chloride ions in the concrete. This problem becomes severe in coastal areas. Corrosion of steel bars forms rust with time. This rust is bigger in volume than iron which results in expansion. This expansion exerts large tensile stresses on concrete leading to the formation of cracks and thus propagation of these cracks leads to the spalling of concrete. To overcome this shortcoming, fibers are incorporated in cement concrete. There are different types of fibers available but here steel fibers are used because of their high tensile strength, ductility, ability to arrest propagation of cracks, improved bond strength, etc.

Extensive research has been done on SFRC using fly ash and silica fume as cement replacement but very little research has been conducted on SFRC using Metakaolin. The present experimental work is mainly done to investigate the different strengths of SFRC using Metakaolin as cement replacement. Silica fume and fly ash are the by-products and so have the uncontrolled engineering properties which sometimes don't give the required results. Instead, Metakaolin is the manufactured product, produced by calcining kaolin at a temperature of 700^0c - 800^0c. Thus its controlled engineering properties yield good results regarding workability and durability of concrete. Silica fume or fly ash when blended with cement darkens the colour of concrete but Metakaolin being white in colour doesn't alter the colour of concrete, thus enhancing aesthetic look.

II. METHODOLOGY

Steel fiber reinforced concrete is homogenous mixture of cement, sand, coarse aggregate and water with uniformly dispersed steel fibers. Concrete mix grade M-60 is used throughout the experimental work. Production of control mix in the laboratory is carried out by IS method designed proportions.

TABLE I
PROPERTIES OF CRIMPED STEEL FIBERS

Sr. No.	Property	Value
1.	Diameter (d_f)	0.7 mm
2.	Length of fiber (l_f)	60 mm
3.	Aspect ratio of fiber (l_f/d_f)	85
4.	Appearance and form	Clear, bright and undulated along length
5.	Modulus of Elasticity	200 GPa
6.	Tensile strength	1000 MPa

TABLE II
PROPERTIES OF METAKAOLIN

Item	% by Weight
SiO_2	52.8
Al_2O_3	36.3
Fe_2O_3	4.21
MgO	0.81
CaO	< 0.10
K_2O	1.41
Loss on Ignition	3.53
Specific Gravity	2 ± 0.1
Bulk Density	320±20

The M-60 grade of concrete having mix proportions 1: 0.8518: 1.1481 i.e., cement: fine aggregate: coarse aggregate with w/c ratio of 0.3 was used throughout the experimental investigation. The concrete mix design was carried out according to I.S.10262. Fibers and Metakaolin in powder form were added in wet state of concrete and again mixed thoroughly. Cubes of 150mm size for compressive strengths, cylinders of size 150mm diameter x 300mm length for split tensile strength, beams of size 100 x 100 x 500 mm for flexural strength and push off specimen of 450 x 150 x 150 mm for shear strength were cast incorporating 0–10%

crimped fibers at an interval of 2.5% and 0-20% Metakaolin at an interval of 5% by weight of cement. For each test, three specimens were cast. Compaction of all the specimens was done using a table vibrator to avoid balling of fibers. All the specimens were water cured for 28 days at room temperature and were tested in surface dry condition on a 1000 kN Universal Testing Machine (UTM) and Compression Testing Machine (CTM) of capacity 2000 kN. Totally, 60 specimens were cast and tested to evaluate the strength performance. Each value of the results presented in this study is the average of three test samples.

A. *Materials:*

1. Steel Fiber: The physicochemical parameter of steel fiber should meet the requirements of JGT 472-2015. The length of steel fiber should be 20 mm~60 mm and diameter or equivalent diameter should be 0.3 mm~1.2 mm; length to diameter ratio was 30~65.
2. Cement. P.O 42.5 ordinary Portland cement was used in this paper, and each performance index of cement and its strength of 3 days and 28 days were checked according to the performance index of "General Portland Cement" (GB175-2007).
3. Fine Aggregate. Good quality graded sand was selected, and fineness modulus should be controlled in 2.3 to 3.0; fine aggregate performance was checked according to GB14684-2011.
4. Coarse Aggregate. Test selection of hard texture, graded continuous gravel, and aggregate shape with a more uniform edge polyhedron was made as well, with a particle size of 5 mm~20 mm and clay content.

B. *Sample Preparation*

To ensure uniform distribution of fibers in the mix, sand and macadam were mixed firstly, and then, cement and fiber were added. After the mixtures were mixed for 30 seconds, the water and additives were added during the course of stirring. The stirring time of steel fiber-reinforced concrete was 3 minutes; and the mixing process is done. The prepared mixture was put into the test mold to vibrate, and then, it was made flat. The mold was removed after 48 hours maintenance, and then specimens were cured in the standard curing room at the temperature of 20°C and relative humidity of 97%. The strengthening mechanism of vibration was to make cement powder and fine material to quickly disperse; water and cement hydration reaction speed was expedited evenly so that the microscopic structure of the cement concrete was improved, and the dosage of cement was effectively reduced. The contrast of effect between vibratory mixing and traditional mixing is done, and the contrast of microstructure between vibratory mixing and traditional mixing.

III. Experimental Set Up

A. Cube Compression of Steel Fiber-Reinforced Concrete

Fig. 1. Cube compressive strength testing machine

The standard length of 150 mm cube specimen was used in the cube compressive strength test, and the methods and procedures of "ordinary concrete mechanical properties test method standard" GB/T 50080-2016 and "test method for fiber concrete" (CECS 13-2009) were referred to conduct the test. The constant-speed stress control was used in this test, and loading speed was 0.6 MPa/s; the specimen would be automatically unloaded, and the strength of damage was recorded by the machine. The cube compressive strength testing machine is shown in Figure below.

B. Flexural Test of Steel Fiber-Reinforced Concrete Beam

The existing literatures showed that the flexural tests of steel fiber-reinforced concrete made by vibratory mixing were very limited up to now. For this purpose, a series of beam specimens (at the age of 28 d) with the size of 100 mm × 100 mm × 400 mm were used to study the flexural strength in this study. The three-point loading tests were carried out using the flexural testing machine (NYL-300C type) in accordance with the Chinese standard (JTG E30-2005). The test apparatus of the flexural strength test is presented in Figure.

Fig.2. Flexural Shear strength test apparatus

C. Split Tensile Test of Steel Fiber-Reinforced Concrete Cylinder

The standard length of 150 mm cube specimen was used in the splitting tensile strength test, and each group includes 3 specimens. The 3000 kN pressure testing machine was used in this test, and the splitting position should be drawn before the splitting test, as shown in Figure.

Fig. 3. Cylinder splitting tensile strength testing equipment

IV. RESULT AND DISCUSSION

4.1 Cube Compressive Strength of Steel Fiber Concrete

Results of compressive strength are as shown in Table III. The 28 days compressive strength is greatest at 10% steel fiber and 20% of Metakaolin over the normal concrete. Hence, 10% steel fiber and 20% Metakaolin is more suitable for improving compressive strength of structural concrete.

TABLE III

COMPRESSIVE STRENGTH OF SFRC CUBE

Mix	Metakaolin (%)	Steel Fiber (%)	Failure Load (kN)	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)
M0	0%	0%	842.15	74.86	74.85
			839.85	74.66	
			843.99	75.02	
M1	5%	2.5%	912.30	81.1	81.15
			916.21	81.44	
			910.00	80.9	
M2	10%	5%	968.99	86.14	85.84
			961.52	85.46	
			966.69	85.92	
M3	15%	7.5%	1002.92	89.14	88.87
			999.47	88.84	
			997.17	88.64	
M4	20%	10%	1019.94	90.66	90.45
			1017.06	90.42	
			1015.34	90.26	

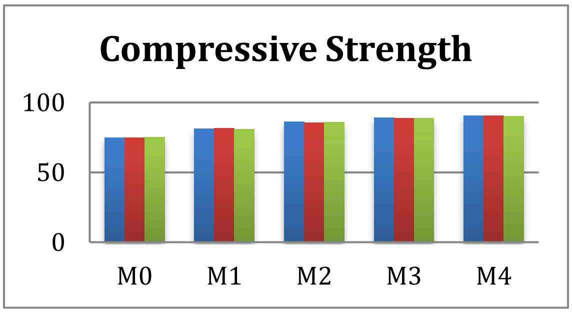

Fig. 4. Cube Compressive Strength Testing Results

As per the results obtained from figure 4, it is found that as much as the quantity of both Metakaolin and Steel fiber increases the compressive strength goes on increases. Also it is found that, the variation in the readings obtained are reduces since it has been concluded that the increase of filler materials provides stability to the compressive strength of the concrete.

4.2 Beam Flexural Strength of Steel Fiber Concrete

It is observed that 28 days flexural strength increased continuously up to 10% of fiber and 20% of Metakaolin, as compared to normal concrete. Hence, fibers are best suitable for improving flexural strength of structural concrete. The increase in flexural load and deflections is observed with increase in fiber and Metakaolin contents. This indicates the increase in ductility of concrete. It is seen that failure of beams occurred in maximum bending moment (flexural) zone i.e., the middle third zone of the beam.

TABLE IV

FLEXURAL SHEAR STRENGTH OF SFRC BEAM

Mix	Metakaolin (%)	Steel Fiber (%)	Failure Load (kN)	Flexural Shear Strength (N/mm^2)	Average Flexural Strength (N/mm^2)
M0	0%	0%	12.94	10.36	10.20
			12.08	9.66	
			13.23	10.58	
M1	5%	2.5%	13.80	11.04	11.12
			14.66	11.74	
			13.23	10.58	
M2	10%	5%	14.09	11.28	12.12
			16.10	12.88	
			15.24	12.2	
M3	15%	7.5%	18.11	14.5	14.34
			18.98	15.18	
			16.68	13.34	
M4	20%	10%	22.14	17.72	17.64
			21.28	17.02	
			22.71	18.18	

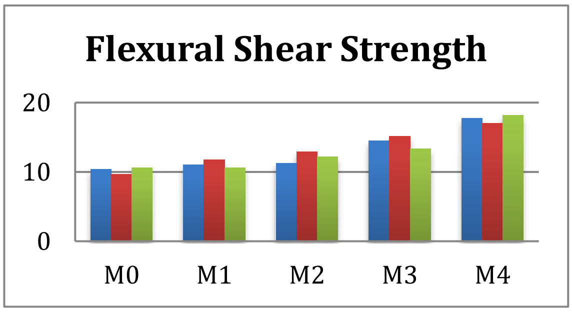

Fig. 5. Beam Flexural Shear strength testing results

Figure 5 shows the variation occurs in the readings obtained by shear strength testing. The properties obtained from composition M0 to M4, it is found that there is huge difference between M0 and M4. The M4 has highest shear strength. It is also found that the stability of readings is less for the same composition.

4.3 Cylinder Split Tensile Strength of Steel Fiber Concrete

The variation of split tensile strength with respect to fiber content and Metakaolin is shown in Table V. It is observed that 28 days split tensile strength increased continuously with increase in percentage of steel fiber and Metakaolin. The maximum split tensile strength is obtained at 10% of steel fiber and 20% of Metakaolin. This increase in strength may be attributed to the improved properties of matrix and strong inter phase bond between the fiber and the matrix as synergistic effect of fibers and Metakaolin.

TABLE V
SPLIT TENSILE STRENGTH OF SFRC CYLINDER

Mix	Metakaolin (%)	Steel Fiber (%)	Failure Load (kN)	Split Tensile Strength (N/mm2)	Average Split Tensile Strength (N/mm2)
M0	0%	0%	115.23	7.34	7.32
			116.27	7.4	
			113.39	7.22	
M1	5%	2.5%	119.95	7.64	7.87
			124.89	7.96	
			126.04	8.02	
M2	10%	5%	137.54	8.76	8.61
			135.82	8.64	
			132.14	8.42	
M3	15%	7.5%	147.66	9.4	9.27
			142.26	9.06	
			146.63	9.34	
M4	20%	10%	155.25	9.9	9.88
			152.03	9.68	
			157.78	10.06	

Figure 6 represents readings obtained for tensile strengths. It is found that, there is very less variation between M0 and M4, and also the variation between all readings of the same composition is less. Since it is found that the stability has been moderate for filler materials.

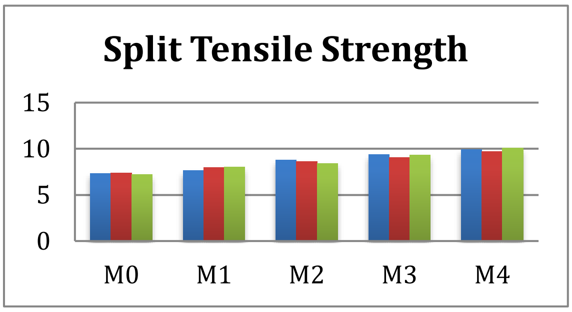

Fig. 6. Cylinder split tensile strength testing results

V. CONCLUSIONS

The following conclusions have been made based on the results obtained from the previous chapter:

1. Density of concrete increases marginally with increase in percentage of fiber content. Density of steel fiber reinforced concrete using Metakaolin has increased marginally over normal concrete. This is due to partial replacement of cement by Metakaolin, which densifies the concrete because of its micro-filler effect due to the relatively finer particle size.
2. Workability of concrete gets reduced; the reason for this is due to increase in percentage of fiber content.
3. Compressive strength of concrete increases with increase in percentage of fiber content. Strength-effectiveness is observed to be maximum than the control concrete at 1% fiber volume fraction.
4. Split tensile strength of concrete increases with increase in percentage of fiber content. Strength-effectiveness is observed to be maximum than the control concrete at 1% fiber volume fraction.
5. Flexural strength of concrete increases with increase in percentage of fiber content. Strength-effectiveness is observed to be maximum than the control concrete at 1% fiber volume fraction.
6. The strength-effectiveness is observed maximum for flexural strength, followed by splitting tensile strength and compressive strength at each fiber volume fraction.
7. Failure of beams occurred in the flexural zone. The width of crack is less in steel fiber reinforced concrete using Metakaolin than plain concrete.
8. In steel fiber reinforced concrete using Metakaolin, slow propagation of crack occurred than plain concrete, which indicates ductile failure in steel fiber reinforced concrete using Metakaolin while the quick propagation of crack in plain concrete shows brittle failure.
9. Plain concrete is a brittle material and fails suddenly. Addition of steel fibers to concrete changes its brittle mode of failure into a more ductile one and improves the concrete ductility.

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