Performance Evaluation of High Strength Steel Fiber Reinforced Metakaolin Concrete At Elevated Temperature

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Abstract— The present work deals with results of investigation of High strength Metakaolin concrete at the high temperature. The Metakaolin is varied from 0 to 15% by replacing cement at the interval of 3% by the weight of cement. The optimum percentage of the Metakaolin in concrete is obtained by the compressive test carried on the concrete. To study the effect of elevated temperature the specimens are put in the furnace at the varying temperature from 2000C to 6000C also the duration is varied. The cube of the size 150mm x 150mm x 150mm for compression strength and the beam of the size 150mm x 150mm x 700mm for the flexural strength. The cylinder of the size 150mm diameter 300mm height for the split tensile test the workability measured with the slump cone. The weight and dry density also calculated. The objective of this work is to provide an overview of the effect of elevated temperature on the behaviour of metakaolin concrete material. The effects of elevated temperature on the high strength concrete materials are observed and their performance compared to the normal strength of concrete.

Key words: High Strength Metakaolin Concrete, Fiber Reinforced Concrete

I. Introduction

A. General

Concrete is a material often used in the construction of high rise buildings and in case of unexpected fire, the concrete properties are changes after fire. Hence, it is important to understand the change in the concrete properties due to extreme temperature exposures. As the concrete used for special purpose, the risk of exposing it to high temperature also increases. To be able to predict the response of structure after exposure to high temperature, it is essential that the strength properties of concrete subjected to high temperatures be clearly understood. High temperature can cause the development of cracks.

These cracks like any other cracks propagation may eventually cause loss of structural integrity and shorting of service life. The influence of elevated temperatures on mechanical properties of concrete is of very much important for fire resistance studies and also for understanding the behavior of containment vessels, chimneys, nuclear reactor pressure vessels during service and ultimate conditions structures like storage tanks for crude oil, hot water , coal gasification, liquefaction vessels used in petrochemical industries, foundation for blast furnace and coke industries, furnace walls industrial chimney, air craft runway etc., will be subjected to elevated temperatures. So that the variation of compressive strength, performance are some of the important parameters to be investigated when concrete structures are subjected to temperatures.

The effect of temperature on different properties of concrete is considerable and remained the subject of research activities of a lot of researchers. Different investigators moved in different ways and investigated temperature effect by changing different parameters such as w/c ratio; mix ratio, early change in temperature etc.

Since human safety in case of fire is one of the major considerations in the design of buildings, it is extremely necessary to have a complete knowledge about the behavior of all construction materials before using them in the structural elements. [1,2]

B. Fiber Reinforced Concrete

Under loading, the micro cracks present in concrete propagate and open up, owing to the effect of stress concentration and also additional cracks form in places where there are minor defects. The development of such minor cracks is the main cause of inelastic deformation of concrete. It has been recognized that the additions of small, closely spaced and uniformly dispersed discontinuous discrete fibers to concrete would substantially improve its static and dynamic properties. This type of concrete is known as fiber reinforced concrete. Fiber reinforced concrete may be defined as a mixture of cement mortar or cement concrete and discontinuous, discrete, uniformly dispersed and closely spaced fibers. Continuous meshes, woven fabrics and long rods do not fall within the category of discrete fiber type reinforcing elements considered for fiber reinforced concrete. Chemical admixtures and fly ash can be used to improve the workability of fiber reinforced concrete (since workability decreases with the addition of fibers to concrete). High-strength concrete is a brittle material, and as the concrete strength increases the post peak portion of the stress-strain diagram almost vanishes or descends steeply. The increase in the strength of concrete lowers its ductility. This inverse relation between strength and ductility is a serious drawback for the use of high strength concrete. This drawback can be compensated by adding discontinuous fibers. The addition of fibers to concrete makes it more homogeneous and isotropic and transforms it from a brittle material to a more ductile material. When concrete cracks, the random propagation improves strength and ductility.

Fiber is a small piece of reinforcing material possessing certain characteristic properties. Generally they are circular or rectangular in cross section. The fiber is designated by its volume fraction and its aspect ratio. Volume fraction represents the volume of fibers used per one m^3 of concrete. The aspect ratio of the fiber is the ratio of the length of the fiber to its diameter.

The concept of fiber reinforcement is to use the deformations of the matrix under stress to transfer load to the fiber. The static and dynamic strength can be improved if the fibers are strong, stiff and loaded to fracture, provided there is a minimum fiber volume fraction. [3-5]

C. *Necessity of the Work*

Concrete generally provides adequate fire resistance for most applications. However, the strength and durability properties of concrete are significantly affected when subjected to elevated temperatures due to chemical and physical changes. At temperatures above 300^0C, evaporation of the bound water increases the deterioration of concrete and causes a decrease in compressive strength.

When temperatures exceed 400^0C, calcium silica hydrates (C–S–H) undergo degradation and the strength of concrete decreases rapidly; at 900^0C, the structure of C–S–H disintegrates. Thus, the critical exposure temperature range is 400–800^0C in terms of compressive strength loss. Most of the original strength is lost between 600 and 800^0C. The effect of high temperatures on the mechanical properties and durability of concrete has been investigated extensively in order to produce fire resistant materials. Important factors here are properties of the aggregate, cement paste and aggregate cement paste bonding, their relative compatibility, the presence of supplementary cementitious materials, high temperature conditioning affected by heating rates, cooling type, loading conditions and moisture regime. Within the factors affecting the high temperature resistance of concrete, the properties of aggregate play an important role in the degradation processes at high temperatures. Porosity and mineralogy of the aggregate have also significant effects. Mineralogy of aggregate determines differences in thermal expansivities a between the aggregate and the cement paste, and thus bond strength at the interface.

II. METHODOLOGY

A. *Tests on Concrete Ingredients*

1) *Cement*

The cement used in this experimental work is “Ultra-tech 53 grade ordinary Portland cement. All properties of cement are tested by referring IS 12269 - 1987 Specification for 53 grade ordinary Portland cement.

2) *Water*

Potable water available in laboratory is used for mixing & curing of concrete.

3) *Aggregates*

The natural sand from Paithan, (Godavari) River confirming to IS 383-1970 is used. The various tests as specific gravity, water absorption, sieve analysis etc. have been conducted on CA and FA to know their quality and grading. The FA of the fine aggregate and coarse aggregate are 3, 23 and 6.87 respectively. Crushed black trap basalt rock of aggregate size 20mm down and 10mm down was used confirming to IS 383-1970.

4) *Properties of super plasticizer (SP)*

The properties of SP supplied by the manufacturer Sika India Ltd., Mumbai in the literature is given in Table 1 which compiles IS: 9103.

Properties	Description
Chemical admixture	Sikament^R 4101 NS
Color	Dark Brown
Type	Modified Sulphonated Naphthalene Formaldehyde Polymer
Specific Gravity	1.27± 0.02 at 30°C
pH Value	7 – 9
Chloride content	Nil
Air Entrainment	Nil
Nitrate content	Nil
Viscosity	Medium Viscous

Table 1: Properties of Superplasticizer Used

1) Properties of Metakaolin

Metakaolin (MK) is available in dry powder form and is procured from 20 MICRONS Limited, Mumbai. It is available in 25kg bags, color of which is white under the product name "Metacem 85S". The chemical & physical properties of MK are shown in Table 2.

Fig. 1: Metakaolin (MK)

Chemical Composition	
SiO_2	50% - 55%
Al_2O_3	38% - 42%
CaO	1%-3%
TiO_2	0.8-1.2
Na_2O	<1%
Fe_2O_3	0.2-0.5
K_2O	<1%
MnO	<0.5%
MgO	<0.1%
Loss on Ignition	Max 1.5%
Physical Properties	
Bulk Density (g/cc)	0.5461 (When packed)
Color	White
Specific Gravity	2.30

Table 2: Properties of Metakaolin Used

B. *Mix Design of Concrete*

M60 grade of concrete designed as per ACI. Trial mixes were cast and the quantity of cement is optimized. The compressive strength obtained was 69.40 MPa at 28 days and workability obtained was 67 mm in terms of slump cone test. The ratio of the quantities obtained were cement: Fine aggregate: Coarse aggregate = 1:0.96:3.64 with w/c = 0.33.

C. *Preparations of Specimen*

1) *Measurement of Ingredients*

The quantities required for the preparation of M-60 grade of concrete with and without Metakaolin and with steel fiber are given in table 3.9. All cement, sand, coarse aggregate (20mm), and coarse aggregate (10mm) measured with Digital balance. The water is measured with measuring cylinder of capacity 1 liter and measuring jar of capacity 1000ml, 2000 ml.

Sr. No.	Type of Mix	C	M	FA	CA	W	SP	SF	Compressive Strength (MPa)
1	OPC	507	0	620	1145	168	-	-	67.40
2	MKC	447	60	620	1145	168	5.07	-	73.92
3	SFRC (0.5 – 60)	507	0	620	1145	168	5.07	40	68.32
4	SFRC (1.0 – 60)	507	0	620	1145	168	5.07	80	69.90
5	SFRC (1.5 – 60)	507	0	620	1145	168	5.07	120	71.09
6	SFRC (0.5 – 80)	507	0	620	1145	168	5.07	40	68.28
7	SFRC (1.0 – 80)	507	0	620	1145	168	5.07	80	69.12
8	SFRC (1.5 – 80)	507	0	620	1145	168	5.07	120	71.05
9	SFRC – MK (0.5 – 60)	447	60	620	1145	168	5.07	40	73.98
10	SFRC –MK (1.0 – 60)	447	60	620	1145	168	5.07	80	74.48
11	SFRC – MK (1.5 – 60)	447	60	620	1145	168	5.07	120	76.60
12	SFRC – MK (0.5 – 80)	447	60	620	1145	168	5.07	40	74.23
13	SFRC –MK (1.0 – 80)	447	60	620	1145	168	5.07	80	75.82
14	SFRC – MK (1.5 – 80)	447	60	620	1145	168	5.07	120	77.27

Table 3: Quantities of Materials required per 1 cu. m of OPCC, MKC, SFRC and SFRC-MK (M60)

2) Mixing of concrete

The ingredients were thoroughly mixed in concrete mixer. The sand, cement and aggregate were measured accurately and were mixed in dry state for normal concrete. Whereas for Metakaolin concrete, first measured quantity of cement and required percentage of MK (0 to 15%) by weight of cement, were mixed thoroughly and then added to dry mix of aggregates. The dry concrete mix was then thoroughly and uniformly mixed till uniform and homogeneous mixing was observed. Care was taken to avoid balling i.e. agglomeration of fibers. Selected percentage of super plasticizer was added to designed quantity of water and stirred vigorously so that it is mixed uniformly in the entire water. The solution is then spread over the concrete mix and remixed thoroughly again for few minutes.

3) Placing of concrete

The fresh concrete was placed in the moulds by trowel. It was ensured that the representative volume was filled evenly in all the specimens to avoid segregation, accumulation of aggregates etc. While placing concretes, the compaction in vertical position was given to avoid gaps in moulds.

a) Compaction of Concrete

Moulds are cleaned and oiled from inside for smooth demoulding. Concrete is mixed thoroughly and placed in the mould in three layers and compacted by electrically operated Table vibrator with suitable fixing frame. It is vibrated till concrete woes out of mould. The vibration is continued till cement slurry just ooze out on surface of moulds. Care is taken of cement slurry not to spill over, due to vibration and segregation.

b) Finishing of Concrete

After removing from vibrating table, the moulds were kept on ground for finishing and covering up for any leftover position. The concrete is worked with trowel to give uniform surface. Care is taken not to add any extra cement, water or cement mortar for achieving good surface finish. The additional concrete is chopped off from top surface of the mould for avoiding over sizes etc. The density of fresh concrete is taken with the help of weigh balance. Identification marks are given on the specimens by embossing over the surface after initial drying.

4) Demoulding of Specimens

The plain cement concrete specimens are demoulded after 24 hours of casting wet concrete and kept in water tank for curing. Specimens are demoulded after 24 hours of casting wet concrete and kept for water curing at 28 days.

5) Curing of test specimens

The specimens were demoulded after 24 hours of casting and immediately stored in the curing tank for continuous curing. M-60 grade plain cement concrete is cured in curing tank for 28 days.

D. Mechanical Properties of Concrete

Test conducted on hardened concrete: Confirming to IS 516-1959

The various mechanical properties of concrete such as cube compression test, flexural test on beams, split tensile

test on hardened concrete were performed. The specimen used was cubes, beams, cylinder the dimension of each test specimen are as follows:
Cube: 150 mm x 150 mm x 150 mm
Beam: 150 mm x 150 mm x 700 mm
Cylinder: 150 mm diameter and 300 mm height

1) Workability of Concrete

Workability of concrete with and without supplementary cementitious material has determined with the help of slump cone test, compaction factor test and Vee-Bee consistometer.

E. Mechanical Properties of Concrete

1) Compressive Strength Test

A cube compression test is performed on standard cubes of plain and concrete with replace of cement by supplementary cementitious material as Metakaolin of size 150 x 150 x 150 mm after 7 and 28 days of immersion in water for curing. The compressive strength of specimen is calculated by the following formula:

$$f_{cu} = P_c / A \qquad (1)$$

Where
P_c = Failure load in compression, kN
A = Loaded area of cube, mm^2

Fig. 2: A Cube Test on CTM

2) Flexural Test

Standard beams of size 150 x 150 x 700mm are supported symmetrically over a span of 600mm and subjected two points loading till failure of the specimen. The deflection at the center of the beam is measured with sensitive dial gauge on UTM.

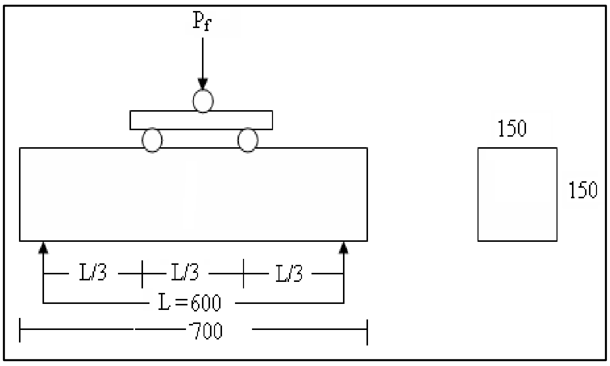

Fig. 3: Two Point Loading Setup in Flexure Test

The flexural strength is determined by the formula

$$f_{cr} = \frac{P_f L}{bd^2} \qquad (2)$$

Where,
f_{cr} = Flexural strength, MPa
P_f = Central point through two point loading system,
L = Span of beam, mm
b = Width of beam, mm
d = Depth of beam, mm

3) Split Tensile Test

The split tensile test is well known indirect test used to determine the tensile strength of concrete. Due to difficulties involved in conducting the direct tension test, a number of indirect methods have been developed to determine the tensile strength of concrete. In these tests, in general a compressive force is applied to a concrete specimen in such a way that the specimen fails due to tensile stresses induced in the specimen.

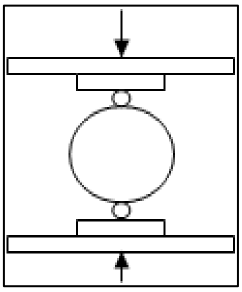

Fig. 4: Setup for Split Tensile Test

The split tensile strength of cylinder is calculated by the following formula.

$$f_t = \frac{2P}{\pi LD} \qquad (3)$$

Where,
ft = Tensile strength, MPa
P = Load at failure, N
L = Length of cylinder, mm
D = Diameter of cylinder, mm

F. Elevated Temperature Test on Cube

A ventilated oven has used to heat the concrete cube with varying temperature from 200oC to 600oC. All cubes are demoulded after 24 hours and stored in water at room temperature. At the age of 28 days, the cubes are removed from water and dried for room temperature. This step of pre-drying is necessary to minimize the explosion of concrete specimen when subjected to high temperature exposure in the furnace. The rate of heating was maintained constant at 200oC for 4 hours.

The test specimens are removed from the furnace after heating time and test were conducted with the test specimens to determine compressive strength.

Fig. 5: Oven used to Heat

III. RESULTS AND DISCUSSION

A. Mix Proportions of OPC Concrete

The experimental investigation adopted ACI-code (ACI-211.9) method of mix design procedure for designing M60 grade concrete. The mix proportions of OPC concrete of M60 grade are given in table 4. The ratio of the quantities obtained were cement: Fine aggregate: Coarse aggregate = 1: 1.22: 2.25 with w/c = 0.33.

B. Trial Mixes of OPC and MK Concrete

Material	Quantity of Material
Cement (Kg/m3)	507
Metakaolin (Kg/m3)	0
Water (Liters/m3)	168
Fine aggregate (Kg/m3)	620
Coarse aggregate (Kg/m3)	1145
Super plasticizer	1.0% by weight of cement
Water Cement ratio (W/c ratio)	0.33
Workability (Slump)	65

Table 4: Mix Proportions of OPC Concrete

The ratio of mix proportions of OPC Concrete of M60 grade are, Cement: Fine Aggregate: Coarse Aggregate = 1:1.22:2.25

Sr. No.	Type of Mix	Cement (kg/m3)	Metakaolin (kg/m3)	Water (l/m3)	FA kg/m^3	CA kg/m^3	Workability mm (Slump)	Compressive strength (MPa)
								28 days
1	Normal	507 (100)	0.00(0)	156	620	1145	68	67.40
2	MK(03)	492 (97)	15 (3)	156	620	1145	66	70.78
3	MK(06)	477 (94)	30 (6)	156	620	1145	65	72.90
4	MK(09)	462 (91)	45 (9)	156	620	1145	63	73.80
5	MK(12)	447 (88)	60 (12)	156	620	1145	60	73.92
6	MK(15)	432 (85)	75 (15)	156	620	1145	58	69.36

Table 5: Trial Mix Proportions and Compressive Strength of Metakaolin Concrete (M60 Grade)

C. Workability of Concrete

Workability of concrete with and without supplementary cementitious material has determined with the help of Vee-Bee Consistometer and Compaction factor test. Results of these properties are shown in figure 6 and Table 7.

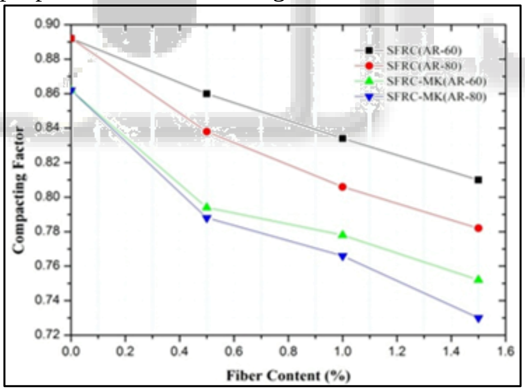

Fig. 6: Relation between Workability of SFRC & SFRC-MK Mixes

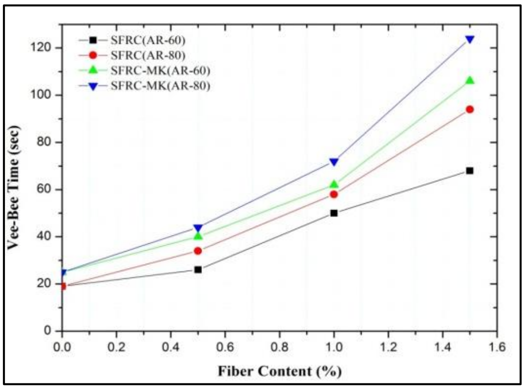

Fig. 7: Relation between Workability of SFRC & SFRC-MK Mixes

The variation of workability in terms of compacting factor and Vee-bee time for MKC, SFRC, and SFRC-MK are given in figures 6 and 7 from these figures we can found that:

1) The super plasticizer content in OPCC, MKC, SFRC, SFRC-MK mixes is taken as 1% of the weight of binding material to improve the workability and to prevent balling of fibers.
2) The workability in terms of compacting factor of OPCC and MKC of M60 grade is found to be 0.892, 0.862. The workability of MKC is less than the OPCC because of high fineness of Metakaolin.
3) The workability of SFRC, SFRC-MK in terms of compacting factor is decreasing from 0.910 to 0.890 with increasing fiber content from 0.50% to 1.50%. The workability of SFRC-MK is less than SFRC due to high fineness of Metakaolin.
4) Workability is reduced as metakaolin as well as fiber percentage increases. The density has lightly decrease after metakaolin content of 12% due to poor bond formation between metakaolin concrete.

D. Compressive Strength of OPCC, MKC, SFRC & SFRC – MK Mixes of M60 Grades

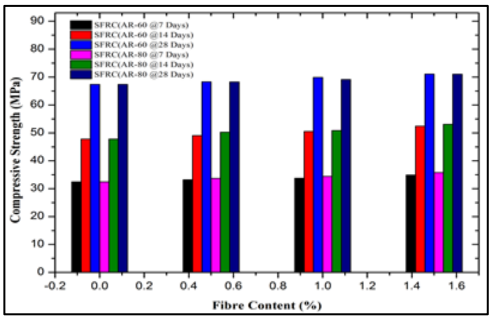

Fig. 8: Relation between Compressive Strength of SFRC Mixes and Fiber Content

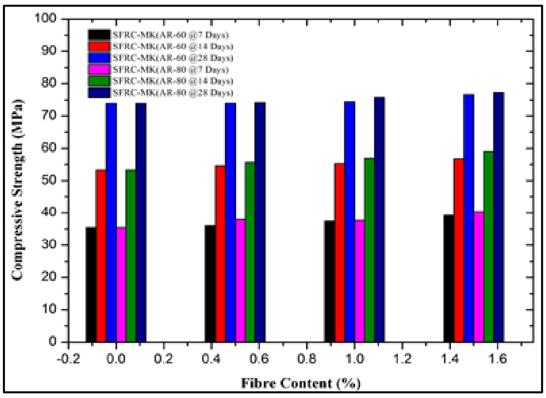

Fig. 9: Relation between Compressive Strength of SFRC-MK Mixes Of M60 Grade and Fiber Content

Compressive strength of OPCC, SFRC and SFRC-MK are shown in figures 8 and 9 respectively. From these figures it is observed that:

1) The experimental compressive strength of OPCC i.e. 68.40MPa at 28 days is greater than the mean strength.
2) The compressive strength of SFRC-MK is increased by 14.85% to 19.86% at 7 days, 29.76% to 36.68% at 14 days and 15.70% to 23.25% at 28 days when compared with its OPC concrete.
3) The compressive strength of SFRC is 2.88% to 8.70% more than that of OPC concrete at 7 days, 3.54% to 10.74% at 14 days and 3.92% to 12.24% at 28 days depending on the fiber factor F. This is due to the addition of crimped steel fibers from 0.50% to 1.50%.
4) The compressive strength of SFRC-MK at 7 days is 14.85% to 19.86% more than that of OPC concrete and 4.26% to 8.80% more than MKC depending on the value of fiber factor F. The compressive strength of SFRC-MK at 14 days is 29.76% to 36.68% more than that of OPC concrete and 2.97% to 8.50% more than MKC depending on the value of fiber factor F.
5) The compressive strength of SFRC-MK at 28 days is 15.70% to 23.25% more than that of OPC concrete and 3.80% to 9.80% more than MKC depending on the value of fiber factor F.

E. Splitting Tensile Strength of OPCC, MKC, SFRC & SFRC – MK Mixes of M60 Grades

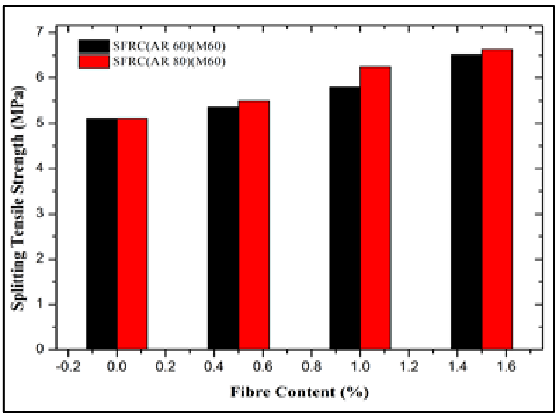

Fig. 10: Relation between Splitting Tensile strength of SFRC mixes of M60 grade and Fiber

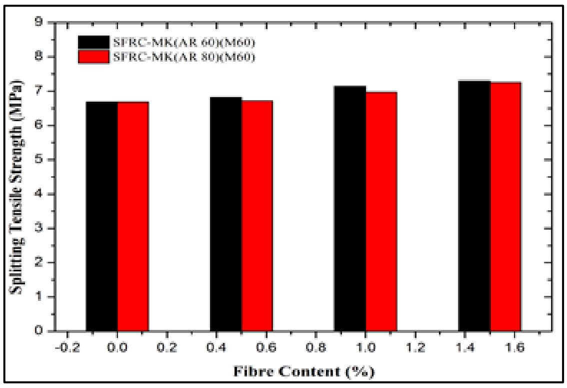

Fig. 11 Relation between Splitting Tensile Strength of SFRC-MK Mixes Of M60 Grade and Fiber Content

Figures 10 and 11shows the variation of splitting tensile strength with fiber content and fiber factor.The addition of crimped steel fibers to concrete improves its splitting tensile strength. From above figures it it observed that:

1) 4.70% to 29.75% increase in splitting tensile strength of SFRC is observed when compared with the splitting tensile strength of OPC concrete.
2) 3% to 10% and 5% to 18.0% increase in splitting tensile strength of SFRC-MK is observed when compared with the splitting tensile strength of MKC and OPC concrete.

F. Modulus of Rupture of OPCC, MKC, SFRC & SFRC – MK Mixes of M60 Grades

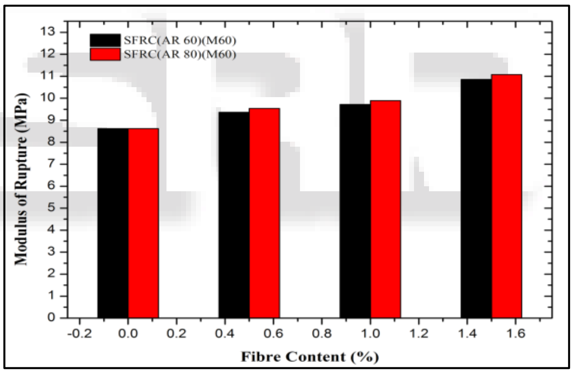

Fig. 12: Relation between Modulus of Rupture of SFRC Mixes Of M60 Grade and Fiber Content

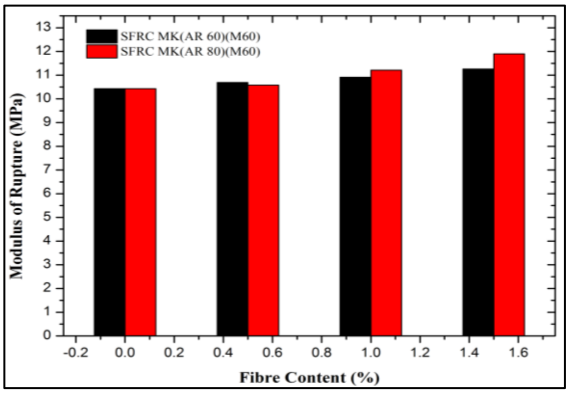

Fig. 13: Relation between Modulus of Rupture of SFRC-MK Mixes Of M60 Grade and Fiber Content

Figures 12 and 13 show the variation of modulus of rupture with fiber content and fiber factor. The addition of fibers to concrete improves its modulus of rupture. The experimental results of the modulus of rupture of the various mixes studied are given below:

1) 19.56% to 68.82% increase in modulus of rupture of SFRC is observed when compared with the modulus of rupture of OPC concrete from table 4.11. The average value of the ratio of modulus of rupture to splitting tensile strength of SFRC mix was found to be 1.43 and that of modulus of rupture to compressive strength was found to be 0.126 from table 4.11.
2) 16.0% to 44.20% and 25.65% to 81.20% increase in modulus of rupture of SFRC-MK is observed when compared with the modulus of rupture of MKC and OPC concrete respectively from table 4.13.

G. Temperature Effects of OPCC, MKC, SFRC & SFRC-MK mixes

1) Percentage Increase/Decrease in Compressive Strength of OPCC, MKC, SFRC& SFRC-MK Mixes of M60 Grade at 200°C, 400°C & 600°C When Compared With Normal Strength

Type of Mix	Temperature	% Decrease in Compressive Strength
OPCC	200 ^{0}C	9
	400 ^{0}C	22.5
	600 ^{0}C	38.5
MKC	200 ^{0}C	9.25
	400 ^{0}C	18.42
	600 ^{0}C	28.35
SFRC (1.5 -80)	200 ^{0}C	5.4
	400 ^{0}C	10.6
	600 ^{0}C	13.88
SFRC – MK (1.5 -60)	200 ^{0}C	9.67
	400 ^{0}C	14.70
	600 ^{0}C	23.56

Table 6: Percentage Decrease in Compressive Strength of OPCC, MKC, SFRC & SFRC-MK Mixes of M60 Grade at Elevated Temperatures

Table 6 gives the percentage decrease in compressive strength of OPCC, MKC, SFRC and SFRC-MK mixes at elevated temperature and variation of these results are shown in Figure 14

1) Compressive strength of OPCC mix of M60 grade at 200°C, 400°C and 600°C in comparison with normal strength. These values are found as -16.40% at 200°C, -31.2% at 400°C and -52.19% at 600°C respectively.
2) Compressive strength of MKC mix of M60 grade at 200°C, 400°C and 600°C in comparison with normal strength. These values are found as -15.60% at 200°C, -26.90% at 400°C and -59.40% at 600°C respectively.
3) Compressive strength of SFRC (1.5-60) mix of M60 grade at 200°C, 400°C and 600°C in comparison with normal strength. These values are found as -34.79% at 200°C, -45.60% at 400°C and -69.0% at 600°C respectively.
4) Compressive strength of SFRC-MK (1.5-60) mix of M60 grade at 200°C, 400°C and 600°C in comparison with normal strength. These values are found as -28.40% at 200°C, -38.46% at 400°C and -75.80% at 600°C respectively. The reason may be due to high brittleness and dense micro structure of high grade concrete.
5) The percentage decrease in compressive strength of MKC beyond 400°C is higher than OPCC. The cause may be due to the buildup of vapour pressure by dense pore structure of the MKC.
6) At 600°C, the loss in strength of MKC is higher than the loss in strength of OPCC. The reason is due to the decomposition of Ca(OH)2 at temperature above 400°C, and also may be due to differential thermal expansion of aggregate.

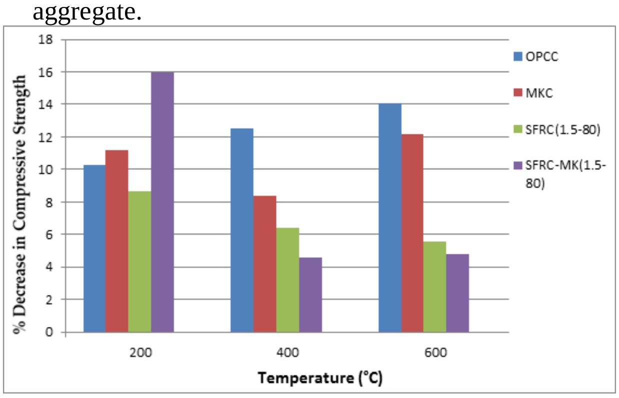

Fig. 14 Percentage Decrease in Compressive Strength of OPCC, MKC, SFRC & SFRC-MK Mixes of M60 Grade after Heating

2) Percentage Increase in Compressive Strength of OPCC, MKC, SFRC& SFRC-MK Mixes of M60 Grade after Cooling To Room Temperature

Table 7 gives the percentage increase in compressive strength of OPCC, MKC, SFRC and SFRC-MK mixes after cooling the elevated concrete to room temperature and variation of these results are shown in Figure 15

Type of Mix	Temperature	% Decrease in Compressive Strength
OPCC	200 0C	10.26
	400 0C	12.55
	600 0C	14.10
MKC	200 0C	11.2
	400 0C	8.37
	600 0C	12.19
SFRC (1.5 -80)	200 0C	8.67
	400 0C	6.43
	600 0C	5.55
SFRC – MK (1.5 -80)	200 0C	16
	400 0C	4.6
	600 0C	4.8

Table 7: Percentage Increase in Compressive Strength of OPCC, MKC, SFRC & SFRC-MK Mixes of M60 Grade after Cooling To Room Temperature

– Percentage increase in compressive strength of OPCC, MKC, SFRC& SFRC-MK mixes of M60 grade after cooling to room temperature from 200°C
– The percentage increase in compressive strength of OPCC mixes of M60 grade after cooling from 200°C. These values vary from 13.0% to 25.0%.
– The percentage increase in compressive strength of MKC mixes of M60 grade after cooling from 200°C. These values vary from 17.0% to 28.0 %.

- The percentage increase in compressive strength of SFRC (1.5-80) mixes of M60 grade after cooling from 200°C. These values vary from 17.0% to 16.0%.
- The percentage increase in compressive strength of SFRC-MK (1.5-80) mixes of M60 grade after cooling from 200°C. These values vary from 26.0% to 19.0%.
- 5.6.2.2. Percentage increase in compressive strength of OPCC, MKC, SFRC & SFRC-MK mixes of M60 grade after cooling to room temperature from 400°C.
- The percentage increase in compressive strength of OPCC mixes of M60 grade after cooling from 400°C. These values vary from 9.0% to 14.0%.
- The percentage increase in compressive strength of MKC mixes of M60 grade after cooling from 400°C. These values vary from 11.0% to 19.0 %.
- The percentage increase in compressive strength of SFRC (1.5-80) mixes of M60 grade after cooling from 400°C. These values vary from 13.0% to 12.0%.
- The percentage increase in compressive strength of SFRC-MK (1.5-80) mixes of M60 grade after cooling from 400°C. These values vary from 17.0% to 17.0%.

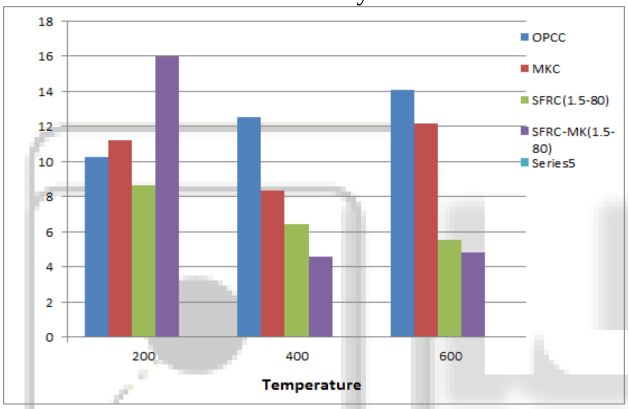

Fig. 15: Percentage Increase in Compressive Strength of OPCC, MKC, SFRC & SFRC-MK Mixes of M60 Grade after Cooling To Room Temperature

- Percentage increase in compressive strength of OPCC, MKC, SFRC& SFRC-MK mixes of M60 grade after cooling to room temperature from 600°C
- The percentage increase in compressive strength of OPCC mixes of M60 grade after cooling from 600°C. These values vary from 10.0% to 20.0%.
- The percentage increase in compressive strength of MKC mixes of M60 grade after cooling from 600°C. These values vary from 7.0% to 18.0 %.
- The percentage increase in compressive strength of SFRC (1.5-80) mixes of M60 grade after cooling from 600°C. These values vary from 15.0% to 22.0%.
- The percentage increase in compressive strength of SFRC-MK (1.5-80) mixes of M60 grade after cooling from 600°C. These values vary from 11.0% to 19.0%.
- One of the reasons for increase in compressive strength of the above mixes on cooling may be due to the re-absorption of moisture from atmosphere which may lead to extra hydration and form extra C – S – H gel and also may be due to the presence of steel fibers.

IV. Conclusions

The following conclusions are drawn from the various experimental results.

1) Metakaolin concrete consisting of 88% OPC + 12% MK (binary blending) with 1.0% super plasticizer gives improved durability and mechanical properties.
2) Mechanical properties like split tensile strength, modulus of rupture, are considerably improved even with the addition of 0.50% of steel fibers. At higher fiber content, the mechanical properties are further improved.
3) The steel fibers of higher aspect ratio are recommended instead of using fibers of lower aspect ratio.
4) SFRC mixes of higher grade are adversely affected after exposure to elevated temperatures for higher duration.
5) At higher temperature, the performance of Metakaolin concrete is poor than the OPC concrete. This may be due to the dense pore structure of Metakaolin concrete.
6) Almost all the mixes gained some compressive strength after cooling to room temperature. Part of the gain in compressive strength may be due to the re-absorption of moisture from atmosphere due to which further hydration might have carried out. Also the gain in strength is due to the presence of fibers.
7) Ductility is increased due to the addition of crimped steel fibers to OPC and MK reinforced concrete beams.
8) The presence of steel fibers with higher content reduced the crack propagation in OPC and MK reinforced concrete beams.
9) The performance of SFRC-MK beams in flexure is on higher side when compared with OPC concrete beams and slabs. This may be due to the good anchorage between the rich matrixes and crimped steel fibers.

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