Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 06, June-2019

Behavior of Fibre Reinforced Concrete at High Temperature

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***Abstract*—The need for concrete to be more sustainable and durable even in most adverse conditions is increasing day by day. Concrete exposed to high temperature is a common situation in case of fire hazards. Therefore it is essential for concrete to be strong and durable. The flexural strength and ductility properties of cementitious concrete under high temperature may be significantly improved by incorporating different types of fibres. In this study, two different types of fibres are added to concrete with the aim to investigate their mechanical contributions to concrete under high temperature, comparatively. Polypropylene, Steel fibers are added into mortars in five different ratios (0.0%, 0.5%, 1.0%, 1.50% and 2.0%) by mass. The concrete is subjected to a temperature of 900°C. The mechanical property investigated is the compressive strength of the concrete**.

Keywords*— Durable, High temperature, compressive strength, fibres

I. INTRODUCTION

As we know that concrete is the most important construction material used all over the world. It is the second most material used all over the world after water, which signifies the necessity of concrete to be durable and sustainable. As we all know concrete is a composite material of fine and coarse aggregate bounded by the cement paste. Concrete offers various benefits derived from its higher mechanical properties high compressive strength, high tensile strength, and high stiffness. But due to extensive use of concrete in adverse conditions, it is expected that concrete should sustain at high temperatures produced during a fire.

Concrete is known to be more fire resistance than steel but it is clear from the statistics of fire hazards that concrete structure needs to be more sustainable against fire to limit the financial and human losses. Fire reduces concrete resistant capacity and rigidity and generates deformations imposed during the fire and the cooling phase. When reinforced concrete is subjected to a high temperature as in a fire, there is deterioration in its properties of particular importance is a loss in compressive strength, cracking and spalling of concrete, destruction of the bond between the cement paste and the aggregates and the gradual deterioration of the hardened cement paste. In recent times it is seen that faulty construction material and practices have caused greater financial and human loss. It was underlined during recent events in Mumbai where 22 lives were lost during six different fire incidences since last six months.

Hence to make concrete more sustainable various methods are analyzed and applied. One of them is using Fibre Reinforced Concrete (FRC). Concrete reinforced with fibres, due to the physical and mechanical properties of the fibres, reduces the permeability and capillary porosity blocking the pores in the concrete. The addition of fibres modifies the nonlinear behaviour of structural concrete, especially its tensile strength, preventing the opening and propagation of cracks and increasing its ductility. Fibres also retard the propagation of micro-cracks hence making concrete sustain higher load as compared to concrete without fibres.

The behaviour of FRC under high temperature with a particular fibre has been carried out. Some of them are Polypropylene fibres, Steel fibres, polyvinyl alcohol fibres, carbon fibres, etc. but the combination of two fibres in a different proportion and its study at high temperature is a new concept and is attempted in our project work.

II. EXPERIMENTATION

A. Testing of Fine Aggregate:

Moisture content, water absorption, specific gravity and fineness modulus of fine aggregate

- *Moisture content*

Ref: IS 2386 (Part III)
Observations:
1. Weight of moist sample = 1000gm
2. Weight of surface dry aggregate = 992gm
Calculations:
Moisture Content = (1000−992)/992×100 = 0.806
Conclusion: The moisture content of fine aggregate is 0.806.

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- *Water absorption*

Ref: IS 2386 (Part III)
Observations:
1. Weight of aggregate after 24hr submerged water = 926gm
2. Weight of surface dry aggregate = 768gm
Calculations: Water absorption = (926−768)/768×100 = 20.57
Conclusion: The water absorption of fine aggregate is 20.

- *Specific Gravity*

Ref: IS 2386 (Part III)
Observations:
1. Mass of Pycnometer = 690gm
2. Mass of Pycnometer + aggregate = 1090gm
3. Mass of Pycnometer + aggregate + water = 1953gm.
4. Mass of Pycnometer + water = 1675gm
Calculations: Specific gravity = 1090−690 (1675−690) − (1968−1122) = 3.28
Conclusion: The specific gravity of fine aggregate is 3.28

- *Fineness Modulus*

Ref: IS 383, IS 2386
The fineness modulus of fine aggregate is 3.09

B. Testing of Coarse Aggregate

Moisture content, water absorption, specific gravity and fineness modulus of coarse aggregate

- *Moisture content*

Ref: IS 2386 (Part III)
Observations:
1. Weight of moist sample = 2000gm
2. Weight of surface dry aggregate for 10mm aggregate = 1976gm
3. Weight of surface dry aggregate for 20mm aggregate = 1912gm
Calculations:
Moisture Content of 10mm aggregate= (2000−1976)/1976×100 = 1.22
Moisture Content of 20mm aggregate= (2000−1912)/1912×100 = 4.60
Conclusion: The moisture content of 10mm aggregate is 1.22.

- *Specific gravity and water absorption*

Ref: IS 2386 (Part III)
Observations:
For 20mm aggregate
1. Weight of saturated aggregates suspended in water with the basket (A1) = 2135.5gm
2. Weight of empty basket suspended in water (A2) = 763gm
3. Weight of saturated aggregate in water (A) = (A1-A2) = 1321.5gm
4. Weight of saturated surface dry (SSD) aggregate in air (B) = 2070gm
5. Weight of oven dried aggregate (C) = 2054.5gm
Calculations:
Specific gravity = 2054.5/(2067.5−1321.5) = 2.75
Water absorption = (2067.5−2054.5)/2054.5×100 = 0.63

For 10mm aggregate
1. Weight of saturated aggregates suspended in water with basket (A1) = 2081.5gm
2. Weight of empty basket suspended in water (A2) = 764gm
3. Weight of saturated aggregate in water (A) = (A1-A2) =1317.5gm
4. Weight of saturated surface dry (SSD) aggregate in air (B) = 1984gm
5. Weight of oven dried aggregate (C) = 1966.5gm
Calculations:
Specific gravity = 1966.5/(1984−1317.5)= 2.95
Water absorption = (1984−1966.5)/1966.5×100 = 0.89
Conclusion:
The specific gravity of 10mm aggregate is 2.95 and water absorption is 0.89
The specific gravity of 20mm aggregate is 2.75 and water absorption is 0.63

- *Fineness Modulus*

Ref: IS 383, IS 2386

The fineness modulus of 10mm aggregate is 2.19 and the fineness modulus of 20mm aggregate is 5.01.

C. Mix Design

Mix design was carried out confined to IS456
Concrete grade: M30
Slump: 75mm
Exposure condition: Mild
Step 1: Target mean strength
f'ck = fck + 1.65(S)
= 30 + 1.65(5)
f'ck = 38.25 N/mm2
Step 2: Selection of w/c ratio, Based on experience w/c ratio = 0.4
Step 3: Selection of water content
For maximum nominal mix of aggregate=20mm
Water content =186 kg (For 50mm slump)
=186+ (0.03×186)
=191.58 kg
Step 4: Calculation of cementitious materials
Adopted w/c ratio=0.4
Water= 0.4×cement
Cement =478.95 kg > 320 kg
Step 5: Proportion of Coarse aggregate and Fine aggregate
For 20mm aggregate 0.5 w/c ratio and zone II
The proportion of Coarse aggregate is 0.62.
As w/c ratio adopted 0.4 which is less than 0.05, so increment of 0.01 in coarse aggregate proportion.
So proportion of Coarse aggregate=0.62+0.02=0.64
Fine aggregate = 1-0.64 = 0.36
Step 6: Mix Calculations
a) Volume of concrete = 1m3
b) Volume of cement = (478.95/3.15)×1/1000 = 0.152 m3
c) Volume of water = 191.58/1000 = 0.1916m3
d) Weight of fibre = 2%×478.95 =9.58kg
e) Volume of aggregate = a-(b+c)
= 1-(0.152+0.1916)

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 06, June-2019

= 0.6564m3
f) Weight of Coarse aggregate = 0.6564×0.64×2.72×1000 = 1134.2kg
g) Weight of Fine aggregate = 0.6564×0.36×2.7×1000 = 639kg

Mix Proportion,
Cement: Fine aggregate: Course aggregate = 1: 1.33: 2.37

D. *Casting of cubes*

The casting of concrete cubes was carried out according to IS456. The standard procedure and specifications were followed during the casting process. The total number of cubes cast was 36. For each Fibre proportion, 6 cubes were cast. The bifurcation is as given in the table.

TABLE I. DETAILS OF TOTAL NUMBER OF CUBE

Sr No.	Proportion of fibres		No. of cubes	
	Polypropylene Fibres	Steel Fibres	For compressive strength w/o exposure to high temperature	For compressive strength after exposure to high temperature
1.	2	0	3	3
2.	1.5	0.5	3	3
3.	1	1	3	3
4.	0.5	1.5	3	3
5.	0	2	3	3
6.	0	0	3	3
Total cubes			36 No. of cubes	

E. *Testing of cubes*

Testing of cubes was carried out in two stages

1. before exposure to high temperature

2. after exposure to high temperature

Fire Testing
Fire test was carried out at Sohan steel industry located in Markal, Alandi Devachi, Pune, Maharashtra. To determine the effect of high temperature on compressive strength, the concrete cubes were directly kept in the furnace. Exposure to high temperature was provided to the cube using furnace available at the steel industry. The furnace is used to melt the scrap steel. The capacity of the furnace was 900°C. Total of 18 numbers of cubes was kept in the furnace for 1 hour. After one hour, the cubes were removed from the furnace and kept for cooling at room temperature. After cubes were cooled down to room temperature, the uniaxial compressive test was carried out on them.

Fig.2. Arrangement of the sample in furnace

Compressive Testing on cubes:

Remove the specimen from the water after specified curing time and wipe out excess water from the surface. Take the dimension of the specimen to the nearest 0.2m. Clean the bearing surface of the testing machine. Place the specimen in the machine in such a manner that the load shall be applied to the opposite sides of the cube cast. Align the specimen centrally on the base plate of the machine. Rotate the movable portion gently by hand so that it touches the top surface of the specimen. Apply the load gradually without shock and continuously at the rate of 140 kg/cm2/minute till the specimen fails. Record the maximum load and note any unusual features in the type of failure.

III. EXPERIMENTAL RESULTS

Compressive test on the concrete samples was carried out on concrete cubes which were exposed to high temperature as well as for normal condition. Their results are shown in the table

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
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TABLE II. RESULTS OF COMPRESSIVE STRENGTH

Sr No.	*Fibre Proportion (%)*		*Average Compressive strength (MPA)*	
	Steel Fibre Proportion	*Polypropylene Fibre Proportion*	*Without exposure to high temperature*	*After exposure to high temperature*
1.	0	0	48.23	31.07
2.	2	0	49.99	30.17
3.	1.5	0.5	52.36	29.10
4.	1	1	52.57	14.53
5.	0.5	1.5	51.36	28.23
6.	0	2	39.49	20.45

Given below are the different graphs representing the nature of the behaviour of individual fibre in the concrete at the high-temperature condition as well as at normal temperature condition.

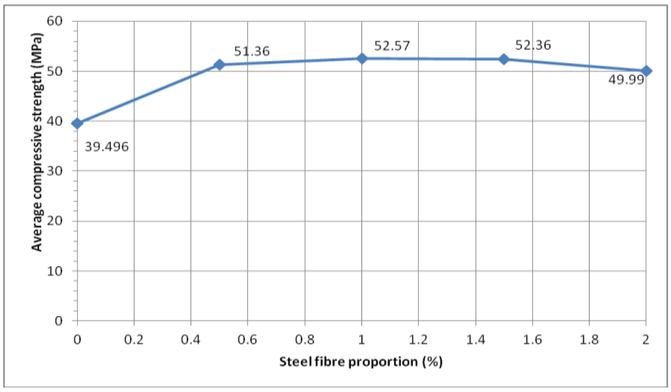

Fig.3. Individual Steel Fibre proportion vs. Average compressive strength for cubes not exposed to high temperature

Above graph shows that steel fibres exhibit consistent results and the addition of the fibre increases the compressive strength of the concrete at normal condition. The results with steel fibres are consistent and hence can be stated that it increases the strength of concrete.

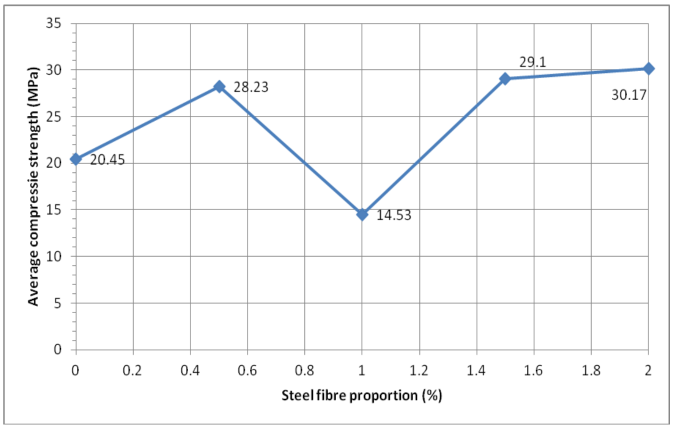

Fig.4. Individual Steel Fibre proportion vs Average compressive strength for cubes exposed to high temperature

Above graph shows the nature of steel fibres individually when exposed to high temperature. It shows that the compressive strength of concrete cubes exposed to high-temperature increases as the amount of steel fibres in them increases. The only exception is for the proportion where steel fibres and polypropylene fibres were added at 1%-1% each. That could be accounted for the randomness in the procedure for exposing the concrete cubes to high temperature. Overall it can be stated that the compressive strength of concrete at high-temperature increases as the proportion of steel fibre increases.

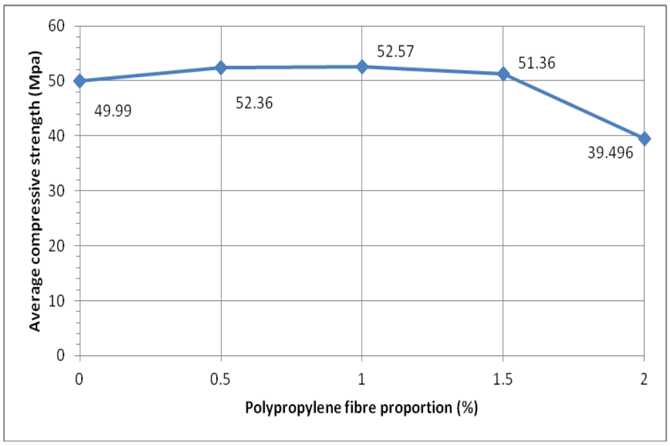

Fig.5. Individual Polypropylene Fibre proportion vs Average compressive strength for cubes not exposed to high temperature

Above graph shows that polypropylene fibres exhibit consistent results and the addition of the fibre decreases the compressive strength of the concrete at normal condition. The results with polypropylene fibres are consistent and hence can be stated that it does not increase the compressive strength of the concrete as much as steel fibres do and the results obtained with the samples of concrete which have a proportion of polypropylene fibres as 2% implies the same.

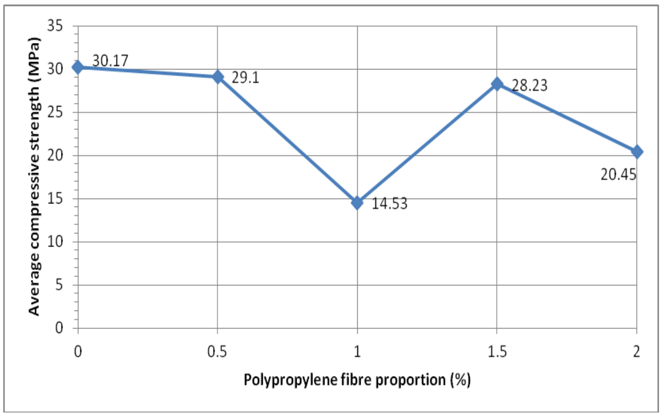

Fig.6. Individual Steel Fibre proportion vs Average compressive strength for cubes exposed to high temperature

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 06, June-2019

Above graph shows the nature of polypropylene fibres individually when exposed to high temperature. It shows that the compressive strength of concrete cubes exposed to high-temperature decreases as the amount of polypropylene fibres in them increases. The only exception is for the proportion where steel fibres and polypropylene fibres were added at 1%-1% each. That could be accounted for the randomness in the procedure for exposing the concrete cubes to high temperature. Overall it can be stated that the compressive strength of concrete at high temperature decreases as the proportion of polypropylene fibre increases. This could be mainly due to the nature of polypropylene fibres. They melt the temperature of around 150°C to 200°C and hence they may not play as much of a significant role to the compressive strength of the concrete cube as much as the steel fibres.

IV. CONCLUSION

The possibility of using polypropylene and steel fibres in concrete in order to improve its fire resistance was investigated in this study. A reference concrete mixture without any fibres and concrete mixtures with different proportions of polypropylene fibre and steel fibre were prepared. Compressive strength testing was conducted on concrete cubes before and after exposure to temperature 900̊ C.

1. For all fibre proportions, results indicate that concrete loses its strength after exposure to high temperature.

2. When no fibre was added in the concrete mix, the compressive strength of cubes after exposure to high temperature reduces up to 35.58%.

3. When only steel fibre (2% 0f cementitious material) were added in the concrete, compressive strength after exposure to high temperature reduces up to 39.65% whereas when only polypropylene fibre (2% of cementitious material) were added in concrete it reduces up to 48.21%.

4. When steel fibre and polypropylene fibre were added of the same proportion in the concrete, compressive strength reduces from 52.37 Mpa to 14.53 Mpa i.e. almost 75%.

5. When steel fibre was added of 1.5 of cementitious material and polypropylene fibre of 0.5 of cementitious material in concrete, compressive strength reduces up to 44.42% and vice versa it reduces up to 45.04%.

We can conclude that when we use a combination of steel and polypropylene fibre of the same proportion in the concrete mixture the compressive strength results are not satisfactory compared to other proportions. Also when we add a slight more proportion of steel fibre than polypropylene fibre results are satisfactory compared to other proportion.

ACKNOWLEDGEMENT

On the very outset of this, we would like to extend my sincere and heartfelt thank towards all the persons who have helped us in this endeavour with their active guidance, help, cooperation and encouragement, in the project. We would like to thank Prof. Mrs. R. R. Purohit for conscientious guidance and encouragement to accomplish this project. Again, we take the opportunity to express our gratitude to Dr. S. T. Mali for valuable guidance. We extend our gratitude to Pimpri Chinchwad college of engineering and the Department of Civil Engineering for giving us this opportunity.

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