NJ-1

Study on Silica Fume Concrete Subjected to High Temperature

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Introduction

High strength concrete incorporating silica fume now-a-days is being increasingly used worldwide. Quite often in various industrial structures such high strength concrete is used at extreme conditions of temperatures. At high temperatures, the compressive strength and coefficient of thermal expansion of concrete get altered[1-6] resulting in redistribution of stresses in various structural members. In reinforced concrete structures the bond between the reinforcement and concrete gets weakened due to cracking[7], which eventually leads to the reduction in load carrying capacity of the structures. All these aspects should be considered by the designer at the design stage itself to avoid possible damages of concrete structures under the influence of high temperatures and also to enhance the durability of such structures.

With this view a detailed experimental investigation has been conducted to know the behaviour of the concrete containing silica fume and subjected to high temperatures with respect to compressive strength.

Experimental Programme

The experimental programme was planned to study the behaviour of concrete cubes under varying temperatures at varying duration of exposures. The temperatures were 300°C, 600°C and 750°C and duration of exposure were 20 min, 40 min and 60 min.

The programme consisted of casting and testing of 60 cubes of size 100 mm. Out of 60 cubes 30 cubes were made up of silica fume concrete. Silica fume concrete cubes (SFC) consisted of 10% of cement replaced with silica fume.

Materials used

Cement

Cement used was ordinary portland cement of 53 grade confirming to IS 12269-1987.

Aggregates

Coarse aggregate

Hard black granite aggregates of maximum size of 10mm having the specific gravity of 2.67 and the fineness modulus of 6.8 was used.

Fine aggregate

Locally available river sand having the specific gravity of 2.55 and the fineness modulus of 3.1 was used.

Combined aggregate

The coarse aggregate and fine aggregate were mixed in the proportion of 70:30 to obtain the combined aggregate as given in the Erntroy and Shocklock method of mix design for high strength concrete. The fineness modulus of this combined aggregate was determined and found to be 6.66.

Water

Potable water was used for mixing and curing purposes.

Silica fume

The silica fume used was obtained from Nava Bharath Ferro Alloys Industries situated at Kothagudem. The physical properties of the silica fume used were as follows.

Specific gravity	:	1.84
Fineness by wet sieving of 45 μm sieve	:	5.04%
Compressive strength	:	14.35 MPa
Initial setting time	:	40 minutes
Final setting time	:	143 minutes
Loss of ignition	:	10%

Superplasticizer

A superplasticizer known as Conplast 430 was used to achieve the required workability maintaining the desired w-c ratio.

Mix Proportion

The quantities of cement, sand and coarse aggregate were taken in proportion of 1:1:2.2 with w-c ratio 0.32. The mix proportion was arrived based on the mix design as per the Erntroy asd Shocklock method. Ten percent of cement by weight was replaced with silica fume. Then the mix proportion was 0.9:0.1:1:2.2 w-c ratio remained constant.

Testing

After casting and curing for 28 days, cubes were placed in a furnace and subjected to higher temperatures. Tempo manufactured furnace with sunvic energy regulator, working under the line voltage of 230 volts was used. Three cubes were subjected to 300°C for 20 minutes, another three cubes for 40 minutes and another three cubes for 60 minutes of exposure to high temperature. For similar duration of exposure the other cubes were also subjected to 600°C and 750°C temperature.

After completion of exposure duration the cubes were allowed to cool down naturally. First, Non-destructive tests were conducted on these cubes using Schimdt test hammer and ultrasonic tester. Loss in weight after subjecting to high temperatures was also measured.

After conducting the non destructive tests the cubes were tested in the compression testing machine of 3000

Table I - Variation of Compressive Strength with Temperature and Duration of Exposure

S.No.	Duration of exposure (min)	Temperature (°C)	Comp. Stress (MPa)		% loss in Comp. stress	
			OHC	SFC	OHC	SFC
1	0	0	58.4	62.8	-	
2	20	300	51.4	62.2	11.9	1.0
3	20	600	47.7	44.4	18.3	29.3
4	20	750	47.1	43.4	19.4	31.0
5	40	300	51.3	53.6	12.2	14.65
6	40	600	34.1	33.9	41.6	45.87
7	40	750	F	F		
8	60	300	46.8	47.8	19.9	23.88
9	60	600	29.2	26.5	50.0	57.7
10	60	750	F	F		

Note: F = Specimen failed to retain the shape due to severe spalling at high temperatures.

Table II - Variation of Ultrasonic Wave Travel Velocity with Temperature and Duration of Exposure

S.No.	Duration of exposure (min)	Temperature (° C)	Ultrasonic Wave Velocity (m/sec)		% reduction in ultrasonic wave velocity	
			OHC	SFC	OHC	SFC
1	0	0	16.7	33.7		
2	20	300	16.8	33.6	0.35	0.37
3	20	600	14.8	16.8	12.28	50.10
4	20	750	12.9	11.3	23.70	66.70
5	40	300	15.7	20.1	7.00	40.00
6	40	600	11.3	16.5	33.30	51.00
7	40	750				
8	60	300	10.4	11.8	38.40	65.10
9	60	600	9.3	1.2	45.10	72.90
10	60	750	-		-	-

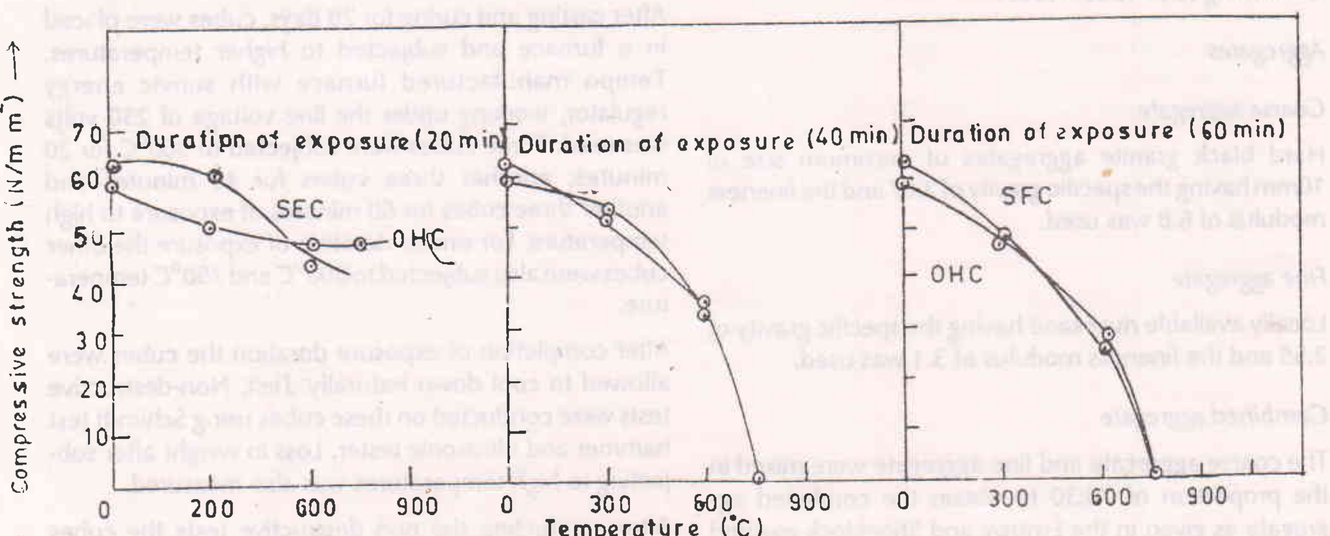

Fig. 1. Variation of Compressive strength with temperature mperature

kN capacity to determine the residual compressive strength of concrete cubes. In addition few cubes were also tested in virgin state.

Results and Discussion

From the experimental investigation the following date were obtained before and after subjecting to the high temperatures.

* The compressive strength of concrete cubes.
* Schimdt test hammer readings.
* Ultrasonci pulse velocities.
* Loss of unit weight of cubes.

The above values were obtained for ordinary high strength concrete (OHC) and Silica fume concrete (SFC) both before and after subjecting to different levels of temperatures and different duration of exposures and presented in table 1.

Variation of compressive strength of high strength silica fume concrete cubes with temperature

Fig(1) and table(1) shows the variation in compressive strength of OHC and SFC cubes with temperature keeping duration of exposure constant.

At 300°C, the strength of SFC was same and as good as that of OHC.But in OHC and average of 12% decrease in strength was observed for exposure of 20min. duration. As the temperature increased to 600°C, the rate of decrease in strength of silica fume concrete was higher than that of ordinary concrete. An average of 30% decrease in the strength of silica fume concrete compared to an average of 18% decrease in the strength of ordinary concrete was observed. As the temperature rises above 700°C, not much decrease in the strength was observed compared to the strength at 600°C.

At 40min. duration of exposure to the higher temperatures the decrease in the strength was observed both in OHC and SFC. The decrease in the strength of OHC at 300°C was 12.15% where as in SFC it was 14.65%. As the temperature increase to 600°C the strength in both OHC and SFC decreased at almost the same rate. An average of the 43.7% decrease in the strength compared to the original strength of both OHC and SFC was observed. As the temperature was increased above 700°C both the types of concrete have failed to retain the shapes due to severe spalling.

At 60 minutes duration of exposure to higher temperatures the strength was decreased both in OHC and SFC compared to original respective strengths. At 300°C, the decrease in strength of SFC was higher than that of OHC. Similar trend was observed even at 600°C but the rate of decrease in strength remained constant in both OHC and SFC, as the temperature increased from 300°C to 600°C. At 750°C both OHC and SFC have failed to retain the shape.

Variation in rebound number with different temperatures and duration of exposure

From rebound number the compressive strength of cubes can be extrapolated. Figs. (5,6) and table(3) shows the variation of rebound numbers with different temperatures and duration of exposure. The variation in rebound number obtained through Schimd test hammer was similar to the variation in compression strength. The reduction in rebound value at 300°C was more for SFC compared to OHC. As the duration of exposure increases, the difference in rebound values between SFC and OHC was also increased. Similar trend was observed at 600°C and 750°C temperatures.

Variation in ultrasonic wave velocity with different temperatures and for different duration of exposure

Ultrasonic wave velocity was decreased in OHC and SFC as the temperature level and duration of exposure increased. Refer figures (3,4) and table 2. More amount of reduction in ultrasonic wave velocity was observed in silica fume concrete compared to that of OHC upto 600°C temperature and 40min. of duration. Thereafter the rate of reduction in ultrasonic wave velocity was decreased in case of silica fume concrete upto 300°C temperature and 20min. of exposure. At the increased temperature level keeping duration of exposure constant, the ultrasonic wave velocity got decreased by almost 50% in case of SFC. In case of OHC the reduction was small even for temperatures above 600°C.

Loss of weight in OHC/SFC with temperature level and duration of exposure

As the temperature level and duration of exposure was increased the reduction in unit weight was noticed both in OHC and SFC. The percentage loss in unit weight was slightly more in OHC compared to SFC upto 600°C and 40 minutes duration of exposure. Thereafter more loss in unit weight was observed in OHC.

Conclusions

From the experimental investigation carried out on ordinary high strength concrete and silica fume concrete subjected to high temperatures the following conclusions were made.

* In both OHC and SFC, the compressive strength decreases with level of temperature and also with duration of exposure to high temperatures.
* At 300°C, the SFC, maintained the original compressive strength upto 20min. exposure compared to OHC. At and above 600°C the loss of compressive strength in SFC is higher than that of OHC.
* At 750°C, the spalling in both SFC and OHC was severe.
* The rebound value of OHC and SFC decreased as the level of temperature and duration of exposure increased. Percentage reduction in rebound number was more in SFC compared to OHC.

Fig. 1. Variation of Compressive strength with temperature

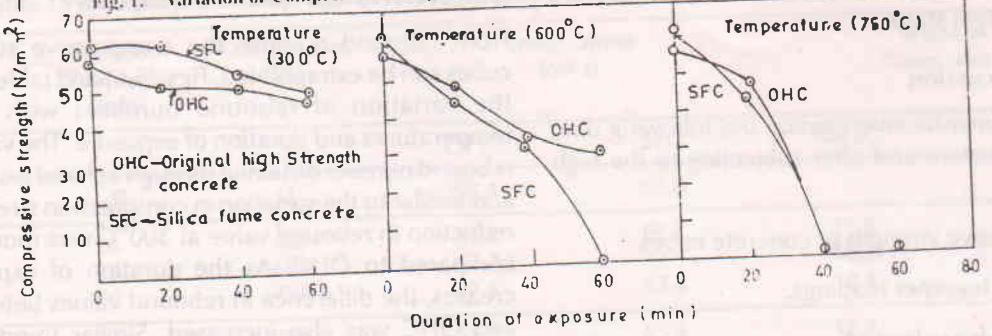

Fig. 2. Variation of compressive strength with duration of exposure to high temperature

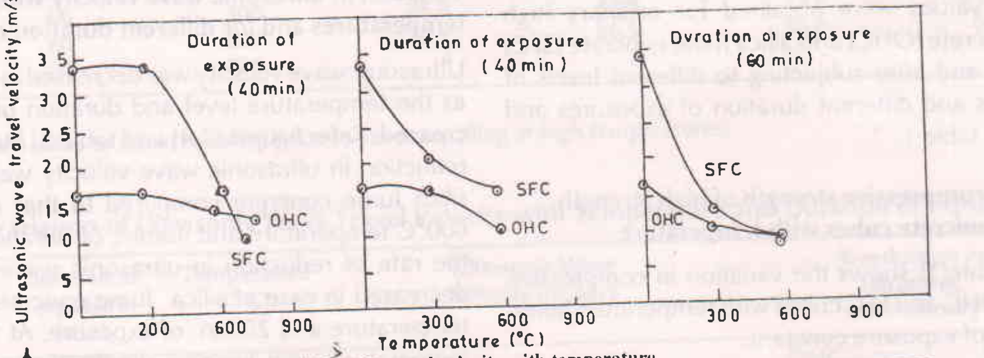

Fig. 3. Variation in ultraconic travel velocity with temperature

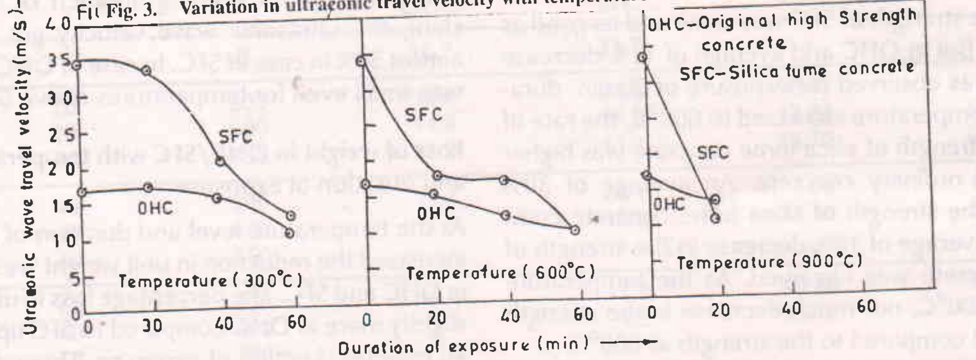

Fig. 4. Ultrasonic wave travel velocity with duration of exposure to high temperatures

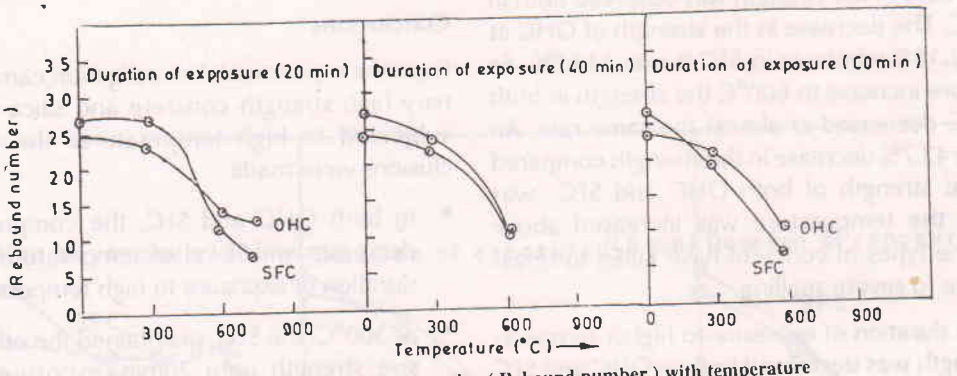

Fig. 5. Variation in Schimdt test hammer value (Rebound number) with temperature

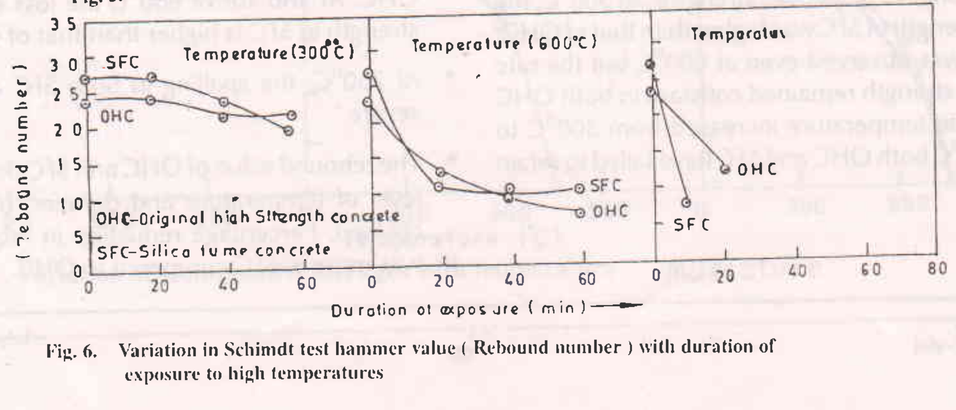

Fig. 6. Variation in Schimdt test hammer value (Rebound number) with duration of exposure to high temperatures

Table III - Variation of Schimdt Test Hammer Value (Rebound Number) with Temperature and Duration of Exposure

S.No.	Duration of exposure (min)	Temperature (°C)	Schimdt test hammer value		% reduction in test hammer value	
			OHC	SFC	OHC	SFC
1	0	0	24.3	27.3	-	-
2	20	300	24.1	27.2	0.82	0.37
3	20	600	13.1	12.1	46.00	55.67
4	20	750	12.9	8.0	46.90	70.70
5	40	300	22.0	23.7	9.50	13.29
6	40	600	10.2	9.9	41.98	63.70
7	40	750	-		-	-
8	60	300	20.8	20.1	14.80	26.40
9	60	600	10.3	6.7	42.40	75.45
10	60	750	-	-	-	-

Table IV - Variation of Weight of Cubes with Temperature and Duration of Exposure

S.No.	Duration of exposure (min)	Temperature (°C)	Weight of cubes (kg)		% reduction in unit weight	
			OHC	SFC	OHC	SFC
1	0	0	2.476	2.337		-
2	20	300	2.430	2.370	1.8	0.3
3	20	600	2.413	2.337	2.5	1.7
4	20	750	2.349	2.272	5.1	4.4
5	40	300	2.402	2.347	2.9	1.2
6	40	600	2.399	2.321	3.1	2.3
7	40	750		-	-	-
8	60	300	2.356	2.327	4.8	2.1
9	60	600	2.331	2.301	5.8	3.2
10	60	750				

* The ultrasonic wave velocities decreased as the level of temperature and duration of exposure increased. The ultrasonic wave velocity in SFC is decreased by 50% at 600°C temperature for 20 min. of exposure. The reduction in ultrasonic wave velocity in OHC, under similar conditions is only 2%.

* The percentage reduction in unit weight of OHC was more compared to that of SFC as the temperature level and duration of exposure increased. As the quantum of tests that were carried out was very limited, the conclusions have to be confirmed by further studies.

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