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Effect of Elevated Temperatures on Compressive Strength of High Volume Fly Ash Concrete

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Abstract: ***Fly ash concrete is finding upcoming applications in concrete industry due to its strength and durability of concrete."For the effective utilization of fly ash in the construction of buildings, fly ash concrete structural members have to satisfy fire resistance requirements specified by building codes" [1]. The majority of the experimental work carried out on HVFA concrete is on mechanical properties like strength, durability etc at normal conditions. The recent awareness towards fire protection requires the mechanical behavior and better understanding of HVFA concrete at elevated temperatures. Total of 150concrete cubes, 100mmx100mmx100mm size were cast and cured for 28 days, out of which 75cubes cast with OPC concrete and other 75cubes with HVFA concrete. The water to cement ratio was adopted on the basis of preliminary investigation [14]. The main test parameters involved were high volume fly ash, temperatures exposure from 100^0 Cto 800^0 C temperature, for 1hour, 2hours, and 3hours duration of exposure is considered. Thereafter the specimens brought to room temperature were tested identically for compressive strength study. The test results have shown that the compressive strengths of all the heated specimens were less than the strengths of companion cubes. The OPC concrete retained slightly more strengths than HVFA concrete cubes for 1 hour duration. However, for 2hours duration of exposure the residual strength variation is similar for both concretes. At 3-hour duration of exposure HVFA concrete cubes showed almost equal strengths but HVFA performed better than OPC concrete at all temperatures***

1. Introduction

Generally buildings are designed for gravity loads, earthquake loads or wind loads. However fire constitutes a major hazard toconcrete structuresfor its safety and integrity. Thereforeit is necessary to design the structures not only for strength considerations also for fire resistance. During fire accidents the structural elements are exposed to ambient temperatures for a particular duration of exposure. National building code of India [1] specifies that Type 1 constructions that include residential, educational, industrial and assembly buildings should be designed to resist fire for four hours. In high-rise buildings, at least three hours time lapse should be there to fight against fire.

Fly ash is a byproduct of thermal power generated companies produced in large volumes. As a result fly ash utilized, but not in large quantities, an ecological waste hazard because of its large quantity, it requires large amounts of land, water and energy for it disposal. In order to increasesignificantutilization of fly ash in concrete industry, it is necessary to use large volumes of fly ash in concrete. The large volumes of fly ash can be used in concrete as useful material by encouraging high volume fly ash concrete (HVFA), where more than 50% of cement can be replaced with fly ash.

The objective of the study is to report experimental data at higher temperatures and to have comparative study on residual compressive strengths.

2. Literature Review

2.1 MetinHusem [2] studied the effects of high temperature on compressive and flexural strengths of ordinary and high-performance concrete. "The variation of compressive and flexural strengths of ordinary (35 MPa) and high-performance micro-concrete (71 MPa) at high temperatures was examined. Experimental results indicate that concrete strength decreases with increasing temperature, and the decrease in the strength of ordinary concrete is more than that in high-performance concrete. The type of cooling affects the residual compressive and flexural strength, the effect being more pronounced as the temperature increases.

2.2 Srinivasarao et al [3] examined the behavior of HSC made with OPC and PPC subjected to fire [14]. The cubes specimens were exposed to temperature in the range of 50^o C to 250^{o}C in increments of 50^{o}C and then tested for compressive strength. The specimens were cured for 1, 3, 7, 28, 56 and 91 days before subjecting them to heating. The test results revealed that the compressive strength of OPC and PPC concretes decreased with the rise in temperature at all ages. While OPC specimens showed higher residual compressive strengths up to 7 days, PPC performed better with more residual strengths at later ages. The residual compressive strength of OPC concrete was lower by 40% while that of the PPC concrete lower by 18% of the un-exposed specimens.

2.3 Chan et al. [4] studied high performance concrete (HPC) of varying strength from 40 to 100 MPaunder fire. Significant drop in compressive strengths were reported for this concrete exposed to temperature range of 100 to 450^{o}C. Randall Lawson et alalso studied the properties of HPC up to temperature 800^0 C the compressive strength of HPC concrete came down more sharply than the conventional concrete with temperature increase, but HPC exhibited a higher residual strength. Phan and Carino carried out tests on the influence of elevated temperatures on the engineering properties of HSC. It was shown that at temperatures between 100^0 C and 400^0 C, the compressive strength of HSC reduced by about 40% compared to the room temperature strength. HSC mixture with a w/c ratio of 0.22 had the lowest strength loss.

3. Material Properties

The materials for the experimental work are as follows.

3.1 Cement

Ordinary Portland Cement (OPC) of 43 grade has been used in the present work. Its properties are specific gravity is 3.13, fineness 91.8% and standard consistency 31%.

3.2 Fine aggregate

Locally available river bed sand conforming to Zone II of IS: 383-1970 [6] with specific gravity 2.66 is used as fine aggregate. The fine aggregate is coarse sand with fineness modulus 2.65.

3.3 Coarse aggregate

The coarse aggregate used in concrete mix is saturated surface dried aggregate which is dark Blue Granite andangular in shape with specific gravity 2.78.

3.4 Fly ash

The fly ash used for the experimental programis low calcium Class-F Fly ash procured form NTPC, Visakhapatnam, which is locally available.

3.5 Water

Locally available potable water conforming to IS: 3025-1986 [7] with a p^H value 7.65 is used.

3.6 Chemical admixture

Chemical admixture (Complast SP 430), usedto achieve workability for HVFA mix, is conforming to IS: 9103-1999 [8]. The dosage used in the present study is 250 ml per 50 kg of cement.

4. Experimental Program

According toIS: 456-2000 [2], grade of concrete M20 is designated as normal grade concrete.Mix proportions M20 grade concrete is achieved based on the guidelines of IS: 10262-2009 [9]. The target strength is 27.6 MPa as per Mix design.

4.1 Casting and Curing of Concrete Specimens

A total of 150 concrete cubes of 100mmx100mmx100mm size were cast and cured for 28 days, out of which 75cubes cast with OPC concrete and other 75 cubes with HVFA concrete with water- binder ratios 0.52 and 0.45 respectively [14]. The total mixing time is 2 minutes. Workability of f mix is measured with slump cone apparatus immediately after mixing, and then the concrete is filled into cube moulds and compacted by means of a table vibrator for 45 seconds..After 24 hours, the specimens were demoulded, marked and are kept in a curing tank with fresh water for a period of 28 days. After curing period the specimens were stored in the laboratory till the temperature exposure.

4.2 Fire exposure to specimens

The specimens were exposed to elevated temperatures in a built electric furnace with the maximum operating temperature of 1000°C.72 cubes of each concrete mix meant for fire exposure and the remaining 3cubes of opc mix and 3 cubes of HVFA mix were used as companions. Three specimens shown in fig 1, each set of concrete mix of OPC and HVFA were kept at same elevated temperatures of 100 ^{0} C, 200^0 C, 300 ^{0} C, 400^0 C, 500 ^{0} C, 600^0 C, 700 ^{0} C and 800^0 C. Each temperature is maintainedconstantly for duration of 1-hour, 2-hours and 3-hours. After this the specimens allowed to natural air-cooling. Then the cubes were tested for ultimate failure load on a compression testing machine (CTM).

Figure 1: Temperature exposure in built furnace and testing of cubes

The cube to be tested was placed concentrically in the CTM and the load applied without shock and increases continuously until the resistances of the cube to the increased load break down. The maximum load applied on the cube was noted down. The residual compressive strengths are calculated and tabulated in table-1

Table 1: Residual cube compressive strengths

Temperature in ^{0}C	specimen mark for respective duration of exposure	Compressive strengths of OPC concrete in Mpa(a.c)			specimen mark for respective duration of exposure	Compressive strengths of HVFA concrete in Mpa (a.c)		
		Duration of Exposure				Duration of Exposure		
		1- hour	2-hour	3-hour		1- hour	2-hour	3-hour
100	OP1,OP2,OP3	36.7	39.3	39	FA1,FA2,FA3	42	36.3	31.7
200	OP4,OP5,OP6	45.7	43	40.7	FA4,FA5,FA6	44.5	39	41.5
300	,OP7,OP8,OP9	41	35.3	36	FA7,FA8,FA9	42.7	35.3	39
400	OP10,OP11,OP12	40.7	35	33.7	FA10,F11,FA12	36.3	27.7	35

500	OP13,OP14,OP15	36	30	31.3	FA13,FA14,FA15	31.3	28	27.7
600	OP16,OP17,OP18	30.3	23.7	21.7	FA16,FA17,FA18	26.3	28.7	24.3
700	OP18,OP19,OP20	22.7	22	20	FA19,FA20,FA21	18	21	18.7
800	OP22,OP23,OP24	21	19	14	F22,FA23,FA24	13.7	15	11

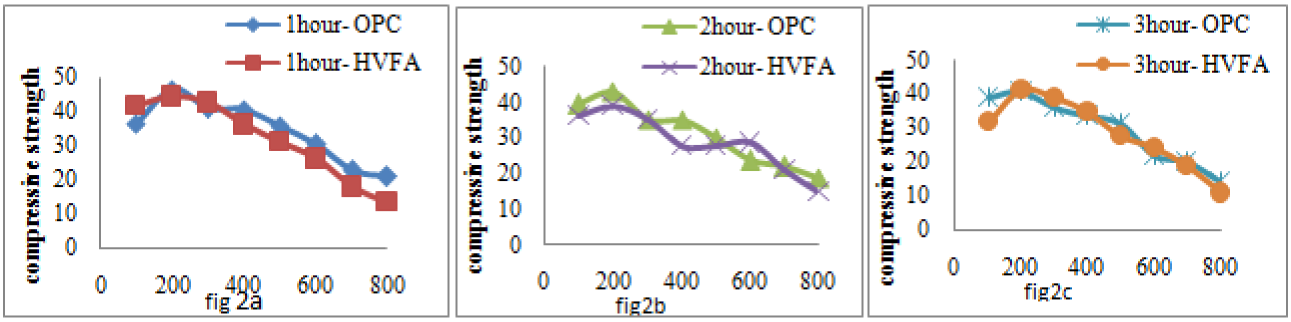

Figure 2: Variation of cube compressive strengths with temperature of OPC and HVFA concretes (a.c)

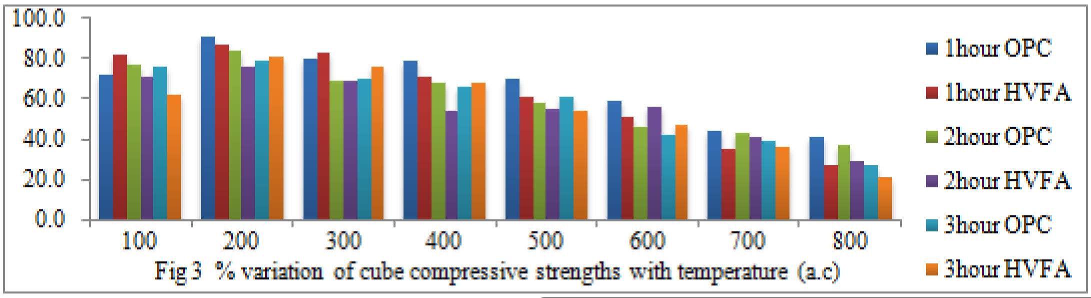

Fig 3 % variation of cube compressive strengths with temperature (a.c)

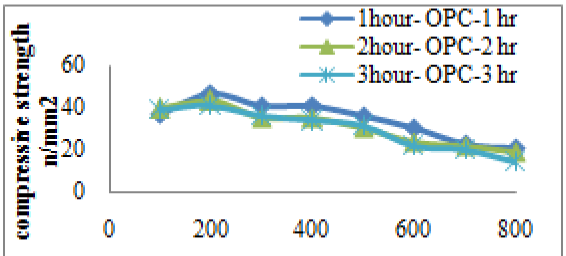

fig 4a variation of cube compressive strengths of (OPC)-duration of exposure

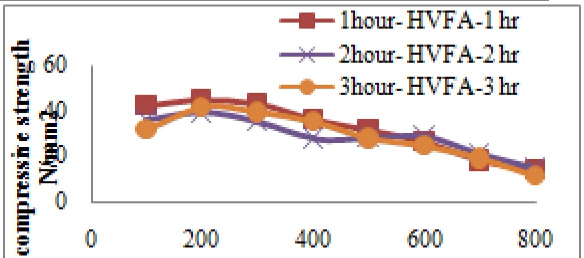

fig 4bvariation of cube compressive strengths HVFA- duration of exposure

5. Test Results and Discussions

Physical Changes due to heating: Thermal cracking and change of colour of concrete, of the specimens was the most obvious signs of physical damage. Thermal cracks were observed at temperatures 700°C and 800°C on surfaces of OPC and HVFA concrete cubes, however these cracks observed were less than 0.5D on vernear scale. Visual examination of the test specimens confirmed that the colour of the concrete gradually changed as the temperature exposure increased. The specimens exposed to temperatures at 700°C and 800°C become red hot in colour when removed from the furnace. After that the cubes turned to light yellow in colour.

Effect of Temperature on Residual Strength

Residual compressive strength is the compressive strength of heated specimen for respective duration of exposure expressed as percentage of 28-days strength of the corresponding controlled concrete.The effect of temperature on residual compressive strength has been studied and compared with the controlled concrete cubes. The results were critically analyzed and discussed in this section.Fig.2 and 3shows the variation of cube compressive strengths of concrete with temperature.

The percentage variations in the residual compressive strength of OPC Concrete retains 71.5, 91, 79.9, 79.3, 70.2, 59.1, 44.2, 40.9 % residual compressive strengths and the HVFA concrete retains 81.9, 86.7, 83.2, 70.8, 61, 51.3, 35.1, 26.7 % compressive strengths with respect to the controlled concrete, at temperatures 100 ^{0}, 200 ^{0}c, 300 ^{0} c, 400 ^{0}c, 500^0 c, 600 ^{0}c, 700 ^{0} c and 800 ^{0}c. The percentagevariation in the residual compressive strengths of OPC and HVFA concretes for 2 hour duration of exposure is, OPC Concrete retains 76.6, 83.8, 68.8, 68.2, 58.5, 46.2, 42.9, 37 % residual compressive strengths and the HVFA concrete retains 70.8, 76, 68.8, 54, 54.6, 55.9, 40.9, 29.2 % compressive strengths with respect to the controlled concrete strengths at temperatures 100^0, 200^{0}c, 300^0 c, 400^{0}c, 500^0 c, 600^{0}c, 700^{0}c and 800^{0}c respectively. And From fig 2c the specimens exposed to 3-hour duration, OPC Concrete retains 76, 79.3, 70.2, 65.7, 61, 42.3, 39, 27.3 % residual compressive strengths and the HVFA concrete retains 61.8, 80.9, 76, 68.2, 54, 47.4, 36.5, 21.4 % compressive strengths with respect to the controlled concrete strengths at temperatures 100^0, 200^{0}c, 300^0 c, 400^{0}c, 500^0 c, 600^{0}c, 700^0 c and 800^{0}c respectively.

The test results have shown that the compressive strengths of all the heated specimens were less than the strengths of companion cubes. The OPC concrete retained slightly more strengths than HVFA concrete cubes for 1 hour duration. However,for 2hours duration of exposure the residual strength variation is similar for both concretes.At 3-hour duration of exposure HVFA concrete cubes showed almost equal strengths but HVFA performed better than OPC concrete at all temperatures.

Effect of duration of exposure on Residual Strength

The residual strength gradually decreased with the increase in temperature of exposure from 200^0 c to 800^0c. Fig 4a and 4b shows that the effect of duration of exposure with increase in temperature for OPC and HVFA concretes shows that for 1hour duration of exposure the residual compressive strengths are little high values than 2hour and 3hour exposure durations for OPC concrete. For 2hours duration of exposure the residual strength variation is similar for both concretes. At 3-hour duration of exposure HVFA concrete cubes showed almost equal strengths and HVFA performed better results.

6. Conclusions

Any structure is subjected to fire accident, then the amount of temperature exposure, exposure time, and method of controlling fire have great impact on the structural performance during fire and after fire. Despite the fact that designing structures fire resistance of structural members should be studied during the design stage to meet certain behavior and performance. From this experimental study the following conclusions are drawn.

1) Up to 500^oC The OPC concrete sustained the residual compressive strength varies from 91 to 58.5% for all three durations of exposure. And HVFA concrete sustained the strength variation is in between 86.7 to 54% of controlled concrete
2) Beyond 500^o C the reduction in strength is about 70%
3) The effect of temperatures on residual strength is loosening the bond between the aggregates and cement paste hydrates are the differential thermal expansion of matrix components.
4) The loss of strength is comparable for both mixes OPC and HVFA, results, from this study are useful for assessing post fire properties of concrete structure.

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