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A Study on High Volume Fly Ash Concrete Exposed To Elevated Temperatures

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ABSTARCT: *The present study aims at investigating the performance of high volume fly ash (HVFA) concrete at elevated temperature exposed upto 800^{o}C at interval of 200^{o}C for three hours duration is investigated. The physical and mechanical properties of high volume fly ash concrete are studied. Variable of the test program includes replacement of cement with fly ash from 30% to 50%, temperatures from 27^{o}C to 800^{o}C at an interval of 200^{o}C for 3 hours duration. The physical and mechanical properties studied are residual compressive strength, weight loss, colour change. The test results showed that the residual strength of concrete having replacements up to 50% was comparative with control concrete. Control concrete specimens showed higher weight loses when compared with fly ash concrete.*

Keywords: *Normal concrete mix, High Volume Fly ash, C70F30, C60F40, C50F5, Residual compressive strength and elevated Temperatures.*

I. INTRODUCTION

Concrete is the most versatile construction material due to its high compressive strength and mouldability. It is most widely usedconstruction material and estimated that it is the second highest consumed material in the world. As the consumption of concrete increases day by day, the use of cement also increases tremendously. The increasing scarcity of raw materials and an urgent need to protect the environment against pollution has stressed the significance of developing new building materials.

It is widely accepted that reduced production of portland cement (PC) and increasing partial replacement of Portland cement withpozzolanic and cementitious by-products such as fly ash, ground granulated blast furnace slag (GGBS), rice husk ash resulting, in the conservation of natural resources such as limestone, which leads to lower energy consumption and reduces green house gas emissions and controlled global warming and climate change in the manufacture of PC. It also improves the service life of cement concrete structures by improving concrete durability, reduced cost of cement. Highly beneficial elimination of environment threatening gigantic fly ash deposits, is the essential element of the foundation, upon which the edifice of sustainable development of the concrete construction industry can be built. High volume fly ash (HVFA) cement and concrete directly serve this highly useful beneficial cause. The Canada Center for Mineral and Energy Technology (CANMET) began work under the guidance of Malhotra around 1985 to develop HVFA cement and concrete for structural and a variety of other applications.[1-4]

HVFA concrete is now getting accepted and used in many structural applications including structures exposed to elevated temperatures. These structures include concrete storage, gasification and liquefaction vessels in metalurgical, chemical, power, glass and cement industries. The other structures whichare exposed to elevated temperature are reinforced concrete chimneys with concrete walls, nuclear reactor vessels, air craft engine test cells, missile launching pads, turbo jet runways. In addition to this fire accidents occur in normal concrete structures in urban industrial areas. The materials used for these structures should be capable of resisting high temperatures.

Although concrete is generally believed to be an excellent fire proofing material, but there is extensive damage or even catastrophic failure at high temperatures. At high temperatures, chemical transformation of the gel weakens the matrix bonding, which leads to loss of strength in concrete.

The effect of high temperature on HVFA concrete has not been investigated in detail so there is need to study the behaviour (mechanical properties & microstructure analysis) of HVFA concrete at elevated temperatures . So an attempt was made to stdy the performance of HVFA concrete exposed to elevated temperature.

II. LITERATURE REVIEW

Highly beneficial and useful HVFA concrete is of recent origin and is currently used in increasing structural applications. Most of the experimental work is carried out on HVFA concrete is on mechanical properties, structural behavior etc. Little work is reported till date in India on HVFA concrete subjected to elevated temperatures. Research on the behavior of concrete at elevated temperature is picking up only in the recent past. The literature accumulated thus far is reviewed briefly

Phan et al: carried out experimental program on effects of elevated temperature on residual mechanical properties of high performance concrete (HPC)5. The test specimens were made of four HPC mixtures with water-to-cementitiousratio ranging from 0.22 to 0.57. At room temperature compressive strength at testing varied from 51 MPa to 93 MPa. It was concluded that HPC mixtures with higher strength (lower w/cm) and with silica fume retain more residual strength afte exposed tor elevated temperature than those with lower original strength(higher w/cm) and without silica fume.

Abid Nadeem et al: carried out an study to evaluate the performance of High Performance Concrete (HPC) made with Fly ash (FA) and Metakaolin (MK) at elevated temperatures. Variables considered in this investigations are partial replacement of cement with FA from 20% to 60%, temperatures from 27^{o}C to 800^{o}C and two types of cooling methods ie air and water.[6]The tests performed are compressive strength, durability and mass loss by using chloride permeability, water absorptivity tests and quantitative analysis of the SEM image test. FA mixes showed improved resistance against chloride ion penetration at 600^{o}C and 800^{o}C. Finally they concluded as the compressive strength of concrete under slow cooling decreased with the increase of elevated temperatures with the exception of PC and FA60 mixes at 200^{o}C. They reported that at temperatures (400^{o}C and above) FA20 showed better performance and MK mixes (MK10 and MK20) showed higher degradation in terms of durability.

Soni D.K. et al: investigated mechanical Properties of High Volume Fly Ash (HVFA) Concrete exposed to elevated temperature of 120^{o}C. They replaced cement with three replacements 30, 40 and 50 % by weight of cement and mix proportion of 1:1.45:2.2 with a water cement ratio of 0.5[7]. Tests parameters considered were compressive strength, split tensile strength and modulus of elasticity at room temperature, 80^{o}C, 100^{o}Cand 120^{o}C for all three types of fly ash concrete. They reported that the compressive strength, split tensile strength and modulus of elasticity of concrete with cement replacement up to 30% was comparable to that of reference concrete without fly ash. Compressive strength, split tensile strength and modulus of elasticity of concrete mixtures with 30%, 40% and 50 % of fly ash as cement replacement exhibited lower strengths than the control mixture at all ages.

Potharaju M et. al: investigated the influence of high temperature (100^{o}C-250^{o}C) on residual compressive strength of concrete made with partial replacement of fly ash[8]. Main test parameters involved in their study were temperature range, time of exposure and percentage of fly ash8. The study was carried out with M28, M33 and M35 grade of concrete. A total of 360 cubes were casted with different fly ash percentages 10%,20% and 30% replacement levels and , were heated at 100^{o}C, 200^{o}C and 250^{o}C for 1 h,2h and 3 hour duration in an electric oven . The replacement by fly ash up to 20 percent resulted in a better performance under compression when exposed to a temperature up to 250^{o}C.

Ramesh K V et. al : investigated the behaviour of high volume fly ash cement concrete columns subjected to elevated temperature[9]. A set of HVFA columns were exposed to temperature ranging from 100^{o}C to 800^{o}C for three hours. Companion columns were cast with conventional concrete were also tested for comparision. They concluded that the fire reduces the strength of columns and residual strength of the HVFA columns were comparable to those of the companion conventional concrete columns.

III. EXPERIMENTAL INVESTIGATION

1.1. Materials

Cement: The hydraulic cement used was ordinary Portland cement (OPC) of grade 53 confirming to IS 12269-1987[10].

Fine aggregate :The fine aggregate was locally available river sand confirming to Zone-II of IS 383-1970[11] . The fineness modulus of fine aggregate was determined as 2.69 acording to the procedure specified in IS 2386(Part I) – 1963[12].

Coarse aggregate : The coarse aggregate used was crushed hard granite stone passing through 20 mm sieve, and retaining on 4.75 mm sieve. The fineness modulus of coarse aggregate was found to be 6.07 and is confirming to IS 383-1970[11].

Fly Ash: Class F fly ash from simhadri NTPC is used .This fly ash conforms to the requirement of IS 3812(part I): 2013[13].

Superplasticizer: Conplast - SP430 is used to give high water reductions up to 25% without loss of workability.

1.2. Mix Proportion

Mix design for M30 grade of concrete is designed as per IS :10262:2009[14] and final mix proportions are shown in Table 1: Each binder composition is given a designation, letters C and F indicates Portland cement and Fly ash respectively. For example C70F30 indicates 70% of Portland cement and 30 percent of fly ash.

Table 1. Mix proportion

S.No.	Mix Designation	Cement (kg/m^3)	Fly Ash (kg/m^3)	Sand (kg/m^3)	C.A (kg/m^3)	Water (Ltr)	W/b	SP%
1	**C100**	380	0	734	1155	133	0.35	0.8
2	**C70F30**	266	114	734	1155	133	0.35	0.8
3	**C60F40**	228	152	734	1155	133	0.35	0.8
4	**C50F50**	190	190	734	1155	133	0.35	0.8

1.3. Casting and curing of Specimens

Totally 120 cubes of size 100 mm×100 mm cubes were casted for the mix designations C100,C70F30, C60F40 and C50F50were cast and the specimens were demoulded after 24 hours of casting and cured for 7 days and 28 days and the specimens exposed to temperature in Bogie Hearth furnace.

1.4. Fire testing

A custom –built electric furnace was used to expose the specimens under study to required temperature. The maximum operating temperature of the furnace is 1000°C .The heating arrangement in the bogie hearth furnace is as per the ISO: 834-1975[15]specifications. The furnace can be separated in to two part, one part can be pulled out after loosening the screws provided for tightening between the two parts and consists of a bed of refractory bricks of size 110 mm on which the specimens are placed.The second partconsists heating chamber consists electrical heating coils at sides and top of it. The total assembly is lined with a heat resistant lining which arrests the heat to escape from the furnace.

The test specimens were subjected to temperatures from 27°C to 800°C at intervals of 200°Cfor a duration of three hours and then were cooled to room temperature. Later the cubes were tested for compressive strength as per IS 516-1959 [16].

IV. RESULTS AND DISCUSSIONS

1.5. Colur Change

Fig. 1 represents the colour changes in normal concrete and flyash mixes at 800°C. No colour change is observed in all the mixes when exposed upto 600°C. Beyond 600°C, the fly ash mixes turned to orange red color and normal concrete mix remains unchanged. This colour change in fly ash mix may be attributed to the possible formation of Fe-silicates/hematite.

Figure 1: Colour Change at 800°C

1.6. Cracks

Fig. 3 shows the cracks observed in normal and fly ash mix at 600°C. no visual cracks were observed upto 400°C in both the concretes. Surface cracks were observed at 600°C and were pronounced at 800°C, which may be because of the formation of additional internal pores due to evaporation of adhered water.

Figure 2: Crack s observed at 600°C

1.7. Weight loss

The general percent weight loss trend is shown in Fig.3. A gradual decrease in percentage weight loss was observed with the increase in percentage replacement of flyashat every temperature. This lower percentage weight loss in fly ash mixes may be because of dense structure when compared to normal mix. It was further observed that, as the temperature increases the weight loss also increases in all the mixes. The higher weight loss at high temperatures may be attributed to the evaporation of total absorbed and adsorbed water form concrete.

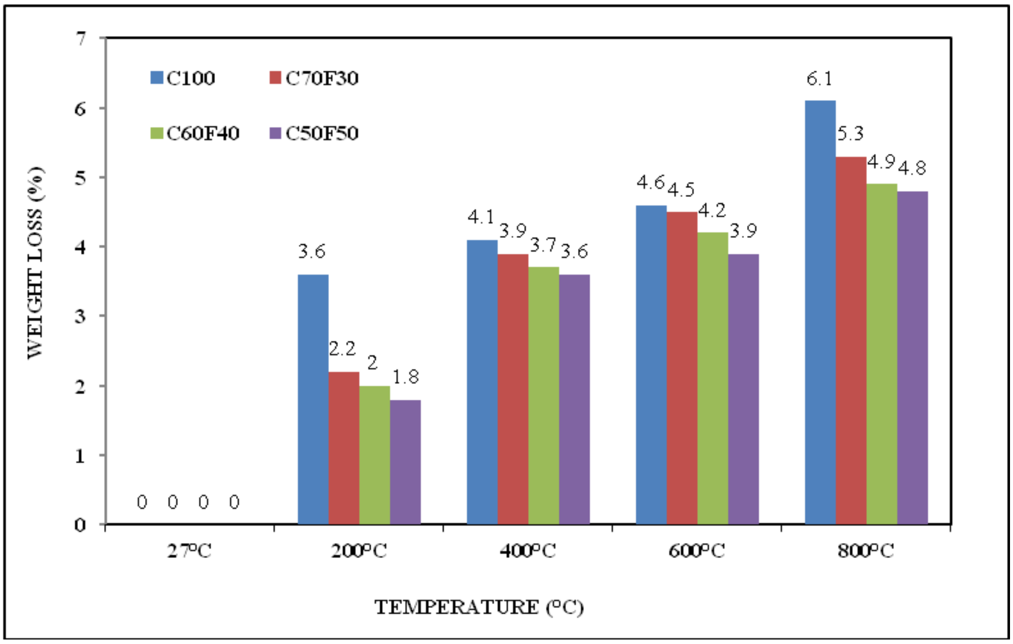


Figure 3: Percentage Weight Loss at Different Temperatures.

1.8. Residual compressive strength

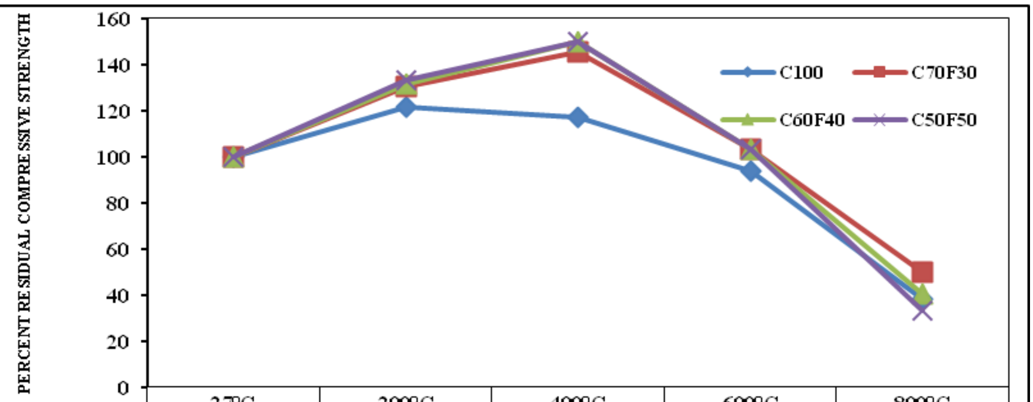
After the exposure of cubes to a temperature from 200°C to 800°C with an interval of 200°C, cubes were cooled down to room temperature then residual compressive strengths are tdetermined by tesying the cube specimens using compression testing machine and their results are shown in table 2.

Table 2: Residual Compressive Strengths of all Fly Ash Mixes at Different Temperatures

Sl. No	TEMPERATURE	RESIDUAL COMPRESSIVE STRENGTHS , MPa							
		7 days				28 days			
		C100	C70F30	C60F40	C50F50	C100	C70F30	C60F40	C50F50
1	27°C	47	34	32	30	50.5	53	48	45.6
2	200°C	57	44.3	42	40	59.7	60.3	56.5	54
3	400°C	55	49.5	48	45	58	64	60.5	59
4	600°C	44	35	33	31	45.3	46	45	46
5	800°C	18	17	13	10	20	21.5	20.7	21

From Table 2, it is clear that the residual compressive strength of all fly ash mixes decreased with the increase in percentage replacement of fly ash and with the increase in temperature both at 7 and 28 days. The higher residual compressive strength is noted at 7 days for normal and at 28 for the mix C70F30 compared to all other mixes at every temperature.

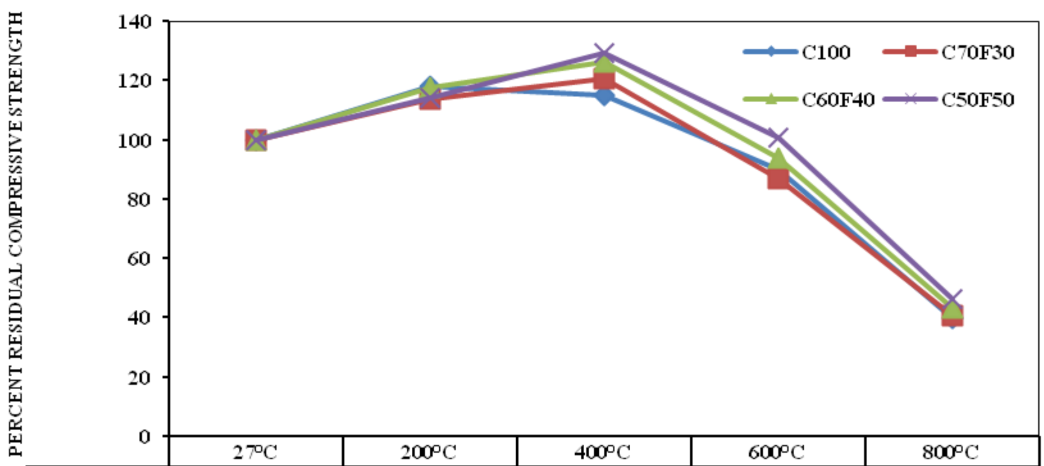
Fig.4&5 shows the percentage residual compressive sterngths of all fly ash mixes after exposed to different tempaeratures at 7 days and 28 days respectively. From Fig. 1 , it is clear that the fly ash mixes showed higher percentage residual compressive strengths at all temperatures compared to normal concrete at 7 days. From Fig. 2 it is observed that at 28days, all the concretes gained strength upto 400°C and decreased beyond 400°C except C50F50. The mix C50F50 showed an increase in residual compressive strength upto 600°C. Between 400 to 800°C, the percent residual compressive strength of C50F50 is higher when compared to the other mixes. Hence, it can be concluded that the mix C50F50 showed better performance at high temperatures when compared to the other mixes.



	27°C	200°C	400°C	600°C	800°C
C100	100	121.3	117	93.61	38.2
C70F30	100	130.2	145.5	102.9	50
C60F40	100	131.5	150	103.1	40.6
C50F50	100	133.3	150	103.3	33.3

TEMPERATURE (°C)

Figure 4: Percentage Residual compressive strength of fly ash concrete exposed to different temperatures at 7 days



	27°C	200°C	400°C	600°C	800°C
C100	100	118.2	114.8	89.7	39.6
C70F30	100	113.8	120.8	86.8	40.5
C60F40	100	117.7	126	93.7	43
C50F50	100	114	129.3	100.8	46

TEMPERATURE (°C)

Figure 5: Percentage Residual compressive strength of fly ash concrete exposed to different temperatures at 28days

V. CONCLUSIONS

1. The Fly ash mixes turned to orange red colour between 600 to 800^{o}C and more number of cracks were also observed at this temperatures.
2. A gradual decrease in percentage weight loss was observed with the increase in replacement of flyashat all temperature. This lower percentage weight loss in fly ash mixes may be because of dense structure when compared to normal mix.
3. The weight loss also increased with the increase in temperature in all the mixes. The higher weight loss at high temperatures may be attributed to the evaporation of total absorbed and adsorbed water form concrete.
4. The fly ash mixes showed higher percentage residual compressive strengths at all temperatures compared to normal concrete at 7 days.
5. All the concretes mixes showed increase in strengthupto 400^{o}C and decreased beyond 400^{o}C except the mix C50F50 and the mix C50F50 showed an increase in residual compressive strength upto 600^{o}C at 28 days.

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