

EFFECT OF ELEVATED TEMPERATURES ON PHYSICAL AND RESIDUAL STRENGTH PROPERTIES OF HPC

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Abstract— This paper reports a study of the effect of elevated temperatures on physical and residual strength properties of High Performance Concrete (HPC) produced on of with incorporat pozzolanic materials, such as Ground Granulated Blast Slag (GGBS) and/or Silica Fume (SF) etc. To evaluate the residual mechanical properties of thermally damaged High Performance Concrete (HPC), 100 mm cube specimen were exposed to elevated temperatures of 150°C to 900°C and retained for 2 hours. After being cooled to room temperature in the furnace, colour change was observed and sorptivity test was carried out on exposed HPC specimen. The compressive strength and split tensile strengths were determined by destructive testing. The result show that HPC containg GGBS performs better than that of HPC containing SF.

Index Terms— Compressive Strength, Elevated Temperatures, Ground Granulated Blast Slag, High Performance Concrete, Silica Fume, Sorptivity Coefficient, Split Tensile Strength.

1 INTRODUCTION

High Performance Concrete (HPC) is a novel construction material with improved properties like higher strength, longer durability, and higher workability etc. than conventional concrete. Generally HPC is prepared with lower water to cement ratio and high content of binder to meets special performance requirement with regard to workability, strength and durability.

Fire accidents, sabotages or natural hazards are the situations where HPC is likely to get exposed to elevated temperatures. Although concrete is generally believed to be an excellent fireproofing material, many recent studies have shown extensive damage or even catastrophic failure at high temperatures, particularly in high strength concrete [1]. After exposure to elevated temperatures the structure needs to be assessed, to know the extent of degradation in mechanical properties.

This paper investigates the effect of elevated temperatures on the physical and residual strength properties of HPC. Two types of mixes are studied in this investigation one is HPC-G mix containing 30% GGBS and 70% Ordinary Portland Cement (OPC) and the second one is HPC-G-SF containing 25% GGBS and 5% of SF and 70% OPC.

2 EXPERIMENTAL INVESTGATION

2.1 Materials Used

53 Grdae OPC conforming to IS 12269-1987 [2], 'JSW Cement Ltd.' GGBS confirming to BS 6699 [3], and 'Corniche SF' silica fume

53 Grdae OPC conforming to IS 12269-1987 [2], 'JSW Cement Ltd.' GGBS confirming to BS 6699 [3], and 'Corniche SF' silica fume confirming to IS 15388:2003 [4] were used. The physical and chemical properties of above materials are tabulated in Table 1 and Table 2.

TABLE 1
PHYSICAL PROPERTIES OF MATERIALS

Properties	Cement	GGBS	SF
Fineness (m ² /kg)	322	410	19700
Specific Gravity	3.07	2.90	2.20
Density (kg/m ³)	1430	1000-1100	650

TABLE 2
CHEMICAL COMPOSITION OF MATERIALS (% BY MASS)

Chemical composition	Cement	GGBS	SF
CaO	63.0	40.0	0.5
SiO ₂	21.6	35.0	90.7
Al ₂ O ₃	5.0	12.0	0.7
Fe ₂ O ₃	3.7	0.2	2.2
MgO	0.8	10.0	1.5

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Fine aggregate (FA)

Fine aggregate is obtained from local river source. The grading of fine aggregate conforms to Zone III of IS 383-1970 [5]. The specific gravity, fineness modulus, and water absorption were found to be 2.65, 2.38 and 1.5% respectively.

Coarse aggregate (CA)

The siliceous coarse aggregate of 12.5 and 20 mm size form local quarrying. The specific gravity, fineness modulus, and water absorption were found to be 2.67, 7.15 and 0.5% respectively.

Super-plasticizer

Sulphonated naphthalene polymer based high range water reducing admixture (HRWRA) ‘CONPLAST 430’ of FOSROC was used. The specific gravity of HRWRA was 1.18.

2.2 Specimen Preparation and Exposure to Elevated Temperature

HPC has been designed for a characteristic strength of 80 MPa and slump of 130 mm. The concrete mix proportions are shown in Table 3. The concrete mixing was done as per the ASTM C 192- 90 [6]. Then concrete cubes of size 100 mm were cast and cured in water for 28 days. After 28 days of curing, specimen were taken out, air dried, exposed to 150°C, 300°C, 450°C, 600°C, 750°C and 900°C temperature and retained for 2 hours in an electric muffle furnace. The muffle furnace time temperature build up curve is shown in Figure 1. After exposure to designated temperature the specimen were allowed to cool in the furnace to the room temperature. After cooling to room temperature the sorptivity test was carried out. In order to assess the residual compressive strength and splitting tensile strengths destructive tests on exposed specimen were performed.

TABLE 3

DETAILS OF DESIGN MIX FOR ONE CUBIC METER OF CONCRETE

Designation	HPC-G	HPC-G-SF
OPC (kg)	350	350
GGBS (kg)	150	125
SF (kg)	--	25
FA (kg)	544	542
CA (kg) 12.5 mm	638	637
20 mm	638	637
WATER (kg)	130	130
SUPER-PALSTICIZER (kg)	8.26	8.26

2.3 Tests on Exposed Concrete

Sorptivity test

The sorptivity test determines the rate of capillary rise absorption by a concrete specimen. Measurement of capillary sorption was carried out using specimen pre-conditioned in the oven at 105°C. Then specimens were cooled for room temperature, to achieve unidirectional flow the specimen’s sides were coated with paraffin. The Figure 2 shows the test set up adopted for the determination of the sorptivity.

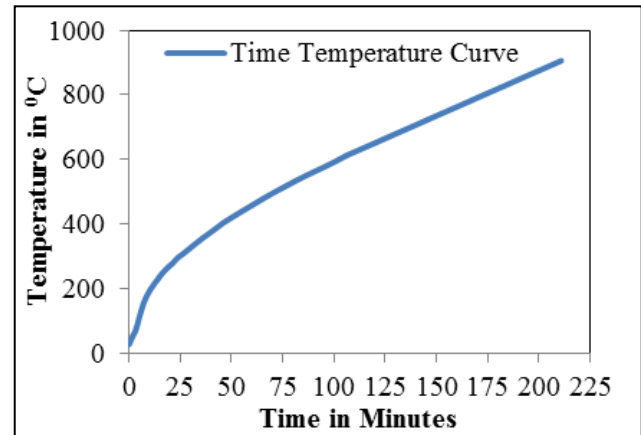


Fig. 1 Furnace time temperature build up curve.

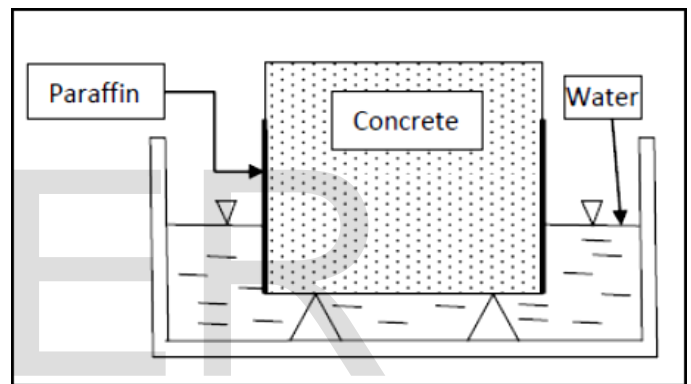


Fig. 2 Test set up for sorptivity

At certain times the masses were measured using weighing balance, and then amount of weight observed was calculated and normalized with respect to cross-sectional area of specimen exposed to water at various times, such as 0, 5, 10, 20, 30, 60, 180, 360 and 1440 min. The rate of capillary rise absorption or sorptivity coefficient (k) was obtained by following equation,

$$\frac{Q}{A} = k \sqrt{t} \tag{1}$$

Where,

Q- Amount of water absorbed (cm³)

A - Cross section of the specimen exposed to water surface (cm²)

t- time (sec)

To determine the sorptivity coefficient, Q/A was plotted against the square root of time (√t), and then k was calculated from the slope of the linear relationship between Q/A and √t [7].

Compressive strength

The compressive strength was carried out as per IS 516- 1959 [8]. The compressive strength ratio is expressed as ratio f_{cT}/f_{c27} , where f_{cT}

is the compressive strength after heating at $T^{\circ}\text{C}$ and f_{27} is the compressive strength of concrete at 27°C .

Split tensile strength

The split tensile strength was carried out as per IS 5816 -1999 [9]. The split tensile strength ratio is expressed as ratio f_{tT}/f_{t27} . Where, f_{tT} is the split tensile strength after heating at $T^{\circ}\text{C}$ and f_{t27} is the splitting tensile strength of concrete at 27°C .

3 EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Physical Observation

In general up to 150°C , the concrete colour doesn't change noticeably. As temperatures is increased to 300°C colour changes from normal to pink, brown/ red at 450°C - 600°C , and buff at 750°C - 900°C is observed for HPC-G and HPC-G-SF mixes.

3.2 Sorptivity Test

Figure 3 shows the variation in sorptivity coefficient of concrete cubes subjected to elevated temperatures. The sorptivity coefficient increases as the temperature increases. Up to 300°C the coefficient is relatively same as unexposed specimens. The sorptivity coefficient of HPC-G -SF mix concrete is greater than that of HPC-G mix at all levels of temperature. The sorptivity coefficient affected greatly by loss of moisture in the concrete after exposure to the elevated temperatures and also due to the formation of micro-cracks or shrinkage cracks when exposure temperature was above 300°C [7-10]. Sorptivity coefficient is observed to increase with increase in temperature, meaning increase in porosity.

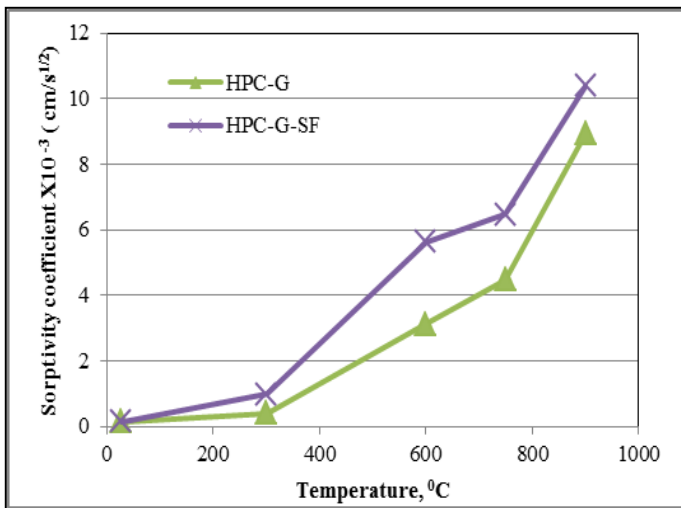


Fig. 3 Variation in Sorptivity coefficient with exposure temperature

3.3 Compressive Strength

Figure 4 shows the variation in compressive strength ratio with temperatures. It is observed that the compressive strength ratio of HPC-G and HPC-G-SF mixes decreases with increase in temperature. The compressive strength ratio is 1.08 at 150°C , 1.10 at 300°C , 0.88 at 450°C , 0.57 at 600°C , 0.35 at 750°C and 0.20 at 900°C for HPC-G mix. The decrease in compressive strength ratio is 0.92 at 150°C , 0.96 at 300°C , 0.94 at 450°C , 0.36 at 600°C , 0.33 at 750°C and 0.14 at 900°C for HPC-G-SF mix. The increase in strength is associated with the increase in surface forces between gel particles (Van der Waals) forces due to the removal of moisture content [11]. The decomposition of calcium hydroxide does not generally occur below 350°C . This conversion may lead to serious damage due to the expansion of lime during the cooling period [12]. This effect of calcium hydroxide eliminated using pozzolanic material such as GGBS and SF. The compressive strength ratio of the HPC-G-SF mix appeared to be not performing so well under elevated temperatures when compared to the HPC-G mix. The strength loss rate is significantly higher for HPC-G-SF concrete than for that of HPC-G concrete. This may be due to high densification of pore structure of concrete.

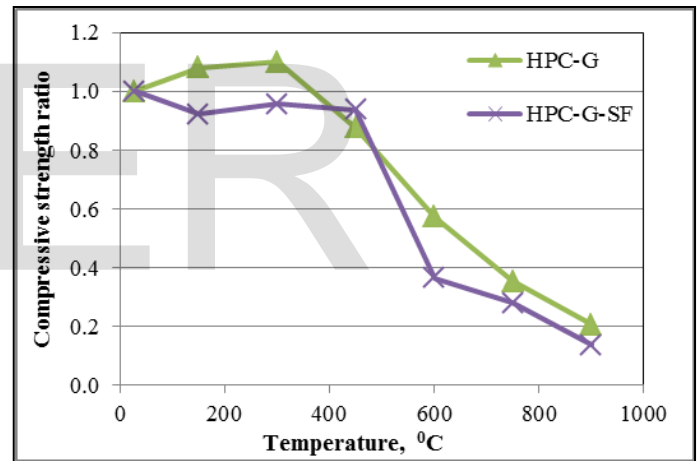


Fig. 4 Variation in compressive strength ratio with exposure temperature

3.4 Split Tensile Strength

Figure 5 shows the variation in split tensile strength ratio with temperature. It is observed that the split tensile strength of HPC-G and HPC-G-SF mixes decrease with increase in temperature. The split tensile strength ratio is 0.98 at 150°C , 0.74 at 300°C , 0.47 at 450°C , 0.25 at 600°C , 0.23 at 750°C and 0.11 at 900°C for HPC-G mix. The decrease in split tensile strength ratio is 0.95 at 150°C , 0.65 at 300°C , 0.43 at 450°C , 0.22 at 600°C , 0.19 at 750°C and 0.06 at 900°C for HPC-G-SF mix.

The rate of decrease in strength is much faster beyond 150°C , similar kind of observation was reported by W. Khaliq, and V. K. R. Kodur [13]. At 300°C as the cracks were observed, this signifies severe reduction in split tensile strength [14-15]. The thermal

stresses induced in the dense microstructure of HSC, which results in many micro cracks and few macro cracks [14]. The loss in split tensile strength is considerably sharp.

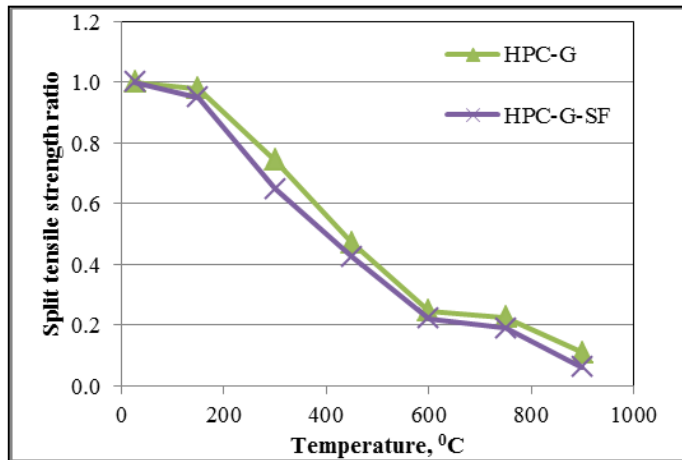


Fig. 5 Variation in split tensile strength ratio with exposure temperatures

4 CONCLUSIONS

From this investigation the following conclusions were drawn:

Sorptivity test can be useful for the qualitative assessment of fire damaged structural concrete. HPC prepared with GGBS shows better performance over HPC containing silica fume. Tensile strength of concrete is more crucial than the compressive strength of concrete when subjected to elevated temperatures.

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