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Research Article

EFFECT OF ELEVATED TEMPERATURES ON MECHANICAL PROPERTIES OF MICROCEMENT BASED HIGH PERFORMANCE CONCRETE

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ABSTRACT
High Performance Concrete (HPC) has become popular due to its superior mechanical and durability properties. The use of HPC has been used extensively throughout the world, predominately in the high rise buildings, bridges, tunnels etc. The first fire that occurred in a HPC structure, was in the channel tunnel fire. From different studies in progress in several countries, it is clear that the fire resistance of HPC does not seem to be as good as that of ordinary concrete. This paper presents experimental work regarding the physical characteristics, mechanical properties of partial micro cement based HPC subjected to elevated temperatures.

Key Words: *High Performance Concrete, Elevated Temperatures, Physical Characteristics, Mechanical Properties.*

INTRODUCTION
The HPC has constantly growing number of applications: marine construction, high-rise buildings, bridge decks and piers, thin wall shells, airport pavements and many others. Fire accidents, sabotages or natural hazards are the situations where HPC is likely to get exposed to elevated temperatures. As construction details, as well as material resistance by itself could influence greatly the fire resistance of HPC. It is important to study the effect of elevated temperatures on HPC made with different materials.

In this investigation, two trial mixes of HPC are designed to produce at least M80 grade concrete having pumpable workability. The two trial combinations attempted are named as HPC-O and HPC-M. HPC-O contains 100 % Ordinary Portland Cement (OPC) and HPC-M contains 30% Micro Cement and 70% OPC.

MATERIALS AND METHODS
Materials Used
Cement: 53 Grade Ordinary Portland cement (OPC) conforming to IS 12269-1987.

Microfine cement: Microfine cement ‘ALCCOFINE-1101’ is a micro fine material with particle size much finer than other cementitious materials.

Table 1 gives characteristics of cement and microfine cement.

Aggregate: Fine aggregate (FA) is obtained from local river source. The grading of fine aggregates conforms to Zone III of IS 383-1970. The siliceous coarse aggregates (CA) of 12.5 and 20 mm size were obtained from local quarries and satisfy the grading requirements as per IS 383-1970. Table 2 gives properties of fine aggregates and coarse aggregates.

Super-palsticizer: Sulphonated Napthalene polymer based high range water reducing admixture (HRWRA) ‘CONPLAST 430’ of FOSROC was used. The specific gravity of HRWRA is 1.18. This HRWRA is a brown liquid containing 41.34% solids.The optimum dosage of HRWRA was determined by Marsh cone test method.

Table 1. Physical and chemical and strength characteristics of cement

Characteristics	Cement	Microfine cement
Physical Tests		
Normal consistency (%)	29	--
Specific Gravity	3.07	3.10
Fineness (m^2/kg)	322	800
Density (kg/m^3)	1430	857
Soundness (mm)	Expansion : 2.50	--
Setting time (minutes)	Initial: 65	Initial: 86
	Final: 265	Final: 165
Chemical composition (%)		
CaO	63.0	61.0-64.0
SiO_2	21.6	21.0- 23.0
Al_2O_3	5.0	5.0-5.6
Fe_2O_3	3.7	3.8- 4.4
MgO	0.8	0.8-1.4
Strength (MPa)		
fc (3days)	28	--
fc (7days)	37	--
fc (28days)	57	--

Table 2. Properties of Aggregates

Property	FA	CA	
		12.5mm	20 mm
Bulk density (kg/m^3)	1600	1459	1413
Water absorption (%)	1.5	0.5	0.5
Specific gravity	2.65	2.67	2.67
Fineness modulus	2.38	7.15	--

Specimen Preparation and Test

HPC is a concrete prepared with a low water to binder ratio. The mix proportions are as shown in Table 3. The concrete mixing was done as per the ASTM C 192- 90 a (1994). Then concrete cubes of size 100 X 100 X 100 mm^3 were cast and cured in water for 28 days. After 28 day of curing, specimen were taken out, air dried, exposed to 150^0C, 300^0C, 450^0C, 600^0C, 750^0C and 900^0C temperature and retained for 2 hours in an electric furnace. The muffle furnace time temperature build up curve is as shown in figure 1. After exposure to designated temperature the specimen were allowed to cool in the furnace to the room temperature. Then the physical properties like colour analysis and sorptivity tests were carried out. Later Non Destructive Testing by Ultrasonic Pulse Velocity (UPV) is measured. Residual compressive and splitting tensile strengths are also ascertained by destructive tests.

Sorptivity test

The sorptivity test determines the rate of capillary–rise absorption by a concrete specimen. Measurement of capillary sorption were carried out using specimen pre-conditioned in the oven at 105 ^{0}C. Then specimen were cooled for room temperature, to achieve unidirectional flow the specimen's sides were coated with paraffin. Figure 2 shows the test set up used for determining the sorptivity.

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Table 3. Details of design mix for one cubic meter of concrete

Designation	OPC (kg)	Micro-Cement (kg)	FA (kg)	CA (kg)		Water (kg)	Super-palsticizer (kg)
				12.5 mm	20 mm		
HPC-O	500	--	546	642	642	130	10.62
HPC-M	350	150	546	642	642	130	10.62

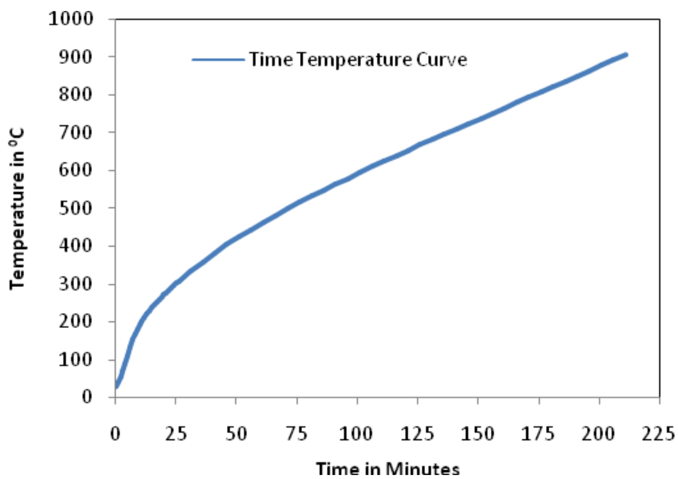

Figure. 1 Furnace time temperature curve

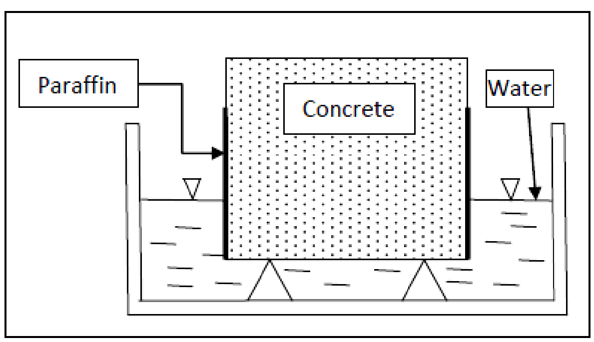

Figure. 2 Test set up for the sorptivity

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,

$$\frac{Q}{A} = k\sqrt{t} \qquad (1)$$

Where,

Q - Amount of water absorbed (cm^3)

A - Cross- section of the specimen exposed to water surface (cm^2)

t - time (sec)

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To determine the sorptivity coefficient, Q/A was plotted against the square root of time ($\sqrt{t}$), and then k was calculated from the slope of the linear relationship between Q/A and $\sqrt{t}$ (Demirel, B and Kelestemur, O, 2010). The sorptivity coefficient is represented as cm/s$^{1/2}$.

Ultrasonic Pulse Velocity (UPV)

The Pulse velocity was measured on 100 mm cubes according to IS 13311 (Part 1):1992 by using PUNDIT ultrasonic pulse velocity device. On the two sides of cubes the pulse velocity is measured (for one cube two readings were taken), average of such 3 cubes is reported in this investigation. The relative UPV after heating was expressed as ratio V_T/V_{27}, where $V_T$is the UPV after heating at T^0C and V_{27} is the initial UPV of concrete at 27^0C.

Compressive strength

After the UPV test the compressive strength of concrete specimen was carried out as per IS 516- 1959. The residual compressive strength is expressed as ratio f_T/f_{27}, where f_T is the compressive strength after heating at T^0C and f_{27} is the compressive strength of concrete at 27^0C.

RESULTS AND DISCUSSION

Table 4 represents measured slump in mm along with 7 days and 28 days concrete compressive strength. As HPC-M mix is containing micro cement, it shows more strength than as compared to HPC-O mix.

Table 4 Fresh and Hardened properties of concrete

Type of Mix	Slump (mm)	7 days compressive strength (MPa)	28 days compressive strength (MPa)
HPC-O	130	55.7	77.7
HPC-M	120	58.2	89.7

Physical Observation

Figure 3 shows the crack pattern of both mixes at three temperatures. No visible cracks and spalling were found up to 450^0C for HPC-O mix, but normal visible cracks were seen to be appeared on HPC-M mixes, and these cracks were more pronounced in the case of specimen subjected to 600^0C, 750^0C and 900^0C. Above 750 ^{0}C, small amount of spalling was observed, corners were damaged and very sensitive to handle. At 900^0C, specimens of both types of mixes were found to be heavily damaged and cracks were found to closer.

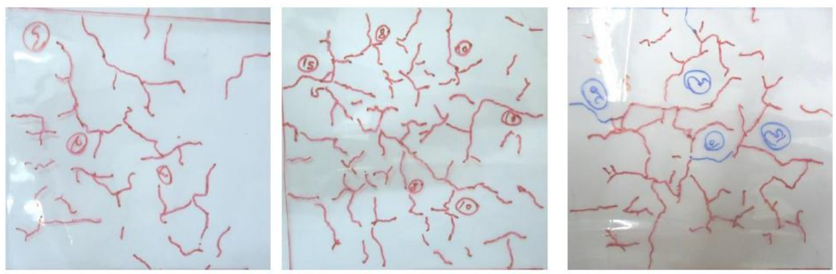
The variation in the colour is observed with respect to temperature exposed. In general at 150^0C, the concrete colour doesn't change noticeably. As temperatures is increased from 300^0C to 450^0C the colour changes from normal to pink or red, changes to whitish grey from 600^0C to 750^0C, and is buff at 900^0C.

Sorptivity Coefficient

The sorptivity coefficient increases with the temperature, hence it can be considered as one of the parameters for the concrete residual strength assessment after exposure to high temperature. Figure 4 shows sorptivity coefficient as a function of temperature. At 300^0C the coefficient shows same trend for both the mixes. The trend changes thereafter, the HPC-O mix shows higher sorptivity coefficient due to the more degradation in the concrete. The sorptivity coefficient of HPC-O and HPC-M mixes at 600^0C are 3.253×10^{-3} and 2.674×10^{-3} respectively. The sorptivity coefficient of HPC-O and HPC-M mixes at 750^0C are 4.672×10^{-3} and 3.875×10^{-3} respectively. The sorptivity coefficient of HPC-O and HPC-M mixes at 900^0C are 7.951×10^{-3} and 6.099×10^{-3} respectively. At all levels of temperature HPC-O mix is showing higher sorptivity. This shows more thermal degradation in HPC-O mix than HPC-M mix.

600 ^{0}C **750 ^{0}C** **900 ^{0}C**

(a) HPC-O



600 ^{0}C **750 ^{0}C** **900 ^{0}C**

(b) HPC-M

Figure. 3 (a) –(b) Crack pattern for both mixes

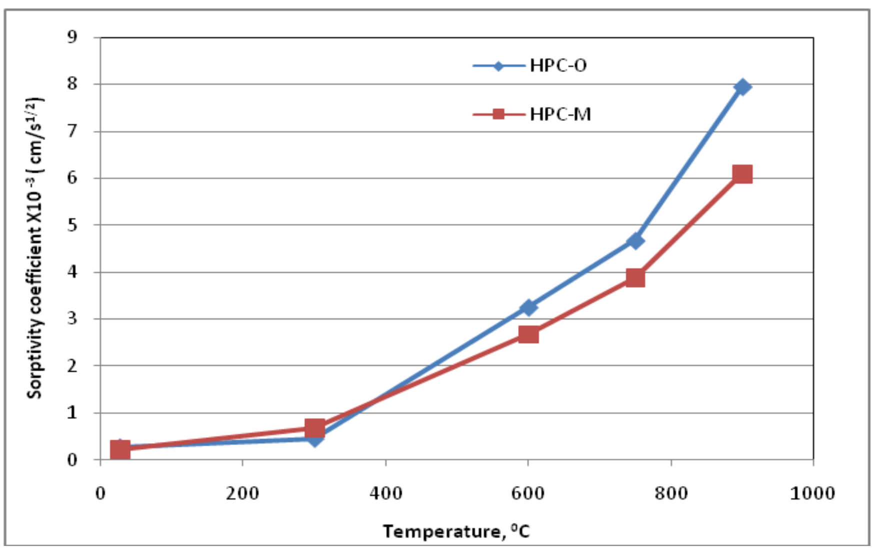


Figure. 4 Sorptivity coefficient as a function of temperature

Ultrasonic Pulse Velocity (UPV)

From figure 5 it is observed that the relative UPV value is found to be the same at 150^{0}C exposure and then it drop continuously. For HPC-O mix concrete relative UPV is 0.86 at 300^{0}C, 0.29 at 450 ^{0}C, 0.31at 600^{0}C, 0.20 at 750^{0}C and 0.20 at 900^{0}C. Whereas for HPC-M mix concrete relative UPV is 0.67 at 300^{0}C, 0.53 at 450 ^{0}C, 0.38 at 600^{0}C, 0.22 at 750^{0}C and 0.22 at 900^{0}C. From 750^{0}C onwords both the mixes show 20 % retention in UPV. For HPC-O mix from 300 ^{0}C to 450 ^{0}C, a sharp reduction in UPV is observed, this may be due to the dehydration of C-S-H gel and transmission of pulse waves from concrete mass is highly influenced by the micro cracking of concrete (Savva, A. et al., 2005). Hoff, G. et al.

(2000), reported that HSC after exposure to elevated temperatures, there was a gradual but significant decrease in pulse velocity with increasing exposure temperatures up to 900^0C. UPV gives quantitative assessment of thermal deterioration in concrete.

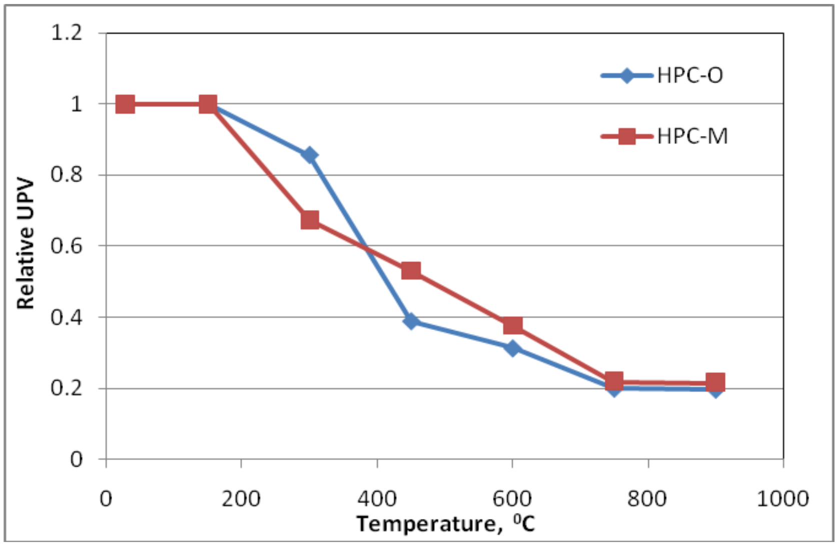


Figure 5: Relative Ultrasonic Pulse Velocity of the concrete exposed to elevated temperatures

Compressive Strength

Form figure 6 the residual compressive strength of HPC- O mix is 92% at 150^0C, 103% at 300^0C, 77% at 450^0C, 54% at 600^0C, 40% at 750^0C and 20% at 900^0C respectively. The residual compressive strength of HPC-M mix is 87% at 150^0C, 94% at 300^0C, 84% at 450^0C, 57% at 600^0C, 26% at 750^0C and 23% at 900^0C respectively. The strength of concrete exposed to high temperature decreases at 150 ^{0}C, then increase between 150 and 300 ^{0}C. 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 (Ghandehari, M. et al. 2010). At 600^0C, the possible chemical transformations include; decomposition of the cementing compound CSH with its different phases, dehydration of calcium hydroxide (CH) into free lime, α-β quartz transformation. These changes would affect the volume occupied by these cementitious products and when combined with the weakened cohesion between the mixture constituents due to the different expansions experienced by each of them. As the temperature reaches to 900^0C, calcium carbonate also decomposes through the loss of CO_2 and all the free or bound water is lost (Chang, W. T. et al. 1994).

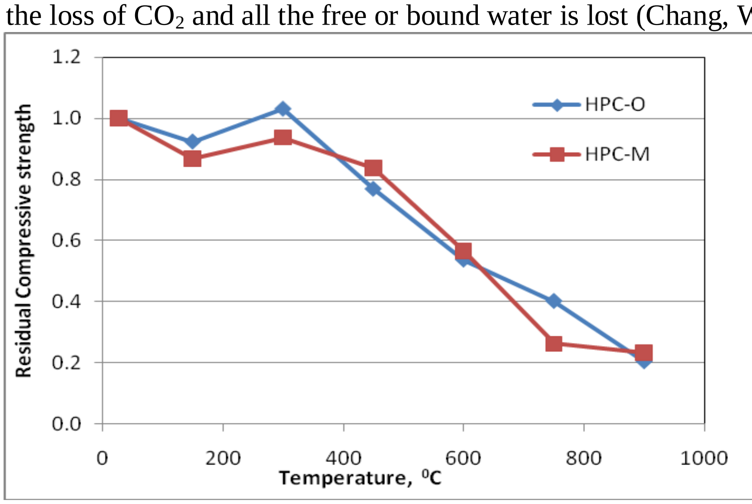


Figure 6: Normalized compressive strength variation with temperatures

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Comparison of research work

Figure 7 shows the residual compressive strength of HPC mix and compared with other researchers. It can be observed that the presented data matches well with the data of Poon, C. S. et al. and Lau, A. and Anson, M. No change in strength up to 400^{0}C, then it decreases sharply as reported by Chan, Y. N. (1999). Benhood, A. and Ziari, H reported an increase in strength from 100^{0}C to 200^{0}C, similar trend is reported in this study, but the magnitude is slightly different. Behnood, A. and Ziari, H. studied the exposure temperature effect with 3 hrs retention period, which has shown larger damage to concrete.

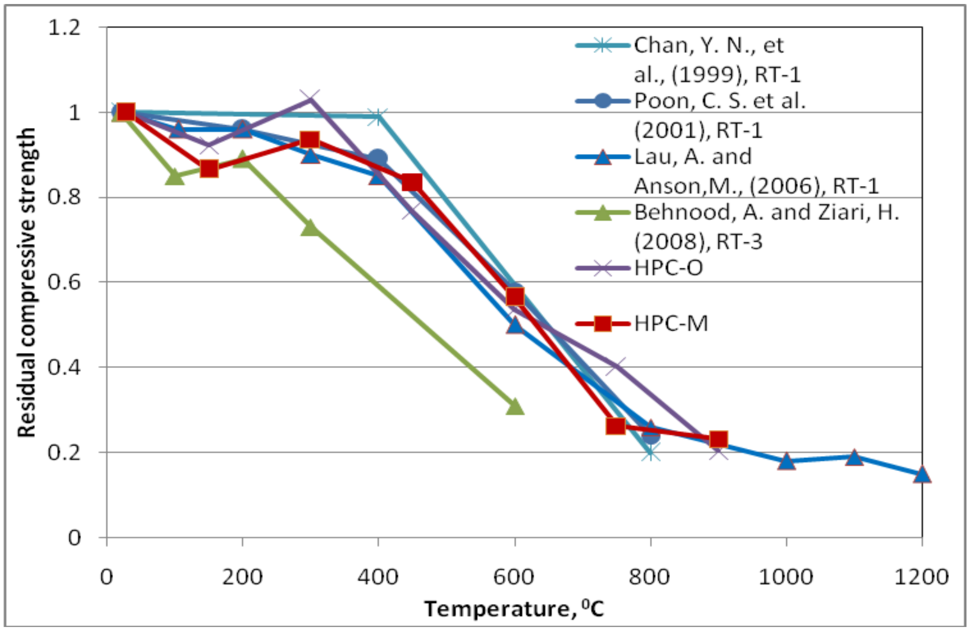

Figure. 7 Comparison of residual compressive strength with other researchers

Conclusions

Overall, HPC at elevated temperatures loses significant amount of its compressive strength above 400^{0}C and attains a strength loss of about 80% at 900^{0}C. HPC-O and HPC-M mixes have shown the same performance under elevated temperatures. The UPV can be used to qualitatively evaluate the residual compressive strength of fire damaged specimen. UPV test offers a rapid and convenient method for the estimation of the residual quality of the concrete after exposure to elevated temperatures. Sorptivity coefficients also gives some valuable information, which can be used as a Non Destructive indicators for the assessment of concrete.

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