TEMPERATURE RISE EFFECT ON HYBRID FIBER REINFORCED SELF COMPACTING CONCRETE USING WASTE MATERIALS

Chinmaya Kumar Mahapatra[1], **Sudhirkumar V Barai**[1]

1. Indian Institute of Technology, Kharagpur, West Bengal, India

ABSTRACT. The current study investigates the residual mechanical properties of self-compacting based hybrid fiber reinforced concrete with low volume class F grade of fly ash and colloidal nano silica exposure to 100°C to 600ºC in a muffle furnace for a time period of 1 h at a constant temperature. Two types of concrete mixes are used in this study: normal control concrete mix and the optimized concrete mix with optimized proportion of four additives. In optimized mix, the recommended proportion of additives are 10% fly ash and 0.4% colloidal nano silica as partial replacement to binder cement by mass; with 1.25% crimped steel fibers and 0.167% of polypropylene fibers by volume of concrete. The tested mechanical properties include residual compressive strengths, residual tensile strength, weight loss, ultra-sonic pulse velocity. Experimental test results inform dependence of mechanical properties on increase in temperature

Keywords: Self-compacting concrete; HyFRC with fly ash and colloidal nano silica; Temperature rise up to 600°C; Mechanical properties

Mr Chinmaya Kumar Mahapatra is a Doctoral scholar of the Departmental of Civil Engineering in Indian Institute of Technology, Kharagpur, West Bengal, India. His interest research area is self-compacting based hybrid fiber reinforced concrete using waste materials.

Dr Sudhirkumar V Barai is the Professor of Structural Engineering, Department of Civil Engineering in Indian Institute of Technology, Kharagpur, West Bengal, India. His research interests are concrete technology, structural health monitoring and computational intelligence applications.

INTRODUCTION

During service life, cement concrete may be in contact with heat, high temperature or fire on its exposed surfaces resulting in deterioration, reduction of resistance even if complete collapse of concrete structure. Upto a temperature of 105°C, water evaporates; within 110 to 170°C gypsum burns. Within 180°C to 300°C burning of C-S-H compound starts. Within the temperature of 450 to 550ºC CH dehydrates; at 700 to 900°C products of $CaCO_3$ melts. Within the temperature range of 400 to 600ºC, Ca $(OH)_2$ available in cement get dehydrated and is converted to CaO resulting in liberation of water and occurrence of shrinkage causes the reduction of compressive strength of concrete [1]. Dehydration and decomposition process within the microstructure of hardened concrete increase the porosity, pore size and affect the chemical bond, thus reduces strength and resistance. The effect of high temperature can be observed in airport aprons, high fire risk chemical industries, chimneys and heavy industries. The behaviour of concrete exposed to high temperature during its service life depends on factors like properties of concrete, rate of heating, maximum temperature of operation, time period of exposure, cooling method after attaining peak temperature with time and method of cooling.

Mixing randomly distributed fibers to concrete can improve toughness against impact, flexural tensile, mechanical properties, ductility and durability. In the study on effect of high temperature on mechanical properties of SFRC, three fiber volume of 0.5%, 1% and 1.5% were used in concrete and exposed to high temperature of 900ºC to 1200ºC and it informs that, the use of steel and polypropylene fibers in concrete can have sufficient resistance against temperature rise. Fibers in concrete modify the nonlinear tensile behaviour, prevent crack propagation and increases its ductility [2]. However, the increased temperature melts the available fibers in the concrete and creates a network of passages to escape steam and prevent the explosions in RC structures [3]. PPF on melting at high temperatures were more effective in mitigating developed maximum pore pressure as compared to polyvinyl alcohol fibres while steel fibres had a slightly low effect [4]. An experimental investigation on hybrid fiber reinforced concrete mixing steel and polypropylene fibers at 27ºC, 200ºC and 400ºC was also conducted and the concrete mix containing a combination of 75% of steel fibers and 25% of PP fibers had better results [5].

In late 80’s in Japan, self-compacting concrete (SCC) was developed. SCC has enough fluidity so that, it can be poured into and filled in the form work completely and compacted by its own weight without any compaction and has resistance against segregation, bleeding. SCC contains more paste volume by adding mineral admixtures and has lower water binder ratio than normal vibratory concrete. FA is a waste product of thermal power plant. By adding in OPC as a partial replacement, it can improve the engineering and durability properties of concrete.

The man objective of the current study is to explore the contribution of an optimized self compacting based hybrid fiber reinforced concrete mix with class F fly ash and colloidal nano silica exposed to temperature rise.

EXPERIMENTAL INVESTIGATION

Raw Materials

Cement

In both concrete mixes, ordinary Portland cement (OPC) of 53 grade confirming to the requirements of Bureau of Indian Standard specifications was used as the main binder [6]. The specific gravity and standard consistency of OPC are 3.16 and 30% respectively. Physical properties of cement are given in Table 1.

Table 1 Physical properties of ordinary Portland cement : OPC (53 grade) [6]

PROPERTY	FINENESS (m^2/kg)	SETTING TIME (MIN)		COMPRESSIVE STRENGTH (MPA)			SOUNDNESS (MM)
		Initial	Final	3 days	7 days	28 days	
Requirement	225.0	30	600	27	37	53	10.0
Tested result	322.5	84	197	38.93	48.34	61.70	1.0

Fly Ash (FA)

Class F grade of FA with specific gravity 2.18 and fineness of 115.2 m^2/kg in accordance with codal provisions of Bureau of Indian Standard specifications [7]. It was procured from thermal power plant at Kolaghat, West Bengal. The properties of FA are given in Table 2.

Table 2 Properties of Fly ash

PHYSICAL PROPERTIES	TEST RESULTS	CHEMICAL COMPOSITIONS	PERCENTAGE BY MASS
Colour	Brackish grey	Loss on ignition	2.57
Specific gravity	2.18	Silica (SiO_2)	55.81
Av. 28 d CS (MPa)	5.21	Iron Oxide (Fe_2O_3)	4.61
		Alumina (Al_2O_3)	35.17
		Calcium Oxide (CaO)	2.29
		Magnesium oxide (MgO)	0.37
		Total Sulphur (SO_3)	0.09
		Alkalis ($Na_2O + K_2O$)	0.77

Colloidal Nano-silica

Locally available colloidal nano silica was used in this experimental work. CNS was in liquid state and white in colour with spherical particles. The physical properties like specific gravity, solid content, particle size, SiO_2 content and pH value were 1.14, 45%, 8-20nm, 99.1% and 10.14 respectively.

Fibers

Crimped steel fibers with circular cross section and PPFs had been used in the current study. The properties of the fibers are mentioned in Table 3.

Table 3 Properties of fibers

PROPERTY	LENGTH (MM)	DIA (MM)	ASPECT RATIO	GEOMETRY	DENSITY (G/CM^3)	MELTING TEMP (ºC)
Steel	25	0.55	45.25	Crimped	7.85	958
Polypropylene	10	0.15	66.67	Straight	0.911	192

Aggregates

River sand with a maximum size of 4.75 mm in confirmation to Zone II gradation was used as fine aggregate to produce concrete mixes [10]. The crushed granite stone of 16 mm maximum size was used as coarse aggregate. Both fine and coarse aggregates conformed to Bureau of Indian Standard specifications [8]. The properties of used fine and coarse aggregates as obtained from laboratory tests are given in Table 4.

Table 4 Properties of aggregates

PROPERTY	SPECIFIC GRAVITY	FINENESS MODULUS	BULK DENSITY ($KG/M^{3)}$	WATER ABSORPTION (%)
Coarse	2.97	6.69	1654	0.91
Fine	2.67	2.56	1798	0.97

Superplasticizer

Liquid polycarboxylate ether based superplasticizer with density of 1.11 and pH nearly 5.6 was used. To ensure proper self-compacting properties of fresh concrete, superplasticizer of 0.2% by weight of total binder was mixed in each concrete mix.

Mix Proportions and Mixing Procedure

Mix proportions

In self-compacting mixes, quantity of fine aggregates used is more than that of coarse aggregates. In each mix in this study, the amount of coarse aggregates and fine aggregates was kept constant as 800 kg/m^3 and 930 kg/m^3 respectively. Mix proportion for M_{60} grade of self-compacting based normal control concrete (NC) without any additive is as per Table 5. Tap drinking water available in the laboratory was used for the preparation of concrete mixes.

Table 5 Ingredient proportions in normal concrete (per cubic meter)

INGREDIENTS	BINDER	FINE AGGREGATES	COARSE AGGREGATES	WATER	SUPERPLASTICIZER
By mass	1.0	1.368	1.176	0.38	0.2% of binder

Mix procedure

A 300 lt. capacity drum type mixture was used for the mixing operation. Prior to mixing, one third mixing water and required amount of PPF were mixed properly and kept in container one. Similarly, one third mixing water along with colloidal NS was mixed separately in container two. In container three, the remaining one third water with superplasticizer were mixed. Initially, dry coarse and fine aggregates and CSF were fed into the drum mixture and mixed for one minute. Then, the mixture of water and PPF kept in container one were poured and mixed for two minutes. The solution of water and CNS kept in container two were fed into the drum and mixed for two minutes. Then, required amount of cement and FA was placed into the mixing drum and mixed for two minutes. Finally, water mixed with superplasticizer kept in container three was poured mixed two minutes to obtain fresh HyFRSCC with FA and colloidal NS with better workability. Total mix time was nine minutes.

Casting of Specimens

After mixing, various self-compacting tests of each fresh concrete mix were conducted. Those include slump flow spread (mm), T_{500} time (s), L-box height ratio and V-funnel time (s) as per the guidelines of EFNARC [9]. Cubes of 100 mm size were casted, cured and tested to find out compressive strength and 100 mm diameter and 200 mm height cylinders were used to find out split tensile strength of concrete at 90 days of curing of each mix.

2.4. Curing and heating of specimens

Immediately after the casting, all the moulds were covered with wet jute bags and plastic sheets. Those were stored at a room temperature of 27ºC for 24 h. Then, demoulded and cured in cold water in the curing tank until the age of 90 days. After removing from water tank, the samples were dried in air for 24 h. Prior to heating in the muffle furnace, each sample had gone through the measurement of size, mass and passing of ultra-sonic pulse velocity. Three number of samples of each mix were tested to find out the mechanical properties at the room temperature of 27°C. Three cubes and three cylinders of each mix were exposed to temperature rise of 100 to 600°C with an increment of 100°C. Temperature rise in the muffle furnace was at the rate of 10ºC per 4 minutes. Once the target temperature was reached within the muffle furnace, a constant temperature was maintained for a period of 1h. to have a thermal steady state condition in each sample, and then cooled down to room temperature within the furnace. During heating, the produced moisture was allowed to escape freely from the furnace.

Testing

Fresh properties

Filling ability, passing ability and segregation resistance are three most important fresh properties of a quality SCC. Viscosity of SCC is specified by slump flow test. V-funnel test is used to evaluate the stability of SCC. V-funnel test informs the flowing stability of SCC. The L-box test informs an indication to both filling ability and passing ability Normally, T_{500} slump flow time (s), spread of slump flow diameter (mm), V-funnel flow time (s), L-box tests are required to check the self-compacting qualities of fresh concrete. Measuring the diameter of the spread in orthogonal directions, the time taken by fresh concrete to reach a diameter of 500 mm is called T_{500} (s). As usual, compressive strength (CS), split tensile strength (STS) and flexural tensile strength (FTS) tests are conducted to ensure the hardened properties of SCC.

Hardened properties

A servo controlled 3500 kN capacity INSTRON testing machine was used to test and ensure the compressive strength of standard cubes of size 100 mm. Compressive strength of concrete cubes was determined at 28, 56 and 90 days of casting. Tensile strength of concrete can be measured indirectly by conducting split tensile test (STS). STS of concrete was conducted after 90 days of curing on concrete cylinders of 100 mm dia x 200 mm height by using displacement controlled 3000 kN capacity servo controlled compression testing machine (CTM). The displacement rate was 1mm/minute.

Concrete mass loss

The average mass of three air dried samples prior to and after heating operation at a pre-defined temperature of one hour within the muffle furnace was recorded. The mass loss of specimens is an index to evaluate the effectiveness to temperature rise.

Ultra-sonic pulse velocity (UPV) test

UPV test is a non-destructive test to evaluate the denseness and homogeneity of the hardened concrete. UPV test was performed. The basic principle of UPV test involves the principle of sending of a wave pulse through concrete sample at one end by an emitter and capturing those by a receiver at the other end; thus measuring the velocity and travel time. In the present experimentation work, the ultra-sonic pulse velocities were measured by using direct transmission method through a Tico ultrasonic testing instrument with a frequency of 54 kHz. UPV was measured for three cylinder specimens of 100 mm diameter and 200 mm length at 90d for each mix.

EXPERIMENTAL TEST RESULTS AND DISCUSSIONS

Properties of Fresh Concrete

The fresh properties like slump flow spread, T_{500} time, V-funnel time and L-box height ratio tests were performed on both types of concrete according to the procedure and guidelines for SCC proposed by EFNARC [9].

Table 6 Fresh properties (average test results)

TYPE OF CONCRETE	AV. SLUMP FLOW SPREAD (MM)	T_{500} TIME (s)	V-FUNNEL TIME (s)	L-BOX HT. RATIO
Normal	722	3.12	3.38	0.99
HyFRC	542	6.74	6.82	0.82

Residual Compressive Strength and Failure Mode

Figure 3 shows the variation of average compressive strength with increase in temperature. It informs that, at 600°C, normal concrete losses its strength upto 70-75 % of its strength at room temperature. Whereas, HyFRC with FA and CNS losses its strength upto 50 % at 600°C temperature. Figure 1 and 2 show the muffle furnace and the condition of HyFRC cube after uniaxial compression test at room temperature respectively.

Residual Tensile Strength

Indirect tensile strength of both normal concrete and HyFRC decrease with increase in temperature. The normal concrete specimens were broken with the application of a minimum load. So, this study was restricted to maximum temperature of 600ºC only. Figure 4 shows the variation of split tensile strength (STS) of both normal concrete and HyFRC with rise in temperature. At a temperature of 600ºC the average STS of HyFRC had reduced to a value of 35.8% of average STS of HyFRC at room temperature, while at 600°C, the average STS of normal concrete had reduced to 25% of average STS of normal concrete at room temperature.

Ultrasonic Pulse Velocity

From the experimental results, the 90d ultrasonic pulse velocity ranged from 4268 to 4789 m/s at room temperature. According to reference [10], the test results more than 3660 m/s are considered as good. After heating the specimens, up to 600ºC again the UPV test was conducted. It was observed that, during initial temperatures, UPV was high and at higher temperatures UPV was lower. Figure 5 shows the average ultra-sonic pulse velocity (m/s) of NC and HyFRC at different temperatures of heating. Within the temperature of 400ºC, both normal and HyFRC was classified as good quality of concrete (UPV ranging from 3500 to 4500 m/s). But, at 600ºC a doubtful type of concrete in term of quality was observed. This reduction in UPV may be due to deterioration of microstructure and degradation of C-S-H gel within harden concrete when exposed to higher temperature.

Concrete Spalling and Mass Loss

In RC structures, the occurrence of spalling may be due to low water to binder ratio, high moisture content and exposure to thermal rise. There are many factors influencing the explosive spalling due to rise in temperature in concrete. Those include heating rate, heating profile, specimen shape and size, moisture content, pore pressure, permeability, age of concrete, strength of concrete, size and type of aggregates, cover to reinforcement, mixing of fibers and air-entrainment agent. Figure 6 shows the average weight loss of both HyFRC and normal concrete at various temperatures. It is observed that, higher loss in weight of samples was observed at higher temperatures. Upto 200ºC, loss was minimal in both NC and HyFRC. At this stage, the loss may be due to evaporation of water from the surface. The weight loss at higher temperatures may be one of the major causes of change in strength and stiffness of concrete. The reason behind this may be due to evaporation of water from C-S-H structure and decomposition of $Ca(OH)_2$ at higher temperatures. It was observed that, in comparison with normal concrete, the weight loss in HyFRC was less.

Figure 1 Muffle furnace

Figure 2 Tested cube at room temperature

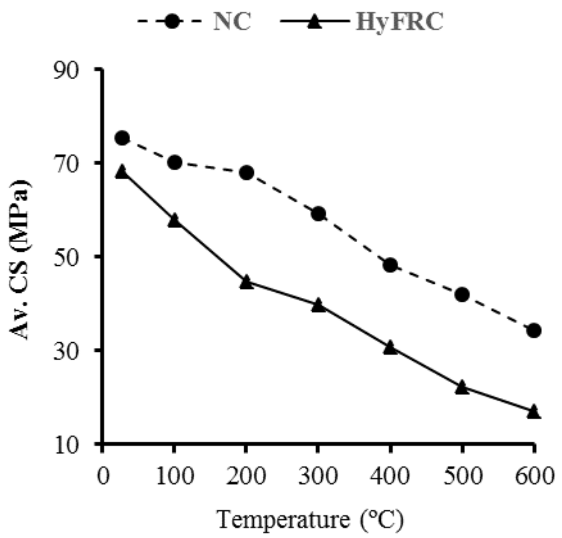

Figure 3 Variation of average compressive strength

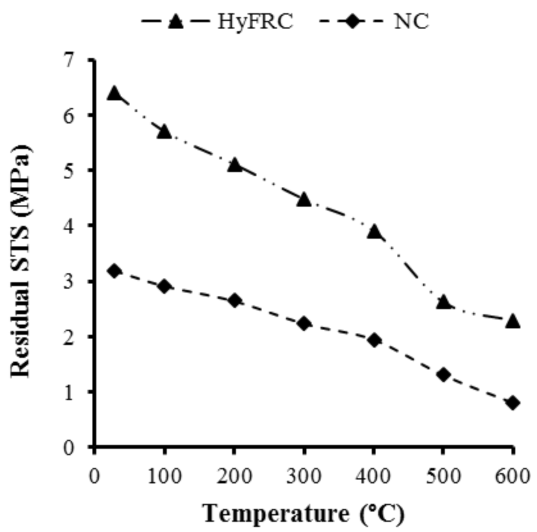

Figure 4 Variation of STS with temperature

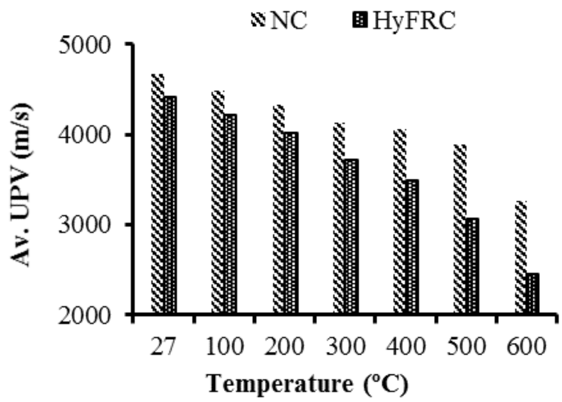

Figure 5 Variation of residual UPV

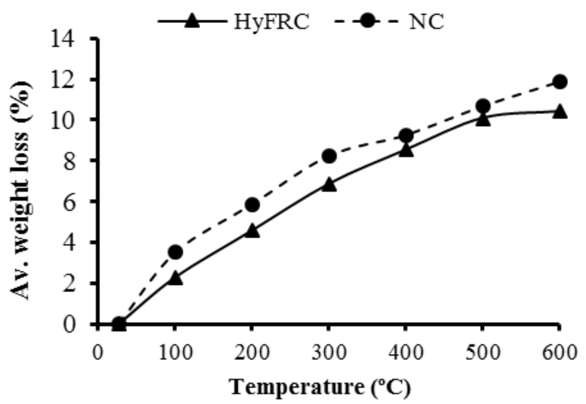

Figure 6 Average weight loss

It was observed that, during heating operation, there was no observation of any explosive spalling.

CONCLUDING REMARKS

Systematic experimental study on one-hour exposure of concrete upto 600ºC temperature lead to the following conclusions.
All the mixes of HyFRC had passed through the self-compacting properties as per specifications.
The test results were within the permissible limit. Upto a temperature of 600ºC, sustainable residual strengths were available in HyFRC with FA and CNS. Within the temperature of 400ºC, with respect to UPV values, NC had shown a good quality of concrete, but at 600ºC the quality of NC was doubtful. In the other way, HyFRC had retained its good quality property upto 600ºC. There was no indication of any spalling in HyFRC up to a temperature of 600ºC, whereas micro cracks were available on the surface of normal concrete. In general, more loss in weight had occurred at higher temperatures. But, out of both types of concrete, in average, HyFRC with FA and CNS had shown comparatively less loss in weight than normal concrete at each temperature increment.

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