International Journal of Advance Research in Science and Engineering
Vol. No.5, Special Issue No. 01, March 2016
www.ijarse.com
IJARSE
ISSN 2319 - 8354

INFLUENCE OF SUDDEN & GRADUAL COOLING REGIMES ON SPLIT TENSILE STRENGTH OF BLENDED CONCRETES SUBJECTED TO SUSTAINED ELEVATED TEMPERATURES

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ABSTRACT

Human safety in case of fire is one of the major considerations in the design of buildings. High temperature causes dramatic physical and chemical changes, resulting in the deterioration of the concrete due to thermal incompatibility between the cement paste and aggregate. This can be minimized by addition of suitable pozzolanic materials.

The main objective of the research is to study the effect of sudden and gradual cooling regimes on M30 grade blended concrete, when subjected to sustained elevated temperatures for 3 hours. The blending materials are fly ash (FA) and ground granulated blast furnace slag (GGBFS) along with cement (C). The temperatures considered for the study are 100^oC, 300^oC, 500^oC, 700^oC and 900^oC. There is a comparison between conventional concrete (C), binary blended concretes (C+FA& C+GGBFS) and ternary blended concrete (C+FA+GGBFS). After temperature test and cooling, concrete specimen undergone to split tensile test. As a result, all the specimens tested for gradual cooling regime shows better split tensile strength than those tested for sudden cooling. Ternary blended concrete (C+FA+GGBFS) shows better resistance against all temperatures compared to binary blended concrete and conventional concrete.

Keywords: Cooling regime, elevated temperatures, gradual, split tensile strength, sudden.

I. INTRODUCTION

Human safety in case of fire is one of the major considerations in the design of buildings. It is extremely necessary to have a complete knowledge about the behavior of all construction materials before using them in the structural elements. Concrete is a non–homogeneous material consisting of hardened cement paste and aggregates. With an increase in temperature, cracking is initiated due to thermal incompatibilities between the aggregates and the hardened cement paste. Developments in 1990's have seen a marked increase in the number of structures involving the first time heating of concrete. These include nuclear reactor pressure vessels, storage tanks for hot crude oil and hot water, coal gasification and liquefaction vessels, pavements subjected to jet engine blast, and in area's exposed to fire. The extensive use of concrete as a structural material in all the above mentioned structures and public utility buildings, multi–storey buildings, exposed to the elements of terrorism necessitated the need to study the behavior of concrete at high temperature and its durability for the required needs.

[1]The study of thermal properties of concrete is an important aspect while dealing with durability of concrete structure exposed to elevated temperature. Damage to the structure depends on the intensity, duration of exposure and also on the combustibility of the materials used in construction. The degree of damage to the structure ranges from slight damage and deflection to a complete collapse of the members and structures as seen in case of world trade center towers. The main role of concrete in a fire is to protect any embedded steel for as long as possible against rise in temperature. Concrete is in itself incombustible and its temperature coefficient is practically the same as that of steel, thus giving it an advantage over materials like structural clay tile, which expands much more rapidly than steel, and hence tends to fail by reason of the destruction of the bond caused by unequal expansion. The rate of heat conductivity of concrete is very low, partly to its porosity and consequent air content, and partly to the dehydration of the water of chemical combination. This later action increases the porosity, and hence the conductivity of the concrete which leads to dehydration. One of the main reasons why Portland cement concrete is so widely used in building construction is that it can help satisfy the need for public safety in face of the hazards of fire better than most of its competitors.

[2] Concrete is incombustible and a reasonable insulator against the transmission of heat. These qualities alone help to counter the fire and limit the extent of damage. The influence of elevated temperature on the mechanical properties of concrete is important for study of behaviour of concrete subjected to fire. The properties of concrete vary according to its constituents.

[3]Two main constituents of concrete viz., cement paste and aggregate have dissimilar thermal co–efficient of expansion. The co–efficient of thermal expansion of cement paste is higher than the coefficient of thermal expansion of the aggregate. It means that the co–efficient of thermal expansion of mortar and concrete is a function of quality of aggregates in the mix and of the co–efficient of thermal expansion of the aggregate itself.

[4] Large difference between the thermal expansion of cement and aggregate causes differential expansion resulting in the rupture of bond at the interface of paste and aggregate. When the stresses developed due to thermal incompatibility are greater it will cause cracking. [5]

II. OBJECTIVES

The experimental investigation has been made to study the effect of sudden and gradual cooling regimes on split tensile strength of M30 conventional concrete (C), binary blended concretes (C+FA& C+GGBFS) and ternary blended concrete (C+FA+GGBFS) against sustained elevated temperatures for 3 hours. The temperatures considered for the study are 100^{o}C, 300^{o}C, 500^{o}C, 700^{o}C and 900^{o}C.

III. MATERIALS

Cement (C) used in this experiment is OPC 43 grade Ultratech brand. Cement is tested and the test results satisfy the requirements of IS: 8112–2013. The physical properties of the tested cement are given in Table 1.

The fly ash (FA) used in the research work is brought from Raichur thermal power plant, Shaktinagar, Raichur, Karnataka and is of class F fly ash. The physical characteristics of fly ash are given in Table 2.

Ground granulated blast furnace slag (GGBFS), the JSW product, used is procured from Quality Polytech, Baikamady industrial area, Mangalore, Karnataka. Physical properties of GGBFS are shown in Table 3.

Locally available sand from Harihara is used as fine aggregate conforming to grading zone II as per IS 383–1970 specifications. The local crushed stone aggregate from Mandihal is used as coarse aggregate (Greywacke) of 20 mm and down size and tested as per IS: 383–1970 [6]and IS: 2386–1963 specifications. Sieve analysis of the fine and coarse aggregate is given inTable 4 and the physical properties for the tested fine and coarse aggregate is given in Table 5.

To improve the workability and to reduce the water content a superplaticizer conplast SP430 conforming to IS: 9103–1979 was used at the rate of 1.0% by weight of cementitious material. It is manufactured by Fosroc chemical (India) limited, Bengaluru, Karnataka. Physical and chemical properties of superplasticizer are shown in Table 6.

Water available in the college campus conforming to requirements of water for concreting and curing as per IS: 456–2000 is used. Water fit for drinking is considered for concrete.

IV. METHODS & TECHNIQUES

In this experiment, concrete is designed for M30 grade as per IS 10262–2009. [7]The maximum nominal size of aggregate is 20mm. Based on several trials, the water-cement ratio is fixed as 0.45. Slump maintained is 100mm. The mix proportion obtained 1: 2.02: 3.45.

Here, we have 6 sustained elevated temperatures, 4 blends in percentage by weight and 2 cooling regimes. Totally it became 48 combinations. The details of combinations are as shown in Table 7.

The mixing procedure is according to following steps:

- Separately mixed the cementitious materials (C, C+FA, C+GGBFS, C+FA+GGBFS).
- Dry mixed the sand and cementitious materials.
- Added coarse aggregate to it and mixed thoroughly to achieve a homogeneous dry mix.
- Water quantity is separated as 80% and 20%.Calculated quantity of superplasticizer (1% by weight of cementitious material) is mixed with 20% of water.
- 80% of total quantity of water is added to the dry mix and started mixing.
- Immediately, remaining 20% of water with superplasticizer is added to it to achieve homogeneous wet mix.

Fresh concrete is poured into the cylinder moulds in five layers, each layer being compacted by using standard tamping rod thoroughly and vibrated using table vibrator to achieve an adequate compaction. After adequate compaction, top surface of specimens were covered by wet gunny bags. After 24 hrs, they were demoulded and transferred to curing tank wherein they were allowed to cure for the required period of 28 days. For assessing split tensile strengths of concretes, standard cylinder specimens of 150 mm diameter and 300 mm height were cast.

Sustained elevated temperature test is conducted at Pyrotech Engineers, Heat treatment plant, Udyambag, Belagavi, Karnataka. A pit type electrical furnace buried inside the ground consisting of elements of Canthol wire giving electrical load of 32kW was used for sustained elevated temperature testing of concrete specimens. The maximum temperature of the furnace is 1200^{o}C. Furnace was cylindrical in shape having 400mm diameter and 1.2m deep. Furnace having control panel with temperature indicator, temperature sensor, and ampere rating. Fig. 1 shows the time v/s temperature curve graph of furnace used for heating the specimens which resembles the graph in ISO 834.[8]There is a knob to set the desired oven temperature. Once the set temperature is reached, specimens were kept inside the furnace, unstressed for 3 hours (retention period).

There are two types of cooling regimes. One is sudden cooling and another is gradual cooling. Sudden cooling means, after taking the concrete specimens from the furnace, water is poured on it. Gradual cooling means, after taking out the concrete specimens from the furnace were kept as it is for air cooling.

After sustained elevated temperature test and cooling regimes, the split tensile strength test is carried out in accordance with IS: 5816–1999.[9]

V. RESULTS & DISCUSSIONS

Table 8, Table 9 and Fig. 2, shows the split tensile strength results and its variations for all the blend combinations, for both sudden and gradual cooling regimes v/s all the sustained elevated temperatures for 3 hours.

Observing table 7, table 8 and fig. 2, it is clear that,at RT (30^{o}C), all the combinations shows better split tensile strength results. As temperature goes on increasing, split tensile strength goes on decreasing for all the combinations. Till 300^{o}C, there is slight variation, beyond that split tensile strength reduced drastically and maximum loss of split tensile strength observed at 900^{o}C for all the combinations.

There is slight variation in split tensile strength between two cooling regimes, in that gradual cooling shows better results compared to sudden cooling against all the temperatures and for all the combinations. This is because, due to sudden cooling there is a thermal shock on concrete, thus it ruptures the intermolecular bond between the constituents. Meanwhile at gradual cooling, specimens absorbed moisture from the atmosphere and rebuilding of strength may take place. Ternary blended concrete (C+FA+GGBFS) shows better resistance against all temperatures compared to binary blended concrete (C+FA and C+GGBFS) and conventional concrete (C) because, ternary blend reduces the porosity.

VI. TABLES AND FIGURES

6.1 Tables

Table 1 Physical properties of OPC 43 Grade Cement (C)

Particulars	Test Results	Requirements as per IS: 8112–2013
Fineness (m^2/Kg) by Blaine's air permeability method	270	225 (Min.)
Fineness (%) by dry sieving	4	
Specific Gravity	3.15	
Setting Time (minutes) a. Initial, b. Final	60, 320	30 (Min.), 600 (Max.)
Soundness by Le–chatelier's expansion method (mm)	2	10 (Max.)
Soundness by Autoclave method expansion method (%)	0.2	0.8 (Max.)
Compressive strength (MPa) a. 3, b. 7, c. 28 days	27, 38, 44	23, 33, 43 (Min.)

Table 2 Physical properties of fly ash (FA)

Particulars	Test Results	Requirement as per IS: 3812 (Part 1)–2013
Fineness (m^2/kg) by Blaine's permeability method	333	320 (Min.)
Particles retained on 45 micron IS sieve by Wet sieving (%)	4.52	34 (Max.)
Specific Gravity	2.15	
Lime reactivity, average compressive strength (MPa)	4.68	4.5 (Min.)
Compressive strength at 28 days (MPa)	23	
Soundness by autoclave test – Expansion of specimen (%)	0.2	0.8 (Max.)

Table 3 Physical properties of Ground granulated blast furnace slag (GGBFS)

Particulars	Test Results	Requirement as per IS: 12089–1987
Fineness as specific surface m^2/Kg	350	275 (Min.)
Compressive strength (MPa) a. 7, b. 28 days	31.66, 48.33	12, 32.5 (Min.)
Soundness, Le–Chatelier Expansion (mm)	0.0	10 (Max.)
Initial setting time (min)	120	30 (Min.)
Specific Gravity	2.85	

Table 4 Sieve analysis of fine aggregate and coarse aggregate

IS sieve size	Sieve analysis of fine aggregate		Sieve analysis of coarse aggregate	
	Cumulative percentage passing finer (%)	Grading limit for zone II as per IS: 383–1970	Cumulative percentage passing finer (%)	Grading limit for 20mm as per IS: 383–1970
40mm	100	100	100	100
20mm	100	100	99	95–100
10mm	100	100	45.8	25–55
4.75 mm	97	90–100	0.4	0–10
2.36 mm	91	75–100	0	–
1.18 mm	69	55–90	0	–
600 µm	41	35–59	0	–
300 µm	12	8–30	0	–
150 µm	2	0–10	0	–
Pan	–	–	–	–
Fineness modulus	2.88		6.54	

Table 5 Physical properties of fine aggregate and coarse aggregate

Particulars	Fine aggregate		Coarse aggregate	
	Test Results	Permissible limit as per IS: 2386–1963	Test Results	Permissible limit as per IS: 2386–1963
Organic impurities	Colourless	Colourless	–	
Silt content (%)	1.8	6–10% (Max.)	–	
Specific gravity	2.60		2.65	
Bulking of sand (%)	8.2	40% (Max.)	–	
Free moisture content	0.0		0.0	
Water Absorption (%)	1.0		0.6	
Bulk Density (Kg/m^3) a. Loose condition b. Compact condition	 1752.09. 1827.12		 1782.64 1886.53	
Impact value (%)	–		15	30% (Max.)
Crushing value (%)	–		14.5	30% (Max.)

Table 6 Physical and chemical properties of superplasticizer

Particulars	Properties
Specific Gravity	1.22
Physical state & Chloride content	Liquid &Nil (IS: 456–2000)
Air entrainment	1%
Colour, Odour	Brown, Slight/faint
pH (Concentrate)	7–8
Boiling point (°C) & Flash point, closed (°C)	>100 & None
Vapour pressure (kPa @ 20 °C)	2.3
Relative density (@ 20 °C)	1.2
Water solubility	Soluble
Dosage	0.5–2.0 litre/100Kg cement

Table 7 Combinations

Combination Details			
Sustained elevated temperature	Blend	Percentage by weight	Cooling regime
RT (30°C)	C	[100% Cement]	Sudden Cooling
100°C	C+FA	[70% Cement + 30% Fly Ash]	Gradual Cooling
300°C	C+GGBFS	[70% Cement + 30% GGGBFS]	
500°C	C+FA+GGBFS	[70% Cement + 15% Fly Ash +15% GGBFS]	
700°C			
900°C			

Table 8 Split tensile strength results for C, C+FA blend combinations, for both sudden and gradual cooling regimes v/s all the sustained elevated temperatures for 3 hours

Sustained elevated temperature (°C)	Blend Combination	C				C+FA			
	Cooling Regime	Sudden cooling		Gradual cooling		Sudden cooling		Gradual cooling	
	Particulars	Avg. Split Tensile Strength (MPa)	% increase or decrease	Avg. Split Tensile Strength (MPa)	% increase or decrease	Avg. Split Tensile Strength (MPa)	% increase or decrease	Avg. Split Tensile Strength (MPa)	% increase or decrease
RT (30°C)	Results	3.86		3.98		4.18		4.28	
100°C		3.76	-2.59	3.88	-2.51	4.08	-2.39	4.18	-2.34
300°C		3.40	-11.92	3.51	-11.81	3.72	-11.00	3.82	-10.75
500°C		2.18	-43.52	2.32	-41.71	2.54	-39.23	2.68	-37.38
700°C		0.90	-76.68	1.12	-71.86	1.66	-60.29	1.78	-58.41
900°C		0.18	-95.34	0.45	-88.69	1.08	-74.16	1.25	-70.79

Table 9 Split tensile strength results for C+GGBFS, C+FA+GGBFS blend combinations, for both sudden and gradual cooling regimes v/s all the sustained elevated temperatures for 3 hours

Sustained elevated temperature (°C)	Blend Combination	C+GGBFS				C+FA+GGBFS			
	Cooling Regime	Sudden cooling		Gradual cooling		Sudden cooling		Gradual cooling	
	Particulars	Avg. Split Tensile Strength (MPa)	% increase or decrease	Avg. Split Tensile Strength (MPa)	% increase or decrease	Avg. Split Tensile Strength (MPa)	% increase or decrease	Avg. Split Tensile Strength (MPa)	% increase or decrease
RT (30°C)	Results	4.38		4.50		4.78		4.90	
100°C		4.28	-2.28	4.40	-2.22	4.69	-1.88	4.81	-1.84
300°C		3.92	-10.50	4.04	-10.22	4.32	-9.62	4.45	-9.18
500°C		2.80	-36.07	2.94	-34.67	3.42	-28.45	3.68	-24.90
700°C		1.98	-54.79	2.12	-52.89	2.68	-43.93	2.82	-42.45
900°C		1.34	-69.41	1.48	-67.11	1.78	-62.76	1.89	-61.43

6.2 Figures:

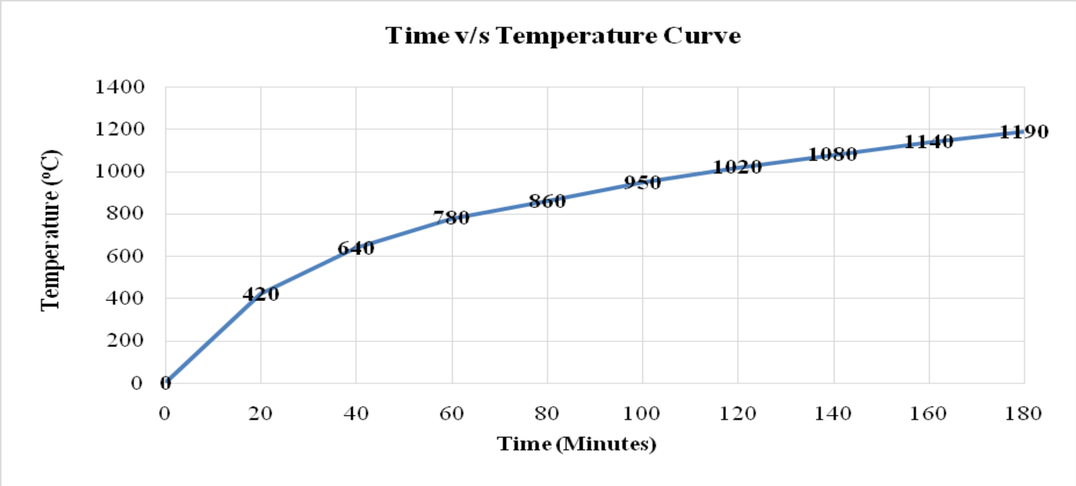

Fig. 1 Time v/s temperature curve graph of the furnace

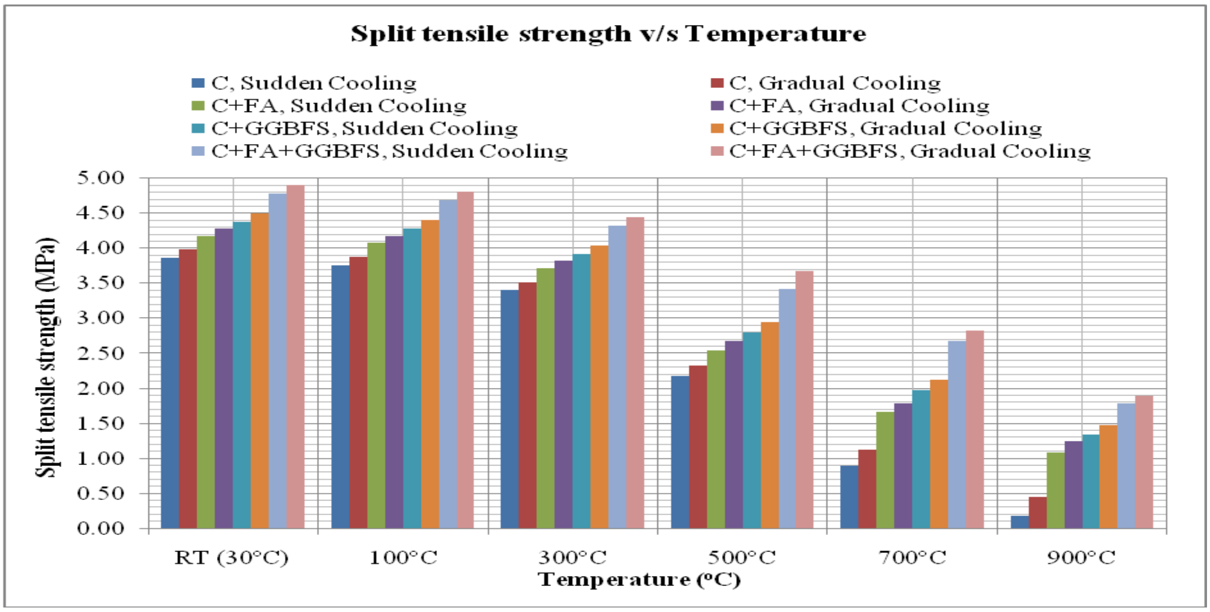

Fig. 2 Variation of split tensile strength results for all the blend combinations [C, C+FA, C+GGBFS, C+FA+GGBFS] for both sudden and gradual cooling regimes v/s all the sustained elevated temperatures for 3 hours

VII. CONCLUSIONS

At RT (30°C), all the combinations shows better split tensile strength results. As temperature goes on increasing, split tensile strength goes on decreasing for all the combinations. Till 300°C, there is slight variation, beyond that split tensile strength reduced drastically and maximum loss of split tensile strength observed at 900°C for all the combinations. Gradual cooling shows better results compared to sudden cooling against all the temperatures and for all the combinations. Ternary blended concrete (C+FA+GGBFS) shows better resistance against all temperatures compared to binary blended concrete (C+FA and C+GGBFS) and conventional concrete (C).

VIII. ACKNOWLEDGEMENTS

We are thankful to Pyrotech Engineers, Heat treatment plant, Udyambag, Belagavi, Karnataka, India for assisting and permitting us to conduct sustained elevated test at reasonable rate. We are also thankful to Principal, for permitting us to conduct split tensile test at B. M. T. Laboratory, Department of Civil Engineering, of K. L. E's. Dr. M. S. Sheshgiri College of Engineering & Technology, Udyambag, Belagavi, Karnataka, India.

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