EXPERIMENTAL INVESTIGATION ON MECHANICAL PROPERTIES OF SELF COMPACTING CONCRETE UNDER ELEVATED TEMPERATURES

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Abstract- Self-compacting concrete or self-consolidating concrete has potential application in many places specially in areas where concrete has to be placed inhighly congested reinforcement. Self Compacting Concrete (SCC) is defined as a category of high performance concrete that has excellent deformability in the fresh state and high resistance to segregation, and can be placed and compacted under its self weight without applying vibration. The higher density and lower permeability of SCC make it susceptible to spalling under severe exposure to fire environment. A mix design procedure for the design of SCC mixes has been developed by modifying the mix proportions arrived from Indian Standard mix design method for different grades of concrete. Flow and strength properties were determined by experimental investigation. The flow properties such as filling ability, passing ability and segregation resistance were found using the Slump Flow, J-Ring and V-Funnel test setups respectively. It was found that the requirements of SCC were satisfied. An attempt has been made to study the effect of elevated temperature on SCC specimens heated from 27ºC to 900ºC under hot condition. The specimens were heated using aElectrical furnace. Mechanical properties such as compressive strength, tensile strength, flexural strength and modulus of elasticity of the refernce and heated specimens were found.The reduction in the compressive, tensile and flexural strengths of SCC specimens were found to be 82.63%, 80.22%and 79.14% respectively for M40 concrete when compared with the reference specimen.

Keywords- Self Compacting Concrete, Elevated Temperature, Superplasticizer, Viscosity Modifying Agent, Compressive Strength, Tensile Strength, Flexural Strength.

I. INTRODUCTION

Concrete is a material often used in the construction of high rise buildings. In case of unexpected fire, the propertiesof concrete may change after fire.It is important to understand the changes in the properties concrete after exposureto extreme temperature. As SCC is a special purpose concrete containing mineral and chemical admixtures, the risk of damage due to exposure to high temperature also increases. To be able to predict the response of structure after exposure to high temperature, it is essential that the strength properties of concrete subjected to high temperatures be clearly understood.

High temperature can cause the development of cracks and spalling. These cracks like any other cracks may eventually cause loss of structural integrity and shortening of the service life. The reinforced concrete structures are inherently fire resistant. However, the spalling of concrete would expose steel reinforcements in a reinforced concrete member during fire hazard, which could further damage the components or structure. The influence of elevated temperatures on mechanical properties of concrete is important for fire resistance studies and also for understanding the behavior of containment vessels, chimneys, nuclear reactor pressure vessels during service and ultimate conditions. The variationsin the compressive strength, tensile strength and flexural strength are some of the important parameters to be investigated when concrete structures are subjected to temperatures.

II. LITERATURE REVIEW

Y.N.Chan et al (2000)reported that high performance concrete exposed to high temperature may result in spalling which may occur due to the dense internal microstructure, which makes it difficult for water vapour to escape from concrete.

Persson(2004)indicated that fire spalling is mainly dependent on the stress in the concrete, the cement-powder ratio and water cement ratio. Lower elastic modulus at fire temperature was observed in SCC than vibrated concrete.

Metin husem (2006) indicated that strength of concrete decreases with increasing temperature, and the decrease in the strength of ordinary concrete is more than that in high-performance concrete. The type of cooling affects the residual compressive and flexural strength, the effect being more pronounced as the temperature increases.

Noumowe et al(2006)found that the risk of spalling for self-compacting high-strength concrete was greater than that of conventional high-strength concrete.

Kosmas K Sideris (2007) found that the main reason for concrete's spalling at elevated temperatures is considered to be the internal pore pressure build-up due to the vaporization of the free and chemically bound water. In concrete mixtures with finer pore structure, such as HPC, this internal pressure is not

released, thus leading to spalling of the concrete surface. Omer Arioz (2007) indicated that weight of the concrete specimens significantly reduced with an increase in temperature. This reduction was found to be very sharp beyond 800°C. Jin Tao et al(2010)found that SCC, High strength concrete and Self compacting concrete with polypropylene fiber are very sensitive to high temperature in spite of their good mechanical properties at room temperature. The hot compressive strength of SCC was found to decrease as the exposure temperature increased. Strength grade had an effect on the strength loss of concrete, especially in the temperature range above 400°C.

Bakhtiyari et al(2011) found that SCC mixes showed a higher susceptibility to spalling at high temperatures but the normal concrete mixes suffered much more loss of the mechanical strength. Both the powder type and the compressive strength notably influenced the fire behavior of the SCC. The main reasons for failure of a concrete element at high temperatures were spalling and loss of strength.

Dougill et al (1968) indicated that the differential strains between the aggregate and cement paste can initially induce a small compressive stress in the paste. As the temperature increases, the compressive stress decreases and changes into a larger tensile stress. Roux et al(1974) reported that the tensile stress developed due to thermal incompatibility may be large enough to cause cracks in concrete.

Anand.N et al (2013) investigated the effect of different grade of concrete on the performance of SCC beams exposed to high temperatures. This research was carried out for various grades of SCC beams under different heating and cooling conditions. It was found that the reduction in the compressive strength, tensile strength and the flexural strength of SCC specimens slightly increases as the grade increases for all heating and cooling conditions. The maximum reduction in the compressive strength, tensile strength and the flexural strength was 79.8%, 82.9% and 82.2% respectively for the M40 grade specimens that are heated from room temperature to 900°C and cooled by spraying water.

Anand.N et al (2014) found that the percentage reduction in compressive strength is more for SCC compared to normal concrete in the case of specimens heated from 27°C to 600°C and 900°C. For normal concrete of M40 grade, the percentage reduction was 60.06% and for SCC, the percentage reduction was 81.50%.

III. OBJECTIVES OF THE RESEARCH

Following are the objectives of the research.
i) To develop selfcompacting concrete mixes of grades M25, M30, M35 and M40with mineral admixture (Flyash) and chemical admixture (SP& VMA)
ii) To study the mechanical properties of SCC specimens under elevated temperature of 900º

IV. EXPERIMENTAL INVESTIGATION

A. Materials
Ordinary Portland Cement (OPC) conforming to IS: 12269 was used for the investigation. The specific gravity was 3.15. Locally available river sand was used as fine aggregate. The specific gravity of the sand was 2.70 and it was conforming to Zone-II of IS: 383–1970. The sand was dried before use to avoid the problem of bulking. Locally available granite with a size 10 mm and down was used as coarse aggregate. The specific gravity of the coarse aggregate was 2.96. Potable water was used for mixing and curing. In order to achieve the necessary flowability without segregation, flyashfrom a local thermal power station was used. Two types of chemical admixtures were used for the production of SCC, one was Super Plasticizer (SP) and the other one was Viscosity Modifying Agent (VMA). Master Glenium Sky 8630 was used as a super plasticizer in this study. The specific gravity of the SP used was found to be 1.09. Glenium Stream 2 was used as VMA.

B. Mix Design
Using the mix design procedure developed by Prince Arulraj and Jemi Elizabeth(2008), M25, M30, M35 and M40 grades of SCC were designed. Concrete was made self compactable by adjusting the proportions of the Conventional Concrete obtained as per IS 10262:2009 method. Cement was not replaced with flyash. flyash was added to the mix such that it replaces either the fine aggregate or coarse aggregate whichever is more till the coarse aggregate content is slightly less than the fine aggregate. The flow properties such as filling ability, passing ability and segregation resistance were checked by conducting the Slump flow test, J-ring test and V-funnel test and found to be satisfactory. Hardened properties of SCC such as compressive strength, tensile strength and flexural strength were found following the procedures given in respective Bureau of Indian Standards. The proportions of admixtures, workability test results on fresh SCC and the mix proportions are givenin Table I, Table II and Table III respectively.

Table I :Proportions of Admixtures

Grade of concrete	Quantity of Flyash (%)	Quantity of SP (%)	Quantity of VMA (%)	
M25	8	1.0	0.12	
M30	13	1.2	0.10	
M35	17		1.8	0.05
M40	20		2.0	0.05

Table II : Workability Test Results on Fresh SCC

Grade of Concrete	Slump flow spread diameter (mm)	T_{50} Slump Flow Time (sec)	J-Ring height difference (mm)	V-Funnel Time (sec)	V-Funnel T_5 (sec)
M25	745	3.23	8	9.2	12.2
M30	695	2.89	7	9.4	12.4
M35	734	4.31	7	10.5	12.5
M40	730	3.10	9	11.1	13.0

Table III. Mix Proportion of SCC

Grade of Concrete	Cement (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)	Flyash (kg/m^3)	w/c ratio	SP (lt/m^3)	VMA (lt/m^3)
M25	359	911.6	931.2	125.8	0.44	4.38	0.52
M30	405	878.8	898.17	170.9	0.40	6.87	0.54
M35	441	855.6	863.2	201.8	0.38	8.9	0.38
M40	479.3	802.8	844.9	224.4	0.36	11.92	0.33

C. Testing of Specimens under Elevated Temperature

An electrical furnace was used to heat the specimens. The inner dimensions of the furnace are 500mmx500mmx500mm. The sides and top are lined with electrical heating coils embedded in refractory bricks. The SCC specimensafter 28 days of curing were exposed to fire inside the furnace and the specimens were heated from 27°C to 900°C. After exposing the specimens to desired temperature and duration, the furnace was switched off and the specimens were taken out of the furnace.Mechanical properties of the SCC specimens were found for the reference and the specimens that were subjected to elevated temperatures. The view of the furnace used is shown in Fig. 1. The compression testing machine used is shown in Fig. 2.

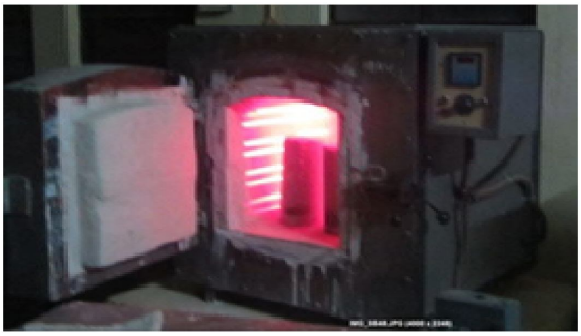


Fig. 1. View of Muffle Furnace



Fig. 2. Testing of Cube Specimen

D. Experimental Investigation on SCCUnder Elevated Temperature

In order to understand the effects of elevated temperature on the properties of SCC, an extensive laboratory investigation was carried out. Experimental investigation was carried out to determine the mechanical properties of different grade of SCC specimens. Tests were carried out on cube, cylinder and beam specimens. Specimens were heated to the test temperature in an unloaded condition and then loaded to failure. This type of test is known as unstressed test. Unstressed test was carried out to determine the performance of SCC specimens subjected to elevated temperatures. The heating curve is shown in Fig. 3.

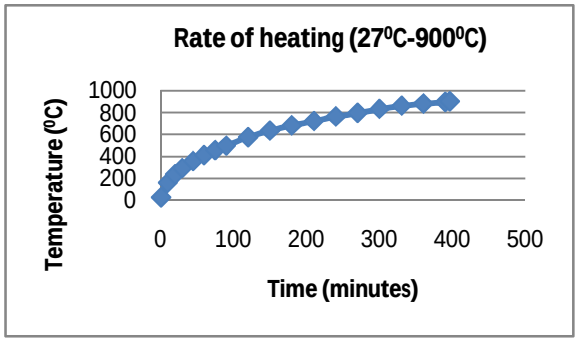


Fig. 3. Rate of Heating

During the present investigation 48 cube specimens, 48 cylinder specimens and 48 beam specimens were tested. Table IV gives the details of the specimens used for the experimental investigation. The compressive strengths of reference and hot specimens are given in Table V and the percentage reductions in the compressive strength of heated specimens with respect to the reference specimens are given in Table VI.

Table .IV Details of Specimens Used for Experimental Investigation

Size of beam (mm)	Size of cube (mm)	Size of cylinder (mm)	Grade of concrete	Temperature
500x100 x100	150x150 x150	150x 300	M25, 30, M35, 40	Reference specimen
500x100 x100	150x150 x150	150x 300	M25, 30, M35, 40	27°C to 300^0C,600^0C &900^0C

Table .V Compressive Strength of Self Compacting Concrete

Grade of Concrete	Compressive Strength (N/mm^2)			
	Reference Specimen	300°C	600°C	900°C
M25	27.56	28.85	14.05	8.10
M30	32.20	34.50	16.41	7.95
M35	36.68	38.80	18.62	7.86
M40	42.50	44.52	20.75	7.75

Table .VI Percentage Reduction in Compressive strength w.r.t reference specimen

Grade of Concrete	% Increase/ Reduction in Compressive strength w.r.t reference specimen		
	300°C	600°C	900°C
M25	4.47	49.02	70.60
M30	6.66	49.03	75.31
M35	5.46	49.23	78.57
M40	4.53	51.17	81.76

Table VII gives the details of the tensile strength of reference and hot specimens and Table VIII gives the reduction in the tensile strength of heated specimens with respect to the reference specimens.

Table .VII Tensile Strength of Self Compacting Concrete

Grade of Concrete	Tensile Strength (N/mm^2)			
	Reference Specimen	300°C	600°C	900°C
M25	2.72	2.46	1.62	0.67
M30	3.56	3.22	2.16	0.80
M35	4.02	3.64	2.40	0.83
M40	4.45	4.03	2.65	0.88

Table .VIIIPercentage Reduction in Tensile strength w.r.t reference specimen

Grade of Concrete	% Reduction in Tensile strength w.r.t reference specimen		
	300°C	600°C	900°C
M25	9.55	40.44	75.36
M30	9.55	39.32	77.52
M35	9.45	40.29	79.35
M40	9.43	40.44	80.22

Table XI gives the details of the Flexural Strength of reference and hot specimens.

Table .XI Flexural Strength of Self Compacting Concrete

Grade of Concrete	Flexural Strength (N/mm^2)			
	Reference Specimen	300°C	600°C	900°C
M25	4.86	4.33	2.85	1.05
M30	5.29	4.66	3.22	1.11
M35	5.76	5.10	3.55	1.24
M40	6.26	5.55	3.85	1.35

Table .X Percentage Reduction in Flexural strength w.r.t reference specimen

Grade of Concrete	% Reduction in Flexurale strength w.r.t reference specimen		
	300°C	600°C	900°C
M25	10.91	41.36	78.40
M30	11.91	39.13	79.02
M35	11.46	38.37	78.47
M40	11.34	38.50	78.43

Table XI gives the details of the Modulus of elasticity of reference and hot specimens.

Table.XI Modulus of Elasticity of Self Compacting Concrete

Grade of Concrete	Modulus of Elasticity (N/mm^2)			
	Reference Specimen	300°C	600°C	900°C
M25	20650.80	20955.5	15930.4	9035.4
M30	21576.01	21876.2	16811.3	9132.7
M35	22905.02	23115.3	17691.9	9253.8
M40	23616.94	23891.5	18448.6	9360.8

CONCLUSIONS

Self compacting concrete mixes of grade M25, M30, M35 and M40 were developed using flyash, Superplasticizer and Viscosity Modifying Agent.Compressive strength of SCCwas found to decrease by70.60%, 75.31%, 78.57% and 81.76% respectively for M25, M30, M35 and M40concretewhen exposed to a temperature of 900° compared to reference specimen.

Tensile strength of SCC was found to decrease by75.36%, 77.52%, 79.35% and 80.22% respectively for M25, M30, M35 and M40 concrete when exposed to a temperature of 900° compared to reference specimen.Flexural strength of SCC was found to decrease by78.40%, 79.02%, 78.47% and 78.43% for M25, M30, M35 and M40 grade concrete under elevated temperature (900°) compared to reference specimen.

It is found that as the temperature increases, compressive strength, tensile strength and flexural strength of Self Compacting Concrete was found to decrease. The pecentage reduction in strength of SCC specimens were found to increase as the grade of concrete increases. It was marginal and insignificant.

REFERENCES

[1]. Chan. Y. N., Luo. X. and Sun. W."Compressive strength and pore structure of high-performance concrete after exposure to high temperature up to 800ºC", Cement and Concrete Research 30, pp.247–251, 2000.

[2]. Persson. B."Fire resistance of self-compacting concrete, SCC", Materials and Structures, Vol. 37, pp.575-584,November 2004.

[3]. Metinhusem "The effects of high temperature on compressive and flexural strengths of ordinary and high-performance concrete", Fire safety Journal 41, pp.155–163. 2006.

[4]. Noumowe. A., Carre. H., Daoud. A. and Toutanji. H. "High-Strength Self-compacting concrete exposed to fire Test", Journal of Materials in Civil Engineering, pp.754-758, December 2006.

[5]. Kosmas K. Sideris "Mechanical Characteristics of Self-Consolidating Concretes Exposed to Elevated Temperatures", Journal of Materials in Civil Engineering 19, pp.648-654, August 2007.

[6]. Omer Arioz "Effects of elevated temperatures on properties of concrete", Fire Safety Journal 42, pp.516–522, March 2007.

[7]. Jin Tao., Yong Yuan and Luc Taerwe "Compressive Strength of Self-compacting Concrete during High-Temperature Exposure", Journal of Materials in Civil Engineering, pp.1005-1011, October 2010.

[8]. Bakhtiyari. S., Allahverdi. A., Rais-Ghasemi. M., Ramezanianpour. A. A., Parhizkar. T. and Zarrabi. B. A. "Mix design, compressive strength and resistance to elevated temperature (500°C) of self-compacting concretes containing limestone and quartz fillers", International Journal of Civil Engineering, Vol9, No 3,pp.215-222, September 2011.

[9]. Recommended Guidelines For Concrete Mix Design IS 10262-2009.

[10]. PrinceArulraj G, JemiElizabeth J,"Experimental investigation on properties of self compacting concrete" In: Proceedings of the 3rdCUSAT national conference on recent advances in civil engineering, pp 119–122, December 2008

[11]. Anand.N and Prince Arulraj. "Effect of grade of concrete on the performance of self compacting concrete beams subjected to elevated temperatures", Fire Technology (2013).

[12]. Anand.N and Prince Arulraj "Stress-Strain Behaviour of Normal Compacting and Self Compacting Concrete Under Elevated Temperatures", Journal of Structural Fire Engineering,Vol 5, No 1, pp.63-75, March 2014.

[13]. J.W. Dougill, "Some effects of thermal volume changes on the properties and behavior of concrete", The Structure of Concrete, Cement and Concrete Association, London, 1968, pp. 499–513.

[14]. F.J.P. Roux. "Concrete at elevated temperature", PhD Thesis, University of Cape Town, 1974.



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