Influence of Elevated Temperature and Steel Fiber on High Volume Fly Ash High Strength Self Compacting Concrete

Ved Amonkar[#], V. D. Gundakalle[*]

[#]Postgraduate Student, Department of Civil Engineering, KLE Dr. M. S. Sheshgiri College of Engineering and Technology, Belagavi, Karnataka, India

*Professor, Department of Civil Engineering, KLE Dr. M. S. Sheshgiri College of Engineering and Technology, Belagavi, Karnataka, India

***Abstract*- High strength self-compacting concrete (HSSCC) has gained popularity in the recent years as it can flow and fill up gaps under its own self-weight without the need of any vibration. Workability, strength and durability are the major attributes of concrete used in the construction industry. For concrete to be accepted as SCC it must satisfy certain guidelines in its fresh state which are provided by EFNARC. The flowability required for HSSCC can be achieved by increasing the powder content and thus reducing the volume of aggregates in the concrete, which means the cement content required is more and hence the heat of hydration is more which may cause shrinkage cracks. To avoid this cement is partly replaced with mineral admixtures. For the concrete to be termed as high volume fly ash self-compacting concrete the replacement of cement must be greater than 50%. In this study M60 grade self-compacting concrete was designed, where in 50% of cement replaced with fly ash. This type of concrete is termed high volume fly ash high strength self-compacting concrete (HVFAHSSCC). River sand is the most commonly used fine aggregate in concrete, in due to the boom construction activity there is a scarcity of natural sand. For strength and workability, 30% replacement of river sand by M-Sand was found to be optimum. Steel fibers were incorporated in the mix and varied in terms of volume fraction from 0.5% to 2% at an interval of 0.5%. Non-destructive tests were conducted on the specimens. Further, rapid chloride penetration test (RCPT) was also performed, and it observed that the penetration of chloride ions is reduced with increase in volume fraction of steel fibers as compared to reference mix. All specimens showed very less penetration (<1000 Coulombs) values. The concrete specimens were tested for compressive strength at various temperatures (200°C and 400°C), for a duration of 2 hours. It was observed that all specimens suffered reduction in strength at elevated temperatures.**

***Keywords*-EFNARC, Ground Granulated Blast Furnace Slag (GGBS), Manufactured Sand (M-Sand), Rapid Chloride Penetration Test (RCPT), High Volume Fly Ash High Strength Self-Compacting Concrete (HVFAHSSCC), Steel fibers.**

I. INTRODUCTION

High volume fly ash self-compacting has gained popularity in the modern era, as it takes uses byproducts as an alternative to fresh raw materials. For the concrete to be termed as high volume fly ash self-compacting concrete the replacement of cement must be greater than 50%.SCC is mostly used in high rise structures and incase of abrupt fires, properties of concrete deviate post fire. Hence it is vital to know the change in properties of concrete when exposed to elevated temperatures. Estimating the response of the building when exposed to high temperatures, it is essential to study the alteration in properties of concrete. Elevated temperature can lead to the formation cracks. These cracks can ultimately deteriorate structural stability and shorten its serviceability. The impact of elevated temperatures on residual properties of concrete is important for structures such as hot water tanks, chimneys, nuclear reactors, crude oil storage tanks, foundation for blast furnace, containment vessels, aircraft runways, furnace walls industrial chimney etc. [1].

In the study, optimization of steel fibers in volume fraction varied at an interval of 0.5% from 0% to 1.5% have been carried out with 30% replacement of natural sand with M-sand. For a concrete mix to be considered as self-compacting it must fulfill the EFNARC requirements. At normal temperature, it is tested for durability with the help of rapid chloride penetration test (RCPT). Chandramouli K. et al. conducted RCPT on glass fiber reinforced concrete and concluded that with increase in concentration of fibers, there was reduction in permeability of concrete specimens [2]. To understand the influence of elevated temperature on the compressive strength of high strength SCC, cubical specimens were subjected to elevated temperatures of 200°C and 400°C for duration of 2 hours. Duration is approximated on the fact that high strength SCC is generally used for tall buildings and other structures where there is a possibility of fire persisting for 2 hours approximately. Arabi N.S. studied the effect of fiber content and specimen shape on residual strength of polypropylene fiber reinforced SCC exposed to elevated temperature and concluded that there was significant reduction in spalling after the inclusion of polypropylene fibers [3]. Jin Tao et al. studied the effect of compressive strength of polypropylene fiber reinforced SCC of different types subjected to high temperatures. It was concluded that inclusion of polypropylene fibers did not affect the compressive strength but reduced spalling at elevated temperatures [4].

II. MATERIALS AND METHODS

A. Materials

1. Cement: OPC 53 grade with specific gravity 3.15 was used conforming to IS 12269: 2013.
2. Fine aggregates: Sand used was locally procured and was conforming to zone II, and of specific 2.65.
3. M-Sand: M-sand was procured from local source, conforming to zone II and of specific gravity 2.74. It is observed that for 30% replacement of natural sand with M-sand was optimum.
4. Coarse aggregates: Locally available crushed angular coarse aggregate having the maximum size of 12.5 mm was used. The specific gravity of coarse aggregate was 2.78.
5. Mineral admixture: Fly ash was used as mineral admixture, having specific gravity 2.11.
6. Water: Potable tap water was used for experimental and also for curing specimens.
7. Superplasticizer: Conplast SP 430 was used which imparted high degree of workability and retention time required. Specific gravity 1.20.
8. Steel fibers: Flat crimped steel fibers were used of length: 25 mm, thickness: 0.75 mm, aspect ratio: 33 and density: 7850 kg/m^3.

B. Mix Design

Nan Su (2001) method of mix design was used. This method was developed based on the guidelines set for workability in EFNARC (2005). In this method, volume of aggregate was calculated and the remaining voids were filled with binder paste (mineral admixture and cement) and required superplasticizer dosage and mixing water were calculated to produce concrete which satisfied the requirements of SCC.

TABLE I
MIX PROPORTION

Water	Total Powdered Content(binder)		Fine Aggregate		Coarse Aggregate	Super Plasticizer
	Cement	Fly Ash	M-Sand	Natural Sand		
0.32	1		1.6		1.19	0.011

III. RESULTS AND DISCUSSION

A. Ultrasonic Pulse Velocity Test on HVFAHSSCC

TABLEII

ULTRASONIC PULSE VELOCITY FOR VARIOUS VOLUME FRACTIONS OF STEEL FIBERS FOR HVFAHSSCC

Sr. No	Percentage Variation of Steel Fibers	UPV (km/s) for Different Temperatures		
		25°C	200°C	400°C
1	0.0	4.839	4.156	3.091
2	0.5	4.914	4.207	3.154
3	1.0	4.986	4.232	3.271
4	1.5	5.017	4.312	3.381
5	2.0	5.053	4.473	3.437

Adopting the direct method of testing. From TABLEII it is observed that as the percentage of fibers increased ultrasonic pulse velocity (UPV) also increased. The recorded velocities for all the specimens at room temperature was more than 4 km/s hence it can be concluded that that quality of concrete was excellent. Maximum velocity was observed for 2% volume fraction of steel fibers. But in this study 1.5% was considered to be optimum. The higher value of pulse velocity may be because of densification of the matrix due to the inclusion of steel fibers which may intern decreases its permeability. Fig. 1shows deviation of UPV for different volume fraction of steel fibers.

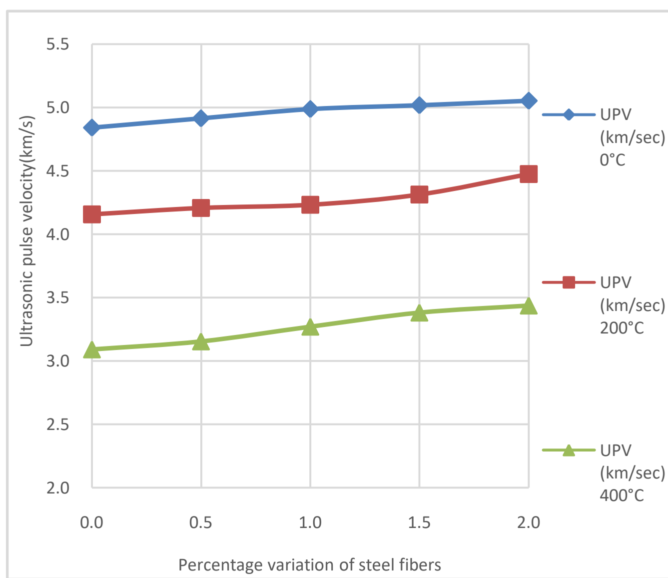

Fig. 1: Variation of ultrasonic pulse velocity for percentage variation of volume fraction of steelfibers

B. Rebound Number Test on HVFAHSSCC

TABLE III

REBOUND NUMBER FOR VARIOUS VOLUME FRACTIONS OF STEEL FIBERS FOR HVFAHSSCC

Percentage of Steel Fibers	Rebound Number			Compressive Strength		
	At Normal Temperature	At Elevated Temperature for 2 hours Duration		At Normal Temperature Strength (N/mm^2)	At Elevated Temperature for 2 hours Duration (N/mm^2)	
		200°C	400°C		200°C	400°C
0.0	49	47	36	62.67	60.01	38.87
0.5	50	47	37	63.85	61.32	39.94
1.0	51	48	39	64.74	62.25	41.47
1.5	51	49	39	65.93	63.67	42.76
2.0	52	50	40	66.96	64.44	44.52

The specimens were tested when they were sufficiently dry. As shown in TABLE IIIit is being observed that the Rebound Number (RN) increases with the increase in volume fraction of steel fibers. It was observed that the RN at 400°C was much lower compared to 200°C which indicates that the surface hardness and the resistance offered by the material reduced due to the formation of micro cracks.

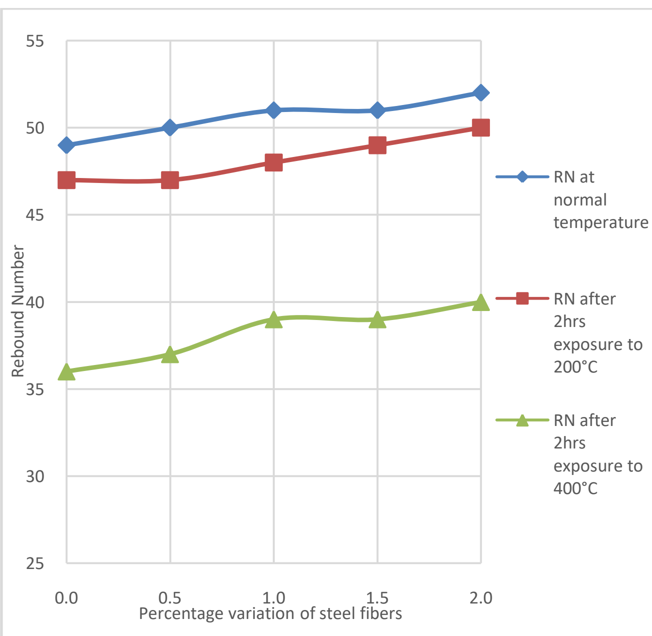

Fig. 2:Variation of rebound number for percentage variation of volume fraction of steel fibers

C. Chloride Permeability Test on HVFAHSSCC

TABLEIV

CHLORIDE PERMEABILITY FOR VARIOUS VOLUME FRACTIONS OF STEEL FIBERS FOR HVFAHSSCC

Sr. No	Percentage Variation of Volume Fraction of Steel Fibers	Total Charge(coulombs)
1	0.0	1407
2	0.5	1396
3	1.0	1343
4	1.5	1311
5	2.0	1299

From TABLEIV it was observed that all the specimens exhibited low chloride penetration (1001-2000 coulombs) values. The increase in percentage of steel fibers reduced the chloride penetration. Least amount of charge in coulombs was seen for 2.0% volume fraction of steel fibers. The inclusion of steel fibers lead to the increase in density of the specimens and interns reduces the permeability of concrete. Lower the permeability means lower will be the penetration of the chloride ions. Hence lower will be the coulombs value. As the percentage of steel fibers increases the resistance offered to penetration of chloride ions by concrete also increased as shows in Fig. 3 variation of coulombs value for different volume fractions of steel fibers.

Total charge $Q= 900 \times (I_0+2I_{30}+2I_{60}\ldots\ldots\ldots\ldots+I_{360})$

Q = Current flowing in Coulombs.

$I_{cumulative}$= Current reading in amperes at time interval (t).

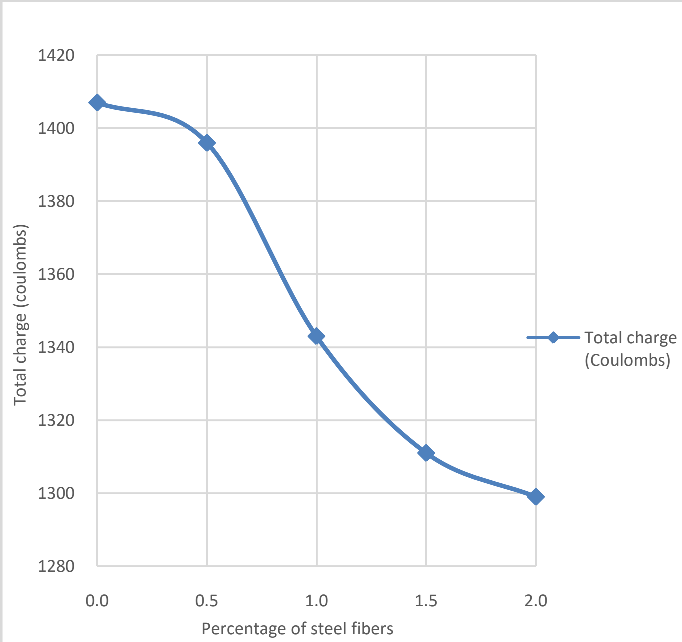

Fig. 3: Variation of chloride penetration for different volume fraction of steel fibers

D. Effect of Elevated Temperature and Steel Fiber on HVFAHSSCC on Compressive Strength

TABLE V
VARIATION OF COMPRESSIVE STRENGTH DUE TO INCREASE IN TEMPERATURE OF STEEL FIBER REINFORCED HVFAHSSCC

Percentage Steel Fibers	Normal Temperature Strength (N/mm^2)	Compressive Strength at Elevated Temperature for 2 Hours Duration (N/mm^2)	
		200°C	400°C
0.0	62.67(100%)	60.01(95.75%)	38.33(61.61%)
0.5	63.85(100%)	61.32(96.03%)	39.62(62.05%)
1.0	64.74(100%)	62.25(96.15%)	40.92(63.21%)
1.5	65.93(100%)	63.67(96.57%)	42.38(64.28%)
2.0	66.96(100%)	64.44(96.23%)	43.06(64.31%)

All the specimens were kept in box type electric furnace where the rate of heating was kept constant for all the specimens under investigation. All the specimens were kept for 2 hours to determine the influence of elevated temperature on HVFAHSSCC. It is seen that up till 200°C there is no significant reduction in strength compared to 400°C. This might be due to the stiffening of the cement gel between 0°C to 200°C since HVFAHSSCC has high amount of powdered material in the mix. For 400°C maximum of 38.84% reduction of strength is observed for reference mix (0% volume fraction of steel fibers). It is also observed that as the concentration of steel fibers increased in the specimens, the percentage reduction in strength reduced. The reduction in strength was as shown in TABLE V. Only 35.72% reduction in strength at 400°C is observed for 1.5% volume fraction of steel fibers. The reduction in strength may be attributed due to chemical and physical changes taking place in concrete when subjected to elevated temperatures.

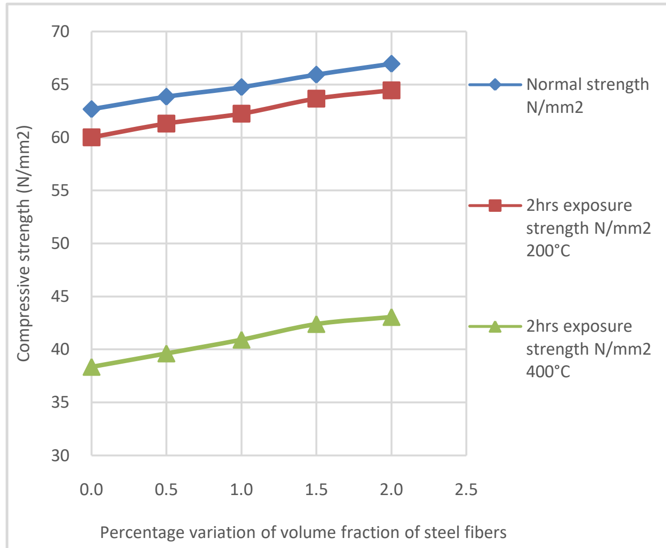

Fig. 4: Compressive strength variation due to increase in temperature of steel fiber-reinforced HVFAHSSCC

E. Combined Graph for Compressive Strength versus Steel Fiber Percentage for Normal and Elevated Temperatures

From Fig. 5 it is noticed that, various best fit polynomial equations satisfy the experimental values for compressive strength with different percentages of steel fibers and curves with different temperatures.

The regression equation for each curve are as follows.

1. Regression equation and coefficient of correlation for mix tested at normal temperature.

$y = -0.3029x2 + 3.0497x + 38.267$

$r^2 = 0.9947$

2. Regression equation and coefficient of correlation for mix tested at a temperature of 200°C.

$y = -0.1686x2 + 2.5791x + 60.012$

$r^2 = 0.9949$

3. Regression equation and coefficient of correlation for mix tested at a temperature of 400°C.

$y = -0.3029x2 + 3.0497x + 38.267$

$r^2 = 0.9947$

Where, x = Percentage of steel fibers, y = Compressive strength (N/mm^2) and r = Coefficient of correlation.

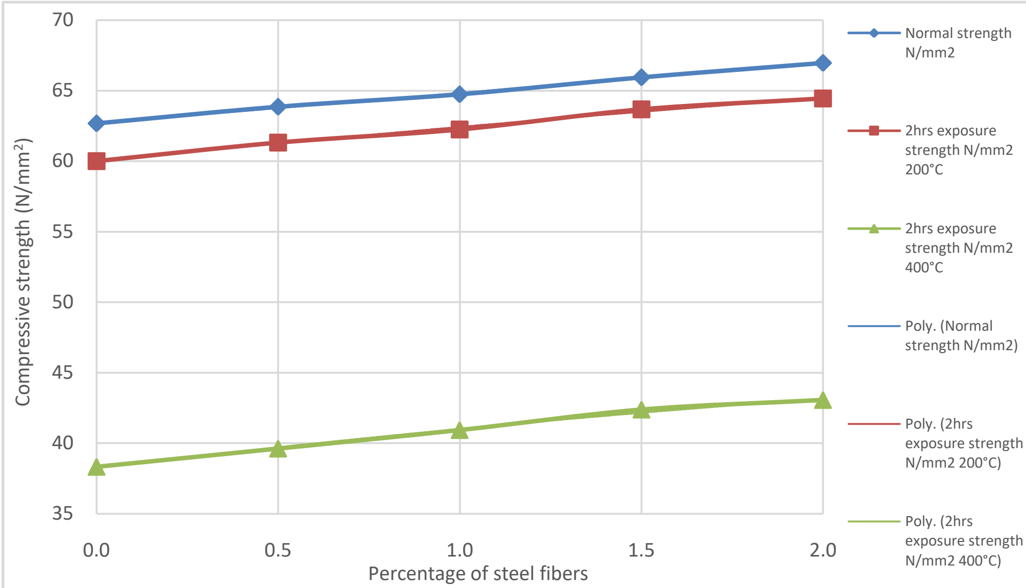

Fig. 5: Best fit curves for compressive strength at normal temperature, at 200°C and 400°C

TABLEVI

COMPARISON OF COMPRESSIVE STRENGTH FROM EXPERIMENTAL TESTS AND CURVES

Percentage of steel fibers	Compressive strength in MPa								
	Experimental results			Results from equations			Error in prediction (%)		
	25°C	200°C	400°C	25°C	200°C	400°C	25°C	200°C	400°C
0.0	62.67	60.01	38.33	62.69	60.02	38.26	0.03	0.02	0.18
0.5	63.85	61.32	39.62	63.76	61.25	39.71	0.14	0.11	0.23
1.0	64.74	62.25	40.92	64.83	62.42	41.03	0.14	0.27	0.27
1.5	65.93	63.67	42.38	65.89	63.50	42.16	0.06	0.27	0.52
2.0	66.96	64.44	43.06	66.96	64.49	43.15	0	0.08	0.21

Discussion for regression analysis

- From the regression and correlation analysis it can be concluded that best fit polynomial curve was found to be satisfied for compressive strength versus steel fibers at normal as well as elevated temperatures of specimens with positive correlation value near to unity.
- From the regression and correlation analysis it can be concluded that best fit polynomial curves were found to be satisfied for combined compressive strength versus steel fibers before heating and at different temperatures with positive correlation value near to unity.

IV. CONCLUSIONS

- Ultrasonic pulse velocity test was conducted on steel fiber reinforced SCC cubes. Pulse velocity continuously increased up till 1.5% volume fraction of steel fiber. Maximum ultrasonic pulse velocity was obtained for 1.5% volume fraction of steel fibers.
- Chloride penetration test on steel fiber-reinforced SCC was performed in this study. It was seen that with increase in steel fibers there was reduction in penetration of chloride ions (Cl-). For 1.5% volume fraction of steel fiber the least value of total charge (coulombs) was observed.
- Marginal increase in compressive strength was observed in the mixes with steel fibers as compared to reference mix.
- All the specimens recorded reduction in strength for temperatures varying from 200°C to 400°C. There was not much reduction in compressive strength at 200°C but distinct reduction was observed at 400°C. Reference mix (without steel fibers) recorded maximum reduction of 38.84% compressive strength at 400°C whereas least reduction was observed for 1.5% volume fraction of steel fibers at 400°C.

REFERENCES

[1] R. Vasusmitha, "Effect of Elevated Temperature on Mechanical Properties of High Strength Self Compacting Concrete" International Journal of Engineering Research & Technology (IJERT), Vol. 1 Issue 8, October – 2012.

[2] Chandramouli K., Srinivasa Rao P., SeshadriSekhar T and Pannirselvam N. "Rapid chloride permeability test for durability studies on glass fibre reinforced concrete" ARPN Journal of Engineering and Applied Sciences, Vol. 5, No. 3, March 2010.

[3] Arabi N.S. Al Qadi, Sleiman M. Al-Zaidyeen, "Effect of fiber content and specimen shape on residual strength of polypropylene fiber self-compacting concrete exposed to elevated temperatures" Journal of King Saud University, Vol.26, pp.33-39, December 2012.

[4] Jin Tao, Yong Yuan and Luc Taerwe "Compressive Strength of Self-Compacting Concrete during High-Temperature Exposure" JOURNAL OF MATERIALS IN CIVIL ENGINEERING, October 2010.

[5] Nan Su, "A simple mix design method for self-compacting concrete" Cement and Concrete Technology, Cement and Concrete research, Vol.31, No.12, pp.1799-1807, 2001.

[6] BurakFelekoglu, SelcukTurkel, Bulent Baradan, "Effect of water/cement ratio on the fresh and hardened properties of self-compacting concrete" Building and Environment, Vol.42, No.4, pp.1795-1802, January 2006.

[7] N. Bouzoubaa, "Self-compacting concrete incorporating high volumes of class F fly ash Preliminary results" Cement and Concrete Technology, Cement and Concrete Research, Vol 31, pp 413-420, 2001.

[8] C.S. Poon, "Compressive behavior of fiber reinforced high-performance concrete subjected to elevated temperatures" Cement and Concrete Technology, Cement and Concrete Research, Vol 34, pp 2215-2222, 2004

[9] EFNARC May 2005: European guidelines for Self-Compacting Concrete.

[10] IS: 2386-3: 1963: "Methods of Test for Aggregates for Concrete - Part 3: Specific Gravity, Density, Voids, Absorption and Bulking", Bureau of Indian Standards, New Delhi, India.

[11] IS: 516-1959: "Method of tests for strength of concrete", Bureau of Indian Standards, New Delhi, India.

[12] IS: 13311 part1:1992 "Method of Non-destructive testing of concrete", Bureau of Indian Standards, New Delhi, India.

[13] Abbas Al Ameeri, "The effect of steel fiber on some mechanical properties of self- compacting concrete" American Journal of civil engineering, Vol.1, No.3, pp.102-110, 2013.

[14] Clotilda petrus, Goh Lyn Dee, Ruqayyah Ismail, "Compressive strength of concrete with fibers at elevated temperature" Journal Technology, Vol.78, No.5-4, December 2015.