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Research Paper

INVESTIGATION ON RESIDUAL COMPRESSIVE STRENGTH OF SELF COMPACTING CONCRETE USING FIBERS UNDER ELEVATED TEMPERATURE

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Fiber reinforced concrete is geometry made of steel, glass or natural fiber. In recent years, Self-Compacting Concrete (SCC) has gained wide use for placement in congested reinforced concrete structures with difficult casting conditions. SCC is basically developed to solve problems of pouring and setting concrete in high rebar densities structures. Now days, it is need to check the safety of structure against fire. It is a challenge to build fire resistant structure in an economical way. For a newly developing material like Glass fiber or Steel fiber SCC studies is of paramount importance for instilling confidence amongst the engineers and builders. The main aim of this experimental is to find out the residual compressive strength of fiber reinforced Self compacting concrete by using two aspect ratio of an Alkali-Resistance glass fiber and crimped type steel fiber. The specimens were heated to different elevated temperature 200°C, 350°C and 500°C and different duration 3 h, 6 h and 9 h for each temperature. From this experimental study concluded that the significant improvement in compressive strength is observed with the inclusion of fibers. The residual compressive strength remains more for AR High Desperation Glass fiber Self Compacting Concrete. Also percentage decrease in compressive strength is less for High Desperation Glass fiber Self Compacting Concrete which is 25% at 500°C for 9 h.

Keywords: Glass fiber, Steel fiber, Self compacting concrete, Elevated temperature, Residual Compressive Strength

INTRODUCTION

Now a day's high-strength and high-performance concrete are widely used throughout the world. To produce them it is necessary to reduce the water and binder ratio and increase the binder content. Super plasticisers are used in these concretes to achieve the required workability. Different kinds of cement replacement materials are usually added to because of desirable porosity and permeability. Behavior of concrete under elevated temperature has recently increased. These studies are very useful for the design of special concrete structures subjected to

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elevated temperatures such as thermal shielding for nuclear reactors, metallurgical and chemical industries, runways, etc. Exposure to elevated temperatures causes physical changes. The physical changes including large volume changes owing to thermal shrinkage and creep related to water loss. The changes in volume will result in large internal stresses thus leading to micro cracking. Elevated temperatures also bring in some chemical and micro-structural changes such as migration of water, increase in dehydration and thermal incompatibility of the interface between cement paste and aggregates. All of these changes will have a bearing on the decrease of the strength and stiffness of concrete. Concrete is an inorganic material and high temperature and its duration decreases the concrete strength and its durability. Fire resistance of concrete is primarily affected by factors like the temperature, duration and condition of the fire. Self Compacting Concrete (SCC) is a high performance concrete that can flow under its own weight to completely fill the form work and self consolidates without any mechanical vibration. Such concrete an accelerate the placement, reduce the labor requirements needed for consolidation, finishing and eliminate environmental pollution. The SCC is also used mainly for repair application and for casting concrete in restricted areas, including sections that present limited access to vibrate. Such value added construction material has been used in applications justifying the higher material and quality control cost when considering the simplified placement and handling requirements of the concrete. The glass fibers are among the most versatile industrial materials known today. They are readily produced from raw materials, which are available in virtually unlimited supply. The glass fibers are derived from composition containing silica. They exhibit useful bulk properties such as hardness, resistance to chemical attack, stability and inertness as well as desirable fiber properties such as strength, flexibility and stiffness. The uses of Steel Fiber Reinforced Concrete (SFRC) over the past 30 years have been so varied and so widespread, that it is difficult to categorize them. The most common applications are tunnel linings, pavements and slabs. There has also been some recent experimental work on roller-compacted concrete reinforced with steel fibers.

RESEARCH SIGNIFICANCE

For a newly developing material like Glass fiber Self Compacting Concrete and Steel fiber Self Compacting Concrete, studies on residual compressive strength is of paramount importance for instilling confidence amongst the engineers and builders. The literature indicates that while some studies are available on the normal concrete, a comprehensive study which involves strength that is not available on Glass fiber Self Compacting Concrete and Steel fiber Self Compacting Concrete. Hence considering the gap in the existing literature, an attempt has been made to study the residual compressive strength of Glass fiber Self Compacting Concrete and Steel fiber Self Compacting Concrete subjected to temperature 200°C, 350°C and 500°C for M30 grade concrete.

LITERATURE REVIEW

Phan *et al.* (2001) describes results on effects of elevated temperature exposure on residual mechanical properties of HPC. Residual mechanical properties were measured by heating the 102 mm X 204 mm cylinders to steady state thermal conditions at a target temperature. The specimens were heated to a maximum core temperature of 400^{0}C, at heating rate of 5^{0}C/min. An examination of the specimens heating characteristics indicate that the HPC mixtures which experienced explosive spalling had a more restrictive process of capillary pore and chemically bound water loss than those which did not experience spalling.

Chen and Liu (2004) investigated residual strengths of High-Strength Concrete (HSC) and hybrid-fiber-reinforced high-strength concrete (HFRHSC) after exposure to high temperatures. The results shows that normal HSC is prone to spalling after exposure to high temperatures and Mixing high melting point fiber (i.e., carbon or steel fiber) with low melting point fiber (i.e., PP fiber) HSC greatly improves the properties of HSC after exposure to high temperatures.

Lau and Anson (2006) investigated different elevated heating temperatures ranging between 105°C and 1200°C the compressive strength, flexural strength, elastic modulus and porosity of concrete reinforced with 1% steel fiber (SFRC) and changes of color to the heated concrete. The results show a loss of concrete strength with increased maximum heating temperature and with increased initial saturation percentage before firing.

Sekhar *et al.* (2011) says that damage in concrete structures due to fire depends to a great extent on the intensity and duration of fire. This work presents an experimental investigation on the residual compressive strength of glass fiber reinforced self compacting concrete using Alkali-Resistance glass fibers subjected to elevated temperature200^{0}C,400^{0}C,600^{0}C at 4 h, 8 h and 12 h duration for various grades of concrete of mixes M 30 to M 65.

OBJECTIVES OF STUDY

1. To study effect of different fibers on compressive strength self compacting concrete.
2. To determine residual compressive strength of self compacting concrete by using glass fiber under different elevated temperature (200^{o}C, 350^{o}C and 500^{o}C) and different durations (3 h, 6 h and 9 h) for each temperature.
3. To determine residual compressive strength of self compacting concrete by using steel fiber under different elevated temperature (200^{o}C, 350^{o}C and 500^{o}C) and different duration (3 h, 6 h and 9 h) for each temperature.
4. To compare the result when self compacting concrete subjected to elevated temperature with and without fiber

PROPOSED WORK AND MATERIAL PROPERTIES

The main aim is to study residual compressive strength of Self Compacting Concrete using fibers under elevated temperature 200^{o}C, 350^{o}C and 500^{o}C for M30 grade concrete.

Cement: Ordinary Portland Cement of 53 grade used. The specific gravity of cement is 3.15.

Coarse Aggregates: The maximum size of aggregate of 12.5 mm size was used. The specific gravity was found to be 2.96 and fineness modulus of coarse aggregate was 7.49.

Fine Aggregate: Locally available Natural River sand of zone I with specific gravity 2.66, water absorption 1.1%, and fineness modulus 2.57 .Conforming to IS 383-1970.

Water

Clean potable water was used for mixing.

Admixture: Superplasticisers

BASF GELLNIUM SKY 784 is used with a proportion of 1.2% with respect to weight of powder content was used to achieve the desired slump flow value for SCC since addition of fibers adversely affects the workability of self compacting concrete.

Fly Ash

Fly ash added to improve the quality and durability of SCC. In the present investigation work, the fly ash used is obtained from Devgad thermal power station in Maharashtra. The specific surface of fly ash is found to be 4250 cm^2/g by blaines permeability apparatus and its specific gravity is 2.3.

Fibers

Shaktiman Steel Fibers flat Crimped in shape of 30 mm and 50 mm in length as shown in Figure 1 are supplied by the Stewols India Pvt. (Ltd.) Nagpur. AR Glass fibers High Dispersion (AR-GFHD) and AR Glass fibers High Performance (AR-GFHP) as shown in Figure 2 are manufactured by Owens Corning, Goa are used. Properties of fibers are given in Table 1.

Figure 1: Steel Fibers (Aspect ratio 30 & 50)

Figure 2: AR Glass Fibers

Concrete Mix Proportion

The Nan-Su *et al.* (2001)method is used for mix proportion of SCC. In this method initial mix proportions were calculated using mix design method of conventional concrete given by Indian Standard method instead of simply assuming the contents of Cement, Coarse Aggregate and Fine Aggregate as given by

Table 1: Properties of fibers

Fiber Type	Shape	Len-gthMm	Equiv-alent Dia.mm	Tensile Strengt-h MPa	Densi-tyKg/m^3
Steel Fibers	Flat Crimped	30	1	1100	7850
Steel Fibers	Flat Crimped	50	1	1100	7850
AR-Gass Fibers	Flat Fibrillated	12	0.014	1700	2600

the literature. These contents were compared with the EFNARC Specifications (2005) and small modifications were done to the contents that arrived in the Indian Standard method to satisfy the SCC mix composition criteria. The quantities of materials required for M30 grad per 1 cum of SCC with and without fiber are given in Table 2.

EXPERIMENTAL PROGRAM

Casting of Specimens

The cube specimens were casted of size 150 mm X 150 mm X 150 mm. Ingredients of the mix were taken as per the mix proportion. Concrete was filled in mould without compaction. The top surface of the specimens was hand trowelled. The moulds were stripped after 24 h. The specimens were casted as shown in Figure 3 and cured for 28 days in curing pond.

Heating Exposure Technique

Electric furnace of maximum temperature of 1200°C was used. The specimens were kept in furnace as shown in Figure 4 at required temperature 200°C, 350°C and 500°C for 3 h, 6 h and 9 h at each temperature. After heating the specimens were taken out and cooled in air.

Testing of Cube Specimens

Then specimens of each mix type were tested for their compressive strength at room temperature. All the cubes were tested on Compression Testing Machine of capacity 2000 kN compressive load as shown in Figure 5.

RESULTS AND DISCUSSION

Compressive Strength of Self Compacting

Table 2: Quantities of Materials Required For M30 Grade Per 1 cum of SCC With and Without Fiber

Mix	Cement Kg/m^3	Fly Ash Kg/m^3	Sand Kg/m^3	Coarse Aggregate Kg/m^3	Water Kg/m^3	SP Kg/m^3	Fibers Kg/m^3
Plain SCC	325	140	874	806	170	5.11	-
GFSCC-HD	325	140	874	806	170	5.58	2.32
GFSCC-HP	325	140	874	806	170	5.58	3.48
SFSCC-30	325	140	874	806	170	5.58	23.21
SFSCC-50	325	140	874	806	170	5.58	23.21

Figure 3: Concrete Curing in Air After Prepartion

Figure 4: Concrete Specimens Ready for Elevated Temperature in Furnace

Figure 5: Compressive Test for Cube

Concrete with and without fibers at room temperature

Table 3 gives the overall results of Compressive Strength of Self Compacting Concrete with and without fibers at room temperature. The compressive strength of GFSCC-HD at the level of 0.1% volume of fibers is 38.42 MPa which is improved by 15.62% and for GFSCC-HP at the level of 0.15% volume of fibers is 39.55 MPa which Table 3 Compressive strength for different concrete mix is improved by 19.00% as compared to plain SCC. The compressive strength of SFSCC-30 at the level of 1% volume of fibers is 44.16 MPa which is improved by 32.89% and for SFSCC-50 at the level of 1% volume of fibers is 41.78 MPa which is improved by 25.72% as compared to plain SCC. The variation of compressive strength of different concrete mix at room temperature is plotted in the graph as shown in the Figure 6.

Overall results of Residual compressive strength of self compacting concrete with and without fibers are subjected to different elevated temperature

Exposure to high temperature resulted in loss of strength for SCC and fiber reinforced SCC. Figure 7 shows the residual compressive strength of SCC mixes after exposure to different high temperature and different duration for each temperature. Within 200^0C, the changes of residual compressive strength values within the temperature for all types of SCC mixes were changed suddenly. However, when temperature was higher than 200^0C, their strength values were changed linearly. For normal SCC, the strength values

Table 3: Compressive Strength for Different Concrete Mix

Concrete Mixes	Plain SCC	GFSCC-HD (0.1%)	GFSCC-HP (0.15%)	SFSCC-30 (1%)	SFSCC-50 (1%)
Compressive Strength (MPa)	33.23	38.42	39.55	44.16	41.78

Figure 6: Compressive Test for Cube

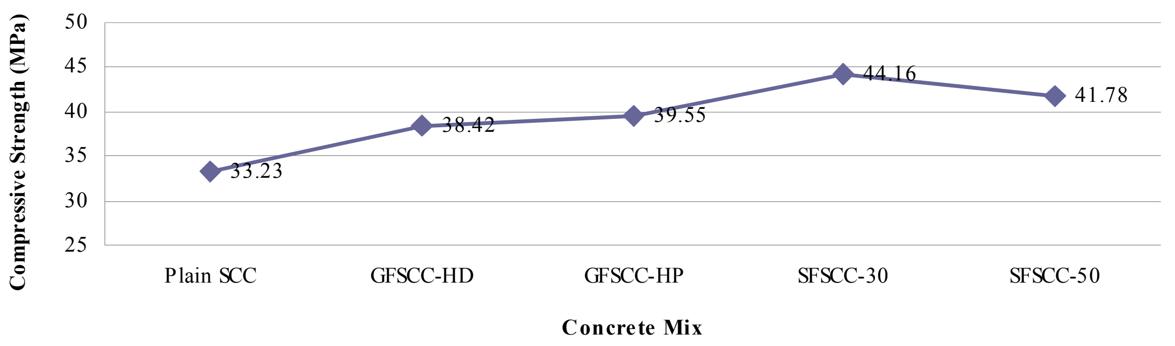


Figure 7: Overall Results Of Residual Compressive Strength of Self Compacting Concrete With and Without Fibers are Subjected to Different Elevated Temperature

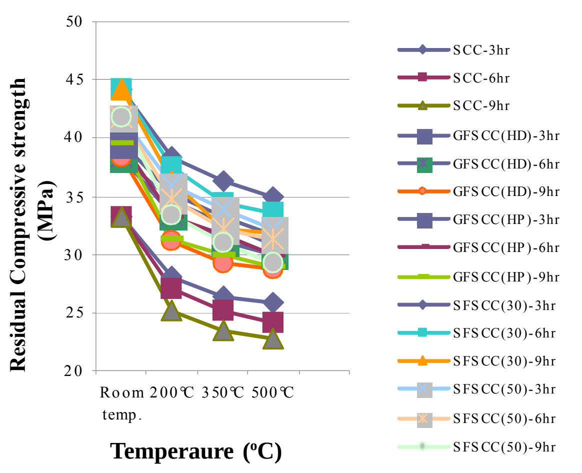
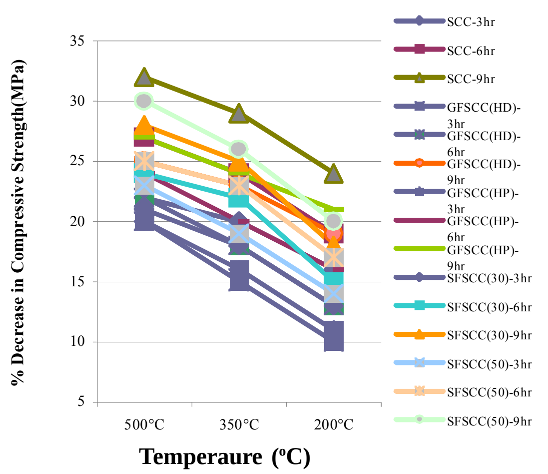


Figure 8: Overall Results Of Percentage Decrement In Compressive Strength of Concrete Cube Specimen are Subjected to Different Elevated Temperature



decreased significantly. When temperature reached at 500°C for 9 h, its residual compressive strength was 68.31% of original strength. Because high elastic modulus fibers such as Steel and Glass fibers resist cracking inside the concrete, they can control volume

Table 3: Overall results of Residual compressive strength of self compacting concrete with and without fibers are subjected to different elevated temperature

Concrete Mixes	Temperatures(°C)	Residual compressive strength for different exposure time (MPa)			
		0 h	3 h	6 h	9 h
SCC	Room temp.	33.23	-	-	-
	200°C	-	28.01	27.05	25.11
	350°C	-	26.40	25.12	23.51
	500°C	-	25.76	24.12	22.70
GFSCC-HD	Room temp.	38.42	-	-	-
	200°C	-	34.58	33.43	31.12
	350°C	-	32.66	31.12	29.20
	500°C	-	30.74	29.97	28.82
GFSCC-HP	Room temp.	39.55	-	-	-
	200°C	-	35.20	33.22	31.24
	350°C	-	33.22	31.64	30.00
	500°C	-	31.64	30.00	28.87
SFSCC-30	Room temp.	44.16	-	-	-
	200°C	-	38.42	37.54	36.21
	350°C	-	36.21	34.44	32.12
	500°C	-	34.88	33.56	31.80
SFSCC-50	Room temp.	41.78	-	-	-
	200°C	-	35.93	34.68	33.42
	350°C	-	33.84	32.17	30.92
	500°C	-	32.17	31.34	29.25

Table 4: Overall Results Of Percentage Decrement In Compressive Strength Of Concrete Cube Specimen Are Subjected To Different Elevated Temperature

Concrete Mixes	Temperatures (°C)	Percentage decrease in compressive strength for Different Exposure Time (%)		
		3 h	6 h	9 h
SCC	200°C	16	19	24
	350°C	20	24	29
	500°C	22	27	32
GFSCC-HD	200°C	10	13	19
	350°C	15	18	23
	500°C	20	22	25
GFSCC-HP	200°C	11	16	21
	350°C	16	20	24
	500°C	20	24	27
SFSCC-30	200°C	13	15	18
	350°C	18	22	25
	500°C	21	24	28
SFSCC-50	200°C	14	17	20
	350°C	19	23	26
	500°C	23	25	30

change of concrete due to rapid change of environmental and large temperature gradient. Also it controls initiation and expansion of inner microdefects of concrete. For concrete with GF-HD, the loss of strength is not significant, for temperature at 500^{0}C kept for 9 h; its residual compressive strength was 75% of original strength. Also for GF-HP, for temperature at 500^{0}C kept for 9 h, its residual compressive strength was 73% of original strength. Adding steel fibers to SCC, the significant decrease in strength occurred. For concrete with SF-30, for temperature at 500^{0}C kept for 9hr, its residual compressive strength was 70% of original strength. Table 3 shows the Overall results of Residual compressive strength of self compacting concrete with and without fibers are subjected to different elevated temperature.

Overall Results of Percentage Decrement in Compressive Strength of Concrete Cube Specimen are Subjected to Different Elevated Temperature

For concrete with fiber, especially GF-HD, their properties exposed to high temperature improved significantly. As shown in Figure 8 their residual compressive strength around 75% of original strength, when it exposed at 500^{0}C for 9 h. It may be because during the rapid temperature increasing process, GF-HD fibers melts and vaporize due to the relatively lower melting point, which results in microchannels in the concrete. Thus, grater vapor tension in capillaries can be released. In addition, GF-HP or SF can to some degree, restrict the initiation and expansion of cracking in the concrete due to their tensile resistance which maintain higher residual strengths of concretes after exposure to high temperature.

CONCLUSION

1. The significant improvement in compressive strength is observed with the inclusion of fibers.
2. The percentage decrease in compressive strength is less for GFSCC-HD is 25% and for GFSCC-HP is 27% at 500^{0}C for 9 h in comparison with room temperature.
3. The percentage decrease in compressive strength for SFSCC-30 is 28% and for SFSCC-50 is 30% at 500^{0}C for 9 h in comparison with room temperature.
4. The percentage decrease in compressive strength for SCC with and without fiber specimens will be higher for higher exposure time and temperature.
5. The loss of compressive strength in SCC is more than SCC with inclusion of fibers due to elevated temperature.

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