Indian Journal of Science and Technology, *Vol 9(6), DOI: 10.17485/ijst/2016/v9i6/87702, February 2016*
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Influence of Mineral Admixture on Stress Strain Behaviour of Self Compacting Concrete under Elevated Temperature

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Abstract

Background: The aim of the research is to study the effect of elevated temperature on different grades of Self Compacting Concrete (SCC), which is having excellent deformability and segregation resistance. **Methodology:** SCC specimens were cast using Silicafume (SF), Flyash (FA) and Metakaolin (MK) as mineral admixture, Master Glenium SKY as Superplasticizer (SP) and Glenium Stream as Viscosity Modifying Agent (VMA). After heating the specimens to 900ºC, samples were allowed to cool naturally in case of air cooling and water was sprayed on the specimens in case of water cooling. Compressive strength and Stress Strain behaviour of specimens were found. **Findings:** Compressive strength of SCC specimens with SF, FA and MK were found to decrease by 53.57%, 65.25% and 72.95% respectively for air cooling. In case of specimens cooled by water, the decrease in strength was found to be 78.67%, 81.19% and 83.01% respectively for specimens with SF, FA and MK. The higher powder content of SCC makes the permeability of concrete as low, thus makes SCC more susceptible to spalling under high temperature. The percentage reduction in compressive strength of M50 grade specimens with MK was found to be 72.95% and 83.01% for the specimens cooled by air and water respectively. Higher strength loss was observed for higher grade of SCC. It was found from the experimental investigations that, higher strain values were observed for the specimens cooled by water as compared to specimens cooled by air and reference specimen. **Application:** Fire safety design of structural elements.

Keywords: Elevated Temperature, Flyash, Metakaolin, Self Compacting Concrete, Silica fume, Stress Strain

1. Introduction

Concrete is a construction material widely used in the infrastructure development, the properties of concrete may change after exposure to high temperature. Hence, it is important to understand the behaviour of concrete materials under elevated temperatures. It is essential that the structural engineers should have idea on mechanical properties of concrete subjected to high temperatures. The variations in the mechanical properties of concrete after exposed to high elevated temperatureareto be investigated. When concrete is exposed to high temperature, strength and stiffness on concrete reduces significantly, due to loss of moisture, dehydration of cement paste and decomposition of aggregate. Due to these changes in the micro-structure of concrete, compressive, tensile and bending strength of the concrete is significantly reduced. To examine and repair the fire affected concrete members, it is essential to understand the effect of temperature on the mechanical properties of concrete, especially the stress-strain behaviour which determines the behavior of structural members under different loads. The stress strain relationship of conventional and high performance concretes (SCC) under elevated temperature may be

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different, due to the changes in the material properties. It was found from the literatures that the information is lacking on the stress-strain behaviour of SCC exposed to elevated temperatures. SCC can be made using suitable chemical and mineral admixtures which are available in the market. In the present study, an attempt has been made to understand the behaviour of SCC made with different mineral admixtures (FA, SF and MK) under elevated temperature.

[1] Investigated the effects of high temperature on the strength and stress-strain relationship of high strength concrete (HSC). Stress-strain curves were plotted at various temperatures (20, 100, 200, 400, 600, and 800°C) for four types of HSC. From the stress-strain diagrams obtained through the investigation, it was found that plain HSC exhibited brittle properties below 600°C, and ductility above 600°C. HSC with steel fibres exhibited ductility above 400°C. The strain at peak load also increased with temperature, from 0.003 at room temperature to 0.02 at 800°C.

[2]Carried out a laboratory investigation to understand on the compressive strength of SCC and HSC. They varied the temperature from room temperature to 800°C. It was reported that compressive strength of SCC in hot state decreased with increase in temperature. They reported that the loss of strength depended on the grade of concrete, especially when the temperature was below 400°C. They found that higher grades of SCC were susceptible to higher loss of strength.

[3]Evaluated the performance of concrete with Metakaolin (MK) at elevated temperatures up to 800°C. They prepared eight normal and eight high strength concrete mixes containing 0%, 5%, 10% and 20% MK. The determined the residual compressive strength, chloride-ion penetration, porosity and average pore sizes. It was found that the MK concrete suffered greater loss of compressive strength and permeability related durability than the corresponding SF, FA and OPC concretes at higher temperatures.

[4]Reported that, the ascending phase of stress –strain curve is getting more linear as the temperature increases, and the descending phase becomes flatter and smoother. They also reported that the pattern of stress–strain curves was almost similar for both SCC and Normal compacting concrete.

[5]Carried out an investigation to determine the effect of grades of concrete on the performance of SCC beams exposed to different heating and cooling conditions. For all heating and cooling condition, a slight reduction in the compressive strength, tensile strength and the flexural strength of SCC specimens were noticed as the grade of concrete increased.The specimens that were heated from room temperature to 900°C and cooled by spraying water suffered maximum loss of strength and the reduction in the compressive, tensile and the flexural strengths was found to be 79.8%, 82.9% and 82.2% respectively for the M40 grade.

[6]Made a comparative study on the behaviour of Normal Compacting Concrete (NCC)andSCC specimens subjected to elevated temperatures. They reported that as the temperature increases compressive strength of normal and SCC decreased. The residual strength of heated NCC and SCC specimens were found to decrease as the grade of concrete increases. They reported that SCC suffered loss in compressive strength than NCC. The percentage reduction for NCC was found to be 60.06% and the percentage reduction for SCC was found to be 81.50% for the M40 specimens that was heated from 27°C to 900°C.

It was understood that, from the existing literatures on fire resistance of SCC, further investigations to be carried out on stress strain behaviour of SCC.The considerable reduction in compressive strength, tensile strength, flexural strength and Young's modulus has been observed for conventional concrete specimens exposed to elevated temperatures. Since normally SCC developed using different mineral and chemical admixtures, the behaviour of SCC specimens subjected to high temperatures may be different from that of Conventional concrete. Hence an attempt has been made to understand the stress strain behaviour of SCC under elevated temperatures.

2. Experimental Investigation

2.1 Materials

The ordinary Portland cement used during the experimental investigation was conforming to IS: 12269. Locally available river sand confirming to zone-II of IS: 383–1970was used as fine aggregate. The specific gravity of cement, fine aggregate and coarse aggregate were 3.15, 2.70 and 2.96 respectively. Potable water was used for mixing and curing. Silica fume, flyash, metakaolin were used as mineral admixture. Master Glenium Sky 8630 and Glenium stream 2 were used as a Super Plasticizer (SP) andViscosity modifying agent respectively.The different mineral and chemical admixtures used for the investigation are shown in Figure 1.

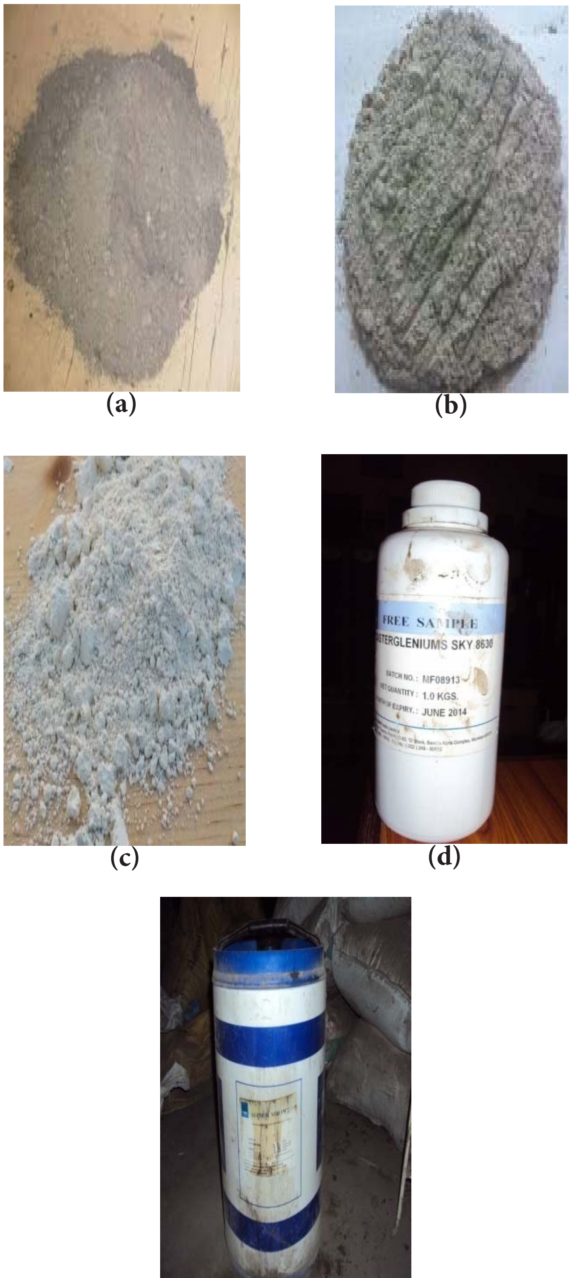


Figure 1. Material Used **(a)** Silica fume **(b)** Flyash **(c)** Metakaolin **(d)** Superplasticizer - Master Glenium Sky 8630 **(e)** Viscosity Modifying Agent –Glenium Stream 2.

2.2 Mix Design

The mix design procedure developed [7] was adopted and M20, M30, M40 and M50 grades of SCC were designed. NCC mixes were designed as per the procedure given in IS 10262:2009[8]. By adjusting the proportions of NCC and by adding suitable proportions of chemical admixtures, concrete b was made self-compactible. Slump flow test, J-ring test and V-funnel tests were used to check the filling ability, passing ability and the segregation resistance. The designed SCC mixes satisfied the requirements of SCC.

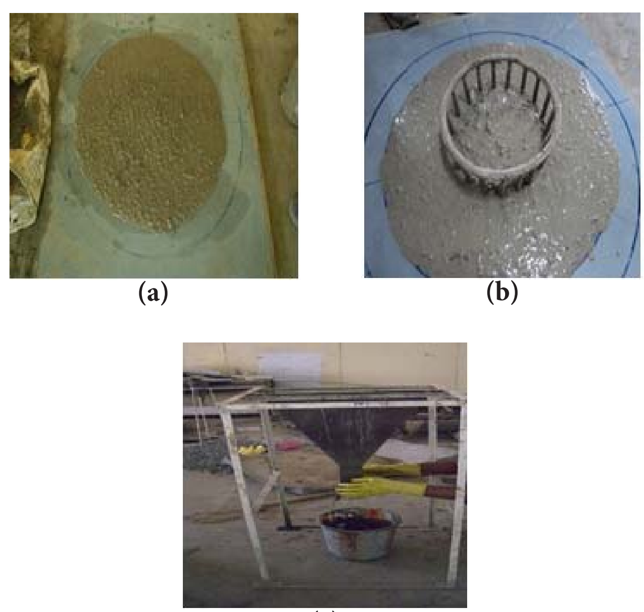
The quantity of silica fume required for the production of SCC is the least and the quantity of flyash required for the production of 1m^3 SCC of same grade is maximum.

2.3 Tests on Fresh SCC

Concrete is normally classified as self compacting, if it satisfies the requirements of filling ability, passing ability and resistance to segregation. Different test methods had been developed in the past to characterize the properties of SCC. A detailed experimental investigation has been carried out on the designed SCC mixes to find out its filling ability, passing ability and resistance to segregation using the Slump flow test, J-ring test and V-funnel test respectively.Figure 2 shows the various workability tests carried out to develop SCC.

2.4 Test on Hardened Concrete

In order to understand the effects of elevated temperature on the stress strain behaviour of SCC, an extensive laboratory investigation was carried out on cylinder specimens of diameter 150mm and height 300mm. The



(c)

Figure 2. Tests on Fresh Concrete **(a)** Slump Cone **(b)** J-ring Test **(c)** V-Funnel.

specimens were heated without any application of load to the required temperature and cooled either by air or water to reach the room temperature.

2.5 Testing of Specimens under Elevated Temperature

A muffle furnace was used for heating the specimens to the required temperature. The inner dimensions of the furnace are 500mmx500mmx500mm. Electrical heating coils embedded in refractory bricks were the source of heat energy. The SCC beams were kept inside the furnace and the furnace was heated from 27°C to 900°C. The temperatures of the specimens were found using an Infrared thermometer. The furnace used for the experiment is shown in Figure 3.

The specimens were exposed to the desired temperature and duration. Then the furnace was switched off and the specimens were removed from the furnace. The specimens were naturally allowed to reach the room temperature in case of air cooling. In case of water cooling water was sprayed over the specimens. Stress-Strain behaviour of the cylinder specimens were found at 28th day for the reference and other specimens that were subjected to elevated temperatures.

From Table 1 it can be seen that the 28th day Compressive, tensile and flexural strengths of SCC with metakaolin is maximum and the strength of SCC with silica fume is the least. The optimal dosage of FA, SF and MK reported in the literature are 30%, 25% and 20% respectively. For making SCC with FA, the FA percentage is 25% which is very close to the optimal range. For making SCC with MK, the MK percentage is 20%. This again is very close to the optimal range. However, the requirement percentage of SF for making SCC is only 10% as against the optimal percentage of 25. Hence SCC with SF has the least strength. The details of the specimens used during the investigation are given in Table 2.

During the present investigation 108 cylinder specimens were cast and tested.

2.6 Experimental Investigation on SCC under Elevated Temperature

In order to determine the effects of elevated temperature on the properties of SCC, an extensive experimental investigation was carried outon cylindrical specimens of diameter 150mm and height 300mm. After heating the specimens were cooled either by air or water to reach the room temperature. The compressive strength was found on the cooled specimens. This type of test is known as unstressed residual strength test. A computerized Universal Testing Machine (UTM) of capacity 1000kN was used for the determination of strength.

Figure 3. View of Muffle Furnace.

Table 1. Mechanical Properties of SCC

Grade of concrete	Compressive strength (N/mm^2)			Tensile Strength (N/mm^2)			Flexural Strength (N/mm^2)		
	SF	FA	MK	SF	FA	MK	SF	FA	MK
M20	22.13	24.69	26.95	3.5	3.8	4.02	5.19	5.39	5.54
M30	34.15	36.97	37.20	4.1	4.34	4.56	5.78	5.91	6.09
M40	45.26	48.24	49.60	4.8	5.17	5.24	6.13	6.42	6.67
M50	56.09	58.99	60.07	5.5	5.84	6.01	6.71	6.95	7.12

Table 2. Details of Specimens

Mineral Admixtures	Grade of Concrete	Specimen Type	Nature of Cooling	Total no. of Specimens
SF, FA, MK	M20	Reference Specimen	–	9
		Heated Specimen	Air/Water	18
SF, FA, MK	M30	Reference Specimen	–	9
		Heated Specimen	Air/Water	18
SF, FA, MK	M40	Reference Specimen	–	9
		Heated Specimen	Air/Water	18
SF, FA, MK	M50	Reference Specimen	–	9
		Heated Specimen	Air/Water	18

Table 3 gives thepercentage reduction in cylinder compressive strength of SCC specimens with SF.

The Stress-strain curves for the reference and heated SCC specimens with silica fume of grades M20, M30, M40 and M50 are shown respectively in Figure 4(a),4(b),4(c) and 4(d).

Table 4 gives thepercentage reduction in cylinder compressive strength of SCC specimens with FA.

The Stress-strain curves for the reference and heated SCC specimens with flyash of grades M20, M30, M40 and M50 are shown respectively in Figure 5(a),5(b),5(c) and 5(d).

Table 5 gives thepercentage reduction in cylinder compressive strength of SCC specimens with MK.

The Stress-strain curves for the reference and heated SCC specimens with metakaolin of grades M20, M30, M40 and M50 are shown respectively in Figure 6(a),6(b),6(c) and 6(d).

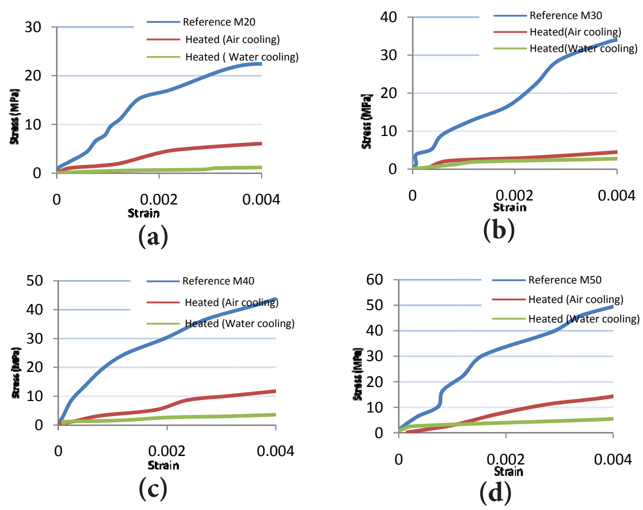


Figure 4. Stress Strain Behaviour of Concrete with SF **(a)** M20 grade **(b)** M30 Grade **(c)** M40 grade (d) M50 Grade.

3. Discussion of Results

SCCs were usually prepared with higher cement and filler content combined with lower water to binder ratios as compared to traditional concretes. [9]Reported that the specific gravity of mineral admixtures is generally lesser than cement. Therefore, more volume is obtained when mineral admixture were replacedwith cement.This resulted in higher compressive strength of SCC as compared with other conventional and high performance concretes and finer pore size distribution, a critical factor responsible for the behaviour of the mixture under elevated temperatures. However, some of the key parameters that affect the performance of concrete under elevated temperature such as grade of concrete, density of concrete, type of admixture and duration of fire as reported [10].

[6]Reported that when concrete is exposed to heat, chemical and physical reactions occur at elevated temperatures, such as loss of moisture, dehydration of cement paste and decomposition of aggregate. These changes will bring a breakdown in the structure of concrete, affecting its mechanical properties. Therefore, concrete members that are exposed to higher temperatures may have reduced strength even without visible damage. To evaluate and repair the fire-damaged concrete members, it is essential to understand the effect of temperature on the mechanical properties of concrete, especially the stress-strain relationships which determines the behaviour of structural elements under strong earthquake. The stress strain relationship of normal and self compacting concretes under elevated temperature may be different, due to the variations in the pore structure.

Table 3. Percentage Reduction in Cylinder Compressive Strength of SCC Specimens with SF

Grade of concrete	Compressive strength of Reference Specimens (N/mm^2)	Compressive strength of Specimens Cooled by air (N/mm^2)	% reduction in Compressive strength w.r.t reference specimen	Compressive strength of Specimens Cooled by water (N/mm^2)	% reduction in Compressive strength w.r.t reference specimen
M20	22.13	10.27	53.57	4.72	78.67
M30	34.15	17.77	47.96	7.77	77.23
M40	45.26	23.04	49.07	10.55	76.68
M50	56.09	30.27	46.03	12.77	77.22

Based on the experimental investigation, it is found that, higher compressive strength was observed for SCC reference specimens developed using MK as compared to SF and FA specimens. It was due to the higher binder phases in MK, thus resulted in accelerating the strength of concrete with MK as reported[9]. From the Fig 4, 5 & 6 can be observed that, the stress strain curve becomes flatter for the specimens exposed to fire. The compressive strength decreases and peak strain increases for the specimens exposed to fire. This indicates that, concrete becomes softer as the temperature increases. Therefore, while evaluating the degree of damage of concrete exposed to higher temperature, it is important to consider the effect of temperature on the elastic modulus of the concrete. For unheated concrete specimens, the ascending and descending curves are steeper.

[11-12]Reported that, increasing the powder content enhances the density of concrete, which reduced the porosity of concrete significantly.[13]Found that the inclusion of mineral admixture significantly influence the compressive strength of the SCC mixes.It was reported [14]That dense internal microstructure and moisture content are the prime factors that induce spalling of concrete.[4]Reported that lower moisture content is advantageous, since the accumulated pore pressure will be minimum for lower moisture content and hence the chances for spalling will be less. Higher moisture content will make concrete susceptible to spalling. [15]Reported that higher percentages of fly ash will increases when subjected to higher

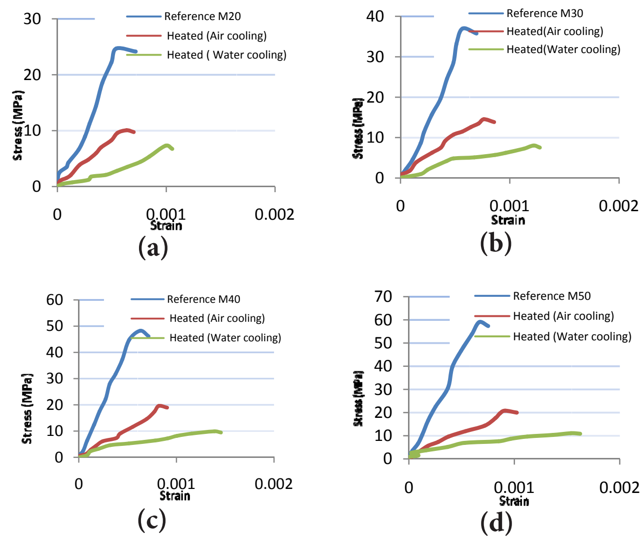


Figure 5. Stress Strain Behaviour of Concrete with FA **(a)** M20 grade **(b)** M30 Grade **(c)** M40 grade **(d)** M50 Grade.

Table 4. Percentage Reduction in Cylinder Compressive Strength ofSCC Specimens with FA

Grade of concrete	Compressive strength of Reference Specimens (N/mm^2)	Compressive strength of Specimens Cooled by air (N/mm^2)	% reduction in Compressive strength w.r.t reference specimen	Compressive strength of Specimens Cooled by water (N/mm^2)	% reduction in Compressive strength w.r.t reference specimen
M20	24.68	10.07	59.17	7.30	70.41
M30	36.97	14.55	60.64	8.03	78.25
M40	48.23	16.75	65.25	9.90	79.46
M50	58.99	20.77	64.77	11.09	81.19

Table 5. Percentage Reduction in Cylinder Compressive Strength of SCC Specimens with MK

Grade of concrete	Compressive strength of Reference Specimens (N/mm^2)	Compressive strength of Specimens Cooled by air (N/mm^2)	% reduction in Compressive strength w.r.t reference specimen	Compressive strength of Specimens Cooled by water (N/mm^2)	% reduction in Compressive strength w.r.t reference specimen
M20	26.95	7.757	71.22	5.77	78.57
M30	37.19	11.10	70.17	7.42	80.06
M40	49.59	13.47	72.83	8.75	82.35
M50	60.07	16.25	72.95	10.20	83.01

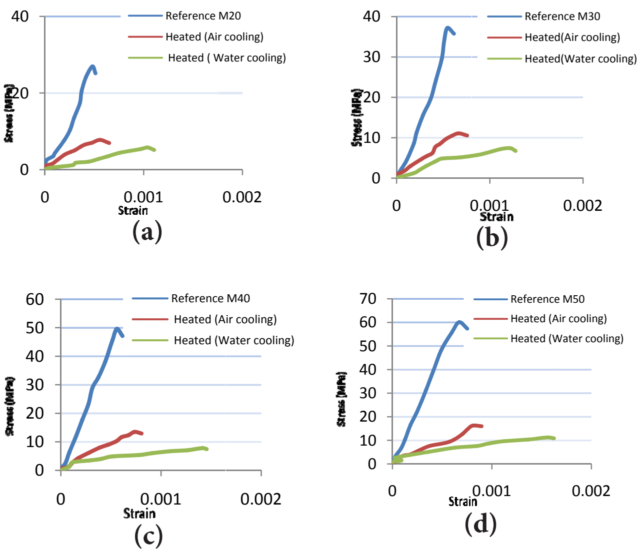


Figure 6. Stress Strain Behaviour of Concrete with MK **(a)** M20 grade **(b)** M30 Grade **(c)** M40 grade **(d)** M50 Grade.

temperatures. This increase in porosity will make SCC into a permeable material at higher temperatures thus reducing the chances for spalling. Since the water content of all grades of specimens is almost same which is around 235 kg/m^3, even the higher grades of concrete had almost the same reduction in strength.The reduction in compressive strength was found to be high for self compacting concrete specimens developed using metakaolin compared with silica fume andflyash. This reduction in compressive strength was found to be more for specimens heated and cooled by water than the specimens heated and cooled by air. The percentage reduction in ultimate strength of self compacting concrete specimens developed using metakaolin is found to be the high. [16]Revealed that the compressive strength of concrete has an important influence on its fire behaviour. A higher compressive strength is usually seen with more packing and less porosity, which may lead to higher pore pressures and spalling under elevated temperature. Density and fineness are some of the key parameters which affect the performance of SCC beams under elevated temperature. Density and fineness of SCC developed using metakaolin are high when compared with self compacting concrete developed using silica fume and flyash. Also the porosity of SCC with metakaolin is less, which had resulted in high pore pressure which led to explosive spalling.SCC can be made in many ways. Many mineral and chemical admixtures can be used to make SCC. In the present study, SSC was made with fly ash, silica fume and metakaolin along with SP and VMA. The findings of the study will be useful in predicting the residual strength of SCC exposed to elevated temperatures.

4. Conclusion

SCC mixes of grade M20, M30, M40 and M50 were developed using SF, FA, MK, SP and VMA. SCC with MK was found to have maximum reduction in compressive strength. The reduction in the compressive strength of SCC specimens with MK was found to be 78.57%, 80.06%, 82.35% and 83.01% for specimens cooled by water respectively for M20, M30, M40 and M50 grades when the specimens were heated from 27 ^{o}C to 900^{o}C. Since the investigation carried out for SCC made with SF, FA and MK, the results will be useful for predicting the behaviour of SCC with different grades under elevated temperature.

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