Fire Technology, 50, 1269–1284, 2014

DOI: 10.1007/s10694-013-0345-6

Effect of Grade of Concrete on the Performance of Self-Compacting Concrete Beams Subjected to Elevated Temperatures

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Received: 20 December 2012/**Accepted:** 6 May 2013

Abstract. Self-compacting concrete (SCC) is a new generation concrete that consolidates without any external effort. Due to its advantages over the conventional concrete, the usage of SCC increases day by day. Understanding the behaviour of SCC is important in the design of structures subjected to elevated temperature. A study was carried out to understand the behaviour of SCC beams of various grades exposed to elevated temperatures under flexural loading. The beams were exposed to a temperature of 900°C. The heated specimens were cooled either by air or water. The research work was carried out for different grades of concrete. It is found from the results that the loss of strength of SCC beams of higher grades was more than that of the lower grade SCC beams. It was also found that the reduction in compressive, tensile and flexural strength of the specimens depends on type of heating and cooling conditions.

Keywords: Self-compacting concrete, Elevated temperature, Fly ash, Compressive strength, Tensile strength, Flexural strength

1. Introduction

The effect of fire on structural members is an important factor to be understood by the designers. The thermal behavior of the members subjected to temperature loads will give an over view about how they react to temperature loads. The selection of fire protection materials having good quality is now getting due attention. It is a positive trend that structural engineers work with fire engineers to protect the structures. Since the responsibility of fire-resistant design is delegated to the structural engineers, they must have an idea about the behaviour of materials under fire. With the increased incidents of major fires in buildings; assessment, repairs and rehabilitation of fire damaged structures has become a topic of interest. This is a specialized field which requires expertise in many areas like concrete technology, material science and testing, structural engineering, repair materials and techniques etc. The reinforced concrete is the one of the most widely used construction material will get affected badly in the form of spalling, exposing of reinforcement etc.

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when exposed to fire. Self-compacting concrete (SCC) is an innovative material developed recently. Only very few literature is available on behaviour of SCC beams subjected to elevated temperatures. An attempt has been made to understand the behaviour of SCC beams subjected to elevated temperatures.

2. Review of Literature

Poon et al. [1] carried out an investigation on the strength and durability of normal and high strength pozzolanic concrete incorporating silica fume, fly ash and blast furnace slag at elevated temperatures up to 800°C. The strength properties were determined using an unstressed residual compressive strength test, while durability was investigated by rapid chloride diffusion test. It was found that pozzolanic concrete containing fly ash and blast furnace slag exhibited better performance particularly at temperatures below 600°C as compared to the pure cement concrete. Explosive spalling occurred in high strength concrete containing silica fume. A distributed network of fine cracks was observed in all fly ash and blast furnace slag concrete, but no spalling or splitting occurred. The high strength pozzolanic concrete resulted in a severe loss in permeability related durability than the loss in the compressive strength. Thirty percentage replacement of cement by fly ash in HSC and 40% replacement of cement by blast furnace slag in normal strength concrete (NSC) were found to retain maximum strength and durability after exposure to high temperatures.

Li et al. [2] investigated the effect of temperature exposure on compressive strength, splitting tensile strength and flexural strength of normal and high-strength concrete (HSC). Oil furnace was used in this study for heating the specimens. The temperature time curve was close to the standard curve, which conformed to Chinese standard GB/T 9978 to 1999. After being heated to temperatures of 200°C, 400°C, 600°C, 800°C and 1,000°C respectively, the mechanical properties of HSC were found. The influence of temperature, water content, size of specimen, strength and temperature profiles on mechanical properties of HSC was discussed. They concluded that the strength losses in larger specimens were found to be less.

Noumowe et al. [3] carried out an investigation to understand the behavior of conventional vibrated high strength concrete and self-compacting high strength concrete at high temperature. Based on the results they concluded that, the residual mechanical properties of self-compacting high strength concretes were similar to that of conventional HSC. The risk of spalling for self-compacting high strength concrete was greater than that of conventional HSC. The test results showed that severe spalling could occur with self-compacting HSC even at a heating rate as low as 0.5°C/min.

Tao et al. [4] reported the results of a laboratory investigation carried out to study the effects of high temperatures ranging from room temperature to 800°C on the compressive strength of SCC and HSC. It was reported that the hot compressive strength of SCC decreased with increase in temperature. It was found that grade of concrete had an effect on the strength loss of concrete, especially in the temperature range below 400°C. Higher grades of SCC resulted in higher loss of strength. But this difference was found to be less in the permanent strength loss stage. Compared with normal strength SCC, high strength SCC was found to possess a larger compressive strength when exposed to high temperature. It was also reported that addition of polypropylene fibers decreased the strength. However the addition reduced the probability of explosive spalling.

Yaragal et al. [5] determined the strengths of cube specimens subjected to elevated temperatures ranging from 100°C to 800°C, in steps of 100°C with a retention period of 2 h. After exposure, weight losses and the residual compressive strength retention characteristics were studied. Test results indicated that weight and strength significantly reduced with an increase in temperature. As the exposed temperature increases, loss in weight of specimen increased, above 200°C. With increase in grade of concrete, there was a decrease in loss of weight of specimen after subjecting to elevated temperatures. In general there was a substantial loss (74%) in strength of M20, M25 and M30 grades of concretes when exposed to higher temperatures. However for M35, M40 and M45 grades, strength loss was around 80%. The observed minimum residual strength was found to be 18% for M45 at 800°C. Equations to predict the residual compressive strength for two ranges of temperature were derived for NSC.

Chan et al. [6] carried out an investigation on the fire resistance of NSC and HSC, with compressive strengths of 39 MPa, 76 MPa, and 94 MPa respectively. After exposure to temperatures up to 1,200°C, compressive strength and tensile splitting strength were determined. The pore structure in HSC and in NSC was also investigated. Results indicated that HSC lost its mechanical strength in a manner similar to that of NSC. The range between 400°C and 800°C was found to be critical to the strength loss. High temperatures had a coarsening effect on the microstructure of both HSC and NSC. On the whole, HSC and NSC suffered damage to almost the same degree, although HSC appeared to suffer a greater worsening of the permeability-related durability.

Netinger et al. [7] assessed the benefits of using materials that were formed at high temperatures as an aggregate for concrete that was exposed to high temperature. The fire resistance of concrete made with some locally available, fire resistant aggregates such as diabase, steel slag, crushed bricks and crushed tiles was investigated. The residual mechanical properties such as compressive strength and flexural strength of these concretes after natural cooling were compared with the residual mechanical properties of concrete made with commonly used river and dolomite aggregates. Steel slag concrete exhibited improved fire resistance at high temperature ranges.

Kodur et al. [8] proposed a simplified approach for evaluating temperature distribution across the cross sections in fire exposed reinforced concrete members. The approach was derived based on statistical nonlinear regression analysis, utilizing data generated from finite element analysis. Sectional geometry, concrete characteristics and fire exposure conditions were the parameters considered in the finite element analysis. The validity of the approach for different types of concrete was established by comparing predictions from the proposed equation with the data from fire tests and finite element analysis. Through these comparisons, it was shown that the proposed equation gave better predictions of temperatures in reinforced concrete members subjected to elevated temperatures.

Quiang et al. [9] carried out an experiment to determine the mechanical properties of high strength steel S460N. Tensile tests were conducted at various temperatures ranging between 20°C and 700°C. It was reported that the deterioration of mechanical properties of structural steel at elevated temperature was dependent on steel grades. Simplified equations were proposed for estimating the deterioration of high strength structural steel S460N at elevated temperatures.

Husem [10] examined the variation of compressive and flexural strengths of ordinary and high performance micro-concrete at high temperature. Compressive and flexural strengths of ordinary and high performance micro-concrete which were exposed to high temperatures (200°C, 400°C, 600°C, 800°C and 1,000°C) and cooled under different cooling conditions (in air and water) were obtained. Compressive and flexural strengths of these concrete samples were compared with each other and then compared with the samples which had not been heated. Strength loss curves of these concrete samples were compared with the strength loss curves given in the codes. It was reported that strength of concrete decreased with increase in temperature and the decrease in the strength of ordinary concrete was more than that of the high-performance concrete. The type of cooling was found to affect the residual compressive and flexural strength, the effect being more pronounced as the temperature increased. Strength loss curves obtained from this study were found to be in agreement with the strength loss curves given in the Finnish Code.

Arioz [11] studied the effects of elevated temperatures on the physical and mechanical properties of various concrete mixes prepared using ordinary Portland cement (OPC), crushed limestone and river gravel. Specimens were subjected to elevated temperatures ranging from 200°C to 1,200°C. After exposure, weight losses and the compressive strength were found out. Test results indicated that weight of the specimens significantly reduced with an increase in temperature. This reduction was very sharp beyond 800°C. The effects of water/cement ratio and type of aggregate on losses in weight were not found to be significant. The results also revealed that the relative strength of concrete decreased as the exposure temperature increased.

Fares et al. [12] carried out an experimental investigation on the performance of self-consolidating concrete (SCC) subjected to high temperature. Two SCC mixtures and one vibrated concrete were tested. Mechanical and micro structural properties were studied at ambient temperature and after heating. Compressive strength, flexural strength, bulk modulus of elasticity, porosity and permeability of these concrete were found. For each test, the specimens were heated at a rate of 1°C/min up to the desired target temperatures (150°C, 300°C, 450°C and 600°C). In order to ensure a uniform temperature throughout the specimen, the temperature was held constant at the target temperature for 1 h before cooling. In addition, the mass of the specimens were found before and after heating in order to determine the loss of water during the test. The risk of spalling was found more for SCC than vibrated concrete.

Anagnostopoulos et al. [13] carried out an investigation to determine the influence of different fillers on the properties of SCC of different strength classes when exposed to high temperatures. They reported that explosive spalling occurred in both the cases of SCC and NCC when the oven peak temperature of 600°C is maintained. SCC was found to spall more compared to NCC due to lower permeability and higher moisture content. SCC with ladle furnace slag in its composition was found to have higher compressive strength at the age of 28 days due to slag's cementitious behavior, but was more susceptible to spalling effects after fire exposure compared to other mixtures. SCC produced with glass filler had greater rheological characteristics at fresh state condition, but did not perform well after heated at high temperatures. SCC produced with limestone filler was found to have better performance compared to mixtures prepared with different filler materials.

Pathak et al. [14] studied the properties of SCC such as compressive strength, splitting tensile strength, rapid chloride permeability, porosity, and mass loss when exposed to elevated temperatures. Mixes were prepared with three percentages of class F fly ash ranging from 30% to 50% and for comparison; one controlled mixture without fly ash was also produced. The specimens were heated to 20°C, 100°C, 200°C, and 300°C. OPC was used for making SCC mixes. The 28 days compressive strength ranged between 21.43 MPa and 40.68 MPa and splitting tensile strength ranged between 1.35 MPa and 3.60 MPa. Test results clearly show that there is little improvement in compressive strength within temperature range of 200°C to 300°C as compared to 20°C to 200°C but there is little reduction in splitting tensile strength ranging from 20°C to 300°C and with the increase in percentage of fly ash.

3. Experimental Investigation

3.1. Materials

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 stones with a size 10 mm and down were 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 flow ability without segregation, additional fine materials were used. In this study, fly ash belonging to class F from a local thermal power station was used. Two types of chemical admixtures were used for the production of SCC viz., super plasticizer (SP) and viscosity modifying agent (VMA). Glenium B233 was used as a SP in this study. The specific gravity of the SP used was 1.09. The VMA used is Glenium Stream 2.

3.2. Mix Design

A mix design procedure developed by Prince Arulraj and Jemi Elizabeth [15] was used for the design of SCC mixes using fly ash and optimized dosage of SP and

VMA. M25, M30, M35 and M40 mixes were designed to carry out the experimental investigation. Concrete was made self-compactable by adjusting the proportions of the normal concrete obtained as per IS 10262:2009 method. Fly ash 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 respectively and found to be satisfactory. Properties of hardened SCC such as compressive strength, tensile strength, modulus of elasticity and flexural strength were found following the procedures given in respective Bureau of Indian Standards. The design mixes for various grades of SCC are given in Table 1.

3.3. Workability Test on SCC

Figure 1 shows the V-funnel and J ring test setup used during the study. The results of the various workability tests are given in Table 2.

3.4. Tests on Hardened SCC

The cube compressive strength, tensile strength and flexural strength of different grades of SCC were found at 28th day and 56th day. The strength at 56th day was found since the mixes had large proportions of fly ash and the mixes having large proportions of fly ash develop strength even after 28 days. The mechanical properties of the SCC mixes are given in Table 3.

3.5. Testing of SCC Beams Subjected to Elevated Temperature

All specimens were heated in an electric furnace. The inner dimensions of the furnace are 500 mm × 500 mm × 500 mm. The sides and top of the furnace were lined with electrical heating coils embedded in refractory bricks. The specimens are heated uniformly on three sides. This resembles the practical case wherein the bottom of the beam and the two sides are exposed to higher temperatures in case

Table 1
Mix Proportion and Quantities of SCC

		Grade of concrete			
Materials	Unit	M25	M30	M35	M40
Cement	kg/m^3	359	405	441	479
Fine aggregate	kg/m^3	843	808	791	748
Coarse aggregate	kg/m^3	862	816	760	722
Fly ash	kg/m^3	233	275	310	297
SP	l/m^3	4.62	8.12	11.02	14.25
VMA	l/m^3	0.59	0.34	0.37	0.38
W/C ratio		0.39	0.35	0.32	0.30
C/P ratio		0.60	0.59	0.58	0.61

Figure 1. Workability Test on Fresh SCC.

Table 2
Results of the Workability Tests on Fresh SCC

Workability test	Permissible limits (EFNARC)		Actual value
	Min	Max	
Slump flow spread diameter (mm)	650	800	737.5
T50 slump flow time (s)	2	5	2.3
J-ring height difference (mm)	0	10	2.5
V-funnel time (s)	8	12	7.3
V-funnel T5 (s)	0	+3	10.2

Table 3
Mechanical Properties of SCC

Grade of concrete	Compressive strength at 28th day (N/mm^2)	Compressive strength at 56th day (N/mm^2)	Tensile strength at 28th day (N/mm^2)	Tensile strength at 56th day (N/mm^2)	Flexural strength at 28th day (N/mm^2)	Flexural strength at 56th day (N/mm^2)
M25	31.25	41.56	2.72	3.26	5.39	6.51
M30	36.39	47.89	3.56	4.16	5.91	7.21
M35	42.80	54.90	4.02	4.67	6.42	7.77
M40	47.55	60.35	4.45	5.17	6.95	8.35

of fire accidents. The top of the beams are usually protected with the flooring. The control panel has a temperature controller to prevent damage to the furnace by tripping off, if the temperature inside the furnace exceeds the specified temperature. The maximum operating temperature of the furnace is 1,200°C. The Muffle furnace used for heating the specimens is shown in Figure 2.

The SCC beams and the specimens were exposed to fire in two ways. In the first case, specimens were kept inside the furnace and the furnace was heated from room temperature to 900°C. In the second case the furnace was heated up to 900°C and the specimens were kept inside the furnace for duration of 90 min. Time temperature curve for the specimen heated from room temperature to 900°C is shown in Figure 3.

The time temperature curve was obtained using infrared thermometer. While keeping and removing the specimens adequate care was taken to protect the researcher from the heat wave by using proper gloves, helmet and chest cover. After exposing the specimens to desired temperature and duration, the furnace was switched off and the specimens were taken out of the furnace. The specimens were naturally allowed to reach the room temperature in case of air cooling and in case of water cooling, water was sprayed uniformly on the heated specimens using a sprayer till the specimens are cooled completely. The strength of the specimens was found after cooling the specimens.

Figure 2. Heating of SCC Specimens at 900°C.

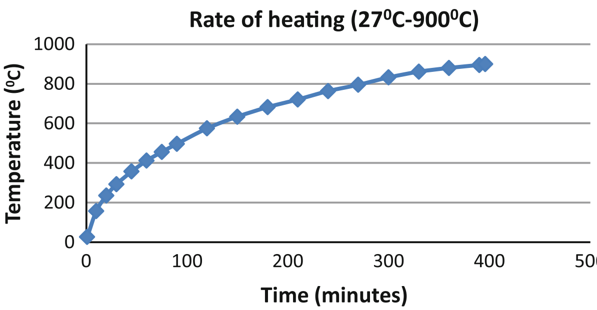

Figure 3. Time Temperature Curve.

Table 4
Details of Specimens Subjected to Experimental Investigation

Size of beam (mm)	Size of cube (mm)	Size of cylinder (mm)	Grade of concrete	Temperature	Type of cooling	Designation of specimen
500 × 100 × 100	150 × 150 × 150	150 × 300	M25, 30, M35, 40	Reference	–	–
500 × 100 × 100	150 × 150 × 150	150 × 300	M25, 30, M35, 40	27°C to 900°C	Air	T1AC
500 × 100 × 100	150 × 150 × 150	150 × 300	M25, 30, M35, 40	27°C to 900°C	Water	T1WC
500 × 100 × 100	150 × 150 × 150	150 × 300	M25, 30, M35, 40	900°C at 90 min	Air	T2AC
500 × 100 × 100	150 × 150 × 150	150 × 300	M25, 30, M35, 40	900°C at 90 min	Water	T2WC

T1 refers to beams heated from room temperature to 900°C, T2 refers to beams kept at 900°C for 90 min duration, AC refers to beams cooled by natural air and WC refers to beams cooled by spraying water

Table 5
Cube Compressive Strength of Reference and Heated Specimens

Grade of concrete	Cube compressive strength (N/mm^2)				
	Reference specimen	27°C to 900°C (WC)	900°C at 90 min (WC)	27°C to 900°C (AC)	900°C at 90 min (AC)
M25	31.25	8.9	9.49	14.03	15.18
M30	36.39	9.32	10.48	15.57	17.18
M35	42.8	10.06	11.38	17.46	19.65
M40	47.55	10.4	12.05	18.59	20.78

4. Analysis of the Results

The beam specimens were tested in a universal testing machine of capacity 1,000 kN under two point loading. The compressive strength and split tensile strengths of the reference and heated specimens were found using a compression testing machine of capacity 2,000 kN. Table 4 gives the detail of specimens used for experimental investigation.

During the present investigation 60 cube specimens, 60 cylinder specimens and 60 beam specimens were tested. Table 5 gives the cube compressive strength of reference and heated specimens.

From Table 5, it can be seen that there is a drastic reduction in the compressive strength of specimens which are exposed to higher temperatures. The reduction in the compressive strength is found to be maximum for the specimens that are heated from room temperature to 900°C and cooled by spraying water. The percentage reduction in the compressive strength for various heating and cooling conditions are given in Table 6.

From Table 6, it can be seen that the percentage reduction in the compressive strength of specimens increases as the grade of concrete increases for all heating and cooling conditions. The compressive strength was found to the minimum for the specimens that were kept at 900°C for 90 min and cooled by air.

The specimens cooled by air exhibited a lower loss of strength when compared with the specimens cooled by water. When the specimens are cooled by water, the temperature of concrete suddenly drops while the temperature of steel still has a

Table 6
Percentage Reduction in Compressive Strength

Grade of concrete	Percentage reduction in compressive strength			
	27°C to 900°C (WC)	900°C at 90 min (WC)	27°C to 900°C (AC)	900°C at 90 min (AC)
M25	71.55	69.62	55.1	51.42
M30	74.4	71.2	57.2	52.8
M35	76.5	73.4	59.2	54.1
M40	79.8	74.66	60.9	56.3

Table 7
Tensile Strength of Reference and Heated Specimens

	Tensile strength (N/mm^2)				
Grade of concrete	Reference specimen	27°C to 900°C (WC)	900°C at 90 min (WC)	27°C to 900°C (AC)	900°C at 90 min (AC)
M25	2.72	0.64	0.73	0.95	1.14
M30	3.56	0.78	0.85	1.16	1.43
M35	4.02	0.81	0.88	1.25	1.54
M40	4.45	0.85	0.91	1.33	1.65

Table 8
Percentage Reduction in Tensile Strength

	Percentage reduction in tensile strength			
Grade of concrete	27°C to 900°C (WC)	900°C at 90 min (WC)	27°C to 900°C (AC)	900°C at 90 min (AC)
M25	76.5	73.25	65.22	58.24
M30	78.2	76.05	67.38	59.7
M35	79.85	77.9	68.85	61.8
M40	80.90	79.55	70.1	62.9

Table 9
Flexural Strength of Reference and Heated Specimens

	Flexural strength (kN)				
Grade of concrete	Reference specimen	27°C to 900°C (WC)	900°C at 90 min (WC)	27°C to 900°C (AC)	900°C at 90 min (AC)
M25	5.39	1.16	1.29	1.71	1.93
M30	5.91	1.18	1.31	1.77	1.97
M35	6.42	1.21	1.34	1.81	2.06
M40	6.95	1.24	1.35	1.88	2.17

Table 10
Percentage Reduction in Flexural Strength

	Percentage reduction in flexural strength			
Grade of concrete	27°C to 900°C (WC)	900°C at 90 min (WC)	27°C to 900°C (AC)	900°C at 90 min (AC)
M25	78.50	76.05	68.34	64.26
M30	80.10	77.90	70.05	66.67
M35	81.15	79.15	71.81	67.96
M40	82.20	80.50	72.95	68.80

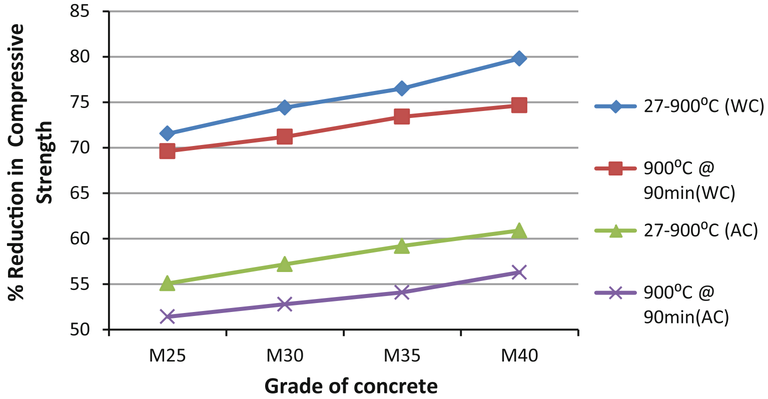

Figure 4. Percentage Reduction in Compressive Strength.

high value resulting in a very large thermal gradient. As a result of this steep thermal gradient, thermal incompatibility develops and as a result, the reduction is strength becomes large. Table 7 gives the tensile strength of reference and heated specimens.

From Table 7, it can be seen that there is a drastic reduction in the tensile strength of specimens which are exposed to higher temperatures. The reduction in the Tensile strength is found to be maximum for the specimens that are heated from room temperature to 900°C and cooled by spraying water. The percentage reduction in the tensile strength for various heating and cooling conditions are given in Table 8.

From Table 8, it can be seen that the percentage reduction in the tensile strength of specimens increases as the grade of concrete increases for all heating and cooling conditions. The tensile strength was found to the minimum for the specimens that were kept at 900°C for 90 min and cooled by air. Table 9 gives the flexural strength of reference and heated specimens.

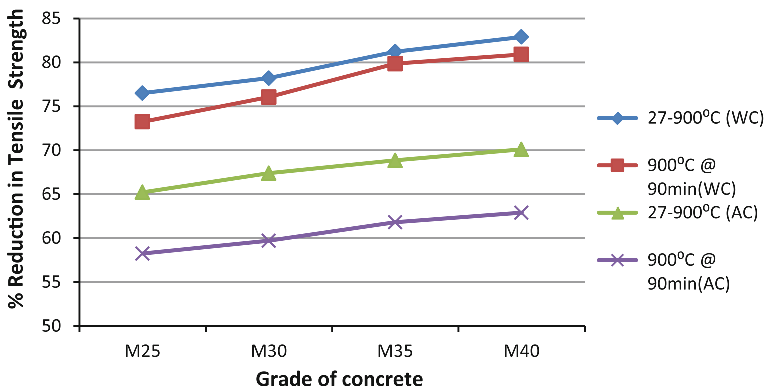

Figure 5. Percentage Reduction in Tensile Strength.

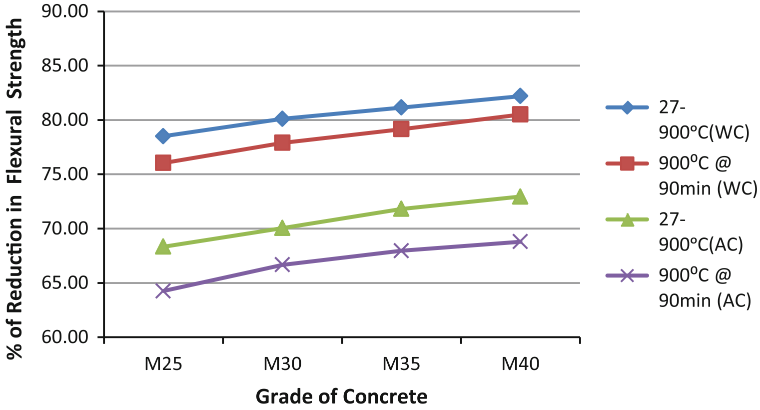

Figure 6. Percentage Reduction in Flexural Strength.

From Table 9, it can be seen that there is a drastic reduction in the flexural strength of specimens which are exposed to higher temperatures. The reduction in the flexural strength is found to be maximum for the specimens that are heated from room temperature to 900°C and cooled by spraying water. The percentage reduction in the flexural strength for various heating and cooling conditions are given in Table 10.

From Table 10, it can be seen that the percentage reduction in the flexural strength of specimens increases as the grade of concrete increases for all heating and cooling conditions. The flexural strength was found to the minimum for the specimens that were kept at 900°C for 90 min and cooled by air. The variation in the reduction of compressive strength with respect to the grade of concrete is shown in Figure 4.

The correlation coefficient between the characteristic strength and the percentage reduction in compressive strength is found to be 0.98, which indicates a very strong positive correlation between the characteristic strength and the percentage reduction in the compressive strength when exposed to higher temperature. The variation in the reduction of tensile strength with respect to the grade of concrete is shown in Figure 5.

The correlation coefficient between the characteristic strength and the percentage reduction in split tensile strength is found to be 0.95, which indicates a very strong positive correlation between the characteristic strength and the percentage reduction in the tensile strength when exposed to higher temperature. The variation in the reduction of flexural strength with respect to the grade of concrete is shown in Figure 6.

The correlation coefficient between the characteristic strength and the percentage reduction in flexural strength is found to be 0.96, which indicates a very strong positive correlation between the characteristic strength and the percentage reduction in the flexural strength when exposed to higher temperature.

As the grade of concrete increases, the strength and stiffness of concrete increase, and the porosity decreases. When higher grade concrete specimens are subjected to elevated temperatures, the pore pressure increases considerably. As the grade of concrete increases, the pore pressure and the tensile strength of concrete increase. However the increase in the pore pressure will be more than the increase in the tensile strength of concrete. This may result in spalling and hence higher grade concrete are more susceptible to thermal gradients.

5. Discussion of the Results

During the present study, it is found that the reduction in the compressive, tensile and flexural strengths of concrete exposed to higher temperatures increases as the grade of SCC increases. There is also perfect correlation between the characteristic strength and loss of strength. However the increase in the reduction in strength between two grades of concrete is less than 5% only. This indicates that the overall reduction in the compressive strength of SCC specimens is in the range of 70% to 80% when the specimens are heated from room temperature to 900°C and cooled by spraying water. Overall reduction in the tensile strength of SCC specimens is in the range of 75% to 80% when the specimens are heated from room temperature to 900°C and cooled by spraying water. Overall reduction in the flexural strength of SCC specimens is in the range of 78% to 82% when the specimens are heated from room temperature to 900°C and cooled by spraying water. The increase in the reduction of strength between different grades of concrete is found to be insignificant.

Chan et al. [6] reported that spalling of concrete depends mainly on dense internal microstructure and moisture content. Anagnostopoulos et al. [13] reported that lower moisture content is of great significance, since the accumulated pore pressure will be minimum for lower moisture content. In the present study, for all the grades of SCC mixes, the water content is almost same which is around 141 kg/m^3. Hence even the higher grades of concrete had almost the same reduction in strength. The higher the moisture content the higher the possibility to spalling. Pathak et al. [14] reported that as the percentage of fly ash increases porosity also increases when subjected to higher temperatures. This increase in porosity values may change impermeable SCC to permeable material at higher temperatures. During the present investigation, a fairly large quantity of fly ash was used and the cement powder ratio of around 0.6 was maintained for all the grades. The large amount of fly ash, same cement powder ratio and the same quantity of water reflected in almost same percentage reduction in strength.

SCC can be made in many ways. Many chemical and mineral admixtures can be used to make SCC. In the present study, SSC was made with fly ash, SP and VMA. The findings of the study will be useful in predicting the residual strength of SCC made with fly ash, SP and VMA exposed to elevated temperatures.

6. Conclusions

Grade of concrete plays a major role in the design of reinforced concrete structures. Higher grades will result in higher compressive strength and shear resistance. However the performance of high performance concrete may not be satisfactory when exposed to higher temperatures. Effect of different grade of concrete on the performance of SCC beams exposed to high temperatures was investigated using an experimental investigation. 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. Exposure to higher temperature will lead to thermal incompatibility between concrete and steel and increase in the internal pore pressure which will result in the reduction of strength.

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