Variation in Strength of SCC with Temperature Elevation: A Review

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Abstract

A review is presented based on the experimental studies on concrete when it is subjected to higher elevated temperature upto 800°C. Self-Compacting Concrete gives better strength than Normal Concrete at normal temperature. Studies show that regardless of strength at normal temperature, SCC gives better mechanical properties as it is exposed to higher temperature. The paper explores the changes in the compressive strength of SCC as the temperature is elevated. The paper also shows the variation when the cooling method after heating of concrete is different. Many researchers have used different admixture to increase the strength and workability of SCC. The review of different duration of heating and their effect on the hardened properties of SCC is also incorporated in this study. The goal of this paper to accumulate the result of different researches and to set an international benchmark for further work related to SCC.

Keywords: *Self-Compacting Concrete, Superplasticizers, Volcanic Ash, spalling, dolamite*

I. INTRODUCTION AND METHOD

Self-Compacting Concrete (SCC) was first proposed by Okamura in 1986. It is defines as a concrete that flows under its own weight and completely fills the formwork, while maintaining its homogeneity. SCC is widely used in those areas where the reinforcement is very dense. The use of SCC in actual structures has gradually increases. It eliminates use of vibration for compaction in structure. Property of segregation and micro cracks has not been found in SCC structures.SCC basically consists the same materials as Normal Concrete (NC). The proportion of aggregate, cement, water is different from NC. However, SCC also incorporate superplasticizers and admixtures. Ultrafine admixtures are used to make the concrete denser as compare to NC.

When NC is exposed in fire, the degradation in strength is seen. Strength of concrete reduces more quickly when it is exposed to higher temperature. Many studies have been conducted to analyse the effect of temperature on SCC. The variation on strength depends on the factors like cement content, admixture used, water content, aggregate content, aggregate size, plasticizer, quantity of plasticizer etc. Main purpose of this review is to compile different researches on SCC at elevated temperature in such a way that it would be beneficial to the researcher to conduct their study.

Hossain, K. M. A. (2006) studied the strength and durability of high strength blended cement concrete incorporating up to 20% of volcanic ash (VA) subjected tohigh temperatures up to 800°C. The strength was assessed by unstressed residual compressive strength, while durability was investigated by rapid chloride permeability (RCP), mercury intrusion porosimetry (MIP), differential scanning calorimetry (DSC), crack pattern observations and micro hardness testing. High strength volcanic ash concrete (HSVAC) exhibited better performance showing higher residual strength, chloride resistance and resistance against deterioration at high temperature compared to the control high strength OPC concrete. However, deterioration of both strength anddurability of HSVAC increased with the increase of temperature up to 800°C due to weakened interfacial transition zone (ITZ) between hardened cement paste (HCP) and aggregate and concurrent coarsening of the HCP pore structure. The serviceability assessment of HSVACs after a fire should therefore, be based on both strength and durability considerations.

Table 1. Salient Features of Experiment Carried by Hossain, K.M.A.

Size of specimens	Temperature range	Time of heating	Cooling Method	Admixture used	Parameter analyzed
150mm cubes	Upto 800°C	1 hour	Gradual cooling	Volcanic ash	Strength and Durability

Sideris, K. K. (2007) investigated mechanical characteristics of Self- Compacting Concrete subjected to elevated temperatures up to 700°C. Eight different concretes four Self-Compacting Concretes (SCC) and four conventional concretes (CC) of different strength categories were produced. At the age of 120 days, specimens were placed in an electrical furnace and the heating was applied at a rate of 5°C/min until the desired temperature was reached. A maximum temperature of 100, 300, 500, and 700°C was maintained for 1 h. Specimens were then allowed to cool in the furnace and tested for compressive strength, splitting tensile strength, and ultrasonic pulse velocity. Similar tests were also performed at room temperature (20°C) for the reference specimens. Residual strength of both SCC and CC was reduced almost similar up to the maximum temperature tested. Explosive spalling occurred in both SCC and CC of the highest strength category at temperatures greater than 380°C. The residual compressive strength of SCC mixtures was higher than the one of CC mixtures for the same strength class. The tentative spalling behavior of SCC and CC was the same and depended only on the strength category.

Abdelalim, A. M. K. *et al.* (2009) investigated the influence of coarse aggregate type and incorporation of polypropylene fibers on the mechanical properties of Normal Conventional Concrete (NCC) and Self-Compacting Concrete (SCC). Three types of local aggregates namely natural gravel, basalt and dolomite were used. Fire resistance of the produced concrete in terms of residual strengths and spalling was studied. Different elevated degrees of temperature of 200, 400, 600 and 800 °C wereconsidered. The latter degree of temperature (800 °C) was maintained constant whilethe effect of exposure durations of 15, 30, 60 and 120 minutes were investigated.Compressive strength, indirect tensile strength, porosity, near surface absorption and spalling were measured before and after exposure to elevated degrees of temperature. The results indicated that, aggregate type has a minor effect on the concrete resistance to fire. However dolomite aggregates provided the highest resistance to fire while natural aggregate gave the least resistance. The incorporation of polypropylene fibers improved the indirect tensile strength results as well as the concrete resistance to spalling. It was also recorded that the degradation of the mechanical and permeation properties of SCC increases with increasing the degree of elevated temperature. It is worth mentioning that the performance of SCC exposed to high elevated degrees of temperature is better than that of the NCC.

Table 2. Salient Features of Experiment Carried by Sideris, K.K.

Size of specimens	Temperature range	Time of heating	Cooling Method	Admixture used	Parameter analyzed
100mm cubes and 150*300mm cylinders	Upto 700°C	1 hour	Gradual cooling	-	Compressive and tensile strength and Ultrasonic pulse velocity

Table 3. Salient Features of Experiment Carried by Abdelalim, A.M.K. et al.

Size of specimens	Temperature range	Time of heating	Cooling Method	Admixture used	Parameter analyzed
100mm cubes and 150*300 mm cylinder	Upto 800°C	15,30,60,120 minutes	Gradual cooling	Polypropylene fibre	Compressive and tensile strength, porosity, surface adsorption,spalling

Khaled M. Heiza (2009) showed that fires and aggressive environment affect the durability of different types of concretes, so experimental investigation of concrete deterioration is very essential. The production of Self–Compacting Concrete (SCC) mixes with two different types of mineral admixtures (silica fume and fly ash) wereincluded in his research. The workability of fresh concrete mixes was investigated using five different international specified techniques. The properties of hardened concrete samples were determined under the exposure of different temperatures, which ranges between 25ºC and 600ºC. The effects of the methods of treatment for concrete samples after being exposed to fire on there, physical and mechanical properties were investigated. Test specimens were exposed to fire with temperatures 200, 400 and 600ºC for two hours according to ASTM E- 119 standard test methods for fire tests of building construction and materials. After that, the specimens were classified into two groups. The first group was cooled down immediately after fire in laboratory atmosphere (air treated) then was left for about 24 hours in laboratory atmosphere before testing. And; the second group was cooled down immediately after fire by immersion in water with 20ºC (water treated) then was left for about 24 hours in laboratory atmosphere before testing. All concrete mixes air treated after exposed to fire at temperature from 25ºC up to 200ºC. There was an enhancement in strength by about 10% of its original values. The compressive strength decreased dramatically when temperature increase from 200ºC up to 600ºC where there was a severe degradations in compressive strength for all mixes.

Table 4. Salient Features of Experiment Carried by Khaled M. Heiza

Size of specimens	Temperature range	Time of heating	Cooling Method	Admixture used	Parameter analyzed
150mm cubes and 100*200 mm cylinders	Upto 600 ºC	2 hours	Sudden cooling	Silica fume and Fly ash	Cube and cylinder compressive strength, splitting tensile strength

Abdelalim, A. M. K. *et al.* (2009) studied the effect of elevated fire temperature and cooling regime on the fire resistance of Self-Compacting Concrete (SCC) and Normal Conventional Concrete (NVC). Both concretes were exposed to elevated degrees of fire temperature of 200, 400, 600 and 800 °C. In addition, the temperature was maintained at 800 °C while the exposure durations have been increased to 15, 30, 60 and 120 minutes. After that the samples were cooled to room temperature using three different cooling regimes namely; air cooling, CO_2powder cooling and water cooling. Reductions in both compressive and tensile strength results along with the extent of spalling were examined. The effect of fire and cooling regime on both porosity and absorption capacity of SCC and NVC were also investigated. The results indicated that residual compressive and tensile strengths of SCC are generally higher than those of NVC. In other words, elevated fire temperature was more damaging to the NC compared with SCC. Same has been confirmed by the obtained results of spalling which were found to be higher for NC compared with those of SCC. The results also indicated that adopting CO_2 powder as a cooling regime provided the leastextent of damage to both NC and SCC concretes while water cooling regime provided the greatest damage. The incorporation of polypropylene fiber improved the fire resistance of concrete regardless of the concrete type and cooling regime. Increasing the dosage of self-compacting admixture did not significantly affect the mechanical properties and fire resistance of SCC.

Table 5.Salient Features of Experiment Carried by Abdelalim, A.M.K. et al.

Size of specimens	Temperature range	Time of heating	Cooling Method	Admixture used	Parameter analyzed
100mm cubes	Upto 800°C	15,30 ,60 and 120 minutes	Air cooling, CO_2 powder cooling and water cooling	Polypropylene fibre, Sica viscocrete-500	Compressive strength and indirect tensile strength

Sharma, Divyesh (2013) investigated the variation of compressive strength, tensile strength and modulus of elasticity of the Self-Compacting Concrete. He took different temperature variation with different time duration for their study. Crushed stone and river sand were used in his experiments. OPC of grade 43 was used with 10% replacement of cement by silica fume. Superpasticizer (Conplast SP 430 SRV) was taken as a water reducer. After 28 days of curing, specimens were heated at different temperature of 100˚C, 200˚C, 300˚C and 400˚C forthe time duration of 1 hour, 2 hours, 3 hours and 4 hours. Each cube was heated for 4 different temperatures. After heating, specimens were cooled by air cooling or gradually cooling regime. On testing of specimens, an increase of 1 to 2 %, 0.5 to 1.5%, 1 to 1.7% and 1 to 2% was observed in cube compressive strength, cylinder compressive strength, split tensile strength and modulus of elasticity of SCC respectively, when the specimens were subjected to a temperature of 100°C for duration of 1 to 4 hour and cooled by gradual cooling. An increase of 1 to 1.5%, 1 to 1.6%, 1 to 2% and 0.9 to 2% was observed in cube compressive strength, cylinder compressive strength, split tensile strength and modulus of elasticity of SCC respectively, when the specimens were subjected to a temperature of 200°C for duration of 1 to 3 hour and cooled by gradual cooling. A decrease of 4 % was observed in cube compressive strength, cylinder compressive strength, split tensile strength and modulus of elasticity of SCC respectively, when the specimens were subjected to a temperature of 200°C for duration of 4 hour and cooled by gradual cooling. An increase of 1.5 to 2 %, 2 to 2.5%, 2 to 4% and 1 to 3% was observed in cube compressive strength, cylinder compressive strength, split tensile strength and modulus of elasticity of SCC respectively, when the specimens were subjected to a temperature of 300°C for duration of 1 to 3 hour and cooled by gradual cooling. A decrease of 4 to 7%, 3 to 6%, 5 to 8% and 4 to 8% was observed in, cube compressive strength, cylinder compressive strength, split tensile strength and modulus of elasticity of SCC when the specimens were subjected to a temperature of 300°C for duration of 4 hour and cooled by gradual cooling. A decrease of 8 to 12 %, 10 to 13%, 12 to 14% and 15 to 18% was observed in cube compressive strength, cylinder compressive strength, split tensile strength and modulus of elasticity of SCC respectively, when the specimens were subjected to a temperature of 400°C for duration of 1 to 4 hour and cooled by gradual cooling.

Table 6. Salient Features of Experiment Carried by Sharma, Divyesh

Size of specimens	Temperature range	Time of heating	Cooling Method	Admixture used	Parameter analyzed
150mm cubes and 100*200mm cylinders	Upto 400°C	1,2,3 and 4 hours	Gradual cooling and quenching	Silica fume	Cube and cylinder compressive strength, split tensile strength and modulus of elasticity

Bishr, H.A.M. (2008) also worked on the compressive strength of concrete at elevated temperature. He replaced 15% of cement by silica fume and compose the concrete by using crushed basalt aggregate, ordinary Portland cement and sand. Total number of cubic specimen of size 100*100*100 mm^3 was 90. All the cube were heated at the temperature of 150, 300, 500, 700 and 900°C in electric oven. After gradual cooling of cubes, they were tested for their residual compressive strength.The residual compressive strength of concrete with 15% silica fume after four hours of exposure at 150, 300, 500, 700, 900°C was 102, 118, 94, 57, and 19 % of its unheated strength respectively, while the compressive strength of blended cement concrete was 103, 112, 95, 78, and 38% of the original unheated value. Table 7 shows the salient feature of the experiment

Table 7. Salient Features of Experiment Carried by Bishr, H.A.M.

Size of specimens	Temperature range	Time of heating	Cooling Method	Admixture used	Parameter analyzed
100mm cubes	Up to 900°C	4 hours	Gradual cooling	Silica fume	Cube compressive strength

CONCLUSION

The literature shows a definite trend of variation in strength with temperature elevation. Following points can be concluded from the review-

- The strength of SCC and NC both increases initially as the temperature increases.
- After a definite temperature, the strength of both SCC and NC starts decreasing drastically.
- Decrement in strength of SCC is less compare to that of NC.
- Partial replacement of cement by some mineral admixture always increases the strength of SCC.
- Adopting CO_2 powder as a cooling regime provides the least extent of damage to both NC and SCC concretes while water cooling regime provides the greatest damage.

It is reported in the literature that behavior of Normal strength concrete, high strength concrete and self-compacting concrete were different when exposed to high temperature. Many parameters influence the test results and affect the performance of concrete specimens exposed to high temperature.

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