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Size And High Temperature Effects On The Compressive Strength Of Self Compacting Concretes

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ABSTRACT

The compressive strength behavior of concrete is one of the fundamental parameters of structural design as most load-bearing concrete elements, such as beams, columns and slabs. However, it was known that compressive behavior of the concrete elements alter depend on the element size and exposed temperature conditions. When the slenderness (height/diameter) of the concrete elements increased, compressive strength decreased relatively and this behavior known as size effect. In this study, compressive strength variation of the self compacting concrete specimens investigated taking in to account the different slenderness ratio and exposure temperatures. For this purpose, a self compacting mixture was prepared with water to cement ratio of 0.40 and 450 kg/m^3 cement dosage. Cylindrical specimens with the diameter of 100 mm and slenderness of 2.0, 1.5, 1.0, and 0.5 were prepared and exposed to the different high temperatures (400, 600 and 800 ^{o}C) for an hour. For a control purpose, same size specimens were also tested under the laboratory conditions. The results show that high temperature exposure has severe strength loss effect on the concrete specimens irrespective of the slenderness ratio. Increasing the exposure temperature increased the strength loss of the specimens drastically. Moreover, it was seen that relative strength change (decrease) is evident when specimens' size increased.

Keywords: *Slenderness; compressive strength; high temperature; size effect*

INTRODUCTION

Cementitious materials that are exposed to high temperatures undergo physical and chemical changes. These changes severely degrade their mechanical properties [1,2]. According to literature, [3-5] those deteriorations at elevated temperatures cannot be attributed to a single factor, rather it is affected by several parameters including heating rate, heating time, specimen size, slenderness, specimen geometry, water-cement ratio, curing conditions, aggregate type, fiber, fiber type and loading. High temperatures, in general, cause deterioration in properties such as compressive strength, flexural strength, modulus of elasticity, bond with reinforcement [6]. Moreover, explosive spalling can be monitored at high temperatures depend on the matrix density, moisture content and aggregate type.

As is well known, compressive strength of the concretes alter depend on the specimen geometry. In general, greater the ratio of specimen height to diameter (slenderness), the lower will be the strength or the specimen strength increased with decreasing slenderness. Though there is a bulk of literature on the resistance of concrete to elevated temperature and size effect on the properties of concretes, there is no paper (to the best knowledge of authors) deal with combine effects of slenderness (height to diameter ratio) and elevated temperatures on the compressive strength of self compacting concretes. The objectives of this paper, therefore, are to report on the compressive strength changes that take place at various temperatures, compressive strength changes depend on the height to diameter ratio under constant specimen diameter, and to find out behavior of self compacting concrete under combine effect of height to diameter ratio and various elevated temperatures.

EXPERIMENTAL STUDY

Materials

General Use (GU) Portland cement equivalent to ASTM Type I was used in the production of the self compacting concretes mixture. The chemical composition and physical properties of cement are presented in Table 1. Natural fine and 19 mm maximum size natural coarse aggregates with bulk specific gravity of 2.58 and 2.63 and water absorption of 0.64% and 1.51%, respectively, were also used. Table 2 presents the particle size distribution of aggregate according to ASTM C136.17. A high-efficiency polycarboxylate ether type superplasticizer (HRWR) was used in the design of the self compacting concrete. The mix proportion of the concrete mixture is provided in Table 3. In mixture, water-cement ratio of 0.40 and 450 kg/m^3 cement dosage were used.

Table 1 Chemical and physical properties of cement

Chemical composition (%)	GU type Cement
SiO_2	21.72
Al_2O_3	5.96
Fe_2O_3	3.60
CaO	60.78
MgO	2.64
K_2O	0.75
Na_2O	0.17
SO_3	2.17
P_2O_5	0.04
TiO_2	0.36
Cr_2O_3	0.0455
Mn_2O_3	0.1496
LOI	2.00
Physical properties	
Blaine (cm^2/g)	3500
45 (µm)	4.50
Density (g/cm^3)	3.18

Table 2 Particle size distribution of aggregates

Sieve size	% Passing by mass	
mm	Coarse Aggregate	Fine Aggregate
19.00	100.0	100.0
12.70	89.3	100.0
9.50	35.1	100.0
4.75	2.3	95.6
2.36	0.0	86.6
1.18	0.0	73.2
0.60	0.0	54.9
0.30	0.0	41.4
0.15	0.0	8.6

Casting and curing of test specimens

Self compacting concrete mixture was mixed for five minutes in a laboratory concrete mixer. Tests were conducted on fresh concrete mixtures to determine slump flow, flow time, V-funnel, J-ring and L-box results. Cylinder specimens at the 200, 150, 100, and 50 mm of height and 100 mm diameters were produced. Specimen diameter was kept constant in all slenderness. Specimens were cast without hand compaction or mechanical vibration. After casting, all the molded specimens were covered with plastic sheets and water-saturated burlap and stored in the casting room for 24 hours. They were then demolded and transferred to the moist curing room, and maintained at 22°C and 100% relative humidity until testing.

Table 3 Mix proportion

w/b	Cement, kg/m^3	Water, kg/m^3	Aggregate, kg/m^3 coarse	fine	SP, kg/m^3
0.4	450	180	796	830	1.6

Testing procedure

Slump flow diameter and time, V-funnel, J-ring and L-box tests were conducted to measure flowability, viscosity and passing ability. The slump flow test was primarily conducted to assess the filling ability of concrete without obstructions; it determined flow diameter and total time for concrete to spread 500 mm (T_{500}). The V-funnel test determined the flow of self compacting concrete per unit time, and included the discharge time measurement of fresh concrete under its own weight from the narrow mouth of the specially designed V-funnel apparatus. The J-ring and L-box tests indicated the passing ability of concrete. All the above-mentioned tests are detailed in the Self Compacting Concrete Committee of EFNARC [7].

The compressive strength of self compacting concretes were determined according to ASTM C39 and test was performed under displacement control at a loading rate of 0.5 kN/s on a closed-loop controlled servo-hydraulic material test system.

RESULTS AND DISCUSSION

Fresh Properties

According to the EFNARC's self compacting concrete guide, the filling ability and stability of self-compacting concrete in the fresh state can be defined by four main properties: flowability, viscosity, passing ability, and segregation resistance. To define above mentioned main properties, EFNARC addresses one or more test methods [7]. For instance, flowing ability might be determined by using the slump flow test, viscosity can be measured through the T_{500} slump flow and V-funnel flow times. EFNARC [7] also classified the self compacting concretes according to the slump, viscosity and passing ability properties. Self compacting concrete classification of the EFNARC is given Table 4. Table 5 shows the results of the fresh concrete properties. In the production stage, self compacting concrete showed no segregation of coarse aggregates. The slump flow diameter difference between the non-restricted and restricted (J-ring) slump flow test was not too big, hence indicating good self-consolidation ability. When Table 4 and 5 evaluated together, it can be seen that self compacting concrete produced can be classified as SF-2, VS2/VF2. According to the EFNARC [7] recommendation, SF-2 class SCC can be applied to many normal structural members (e.g. walls, columns). In the application of VS2/VF2 viscosity class SCC, thixotropy, which may be helpful in limiting the formwork pressure or improving segregation resistance, can be monitored. Negative effects may be experienced regarding surface finish (blow holes) and sensitivity to stoppages or delays between successive lifts [7]. Although, segregation and/or loss of uniformity was not observed, self compacting concrete produced can not be satisfied the lower limit ($H_2/H_1 \geq 0.8$) of passing ability classes.

Table 4 SCC classification of EFNARC

Slump flow classes		
Class	Slump flow diameter [mm]	
SF1	550-650	
SF2	660-750	
SF3	760-850	
Viscosity classes		
Class	T_{50} [sec]	V-funnel time [sec]
VS1/VF1	≤2	≤8
VS2/VF2	>2	9 to 25
Passing ability classes		
PA1	≥0.8 with two rebar	
PA2	≥0.8 with three rebar	

Table 5 Fresh properties of self compacting concretes

Slump Flow		J Ring		V funnel Time (s)	L Box		
Diameter (mm)	T_{500} (s)	T_{500} (s)	Slump flow diameter (mm)		T_{200} (s)	T_{400} (s)	H_2/H_1
660	4.1	5.0	560	8.3	2	4.8	0.61

Compressive Strength

Figure 1 presents the compressive strength variation of the self compacting concretes depending on the exposure temperature and slenderness ratio. As seen in figure, irrespective of the slenderness ratio, compressive strength of the concretes decreased drastically with the increasing of exposed temperature. It can be observed in figure that the reduction in compressive strength is noticeable, but not disastrous, if concrete is not heated above 400 °C. However, the reduction in strength is considerable at 600 °C but even then remains useful at around 20 MPa for the highest slenderness ratio. However, beyond 600°C, at standard slenderness ratio (h/d=2.0) compressive strength of the self compacting concretes decreased under 10 MPa. According to Mindess and Young [8] at 105^{o}C, the capillary water and free water vaporize. At 250–700 ^{o}C, the cement hydration product decomposes [8,9]. As the temperature rises above 650^{o}C, small part of the decomposed paste is re-sintered into clinker and recovers little binding capability [8,9]. In addition, the cement paste also tends to expand rather than shrink [8,9] at elevated temperatures. Aggregates are different in their composition as well as in their heat endurance properties. The crystal transition temperature of aggregates, generally, is around 600^{o}C. The strength of concrete is reduced as the volume of aggregate expands with temperature. In addition, cement paste starts to shrink when heated above 200^{o}C. Due to different rates of expansion, cracks may occur on the surface of the concrete and compressive strength of the concretes affected negatively [9]. As is also seen in Figure 1 and as expected, compressive strength of the self compacting concretes decreased gradually when the slenderness ratio increased.

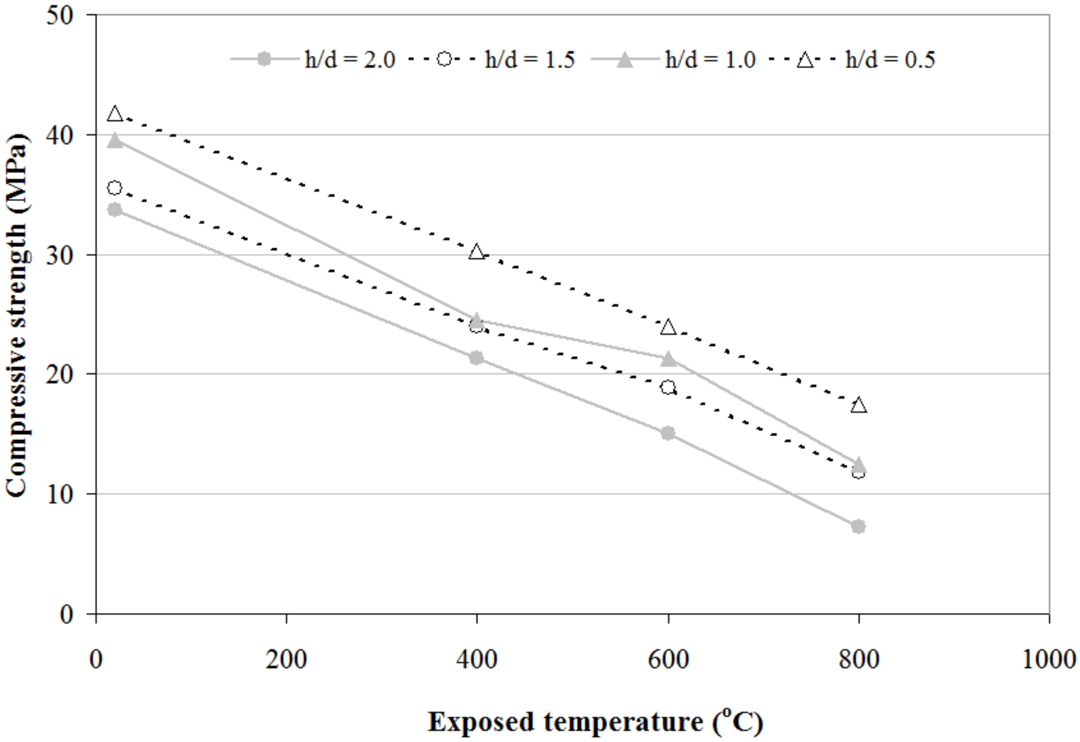

Figure 1 Compressive strength variation of specimens

Figure 2 shows the percent decrease in the compressive strength of the self compacting concretes. As seen in figure, the highest reduction observed in the highest slenderness ratio. Reduction in compressive strength of the highest slenderness ratio was reached to 80%.

Generally, decrease in the compressive strength was linear and there seemed to be an order in the reduction depends on the slenderness ratio.

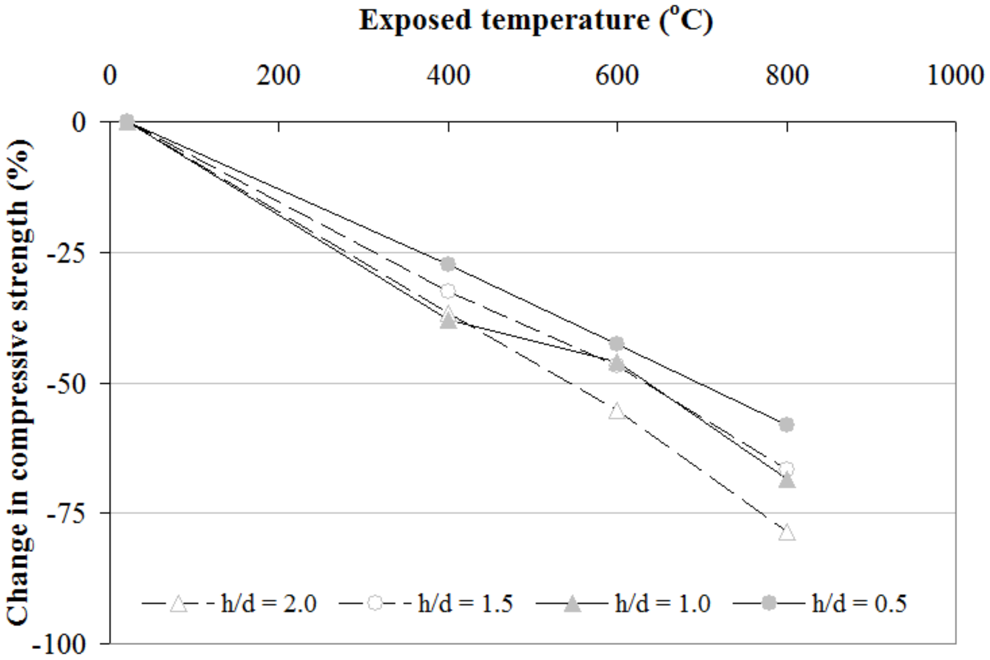

Figure 2 Percent change in compressive strength

Figure 3 illustrates the regression relationship between the compressive strength and exposed temperature. As is seen in figure, correlation coefficients were around 0.99 irrespective of the slenderness ratio. High correlation coefficients show that compressive strength is related with exposed temperature and it will be decreased linearly with the increase in exposure temperature.

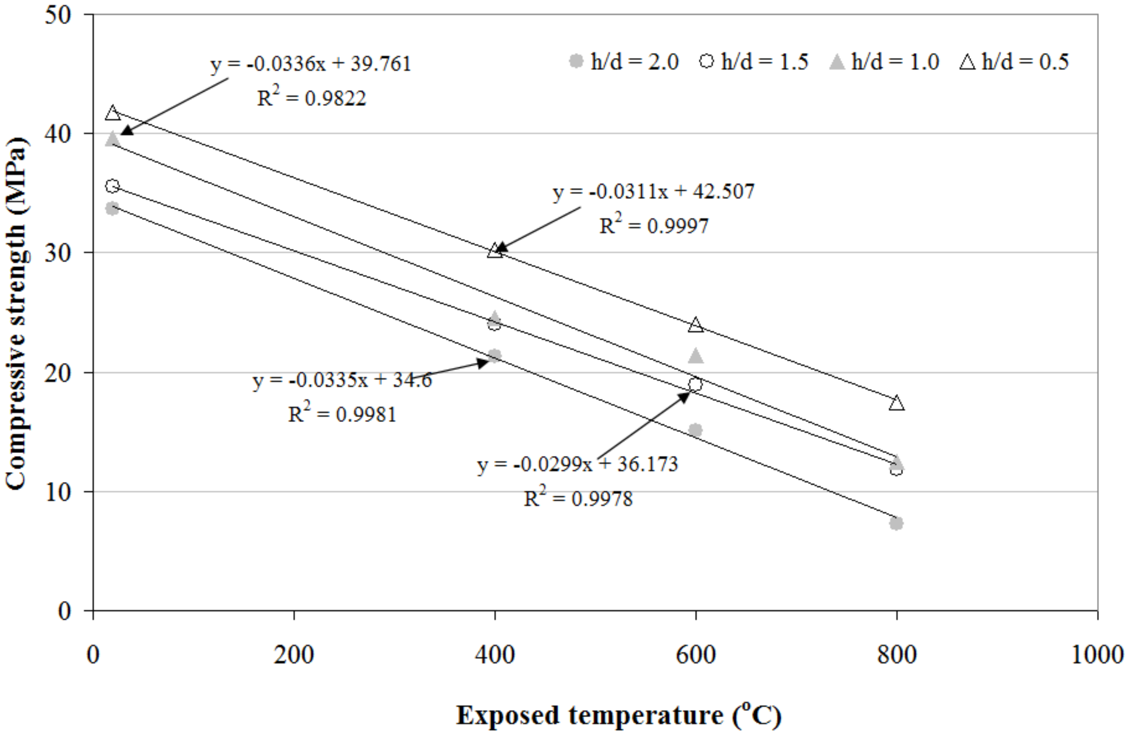

Figure 3 Correlations between the compressive strengths and exposure temperature

Figure 4 presents the relative strength (M_i/M_0) change of the self compacting concretes. Where M_i is the compressive strength at i^{th} slenderness ratio and M_0 is at standard slenderness ratio (h/d = 2). As is seen in figure, decreasing the slenderness ratio increased the relative strength of self compacting concretes. Relative strength increased depends on the slenderness ratio around to 1.5 up to 600°C. However, relative strength increased drastically at 800 °C and reached to 2.5 at the 0.5 slenderness ratio. Therefore, it could be concluded that size effect increases with the increase in exposure temperature.

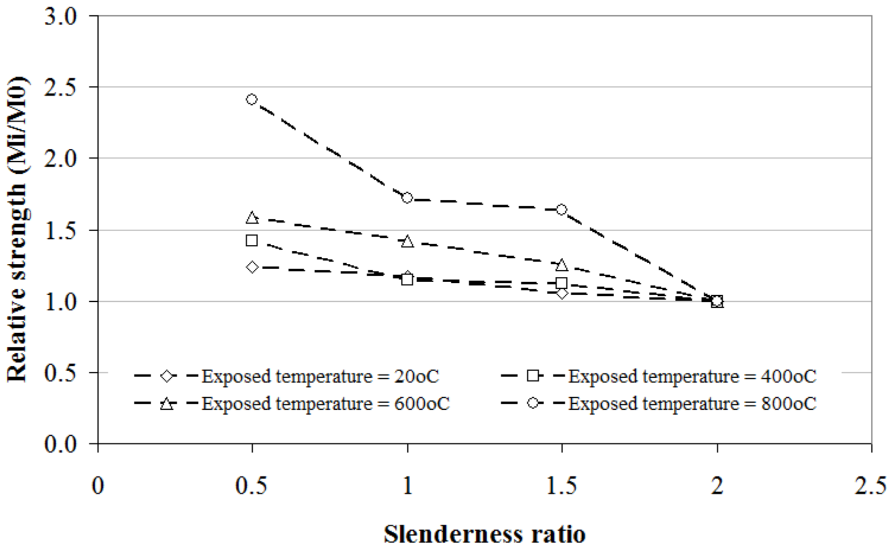

Figure 4 Relative strength variations specimens

CONCLUSIONS

Based on the effects of elevated temperature and slenderness ratio on the compressive strength of self compacting concrete study following conclusions can be drawn:

- Based on the EFNARC criteria, SF-2, VS2/VF2 class self compacting concretes was produced without any segregation and/or loss of uniformity.
- Compressive strengths of self compacting concretes decreased linearly depend on the exposed temperature.
- Increasing the slenderness ratio decreased the compressive strength.
- Relative strength increased around to 1.5 up to 600^{o}C, however, increasing the temperature to 800^{o}C, relative strength increased drastically and reached to 2.5.
- A good linear correlation was monitored between the compressive strength and exposed temperature irrespective of the slenderness ratio.
- Increasing the exposure temperature increased the size effect remarkably.

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