CD05-002

SCC CONTAINING POZZOLANIC MATERIALS AS FILLER REPLACEMENT AT ELEVATED TEMPERATURES

A.A. Ramezanianpour[1], R. Esmaili[2]
[1]Professor in Civil Engineering, Amirkabir University of Technology, Tehran, Iran
[2]BSc. Student in Civil Engineering, Amirkabir University of Technology, Tehran, Iran

ABSTRACT
Few investigations have been reported on the properties of Self-Compacting Concrete (SCC) when it is exposed to elevated temperatures; because it is commonly understood that concrete can resist very well against elevated temperatures. Even so, it's necessary to evaluate all structures after they exposed to elevated temperatures.
Mechanical properties of SCC containing two types of Pozzolans (Silica Fume and Pumice) as filler replacement at elevated temperatures were experimentally investigated in this paper. At the age of 28 days, the specimens were placed in an electrical furnace and heating was applied up to the maximum temperatures of 200, 450, 600 and 800°C for 2 hr. Then, the specimens were allowed to be cooled in the furnace and subsequently tested for compressive strength, rebound hammer, ultrasonic pulse velocity and weight loss. The results show that concretes without Silica Fume and Pumice as a replacement for filler show slightly better performance in terms of lower strength loss.

Keywords: SCC, pozzolanic materials, elevated temperatures, mechanical properties, filler

1. INTRODUCTION
Self-Compacting Concrete (SCC) was first developed in 1988 to achieve durable concrete structures. Since then it has been used for a wide range of structures and infrastructures, such as bridges and tunnels. SCC is usually considered as a special type of High-Performance Concrete (HPC) produced with higher amounts of filler materials and lower water/binder ratios as compared with other concretes. Thus, porosity of SCC is usually reduced and the material is characterized by a high diffusion resistance [1]. Concrete mixture of high diffusion resistance such as SCC and HPC, are usually considered as more vulnerable to fire attack. Due to the lower porosity and lower connectivity of pores in SCC and HPC, the accumulating moisture and water vapor can hardly escape from the structure. So, very high pore pressure may be built up as functions of temperature, heating rate, and size of the specimens [2].
The cracking starts around the $Ca(OH)_2$ crystals and then progresses to areas near the unhydrated cement grains, as supported by Scanning Electron Microscopy (SEM) observations [3]. Cracking increases significantly as the temperature is

raised beyond 300°C [3,4]. When the maximum exposure temperature is below 300°C, concrete damage is dominated by only localized boundary cracking between the aggregates and the cement paste [5]. Cracks of the heated concrete could be further extended and developed during postcooling [6]. Therefore, a reduction of $Ca(OH)_2$ content in the cement paste containing supplementary cementing materials such as Silica Fume (SF), Pumice, etc., due to the pozzolanic reaction could help to reduce cracking due to postcooling. However, it should be noted that, above the dissociation temperature of $Ca(OH)_2$ at about 500°C, most concretes are likely to lose their structural properties [5].

Pozzolanic concretes are used extensively throughout the world; the oil, gas, nuclear, and power industries are among the major users. The applications of such concretes are increasing day by day due to their superior structural performance, environmental friendliness, and energy conserving implications [7]. As the use of Pozzolanic concretes becomes common, the risk of exposing them to elevated temperatures increases. So, it's necessary to evaluate all these structures after they are exposed to elevated temperatures.

This paper presents the results of an experimental investigation studying the mechanical properties of SCC containing two types of Pozzolans; Silica Fume (SF) and Pumice (P) that were used as filler replacement, subjected to elevated temperatures.

2. EXPERIMENTAL PROGRAM

2.1. Materials and Mix Designs

A total of four different mixtures were made; control SCC, Traditional Concrete (TC), one SCC with 7.5% Silica Fume (SF) replacing filler by weight and the other with 15% Pumice (P) replacing filler by weight.

Table 1 lists mix design proportions of SCCs and the TC. Properties of fresh and hardened concretes are depicted in Table 2. Local natural aggregate with maximum size of 10 mm; city potable water and Type I Portland cement were used. Limestone was used as filler. Superplasticizer was used according to the results obtained for the slumps. SCCs were prepared and tested in fresh conditions according to the EFNARC specifications [8].

2.2. Preparation of Specimens and tests

The specimens prepared were 100 (mm) cubes. Concrete test specimens were kept protected after casting to avoid water evaporation. After 24 hr the 100 (mm) cubes were cured for 28 days in lime-saturated water at 23 ± 2 °C to prevent possible leaching of $Ca(OH)_2$ from these specimens. Then the specimens used for measuring the 28 day compressive strength, rebound hammer number, pulse velocity and weight loss. At the age of 28 days, specimens were placed in an electrical furnace with heat applied at the rate of 2.5 (°C /min) until the desired temperature was reached (Figure 1). Before fire testing, two cubes were dried to reach to a constant mass.

A maximum temperature of 200, 450, 600 and 800 ^{o}C was maintained for 2 hr under the same conditions and without any imposed load. Specimens were then

allowed to cool in the furnace and tested for compressive strength, rebound hammer, pulse velocity and weight loss. Control tests were also performed on specimens cured at room temperature (23 ± 2°C).

Residual compressive strength was determined as the mean value of two cubes tested per temperature, whereas rebound hammer was determined as the mean value of two measurements (two opposite sides of the cubes used for compressive strength measurements). Pulse velocity measurements were determined as the mean value of four measurements (two other opposite sides of the cubes used for compressive strength measurements) at any temperature. The weight loss of specimens was determined as the mean value of two cubes' weight loss, with which their weight being measured before and after the fire testing.

Table 1: Mix design proportions of self-compacting concretes and the traditional concrete

Mixture				
P2	**SF2**	**SCC**	**TC**	**Constituents (Kg/m$^{3)}$**
450	450	450	450	Type I Portland cement
—	34	—	—	Silica Fume (SF)
67.5	—	—	—	Pumice (P)
82.5	116	150	—	Filler
890	898	900	900	Coarse Aggregate
593	598	600	600	Fine Aggregate
180	180	180	180	Water
0.4	0.4	0.4	0.4	w/c
1.1	0.9	0.85	1	Superplasticizer (lt/100 kg of binder)

Table 2. Proportions of fresh and hardened concretes

Mixture				
P2	**SF2**	**SCC**	**TC**	**Mixture properties**
—	—	—	100	Slump (mm)
700	680	720	—	Slump flow (mm)
1.1	0.97	0.95	—	L Box (H_2/H_1)
5.7	5.16	9	—	V-funnel (s)
69	70	55	60	f_{c28} (Mpa)

Figure 1. Specimens in the electrical furnace

3. RESULTS AND DISCUSSION

3.1. Compressive Strength

The residual compressive strength at the age of 28 days for all mixtures is shown in Figure 2. When concretes are exposed to high temperatures, there are changes in the mechanical properties and the durability of them. However, the mechanisms causing these changes in properties is quite complex as a result of the concurrence of chemical and physical changes in hardened cement paste (HCP) , aggregate, and at the interfaces.

The results show that all mixtures had an increase in their residual compressive strength up to 200 ^{o}C and then a sudden decrease occurred in SCC mixtures containing silica fume and pumice as replacement for filler. No spalling occurred at any temperature for all mixtures. In general, SCC with 15% pumice and another one with 7.5% silica fume replacement with filler (P2 & SF2) have higher strength loss with increasing temperatures than other mixtures without pozzolanic materials. The increase in compressive strength can be partially due to the strengthened HCP during the evaporation of free water [9,10]. Further hydration of cementitious materials is another important cause of the hardening of HCP [9].

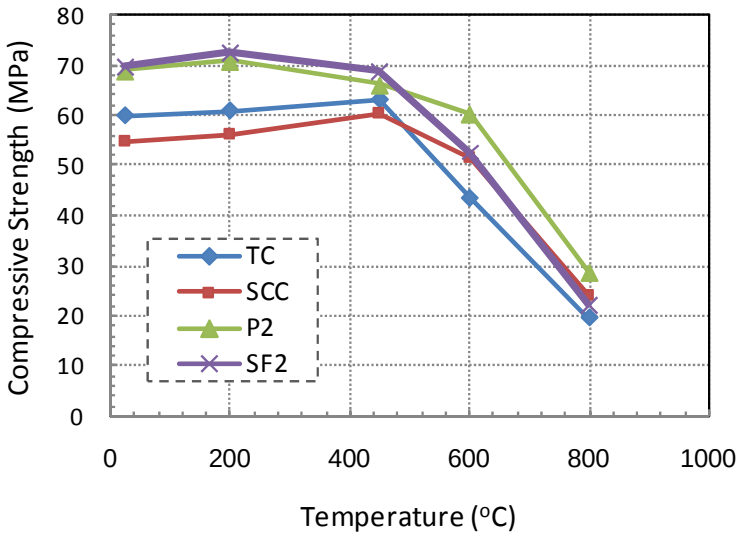

Figure 2. Residual compressive strength of all mixtures

3.2. Rebound Hammer

The residual rebound hammer number at the age of 28 days for all mixtures is shown in Figure 3. The rebound values are influenced mainly by the condition of the surface of concrete to a depth not exceeding 3 cm approximately [11].

Since a temperature rise up to 200^{o}C causes drying and hardening of the surface layer, rebound measurements present a small increase. At temperatures above 450^{o}C, intensive internal cracking and chemical decomposition of the surface layer become more significant and rebound numbers show a significant reduction.

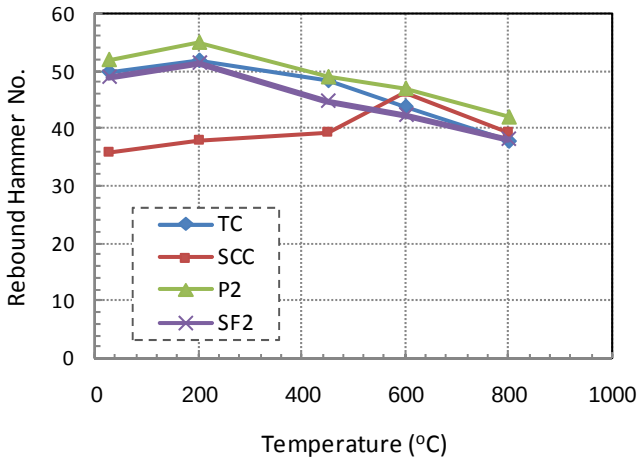

Figure 3. Residual rebound hammer number of all mixtures

3.3. Ultrasonic Pulse Velocity

The residual pulse velocity at the age of 28 days for all mixtures is shown in Figure 4. It is clearly seen that pulse velocity reduces almost linearly with increasing temperature.

It is obvious that the transmission of pulse waves through a concrete mass is highly influenced by the microcracking of concrete. Thus, the decrease in pulse velocity with increasing temperature is a sensitive measure of the progress of microcracking in the material.

Because microcracks might have developed along the boundary due to the swelling of physically bound water layers and the thermal incompatibility between aggregates and cement pastes [12]. Microcracking also increased significantly beyond 300°C, which is responsible for further durability loss in specimens heated to 450, 600, and 800°C [4,13].

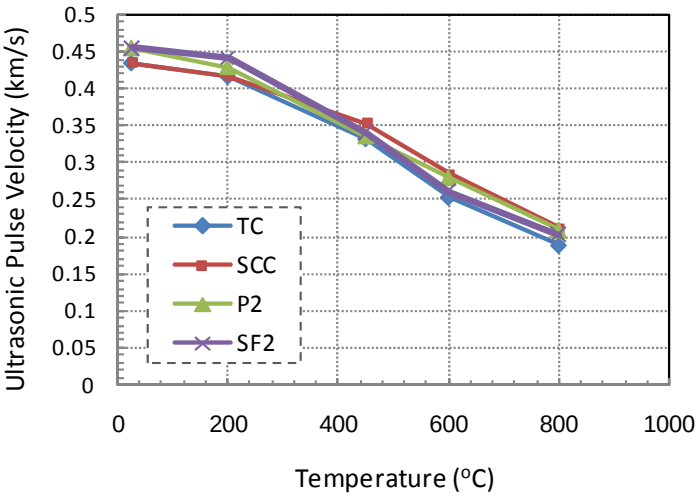

Figure 4. Residual ultrasonic pulse velocity of all mixtures

3.4. Weight Loss

Figure 5 shows the weight loss at the age of 28 days for all mixtures at various temperatures. It can be observed that the TC samples show higher levels of weight loss than the others. Between 23 ±2°C and 200°C, a quick weight loss occurred in all samples, especially the TC and control SCC samples. This corresponds to the loss of the evaporable water and part of the physically bound water [2].

From 200 to 600°C, the weight loss includes the loss of chemically bound water from the decomposition of the CSH [2]. The weight loss of TC is higher than the others for temperatures up to 800°C. However, when the temperature is higher than 600°C, a dramatic loss of weight was observed in all samples. This is due to the decomposition of limestone filler, releasing carbon dioxide [14]:

$$CaCO_3 \rightarrow CaO + CO_2 \quad (1)$$

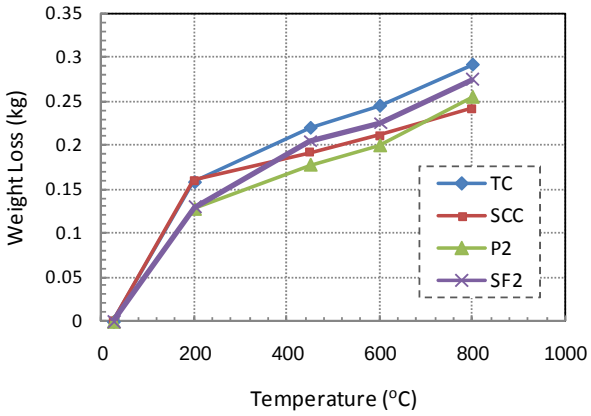

Figure 5. Weight loss of all mixtures

3.5. Residual Compressive Strength and Residual Ultrasonic Pulse Velocity

Figure 6 shows the relation between residual compressive strength and residual ultrasonic pulse velocity for all concrete mixtures. At temperatures above 450°C, both compressive strength and ultrasonic pulse velocity decrease almost linearly with increasing temperature because of intensive internal cracking progress in the samples.

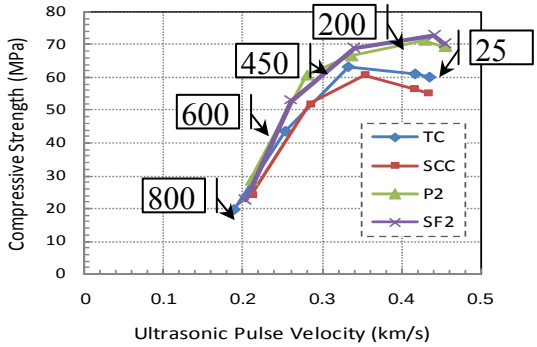

Figure 6. Relation between residual compressive strength and residual ultrasonic pulse velocity for all mixtures

It can be seen that in spite of the residual ultrasonic pulse velocities of all concrete mixtures were nearly equal, the residual compressive strength loss of SCC with 7.5% Silica Fume replacement with filler (SF2) was higher than others.

3.6. Residual Compressive Strength and Weight Loss

Figure 7 shows the relation between residual compressive strength and weight loss for all concrete mixtures. It is observed that the SCC mixtures with 15% pumice replacement with filler (P2) and the one with 7.5% silica fume replacement with filler (SF2) had higher residual compressive strength than the other specimens. As shown in this Figure, a linear relationship can be obtained for compressive strength and weight loss at temperatures between 450-800 °C.

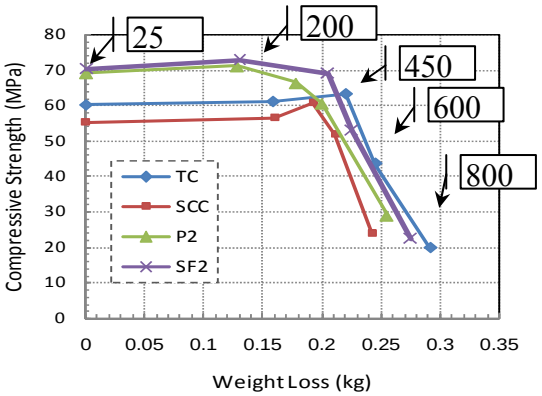

Figure 7. Relation between residual compressive strength and weight loss for all mixtures

3.7. Residual Ultrasonic Pulse Velocity and Weight Loss

The relation between residual ultrasonic pulse velocity and weight loss at the age of 28 days for all mixtures is shown in Figure 8. It can be seen that higher temperature has resulted in higher weight losses due to the chemical decomposition of materials. This has caused microcracks in the cement pastes and micro-structure change and hence lower pulse velocity results. There is also no linear relationship between Ultrasonic Pulse Velocity (UPV) and weight loss at all temperatures.

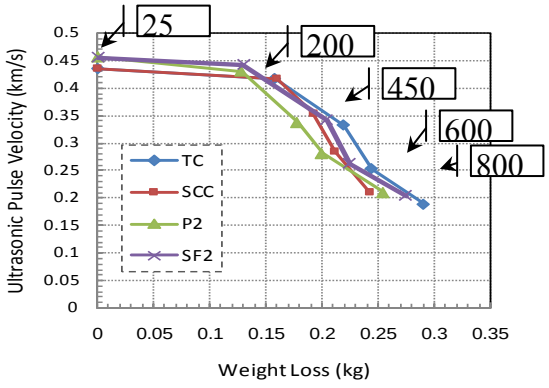

Figure 8. Relation between residual ultrasonic pulse velocity and weight loss for all mixtures

4. CONCLUSIONS

The following conclusions were drawn from the study:

(1) In the range of 25–200°C, an increase in strength was observed in all concrete mixtures which can be resulted due to the evaporation of free water and further hydration of cementitious materials. From 200 to 450°C, a decrease in strength was observed in SCCs containing Silica Fume and Pumice as a replacement for filler. A loss in strength within the range of 70–75% was observed in the 400–600°C temperature range. At 800°C residual strength of SCCs varies between 25 and 30%. The sever loss in strength at an elevated temperature is probably due to the intensive internal cracking and chemical decomposition of concrete components.

(2) In general, concretes without Silica Fume and Pumice as a replacement for filler show slightly better performance in terms of lower strength loss.

(3) Results obtained for residual strength of heated samples by standard crushing test, rebound hammer and pulse velocity are different. This variation is attributed to the surface hardness measurement by hammer test and the influence of the microcracks on UPV test results.

(4) It is important that building designers, building officials, and the fire service organization be aware of the loss in mechanical properties of concretes which could reduce the load carrying capacity and durability of affected structural components.

REFERENCES

1. Kosmas K. Sideris, Mechanical Characteristics of Self-Consolidating Concretes Exposed to Elevated Temperatures, Journal of Materials in Civil Engineering, 2007, Vol. 19, No. 8, 648-654.
2. Bazant, Z.P., Kaplan, M.F., Concrete at high temperatures: Material properties and mathematical models, Longman, London, 1996.
3. Piasta, J., Heat deformations of cement phases and the microstructure of cement paste, Mater. Struct. 1984, 17(102) 415-420.
4. Riley, M. A., Possible new method for assessment of fire damaged concrete, Mag. Concrete Res., 1991, 43(155) 87-92.
5. Khandakar M. Anwar Hossain, Macro and Microstructural Investigations on Strength and Durability of Pumice Concrete at High Temperature, Journal of Materials in Civil Engineering, 2006, Vol. 18, No. 4, 527-536.
6. Petzold, A., Rohr, M., Concrete for high temperatures, Maclare, London, 1970.
7. Mehta, P.K., Advancements in concrete technology, Anim. Reprod. Sci. 1999, 96(4), 69-76.
8. Efnarc, Specification and Guidelines for Self-Compacting Concrete, Feb. 2002.
9. Khoury, G.A., Compressive strength of concrete at high temperatures: A reassessment, Mag. Concrete Res., 1999, 44(161), 291-309.
10. Dias, D.P.S., Khoury, G.A., Sullivan, P.J.E., Mechanical properties of hardened cement paste exposed to temperatures up to 700°C (1,292°F), ACI Material Journal, 1990, 87(2) 160-165.
11. A. Savva, P. Manita, K.K. Sideris., Influence of elevated temperatures on the

mechanical properties of blended cement concretes prepared with limestone and siliceous aggregates, Cement & Concrete Composites, 2005, 27, 239-248.
12. Malhotra, H.L., Effect of temperature on the compressive strength of concrete, Mag. Concrete Res., 1956, 8(23) 85-94.
13. Lin, W.M., Lin, T.D., Powers-Couche, L.J., Microstructures of fire-damaged concrete, ACI Mater. J., 1996, 93(3) 199-205.
14. G. Ye, X. Liu, G. De Schutter, L. Taerwe, P. Vandevelde., Phase distribution and microstructural changes of self-consolidating cement paste at elevated temperature, Cement & Concrete Research, 2007.