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ENGINEERING PROPERTIES AND DURABILITY OF SELF-CONSOLIDATING CONCRETES (SCC) CONTAINING VOLCANIC PUMICE ASH

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ABSTRACT

Self-consolidating concrete (SCC) has been used increasingly over the last two decades, especially in the pre-cast concrete industry because of its ability to consolidate without vibration even in congested areas. The development of SCC mixture design has been driven mostly by private companies who desired to utilize SCC's advantages and consequently there exists limited public information regarding the performance of SCC mixtures.

The present study has attempted to present an experimental study on fresh and hardened properties of SCCs containing Volcanic Pumice (VP) as natural pozzolans which was used for both cement and filler replacements, in comparison with ordinary SCC mixture, SCCs containing Silica Fume (SF) and conventionally vibrated concrete mixture. Properties such as slump-flow, J-ring, L-box, V-funnel and sieve segregation resistance were investigated for fresh concrete and tests such as compressive strength, water and chloride-ion permeability and capillary water absorption at various days were performed for hardened concrete. The results indicate that natural pozzolanic materials such as VP can be used to produce SCCs. In addition, the results prove that natural pozzolans have enhanced the mechanical properties and durability of SCC and reduced the chloride penetration, significantly.

Keywords: Durability; engineering properties; high-performance; pozzolan, self-consolidating concrete; volcanic pumice

1. INTRODUCTION

The construction of concrete structures needs thorough placement and good consolidation of fresh concrete to obtain good hardened properties and durability. However, the proper placement and consolidation were not always achievable with ordinary concretes, even though placed by skilled labors. The lack of skilled labors was also a great concern in construction industry. Then, the concept of SCC first came out in Japan to build durable

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concrete structures and to offset the growing shortage of skilled labors. Okamura and Ozawa advocated the development of SCC in 1986 [1] and developed the first prototype in 1988 [2,3]. SCC can be produced by achieving self-consolidation capacity through optimum flowing ability and optimum segregation resistance.

In recent years, researchers have set some guidelines for mixture proportioning of SCC, which include controlling the volume ratio of aggregate to cementitious material [4,5] and increasing the paste volume and using various viscosity enhancing admixtures [6,7]. Generally, for SCCs, it is necessary to use superplasticizers in order to obtain high mobility. Adding a large volume of powdered material or viscosity modifying admixture can eliminate segregation. The powdered materials that can be added are silica fume, inert filler or natural pozzolans.

Pumice is one of the natural volcanic pozzolanic materials consisting of mineral materials and consolidated volcanic ash ejected from vents during a volcanic eruption. Due to frequent volcanic eruption, it is found plentifully in the world and been widely used with Portland cement or blended cement either individually or in combinations. The pozzolanic activity of this material is related to its siliceous ingredients and to its physical effects [8].

Tasdemir [9,10] indicated that the durability of concretes with blended trass cement increases and the compressive strength of the concretes decreases. Similar to other performed studies, cements including trass pozzolan may cause a decrease in the compressive strength. However, after a longer period, as the pozzolan starts to react, it can be seen that this strength difference will decrease [11-13].

2. EXPERIMENTAL PROGRAM

The paper has attempted to present an experimental study on fresh and hardened properties of SCCs containing Volcanic Pumice (VP) as natural pozzolans which was used for both cement and filler replacements, in comparison with ordinary SCC mixture, SCCs containing Silica Fume (SF) and conventionally vibrated concrete mixture. Properties such as slump-flow, J-ring, L-box, V-funnel and sieve segregation resistance were investigated for fresh concrete and tests such as compressive strength, water and chloride-ion permeability and capillary water absorption at various days were performed for hardened concrete. The following materials were used in the preparation of the concrete specimens.

3. MATERIALS AND MIXTURE PROPORTIONS

ASTM Type I Portland cement was used in all the concrete mixtures. The coarse aggregate used in this study was crushed limestone and the fine aggregate was local natural river sand. The physical properties of aggregates and its grading are shown in Tables 1 and 2. Potable water was used for casting and curing of all the concrete specimens. A high range water reducing (HRWR) admixture based on modified polycarboxylic-ether, with a specific gravity of 1.05 was employed in all concrete mixtures. Pumice was obtained from Eskandan regions. Physical and chemical characteristics of silica fume, pumice and cement are presented in Tables 3. It should be noted that, the effect of Pozzolanic activity is significantly dependent on their particle size distribution (see Figure 1). The results of pozzolanic activity test in accordance with ASTM C-618 test methods are shown in Table 4. Results demonstrate that pozzolanic materials entirely satisfy the requirements.

Table 1: Physical properties of aggregates

Aggregates	Type	Specific gravity (gr/cm^3)	SSD (%)
Course	Crushed	2.584	1.83
Fine	Natural	2.551	2.56

Table 2: Grading of coarse and fine aggregate

Sieve size		Aggregates (% remaining)	Aggregates (% passing)
ASTM	BS		
1/2	12.7	0	100
3/8	9.5	5	95
# 4	4.75	35	60
# 8	2.36	20	40
# 16	1.18	10	30
# 30	0.6	10	20
# 50	0.3	10	10
# 100	0.15	10	0

Table 3: Physical and chemical characteristics of silica fume, pumice and cement

	Physical tests		Chemical analyses (%)								Bogue composition, (%)			
	Specific Gravity (gr/cm^3)	Blaine (cm^2/gr)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	SO_3	LOI	C_3S	C_2S	C_3A	C_4AF
Silica fume	2.14	—	95.1	0.6	1.1	1.02	0.6	—	1.2	—	—	—	—	—
Pumice	2.12	—	64.6	17.3	3.86	4.6	1.34	4.8	0.35	1.98	—	—	—	—
Cement	3.12	3200	21.5	3.68	2.76	61.5	4.8	0.12	2.5	1.35	51.1	23.1	5.1	8.4

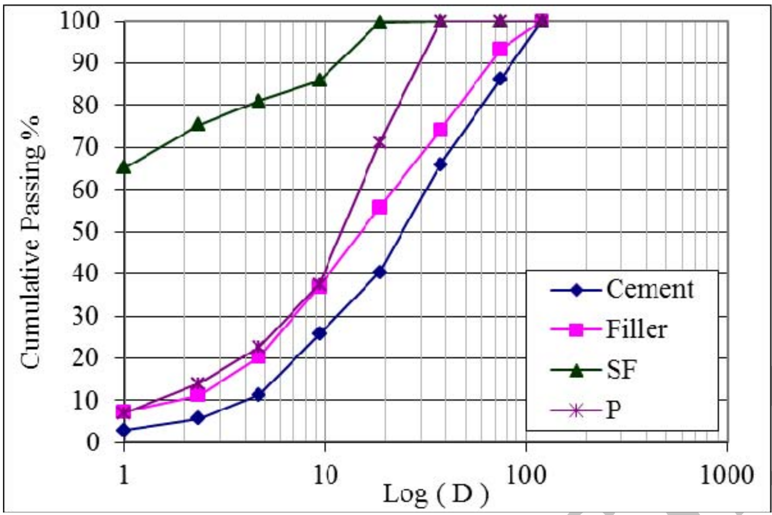

Figure 1. Particle size distributions of silica fume, Pumice, and ordinary Portland cement

Table 4: Comparison in chemical specifications of Pumice and silica fume with ASTM C618-03

	ASTM	**Silica fume**	**Pumice**
$SiO_2 + Al_2O_3 + Fe_2O_3$, %	min. 70	96.8	85.76
SO_3, %	max. 4	1.2	0.35
Moisture content, %	max. 3	—	0.45
Loss on ignition (LOI), %	max. 10	—	1.98

One control mixture (CTL) and five SCC mixtures have been used in this study. The mixture proportions for concrete specimens are summarized in Table 5. During the production of fresh SCC, all aggregates and powder have firstly been mixed in SSD state. Then, cement has been added. After a homogeneous dry mixture has been obtained, the 50% of mixing water by volume was added to the mixture. Afterwards, pozzolanic materials were dissolved in the rest of the mixing water and this solution was added to the mixture. Finally, chemical admixture solution has been added. Adding chemical admixture solution and mixing process has been continued until the mixture has had the consistency of self-compactibility. This duration was not less than 3 min.

Immediately after mixing of the concrete, fresh concrete tests such as slump-flow, J-ring, L-box, V-funnel and sieve segregation resistance were conducted. From each batch, concrete cubes of 100×100×100 mm for compressive strength and sorptivity, 100×200 mm cylinder for rapid chloride permeability test (RCPT) and concrete cubes of 150×150×150 mm for water penetration depth tests were cast. All SCC specimens were cast without hand compaction or mechanical vibration, while CTL specimens were compacted by external vibration. After casting, all the specimens were covered with plastic sheets and water-saturated burlap, and left at room temperature. After 24 hr. they were demolded and cured in lime-saturated water at 23±2°C to prevent possible leaching of $Ca(OH)_2$ from these specimens. All specimens were moist cured until the time of testing.

Table 5: Mixtures proportions of concretes

Mix	Cement (kg)	Filler (kg)	Silica fume (kg)	Pumice (kg)	Water (kg)	Course (kg)	Fine (kg)	S. Plasticizer (%C)	Powder (kg)	W/C	W/b	W/p
CTL	450	—	—	—	180	829	829	0.15	450	0.4	0.4	0.4
SCC	450	150	—	—	180	610	916	0.8	600	0.4	0.4	0.3
SF1	416	150	34	—	180	606	910	1.1	600	0.43	0.4	0.3
SF2	450	116	34	—	180	608	912	1	600	0.4	0.37	0.3
P1	382.5	150	—	67.5	180	600	900	1.6	600	0.47	0.4	0.3
P2	450	82.5	—	67.5	180	604	905	1.2	600	0.4	0.35	0.3

4. RESULTS AND DISCUSSIONS

Fresh concrete Slump-flow, L-box and V-funnel tests were attempted on fresh concrete for determining the properties of SCC such as filling ability and passing ability. During slump-flow test, final diameters of concrete circle through two directions (d1 \ d2) were measured. For the test of V-funnel, required time to make SCC flow through V-funnel by its own weight was measured. In the L-box test, the test was started by removing the control gate suddenly to allow the flow of SCC through the horizontal part of L-box. Then, the flow times were measured by determining the arrival times of SCC batch to 200, 400 mm lengths. When the flow of fresh SCC has stopped, the heights of the concrete at the end (h_2) and the beginning (h_1) of the horizontal section were measured. Then, the blocking ratio was calculated by using the equation (h_2/h_1). The results of fresh concretes are shown in Table 6. Generally, it seems that natural pozzolanic materials such as Pumice, can be added to SCCs and the viscosity of SCC mixtures are greatly influenced by powder (filler and cement) type and content.

Table 6: Results of fresh concrete

Mix	Slump flow	J ring		V funnel	L box		
	Slump (cm)	Δh (mm)	Slump (cm)	Time (s)	t_{40} (s)	t_{20} (s)	(h_2/h_1)
SCC	71	9	69.5	8	4.5	3	0.9
SF1	71	8	70	6.5	3.5	2	0.95
SF2	70	8	68.5	6	2.7	1.5	0.98
P1	72	7.5	70.5	7.2	4.2	2.8	0.95
P2	71.5	7.5	69.5	7.5	4	2	0.86
CTL	Slump = 8 cm						

Hardened concrete The compressive strengths of concrete specimens are shown in

Figure 2. The comparison of the data shows that after 270 days of water curing, the highest compressive strength was 90.2 MPa for SF2 concrete, while for CTL, SCC and P2 concretes, the compressive strength were 64.3, 68.7 and 75.4 MPa, respectively. From the figures, it is found that the strength of concrete increases with replacement level of silica fume and with age. On the other hand, when compared with the SCC, Pumice replacements reduced the compressive strength of concretes at early ages. It is interesting to note that at 270 days, the strength of Pumice concretes is more than SCC.

The average test results for the water penetration depth of the concretes are illustrated in Figure 3. As expected, the lower depth was obtained at 90 days for all concretes and the pozzolanic concretes provided lower water penetration depth than CTL and SCC concretes. For example, SCC specimens provided a water penetration depth close to 8 mm, while SF2 provided 2 mm water penetration depth.

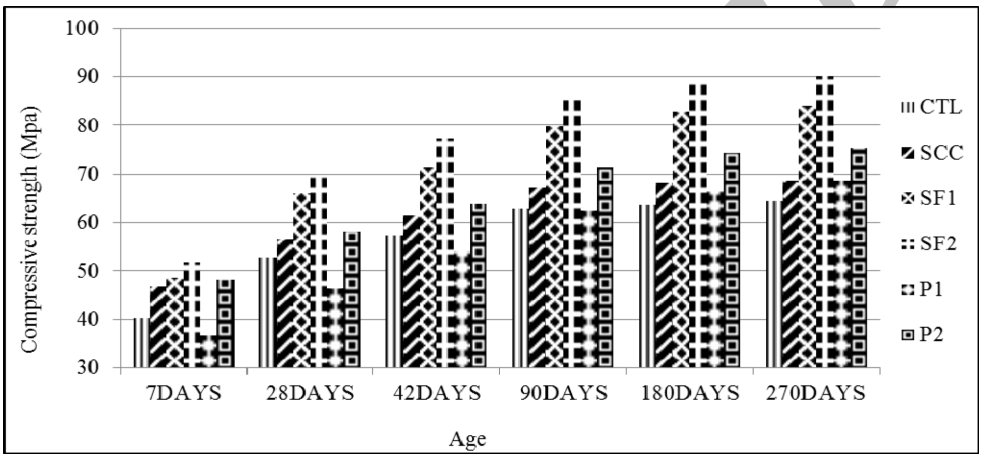

Figure 2. Compressive strength (MPa) of mixtures at various ages

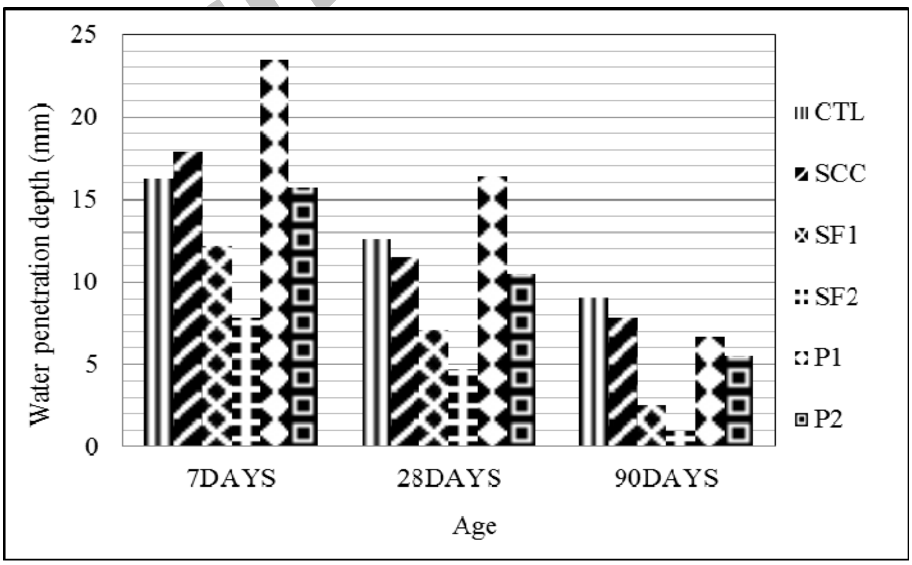

Figure 3. Water penetration depth (mm) of mixtures at various ages

Sorptivity is a measure of the capillary forces exerted by the pore structure causing fluids to be drawn into the body of the material. The sorptivity values of BA blended concrete specimens after 28 days and 90 days moist curing were calculated by the following formula, $i=St^{0.5}$, where i is the cumulative water absorption per unit area of inflow surface; S is the sorptivity coefficient and t is the time elapsed. The sorptivity values calculated for SCC concrete specimens after 42 days and 90 days curing are also presented in Tables 6 and 7. In addition, the final water penetration depth in this test is presented in Figure 4. It can be seen that sorptivity progressively decreases with increase of pozzolanic material content. It is also observed from the water depth that 15% Pumice and 7% silica fume concrete specimens indicate 19% and 54% reduction at 90 days, respectively.

Table 7: Sorptivity coefficients at 42 days ($h^{0.5}\times gr/cm^2\times 10^{-3}$)

	CTL42	SCC42	SF1-42	SF2-42	P1-42	P2-42	RHA1-42	RHA2-42
a-3	0.28	0.2875	0.2225	0.215	0.28	0.2575	0.235	0.225
a-6	0.365	0.3475	0.2625	0.2525	0.365	0.3175	0.305	0.265
a-24	0.7	0.65	0.4475	0.4225	0.65	0.5825	0.555	0.465
a-72	1.1	1.035	0.66	0.61	0.955	0.89	0.82	0.695
S	12.22	11.23	6.56	5.92	10	9.47	8.7	7.06

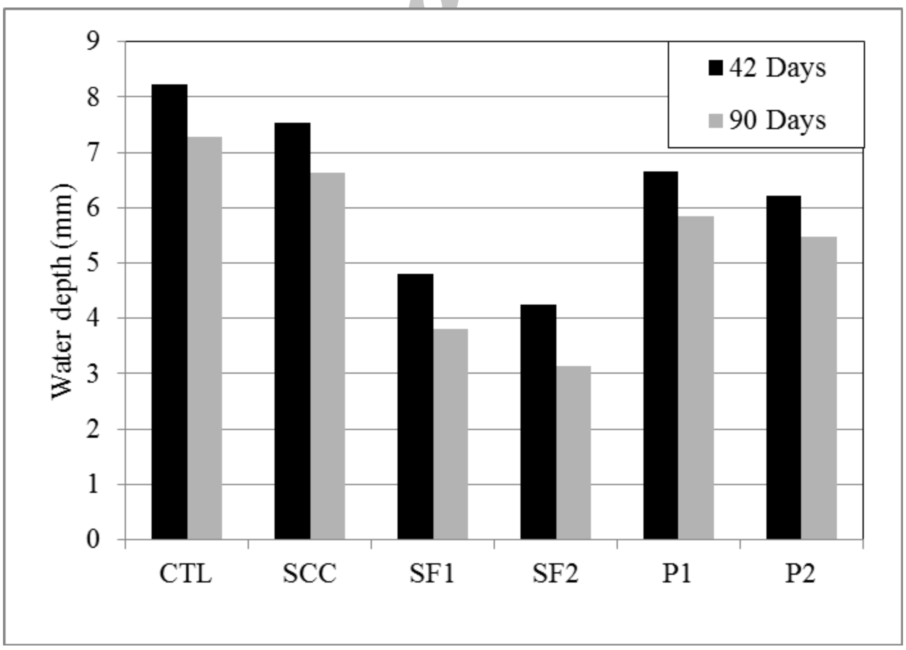

Figure 4. Water depth (mm) in sorptivity test at various ages

Figure 5 presents Coulomb values for each mixture over the test duration of 6 hours. Results show that using silica fume and Pumice significantly enhances the resistance to chloride penetration compared with the control concrete. At the age of 90 days, the CTL concretes specimens showed the highest value of 2675 coulombs while the charge passed through the SF2 and P2 concrete were 539 and 1457 coulombs, respectively.

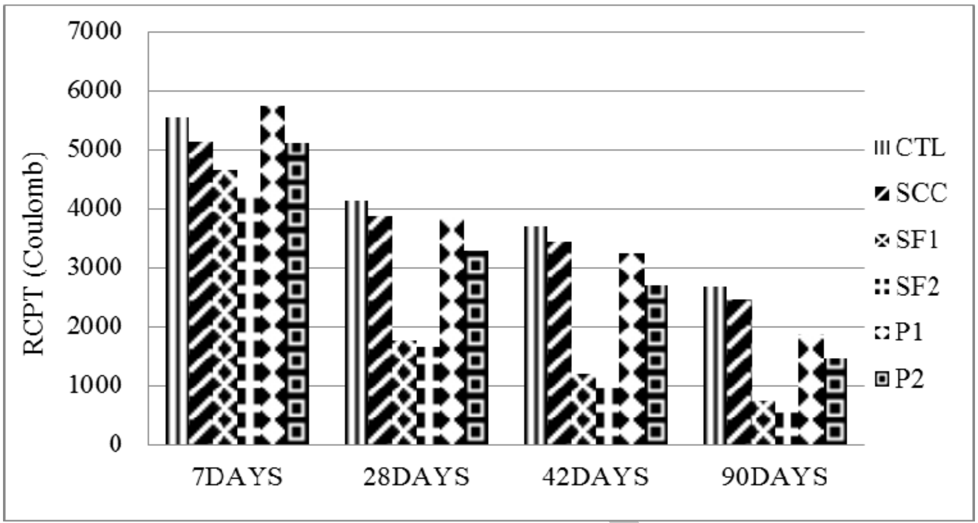

Figure 5. Rapid chloride penetration test (Coulomb) of mixtures at various ages

It suggests that the use of the pozzolans improved the quality of concrete through the reduced porosity and densification of its pore structure. The physical and chemical modification of the pore structure of concrete occurs in the presence of the pozzolans due to its microfilling and pozzolanic effects. These results in the pore refinement and porosity reduction leading to a dense pore structure in both bulk paste matrix and transition zone of concrete that contributes to increasing durability.

Table 8: Sorptivity coefficients at 90 days ($h^{0.5}\times gr/cm^{2}\times 10^{-3}$)

	CTL90	SCC90	SF1-90	SF2-90	P1-90	P2-90	RHA1-90	RHA2-90
a-3	0.27	0.235	0.205	0.185	0.24	0.225	0.205	0.175
a-6	0.345	0.405	0.255	0.225	0.305	0.27	0.27	0.215
a-24	0.66	0.595	0.405	0.355	0.565	0.48	0.455	0.375
a-72	1.035	0.945	0.54	0.495	0.86	0.77	0.64	0.555
S	11.42	10.5	4.94	4.58	8.58	8.16	6.39	5.67

5. CONCLUSIONS

In this study, the effect of Pumice and silica fume as supplementary cementing materials and filling materials on the mechanical properties and durability of SCC concretes was investigated. Based on the results of the present experiments, the following conclusions may be drawn out:

When the properties of fresh SCC such as slump-flow and V-funnel time are considered, it can be said that using Pumice in binary blends slightly decreased the flow diameter of the mixtures whereas on incorporation of silica fume a gradual fall was observed in the flow diameter. Generally, incorporating Pumice increased the cohesion of the SCCs specimens.

1. In comparison with the ordinary SCC specimens and vibrated specimens (CTL), it seems Pumice as a pozzolanic material increases the later age compressive strengths of SCC. However, it decreases the early age compressive strengths. While silica fume increases both early and late age compressive strengths by filling for voids.
2. The performance of Pumice and silica fume to water and chloride ion penetration is better than ordinary SCCs. For instance, adding 15% Pumice and 7% silica fume in SCC specimen reduced the water depth at 90 days by 19% and 54%, respectively.

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