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Effect of Silica Fume on the Performance of Polyvinyl Alcohol Concrete

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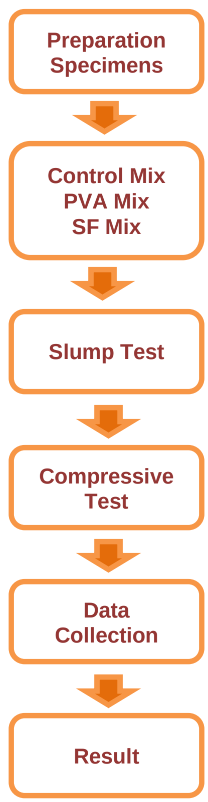
Graphical abstract



Abstract

This paper reports the study with experimental investigation of Silica Fume (SF) concrete made with Polyvinyl Alcohol (PVA). Compressive strength of concrete is considered as a measure to determine the strength of concrete with different age and different cement composition. The major variables of this studied includes workability and compressive strength. Concrete mixtures are prepared under the same proportions, by different replacement of SF content and also used super plasticizer. SF was used to replace PCC at dosage levels of 5%, 10%, 15% and 20% by weight of the binder. The effect of cement substitution was evaluated and both experimental details and preliminary results are presented. The result show that the compressive strength of concrete containing SF was significantly improved and that cement replacement up to 15% SF shown the superior enhancement.

Keywords: Silica Fume, Polyvinyl Alcohol, workability, compressive strength, super plasticizer.

Abstrak

Kertas kerja ini melaporkan kajian dengan siasatan eksperimen Silica Fume (SF) konkrit dibuat dengan Polyvinyl Alcohol (PVA). Kekuatan mampatan konkrit adalah sebagai satu cara untuk menentukan kekuatan konkrit dengan umur yang berbeza dan komposisi simen yang berbeza. Pembolehubah utama kajian ini adalah kebolehkerjaan dan kekuatan mampatan. Campuran konkrit tela disediakan dengan nisbah bahagian yang sama, dengan penggantian kandungan SF yang berbeza dan juga menggunakan super plasticiser. SF telah digunakan untuk menggantikan PCC pada dos 5%, 10%, 15% dan 20% mengikut berat pengikat. Kesan penggantian simen telah dinilai dan kedua-dua butiran eksperimen dan keputusan awal dibentangkan. Keputusan menunjukkan bahawa kekuatan mampatan konkrit yang mengandungi SF menjadi bertambah baik dengan ketara dan penggantian simen sehingga 15% SF menunjukkan peningkatan yang lebih tinggi.

Kata kunci: Silica Fume, Polyvinyl Alcohol, kebolehkerjaan, kekuatan mampatan, *super plasticizer.*

1.0 INTRODUCTION

Silica fume can be used both as a densified or undensified powder, a slurry, as a combination at the concrete mixer, or part of a factory blended cement [1-2]. Silica fume is the most common pozzolan used in the formulation of cellulose and PVA with cement made with different pozzolanic materials were recognized. Silica fume decreases the cement matrix alkalinity [3]. The hydration of silica fume reaction consumes calcium hydroxide (CH) released from the hydration of C 3S and C3S and diminish the CaO/SiO_2ratio of the calcium silicate hydrate phase. As known, the pozzolanic reaction increases the content of C-S-H in the hydrated matrix [4]. Polymers, though introduced in the materials field in meaningful manner only very recently and has been used to improve the durability properties of concrete [5,6].

PVA is the water soluble polymer and always used in cement concrete for improving the durability properties and strength [7]. Use Portland Composite Cement (PCC) with the addition of polymer material, Poly-vinyl Alcohol (PVA) as additive material because PCC contain active mineral admixtures such as fly ash, slag and silica fume or natural pozzolan [8]. This is because the improvement of compressive strength and depletion of porosity of concrete is found when PVA is applied with fly ash blended cement [9]. Concrete containing silica fume can have high strength and can be very strong. In this research, the advantages of using silica fume in concrete in partial replacement of cement are found. The present experimentation has been carried out to determine the workability and compressive strength of control concrete and concrete using silica fume. Suitability of silica fume has been discussed by replacing cement with silica fume and the strength parameters were compared with control concrete. In addition, effect of silica fume (SF) on the fresh and hardened properties of PVA concrete with different dosages levels of SF has been investigated.

2.0 MATERIAL

The experimental study represents a general material used in concrete mix such as cement, aggregate, water, super plasticiser, PVA, SF and the work is performed using locally available material.

2.1 Cement

Portland composite Cement (PCC) supplied YTL Cement Berhad, Kuala Lumpur and complies with MS EN 197-1:2007. The chemical and mineralogical compositions of cement are given in Table 1.

Table 1 Chemical Composition of PCC

Element	Coposition by weight (%) PCC
SiO_2	20.60
Al_2O_3	4.74
Fe_2O_3	3.28
CaO	64.82
MgO	1.84
SO_3	2.4
Na_2O	0.21
K_2O	0.38
LOI	1.73

2.2 Aggregate

Locally available natural sand has been used as find aggregate and crushed granite with maximum particle size 12.5 mm were used as coarse aggregate.

2.3 Silica Fume (SF)

Silica fume is a by-product of producing silicon metal or ferrosilicon alloys and high content of Silicon dioxide (85%-97%) and small amounts of iron, magnesium and alkali oxides are also found [10] and Table 2 show the chemical compounds of silica fume respectively [11]. SF is one of the most beneficial uses in concrete because of its chemical and physical properties, it is a very reactive pozzolan. SF was used as a replacement at dosage levels of 5%, 10%, 15% and 20% by weight of the binder. The silica fume (SF) with high SiO2 content more than 92%, Specific surface area 23.7 (m2/g), specific gravity 2.18, median particle size between 0.1 - 1 µm and with gray color were used and shown in Table 3.

Table 2 Chemical compounds of Silica Fume [11]

Components	SF%
SiO_2	92.6
AL_2O_3	0.89
Fe_2O_3	1.97
CaO	0.94
MgO	0.96
P_2O_5	-
K_2O	1.31
SO_3	0.33
TiO_2	0.25
MnO	0.11
C	0.07
LOI	4.96

Table 3 Typical physical properties of silica fume [12]

No	Property	Value
1	Particle size (typical)	< 1µm
2	Bulk density	
	As-produced	130–430 kg/m3
	Slurry	1,320–1,440 kg/m3
	Densified	480–720 kg/m3
3	Specific gravity	2.22
4	Surface area (BET)	13,000–30,000 m2/kg

2.4 PVA

The PVA powder was ordered from Portal Trading, Bukit Mertajam, Pulau Pinang was used and the amounts of PVA added were 0.5 % and kept constant. The volume of PVA powder is the based on the weight of cement. The molecular weight was 125000 and was 86-89 % partially hydrolysed PVA.

2.5 Super Plasticizer

In this investigation superplasticizer (SP) type F, BASF GLENIUM ACE 309 polymer used as a chemical admixture and was used to improve the workability of concrete. The SP type F used in this study confirmed from ASTM (ASTM, 1999a) [13].

3.0 METHODOLOGY

3.1 Mix Proportioning

For this study, C 30 grade of concrete and water cementitious ratios used is (w/cm 0.5). Four types of concrete mix are prepared, the first one was plain concrete (0% Silica Fume), the second one concrete with SF (5%, 10%, 15%, 20%). According to ACI mix design method, the required quantity of cement, aggregate, sand and water have been mixed for target mean strength 42 N/mm2. The mix components of concrete in this study were included in Table 4

3.2 Preparation of Test Specimens

Concrete specimens have been casted for compressive strength with five different dosage levels of SF. Standard cubic mould with 100×100×100mm prepared to determine compressive strength testing. Concrete casting will be molded in to standard cube and was compacted using vibrating table to achieve highest compaction. Then samples were remaining in moulds 24 h after casting and ten demolded. The total 30 numbers of concrete specimens have been prepared. Figure 1 shows the standard cube moulds fir this study.

Figure 1 Concrete casting in standard cube moulds

3.4 Curing of Specimens

After 24 hours, the moulds were opened and all concrete specimens have been cured in normal water temperature of 27 ± 2 0 C for 7 days and 28 days until they are required for testing.

Figure 2 Concrete specimens in water curing tank

3.3 Test for Workability

Workability is defined as the properties of freshly mixed concrete or mortar which determines the homogeneity with which it can be mixed, placed and finished. The workability or slump test was carried out to determine the workability of fresh concrete mixes and was performed in accordance to BS EN 12350-2:2000.This test was done by using a steel cone with lower diameter is 200 mm and upper diameter is 100 mm, while the height is 300 mm as shown in figure 3a with smooth internal surface. The test processes through filled the steel cone by concrete mixture in three layers and compressing each layer for 25 times by using a 16mm steel rod. After cone filled and compressed kindly the surplus concrete removed Figure 3b.

Figure 3a Slump test instrument

Figure 3b Concrete slump test measurements

3.4 Experimental Procedure

The specimens of standard cube of (100mm x 100mm x 100mm) were used to determine the compressive strength of concrete. Three specimens were tested for 7 & 28 days with each proportion of silica fume replacement. Totally 30 cubes were cast for the strength parameters test. The water binder ratio (W/B) (Binder = Cement + Partial replacement of silica fume) adopted was 0.5 and weight of super plasticizer was estimated as 0.65% of weight of binder. The specimens were demoulded after 24 hours, cured in water for 7 &28 days, and then tested for its compressive. Each cube in use placed in the compressive machine with the cast face in contact with the plantens. These methods were useful into the remaining 3 samples and the average reading was taken as the compressive strength at the age 7 and 28 days.

Compressive strength = P/A

Where:
P = Ultimate compressive load of concrete
A = Surface area in contact the platens (mm2)

Figure 4 Compressive Test Machine

Table 4 Mix Proportioning

Components	Mix 1 Kg/m³	Mix 2 Kg/m³	Mix 3 Kg/m³	Mix 4 Kg/m³	Mix 5 Kg/m³
PCC	5	4.16	3.3	2.49	1.66
PVA	-	42.3	42.3	42.3	42.3
Corse agg.	8.18	8.18	8.18	8.18	8.18
River sand	9.9	9.9	9.9	9.9	9.9
SF	-	0.84	1.67	2.51	3.34
Water	2.5	2.5	2.5	2.5	2.5
SP	0.37	0.37	0.37	0.37	0.37

4.0 RESULTS AND DISCUSSION

4.1 Workability of concrete mixes

Table 4 and Figure 5 below represent the result obtained for concrete spread diameter. Table 4 shows, the Silica Fume content in concrete mix improve workability comparing with PCC workability, the concrete slump with Silica fume improved more than PCC from 119 mm to 130 mm. Figure 5 clearly shows the increase of Silica Fume replacement level with cement in concrete mix produce lower in concrete workability from 130, 128, 120, and 115 mm with SF replacement level 5, 10, 15 and 20 % respectively. This reduction as a result of greater surface area of SF particles, lead to increase the water and SP absorption in concrete mix, and produced increase in water demand and lower in concrete workability.

Table 5 Slump cone Test value

% of SilicaFume added	Slump Test
0%	119
5%	130
10%	128
15%	120
20%	115

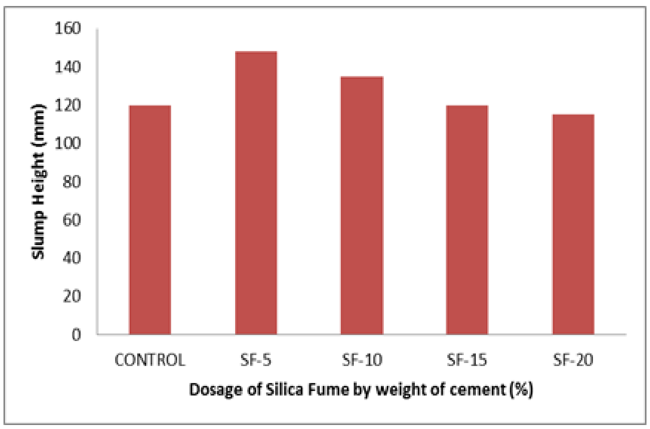


Figure 5 Slump Value at Various Silica Fume Content

4.2 Compressive Strength

The results of compressive strength are shown in Table 6. The test was carried out to find compressive strength of concrete at the age of 7 and 28 days. The cubes were tested using Compression Testing Machine of capacity 3000 kN. From Figure 6, the compressivestrength is up to 42 N/mm^2 and 48 N/mm^2 at 7 and 28 days. The maximum compressive strength is observed at 15% replacement of silica fume. There is a significant improvement in the compressive strength of concrete because of the high pozzolanic nature of the silica fume and its void filling ability (9). In addition Figure 7 shows the relative compressive strength for concrete mixture for this study at different ages.

On the other hand, relative compressive strength in ternary concrete mix (PCC-PVA-SF) is 48.94%, 57.44%, 78.72% and 44.68% at 7day, and 26.01%, 35.01%, 44.01% and 26.01% at 283days, for 5, 10, 15 and 20% SF respectively comparing with PCC control mix. Thus, significantly the SF content in concrete mix increased strength with maximum value 9% more than PCC concrete mix at 7days with 15% SF level addition and recorded 42 MPa.

Table 6 Results Of Compressive

Mix	% of SilicaFume added	Compressive StrengthN/mm^2		Relative compression strength %	
		7 Days	28 Days	7 Days	28 Days
M1	0%	23.5	33.33	-	-
M2	5%	35	42	48.94	26.01
M3	10%	37	45	57.44	35.01
M4	15%	42	48	78.72	44.01
M5	20%	34	42	44.68	26.01

This improvement in strength points to the effect of SF as filler between concrete aggregate by fineness and high surface area particles produce to increase the water demand at early age of hydration of cement and high range water will be reduced.Moreover, in case of comparing ternary composition concrete mix (PCC-PVA-SF) with (PCC-PVA) concrete mix, the relative compressive strength recorded increasing in all percent of SF inclusion, with higher results in 15%SF which recorded relative compressive strength 78.72% and 44.01% at age (7 and 28days) respectively as shown in Figure 7.

That's assigning to combination of SF and PVA lead to increase SiO_2 content and supporting (C-S-H) gel production in concrete mix and improved concrete workability, lower risk of thermal cracking, reduced overall concrete cost and concrete durability and long-term strength.

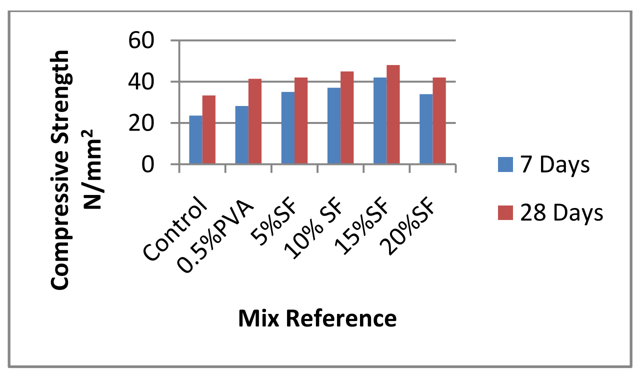


Figure 6 Effect of silica fume on compressive strength of concrete

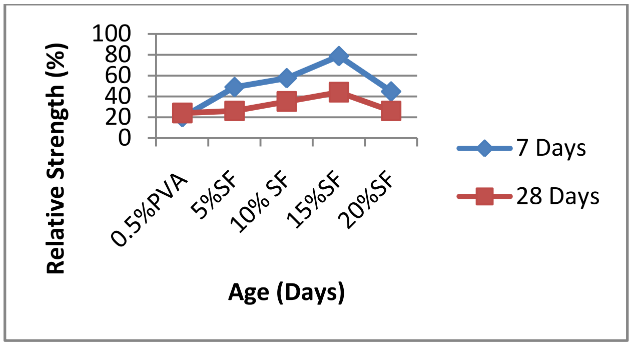


Figure 7 Relative strength of the PCC-PVA-SF ternary blended binder

5.0 CONCLUSION

Based on the present study, the consistency of cement increased with the increase in SF content and depends upon its fineness. Silica Fume has greater fineness than cement and bigger surface area so the consistency increases significantly, when silica fume percentage increases. The optimum 7 and 28-days compressive strength have been obtained in the range of 10-15 % silica fume replacement level.

The compressive strength of PCC-PVA showed that PVA addition reduced concrete strength at early age (1-7) days and improved developing concrete strength after long curing at 28 days. On the other hand, the SF content in PCC-PVA-SF concrete mixture looked positively affection at early age (1-7) days and after 28 days of water curing age, all PCC-PVA-SF record higher compressive strength than the PCC.

The higher value concrete strength with 15% of SF inclusion which recorded 42 N/mm^2 and 48 N/mm^2 at 7 and 28 days respectively comparing with PCC 23.5 N/mm^2 and 33.33 N/mm^{2}at 7 and 28 days. The overall results have shown that, whereas comparing between concrete with PCC-PVA and PCC-PVA-SF, the result presented significantly improvement in compressive strength with ternary combination PCC-PVA-SF in concrete mixture.

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