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Microstructure and Strength Enhancement of Portland Composite Concrete using Polyvinyl Alcohol (PVA) and Silica Fume as Replacement Material

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ABSTRACT. Polyvinyl alcohol (PVA) and silica fume (SF) has been incorporated with Portland composite cement (PCC) to improve its' properties. The first phase was to produce composite concrete with the addition of PVA at different level 0.5, 1.0, 1.5 and 2.0 percent. The second phase was to improve the early strength properties of PCC+PVA concrete by replacing cement with SF at different level 5, 10, 15 and 20 percent. The result shows that 0.5% addition of PVA gives a better result than control specimen in term of compressive strength. In fact, PCC+PVA+15%SF give the highest strength at 28 days. The EDX confirmed the increasing silica content in the concrete specimen when SF was added up to 20%. Furthermore, the morphology of specimens indicates hydration process occurs through the existence of Calcium Silicate Hydrate (C-S-H), Calcium Hydroxide (CH) and Ettringite needle at 56 days.

Keywords: *Microstructure, EDX, Portland composite cement (PCC), Polyvinyl alcohol (PVA), Silica fume;*

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1. INTRODUCTION

The construction of a concrete structure in last few decades has increased rapidly especially in the developing countries. This has burdened the cement manufacturer, and they have come out with composite cement called PCC. In Malaysia, a huge company such as YTL Cement Berhad has come out with this new product to reduce its operational cost. However, this PCC has a shortcoming where it delays the setting time of concrete when compared to normal concrete using the OPC [1].

This delay will affect the construction time where formwork cannot be removed after a few days when casting on site [2]. Therefore, another alternative material such as SF is needed to enhance the quality of concrete without affecting its strength or other characteristics.

The American Concrete Institute (ACI) defines silica fume as a "very fine noncrystalline silica produced in electric arc furnaces as a by-product of the production of elemental silicon or alloys containing silicon". Silica fume is also known as micro silica, condensed silica fume, volatilized silica or silica dust. It is usually a grey

coloured powder, somewhat similar to Portland cement or some fly ashes. It can exhibit both pozzolanic and cementitious properties [3].

Replacement of 15% silica fume gives an optimum value for high early strength [4]. Pradhan (2013), studied the influence of silica fume on normal concrete and confirmed that the strength of concrete is increased and improve the pore structure at transition zone of concrete [5]. Then, silica fume addition in concrete mixture leads to improve concrete strength due to its ultra-fine particle size [6, 7].

The aim of this research is to determine the effect of PVA addition to the PCC+PVA concrete and to evaluate the effect of cement replacement with SF to the PCC+PVA+SF concrete microstructure and mechanical properties.

2. MATERIALS AND METHOD

The works have been divided into three phases. The first phase is to determine the optimum dosage of PVA addition. Portland Composite Cement (PCC) used in this study was supplied by YTL Cement Berhad, Kuala Lumpur Malaysia, complies with MS EN 197-1:2007 which content 20% fly ash (FA). The cement is in dry powder form with grey colour. The fine aggregate (sand) and coarse aggregate (granite) were supplied by the local quarry. Tap water from the domestic supply source available in the laboratory was used for concrete mixing.

The second phase is to improve the early strength properties of PCC+PVA concrete by replacing cement with SF at different level 5, 10, 15 and 20 percent but this time PVA was fixed at 0.5%. PVA value was determined after conducting the compressive strength test in the first phase.

The third phase is the testing of the sample according to standard. Hence, to observe how PVA and SF affect the concrete properties. For the microstructure, the test was perform using the scanning electron microscopy (SEM). In this study, field emission scanning electron microscope (FESEM SUPRA35) with high-resolution imaging was used to characterise the samples. The mechanical properties of concrete were determined such as compressive strength [8] and porosity [9]. Table 1 shows the mix proportion per cubic meter for PCC+PVA and PCC+PVA+SF. Figs. 1-3 show the samples being cured in the water tank, silica fume powder and PVA powder, respectively.

Table 1 Mix proportions for composite concrete – characteristic strength 30 N/mm^2 at 28 days

	Cement	Fine Aggregate	Coarse Aggregate	Water	PVA	SF
	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3
Controlled – 0%PVA	450	882.5	782.5	225	0	0
PVAC 1 - 0.5%PVA	450	882.5	782.5	225	2.25	0
PVAC 2 – 1.0%PVA	450	882.5	782.5	225	4.50	0
PVAC 3 – 1.5%PVA	450	882.5	782.5	225	6.75	0
PVAC 4 – 2.0%PVA	450	882.5	782.5	225	9.00	0
PVAC1 + 5%SF	427.5	882.5	782.5	225	2.25	22.50
PVAC1 + 10%SF	405	882.5	782.5	225	2.25	45.00
PVAC1 + 15%SF	382.5	882.5	782.5	225	2.25	67.50
PVAC1 + 20%SF	360	882.5	782.5	225	2.25	90.00

Fig. 1 Samples cured in water

Fig. 2 Silica fume powder

Fig. 3 PVA powder

3. RESULTS AND DISCUSSION

The increasing of strength can be observed from Table 2 where the compressive strength at 28 days dropped when adding PVA but increased after silica fume was added. Theoretically, the hydration process for ordinary Portland cement stop at 28 days. However, the strength of concrete was kept increasing up to 56 days due to the FA materials in the PCC [10] and also we can observe the influence of silica fume on the strength development on early stage was significant as referred to Table 2. Although the increment or difference is small, if we compare the capacity of load it can carry is significant for example PVAC 1 +15%SF can carry 55% higher than controlled specimen.

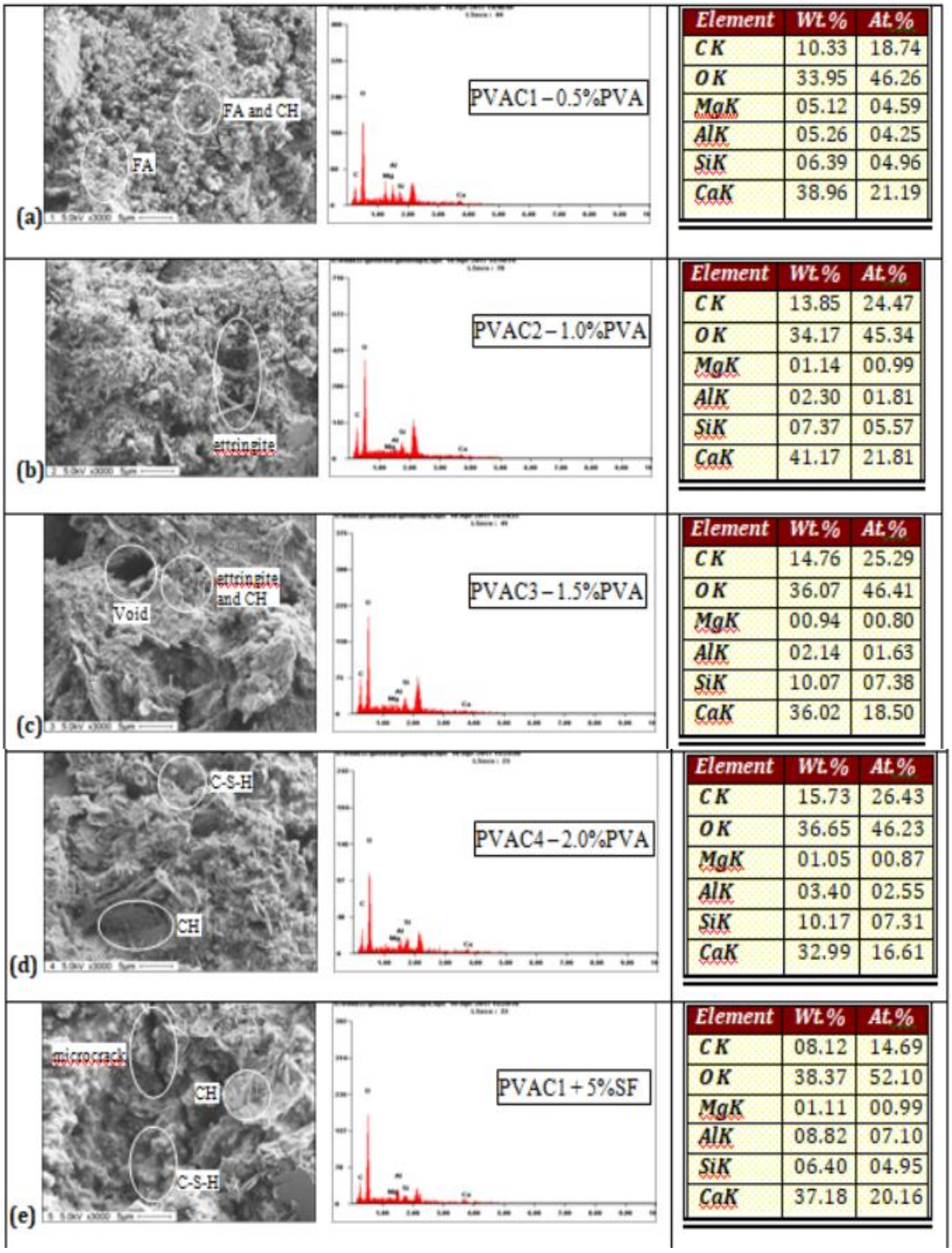
Table 2 Compressive Strength for composite concrete

Concrete Types	Compressive Strength N/mm^2		
	7 Day	28 Day	56 Day
Controlled – 0%PVA	25.50	32.64	34.17
PVAC 1 - 0.5%PVA	29.17	34.50	46.83
PVAC 2 – 1.0%PVA	27.60	30.83	43.37
PVAC 3 – 1.5%PVA	17.57	20.33	40.50
PVAC 4 – 2.0%PVA	18.07	25.33	33.50
PVAC 1 + 5%SF	31.00	41.96	46.33
PVAC 1 + 10%SF	34.17	43.20	48.49
PVAC 1 + 15%SF	40.50	48.03	53.25
PVAC 1 + 20%SF	37.00	45.28	50.33

Fig. 4 shows the EDX result of composite concrete at 56 days for all the samples. Fig. 4(a-d) shows an increment of element carbon (C) due to the increasing of PVA from 0.5% to 2.0%. PVA is a water-soluble synthetic polymer, and when we add to the composite concrete, it will blend homogeneously without creating any cohesive mass during the mixing process plus it reduces the porosity and this help to increase the strength.

Fig. 4(e-h) shows the EDX results of Si element amount which is silica that increase as the result of silica fume addition to the composite concrete. The microstructure has no particular pattern (unstructured

pattern). Also, there are a few visible void and micro crack that can be seen such as Fig. 4e. The crack is due to the shrinkage effect as the hydration took place in the concrete sample. The length of crack however is very small around 5µm and the width of crack is less than 2 µm. This result can be considered as insignificant when compare to the standard of major crack in normal construction practice which is around 3 mm in width.



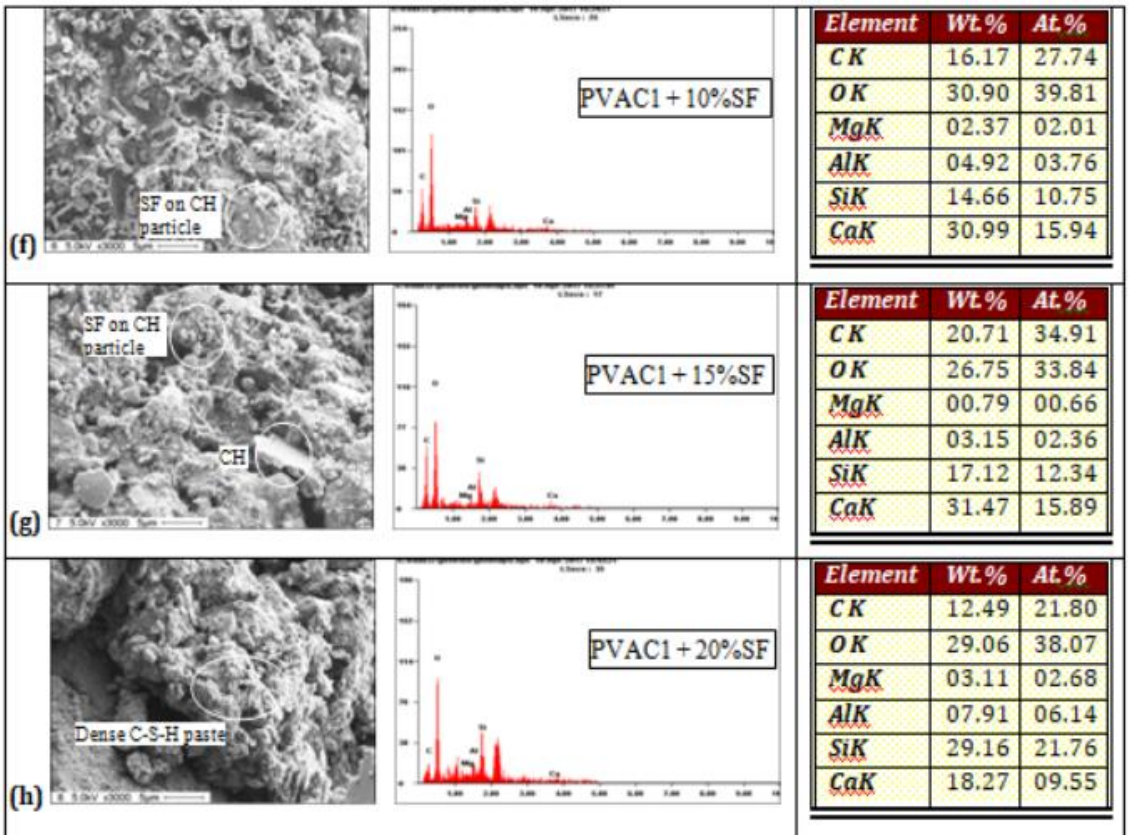
Element	Wt.%	At.%
C K	10.33	18.74
O K	33.95	46.26
MgK	05.12	04.59
AlK	05.26	04.25
SiK	06.39	04.96
CaK	38.96	21.19

Element	Wt.%	At.%
C K	13.85	24.47
O K	34.17	45.34
MgK	01.14	00.99
AlK	02.30	01.81
SiK	07.37	05.57
CaK	41.17	21.81

Element	Wt.%	At.%
C K	14.76	25.29
O K	36.07	46.41
MgK	00.94	00.80
AlK	02.14	01.63
SiK	10.07	07.38
CaK	36.02	18.50

Element	Wt.%	At.%
C K	15.73	26.43
O K	36.65	46.23
MgK	01.05	00.87
AlK	03.40	02.55
SiK	10.17	07.31
CaK	32.99	16.61

Element	Wt.%	At.%
C K	08.12	14.69
O K	38.37	52.10
MgK	01.11	00.99
AlK	08.82	07.10
SiK	06.40	04.95
CaK	37.18	20.16



Element	Wt.%	At.%
CK	16.17	27.74
OK	30.90	39.81
MgK	02.37	02.01
AlK	04.92	03.76
SiK	14.66	10.75
CaK	30.99	15.94

Element	Wt.%	At.%
CK	20.71	34.91
OK	26.75	33.84
MgK	00.79	00.66
AlK	03.15	02.36
SiK	17.12	12.34
CaK	31.47	15.89

Element	Wt.%	At.%
CK	12.49	21.80
OK	29.06	38.07
MgK	03.11	02.68
AlK	07.91	06.14
SiK	29.16	21.76
CaK	18.27	09.55

Fig. 4 EDX result of PCC+PVA at 56 days (a-d) and PCC+PVA+SF at 56 days (e-h), calcium silicate hydrate (C-S-H), calcium hydroxide (CH)

4. SUMMARY

PVA as addition to composite concrete using Portland composite cement was increasing the late strength of composite concrete at 56 days. To improve the early strength of hardened concrete, the usage of silica fume is highly recommended. The micro structure of PCC+PVA concrete shows a good bonding between aggregate, PVA and PCC. The results indicate that 15% SF give the best result and the increment of load capacity is more than 50% than the controlled specimen.

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