Influence of Styrene-Butadiene-Rubber latex (SBR) and Polyvinylidene Chloride (PVDC) on mechanical properties of HPC

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***Abstract*—The major difference between conventional concrete and HPC is basically the use of chemical and mineral admixtures. It is necessary in order to find ways to improve the tensile strength, and eventually design and manufacture concrete materials with high strength. In this study, strengthening effects of polymer materials on the high performance concrete (HPC) were studied. The HPC was manufactured using ordinary class 52.5 N Portland cement, silica fume and superplasticiser. Adopted polymers included the styrene-butadiene-rubber (SBR) latex, Polyvinylidene chloride (PVDC) with contents of 1.5%, 3% and 5% by weight of cement content. The measured included compressive and tensile strengths, modulus of rupture and dynamic Young's modulus. The preliminary test results at 28 days indicate that the addition of 1.5% and 3% SBR and PVDC into the HPC could largely improve the compressive strength by up to 15.7%, while the addition of 5% SBR did not show any enhancement except for 5% PVDC which increased the compressive strength by 10.9%. The tensile strength was significantly increased for all dosages of polymers, with the maximum increases of 72.7% for 3% SBR. The modulus of rupture and dynamic Young's modulus were not improved for lower dosages but slightly decreased for higher dosages of polymers.**

Keywords-component; polymers; high performance concrete; mechnical properties;

I. Introduction

Previous research shows that some polymers added to the concrete mix cause a reduction in the water cement ratio (w/c); an increase in porosity; delayed setting (for a high amount of polymer) and shrinkage reduction [10]. Polymers are widely used in structural concrete due to its high bonding strength with most aggregates; outstanding dimensions at stability from low creep/shrinkage during and after curing, low porosity and permeability, high thermal resistance; improved chemical resistance; outstanding fatigue resistance and good electrical insulation. Polymer concrete has become a significant group of concretes that use polymers to supplement or replace cement as a binder. However, this paper focuses on polymer modified high performance concrete where additive polymers are utilized to improve the mechanical properties of high performance concrete. Styrene-butadiene rubber (SBR) is a polymer produced from butadiene and styrene monomers. It has good mechanical property and processing behaviour and can be used like natural rubber [26]. The SBR has excellent bond strength in the concrete, higher flexural strength, and lower permeability [8]. The purpose of this research was tantamount to study the effects of SBR and PVDC on the mechanical properties of high performance concrete (HPC). In addition, the optimum quantities of polymers in the mix design for the HPC were also determined.

II. Eperimental

A. *Materials for Producing the HPC*

The cement used was Procem ordinary Portland cement, which is classified as Class 52.5 N CEM 1 cement according to BS EN 197-1 [9] and is available in 25kg bags. The chemical compositions of the cement are given in Table 1, according to the manufacturer's specifications.

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Table 1 Chemical compositions of the cement used

Sulphate (SO3, %)	Chloride (Cl, %)	Alkali (EqNa2O, %)	Tricalcium Silicate (C3S, %)	Dicalcium Silicate (C2S, %)	Tricalcium Aluminate (C3A, %)	Tetracalcium Aluminoferrite (C4AF, %)
2.5 to 3.5	<0.1 0%	< 1.0%	40.0 to 60.0	12.5 to 30.0	7.0 to 12.0	6.0 to 10.0

. Dry granite aggregates were used with a maximum size d_{max} = 10 mm, a specific gravity G_{SSD} = 2.90, a water absorption W_{abs} = 0.66% and a total water content W_{tot} = 0%. Siliceous natural sand was used with G_{SSD} = 2.64, W_{abs} = 3.72% and W_{tot} = 3.5%. The silica fume used was the Elkem microsilica grade 940-D Densifiled silica fume powder, which replaced 10% of the total cementitious materials. The chemical compositions of the silica fume are given in Table 2.

Table 2 Compositions of the silica fume used

SiO2 (%)	H2O (%)	Loss on ignition (LOI, %)	Bulk density (kg/m3)	Specific gravity
< 90	> 1.0	> 3.0	500-700	2.20

The Structuro 11180 type superplasticizer, a new generation of polycarboxylate (PC) polymer superplasticizer (high range water reducer), was used for the mix with

– a total solid content of 40%, and

– a specific gravity of 1.10.

Two types of polymers were adopted for this study. The Styrene-Butadiene-Rubber (SBR) latex is in liquid form (Fig. 1). The physical and chemical properties of the SBR are given in Table 3.

Table 3 Physical and chemical properties of the SBR used

State	Colour	Odour	pH	Relative density	Water solubility	Viscosity
Liquid	White	Aromatic	9-11	0.9-1.1	Miscible in water	100-1000 mPa s

Fig. 1 The SBR latex

The Polyvinylidene chloride (PVDC) is in powder (Fig. 2). The physical and chemical properties of the PVDC are given in Table 4.

Table 4 Physical and chemical properties of the PVDC used

State	Colour	Density (g/cm3)	Coefficient of friction	Water absorption – over 24 hours (%)	Hardness (Rockwell)
Powder	White	1.36	0.24	0.1	R98-106

Fig. 2 the PVDC powder

. In general, the quality of water that is used in concrete is usually fit for human consumption, and the water containing large amounts of dissolved or solid impurities should be avoided because it may cause various negative effects on the properties of both fresh and hardened concrete. Therefore the water used for producing high performance concrete was high quality drinkable tap water.

B. The HPC Mix Design

A high performance mix design was utilised according to the proposed method and followed the same approach as ACI 211-

1 Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass [2]. It is a combination of empirical results and mathematical calculations based on the absolute volume method [5]. Fourteen batches of concrete were produced for a total of seven mixes and for moulding twenty eight beams. All the beams were 500 mm long, 100 mm wide and 100 mm deep and were tested at twenty-eight days. Three-point bend tests were performed to determine the flexural strength. The experimental study was divided into seven mixes, whereby different amounts of the SBR and PVDC were used. Table 6 shows the detailed polymer modified HPC mixes used in this study. Along with the beam specimens, a total of eighty four cubes of 100 mm x 100 mm x 100 mm were cast for the seven concrete mixes. The cubes were tested at seven, twenty-eight and ninety days, and had an average compressive strength of 110 MPa. The test set-up is shown in Figure 3.

Fig. 3 The set-up in the testing machine

Table 6 Mix designs of polymer modified high performance concrete

Mix design (per1 m3)	Mix 1 0.0%	Mix 2 1.5% SBR	Mix 3 3.0% SBR	Mix 4 5.0% SBR	Mix 5 1.5 PVD C	Mix 6 3.0% PVD C	Mix 7 5.0% PVD C
Cement (kg)	505	505	505	505	505	505	505
Coarse aggregate (kg)	996	996	996	996	996	996	996
Sand (kg)	830	809	786	756	770	757	739
Water (l)	134	114	99.5	80	134	144	163.8
Silica fume (kg)	55	55	55	55	55	55	55
Sup (l)	20	20	20	20	20	20	20
Polymers (l or kg)	0	17.5 l	35 l	58.3 l	8.4 kg	16.8 kg	28 kg
(w/cm)	0.25	0.25	0.25	0.25	0.25	0.25	0.25

III. Results and Discussions

A. *Unit Weight (Density)*

The unit weight or density of the hardened concrete ρ_C was measured at 28 days and calculated from Unit Weight (Density)

$$\rho_C \text{ (kg/m}^3) = W_{air} / (L_c\, B_c\, H_c) = W_{air} / (W_{air} - W_{water}) \quad (1)$$

Where

W_{air} is the mass of concrete in the air (g),

W_{water} is the mass of concrete under the water (g),

L_c is the length of the cube specimen (mm),

B_c is the width of the cube specimen (mm),

H_c is the depth of the cube specimen (mm).

The test results of the density for the HPC with different polymers at 28 days are shown in Figure 4. For the SBR modified concrete, the density slightly varied for different contents but the trend was inconclusive, with an average density of 2450 kg/m3 which was slightly higher than the density of the reference concrete with ρ_C = 2438 kg/m3. The PVDC modified concrete had a slightly higher average density of 2457 kg/m3.

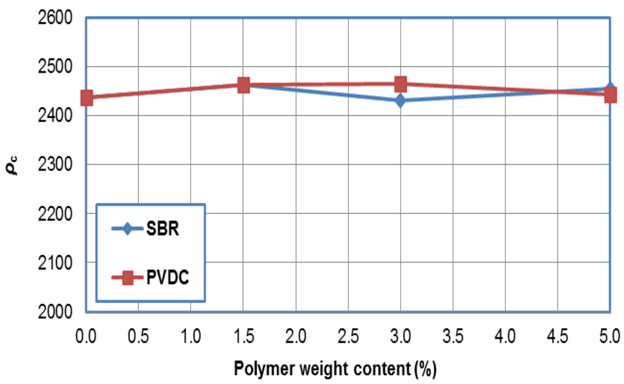

Fig. 4 Densities of the HPC with different contents of polymers at 28 days

B. Compressive Strength

Standard cube specimens of 100×100×100 mm were cast and tested for obtaining the compressive strength at 7, 28 and 90 days. After obtaining the certain strength for nominal high performance concrete through trial mixes and fixing the dosages of the polymer proportion, modified high performance concrete specimens were produced by adding different types and contents of polymers. The cube specimens were demoulded 24 hours after casting and kept in the water in the curing room for 90 days. However, a further 24-hour cure in the air was needed for polymer based composites to complete the polymerisation process. The developments of the compressive strength fcu for the polymer modified high performance concrete for different dosages of polymers and at different ages say 7, 28 and 90 days are presented in Figures 5 to 7, respectively.

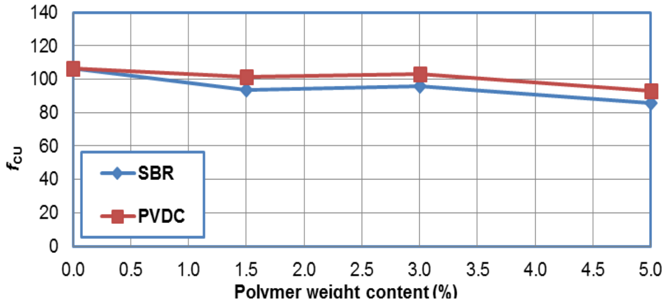

Fig. 5 Compressive strength of the HPC with different contents of polymers at 7 day

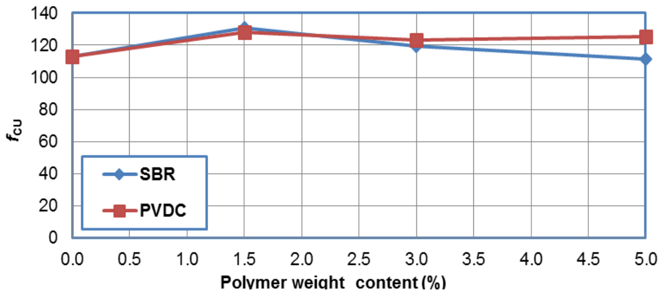

Fig. 6 Compressive strength of the HPC with different contents of polymers at 28 days

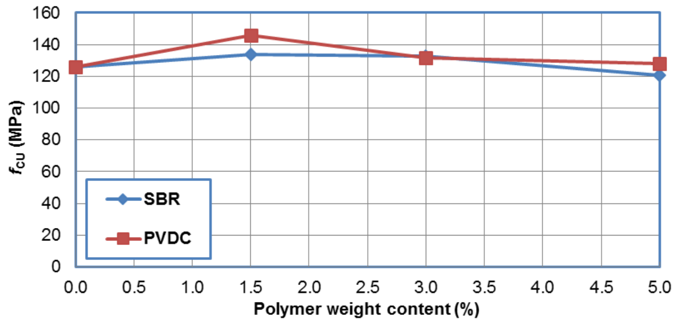

Fig. 7 Compressive strength of the HPC with different contents of polymers at 90 day

The test results of the compressive strength at 28 days indicate that the additions of 1.5% and 3% of the SBR resulted in an increase of approximately 16% and 6% in the compressive strength, respectively, while the content of 5% SBR led to a slight decrease of approximately 1.35%. Additions of 1.5%, 3% and 5% of the PVDC to the mixes increased the compressive strength by 13.6%, 9% and 11%, respectively.

C. Splitting tensile strength

The splitting tensile strengths of the conventional concrete and polymer modified concrete were only determined at 28 days on the cubes of 100×100×100 mm, which had been cured in water until the date of testing. Three cube specimens for each mix were tested and the mean values were obtained. The results are presented in Figure 9.

The splitting tensile strength ft′ was calculated based on the following equation

$$ft' = 2Ft / (\pi\ a2) \quad (2)$$

where

ft′ is the splitting tensile strength (MPa),

Ft is maximum splitting load (N),

a is the length of the cube specimen (m).

It can be seen from Figure 8 that the tensile strength increased when the SBR latex and PVDC powder. For the contents of 1.5%, 3% and 5% SBR, the tensile strength increased by 23%, 72% and 23%, respectively. For the same contents of the PVDC, the tensile strength increased by 35%, 41% and 40%, respectively.

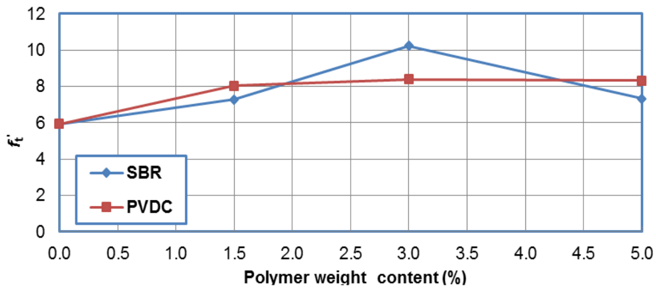

Fig. 8 splitting tensile strength of the HPC with different contents of polymers at 28 days

D. The modulus of rupture

The modulus of rupture of the HPC was obtained at 28 days on the concrete beams of 100 x 100 x 500 mm (see Fig. 10), cured in water until the date of testing. Four beam specimens for each mix were tested and the mean values are presented in Figure 9.

The modulus of rupture, f_r, was calculated based on the following equation:

$$f_r = 6 M / [B (H - a_0)^2] \quad (3)$$

Where

M is the maximum bending moment at mid-span of the beam and M = Fr S / 4,

F_r is the maximum external load at mid-span of the beam specimen,

L is the length of the beam specimen = 500 mm,

B is the width of the beam specimen = 100 mm,

H is the overall depth of the beam specimen = 100 mm,

S is the effective span of the beam specimen = 400 mm,

a_0 is the notch depth of the beam specimen = 50 mm.

The modulus of rupture increased slightly by approximately 2% for the addition of 1.5% SBR in the HPC at twenty-eight days, while with additions of 3% and 5% SBR, f_r decreased by 1.7% and 4.5%, respectively. For the PVDC contents of 1.5%, 3% and 5% in the HPC mixes, the modulus of rupture decreased by 2.3%, 6.8% and 19%, respectively, as shown in Fig. 9. This may be due to the slight increase of the brittleness of the polymer modified concrete.

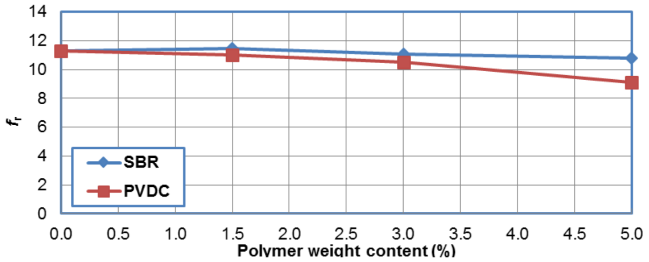

Fig. 9 The modulus of rapture of the HPC with different contents of polymers at 28 days

E. DynamicModulus of Elasticity

The dynamic modulus of elasticity, E_d, was indirectly determined by using the ultrasonic testing method. The dynamic modulus of elasticity of the HPC was measured on three 100 mm cubes at 7, 28 and 90 days for each concrete mix, respectively, and calculated from:

$$E_d = \rho_C V^2 \quad (4)$$

where

V is the velocity of the ultrasonic wave in m/s, and V = L_0 / t,

L_0 is the length of specimen in m,

t is the time for the ultrasonic wave to travel through the specimen length in s.

The test results for the dynamic elastic modulus at 28 days are shown in Figure 10. In general, E_d did not vary largely with the polymer content for each type of polymer. Because of different states, densities, volume contents of the polymers used in this study, the measured dynamic elastic moduli were slightly different. The dynamic elastic modulus did not show significant changes with the increasing SBR content. The average value of E_d for the HPC with the SBR was 72.10 GPa which was slightly larger than the one for the reference concrete with Ed = 68.01 GPa. This is because the addition of SBR improved the interface between the aggregates and cement paste. The dynamic elastic moduli for the HPC with the PVDC slowly decreased with the increasing polymer content. On average, the corresponding values of E_d were 66.70 GPa and 68.13 GPa, either slightly smaller than or approximately the same as the value of the reference concrete.

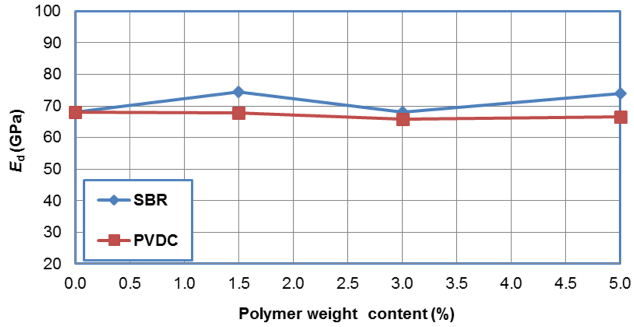

Fig. 10 Dynamic elastic modulus of the HPC with different polymers at 28 days

IV. Conclusion

In this study, the strengthening effects of polymer materials on the high performance concrete (HPC) were investigated. The HPC was manufactured using ordinary Class 52.5 N Portland cement, silica fume and superplasticiser. The adopted polymers were the styrene-butadiene-rubber (SBR) latex and the polyvinylidene chloride (PVDC) with contents of 1.5%, 3% and 5% in weight of cement content. The measured included compressive strength, tensile strength, the modulus of rupture, and dynamic Young's modulus.

The test results at 28 days indicate that the additions of 1.5% and 3% SBR and PVDC into the HPC could largely improve the compressive strength by up to 15.7%, while the addition of 5% SBR did not show any enhancement except for the addition of 5% PVDC which enhanced the compressive strength by 10.9%.

The results for the tensile strength were more encouraging than those on the compressive strength, depending on different dosages of polymers. For the HPC with the SBR, the tensile strength could be increased by up to 72%. For the HPC with the PVDC, the tensile strength could be increased by about 40% on average. The modulus of rupture, fracture toughness and dynamic Young's modulus obtained from the tests on the cubes were not enhanced for lower dosages of polymers and slightly decreased for higher dosages.

Acknowledgment (Heading 5)

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