Improve The mechanical characteristics of High Performance Concrete by polyvinylidene chloride (PVDC) Addition

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ABSTRACT

This paper presents the results of laboratory work carried out on the polyvinylidene chloride (PVDC) modified high-performance concrete, in order to evaluate the mechanical characteristics. A series of high performance concrete (HPC) mixes containing 1.5%, 3% and 5% PVDC by weight of cement were prepared, cured and tested with the twelve 100 mm cubes were cast for each concrete series. Tested parameters included compressive strength at seven, twenty-eight and ninety days, indirect tensile strength and modulus of elasticity at twenty-eight days. The test results at 28 days indicate that the addition of 1.5%, 3% PVDC into the HPC could largely improve the compressive strength by up to 15.7% and for 5% PVDC which increased the compressive strength by 10.9%. The tensile strength was considerably increased for all dosages of PVDC.

Keywords: brittleness, high performance concrete, polymers, PVDC, strengthening

1. Introduction

The modern world largely depends on concrete as a most excellent material for construction. Developments in concrete technology have fostered larger use and paralleled a better understanding of its application in contemporary systems of construction. Compared with most construction materials, concrete is regarded as a brittle material.

The brittleness of concrete increases with the compressive strength; for super-high-strength concrete, failure can be sudden, explosive and disastrous. Therefore, it is necessary to carry out research on the brittleness of concrete in order to establish parameters for assessing the brittleness, find ways to improve the brittleness, and design and manufacture concrete materials with high strength and low brittleness. Three.

Previous research shows that some polymers added to the concrete mix causes a reduction in the water cement ratio (w/c); an increase in porosity; delayed setting (for a high amount of polymer); and shrinkage reduction (Chmielewska, 2008). 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 PVDC modified high performance concrete where additive polymers are used to modify the properties of the high performance concrete. Styrene-butadiene rubber (SBR) is a polymer made from butadiene and styrene monomers. It has a good mechanical property and processing behaviour and can be used like natural rubber (Peng, 2011). The SBR has excellent bond strength in the concrete, higher flexural strength, and lower permeability (Bhutta & Ohama, 2010). Sinan Hinisliog and Emine Agar (2004) show that due to high stability of waste HDPE-modified bituminous binders provide better resistance against permanent deformations and contributes to recirculation of plastic wastes as well as to protection of the environment. The purpose of this research was to study the effects of PVDC on the mechanical characteristics of high performance concrete (HPC).

2. Experimental

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 (BSI, 2011) and is available in 25 kg bags. The chemical compositions of the cement are given in Table 1, according to the manufacturer's specifications.

Table 1: *Chemical compositions of the cement used*

Sulphate (SO3,%)	2.5 to 3.5
Chloride (Cl, %)	<0.10%
Alkali (EqNa2O, %)i	< 1.0%
Tricalcium Silicate	40.0 to 60.0
Dicalcium Silicate	12.5 to 30.0
Tricalcium Aluminate	7.0 to 12.0
Tetracalcium Aluminoferrite	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 (%)	More than 90
H2O (%)	Less than 1.0
Loss on ignition (LOI, %)	Less than 3.0
Bulk density (kg/m3)	500-700
Specific gravity	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.

Polyvinylidene Chloride (PVDC) is in powder and contains Homopolymer and copolymers- usually with vinyl chloride (VC), or methyl acrylate (MA) (Mark, 1999). It is typically used in latex barrier coatings on cellophane, plastic film, paperboard and rigid food containers. Also the films of co-polymers are used as household cling wraps. It serves with other polymers in multilayer barrier films or containers mostly in packaging applications, and is also used in fibres and adhesives (Mark, 1999). Using PVDC as a modified mortar increases the compressive and tensile strengths and gives excellent incombustibility values (Ohama, 1995). Figures 2 and 3 illustrate the chemical structure and packs of the used PVDC in this study. The physical and chemical properties of this PVDC are given in Table 3.

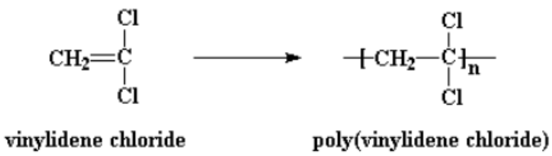

Fig. 2. Chemical structure of the PVDC used in this study

Fig. 3. PVDC Powder

Table 3: *Physical and chemical properties of the PVDC used*

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

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 Designs

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 (ACI, 2009). It is a combination of empirical results and mathematical calculations based on the absolute volume method (Aitcin, 2004). Eight batches of concrete were produced for a total of four mixes and for moulding forty eight cubes of 100 mm x 100 mm x 100 mm. The cubes were tested at seven, twenty-eight and ninety days, and had an average compressive strength of 110 MPa. The experimental study was divided into four mixes, whereby different amounts of the SBR were used.

C. Mechanical Testing

1. Workability Testing

The slump test is most famous and widely used test method to assess the workability of fresh concrete. The test method is widely standardized throughout the world, including ASTM C143/C143M in the United States (ASTM, 2010) and EN 12350-2 in Europe (BSI, 2009). The slump testing equipment consists of a hollow slump cone with a diameter of 200 mm at the bottom, a diameter of 100 mm at the top and a height of 300 mm. The slump cone is filled with concrete in three layers of equal volume. Each layer is compacted with 25 strokes using a tamping rod.

2. Unit Weight (Density) Testing

The apparatus for measuring density is shown in Figure 5, which consists of an electronic balance and a basket attached to the balance. Below this basket is a tank filled with potable water and the basket can be raised and lowered. The cube sample is put into the basket and weighed in air. The tank of water is subsequently raised until the cube sample is completely submerged in water and the sample is re-weighed. The volume of the sample is taken from the difference between the weights in air and in water. Therefore, from these two figures, the densities for the control concrete cubes and SBR modified concrete cubes can be simply determined.

Fig. 5. Density testing apparatus (weight-in-air/weight-in-water method)

The unit weight or density of the hardened concrete was measured at 28 days and calculated from

ρ_c (kg/m^3) = $W_{air} / (L_c B_c H_c) = W_{air} / \ (W_{air} - W_{water})$

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) .

3. Compression Testing

Standard concrete cube specimens of 100 mm × 100 mm × 100 mm were casted and tested to obtain the compressive strength at 7, 28 and 90 days, respectively. This happened after the high performance concrete modified with various dosages of SBR gained certain strength.

Three cubes for every mix at every specified curing age were crushed, and the average compressive strengths were determined.

4. Splitting Tensile Testing

Due to difficulties associated with the direct tension testing, indirect tension testing method has been used to determine the tensile strength of concrete. The splitting testing is well known as an indirect testing used for determining the tensile strength of concrete, the splitting tensile strengths of plain concrete and SBR modified concrete were determined at 28 days on cubes which had been cured in the water tank until the date of testing. Three specimens of each mix were tested and the mean value was recorded. The splitting tensile strength f_t' was calculated based on the following equation

$$f_t' = 2F_t / (\pi a^2)$$

where

f_t' is the splitting tensile strength (MPa),

F_t is maximum splitting load (N),

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

5. Dynamic And Static Elastic Modulus Testing

The technique of ultrasonic pulse velocity provides a method for measuring dynamic elastic modulus and studying the quality of concrete by monitoring the properties of different concrete mixtures with time and the effect of curing conditions. This technique is very sensitive to the development of internal micro cracking. 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

$$E_d = \rho_c V^2$$

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.

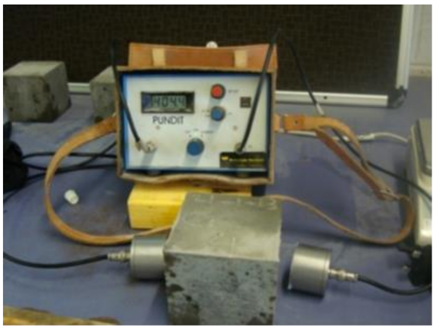

Fig. 8. Pundit ultrasonic tester for measuring the dynamic elastic modulus

3. Results And Discussions

A. Workability

The slump measurement of all high performance concrete mixes studied was investigated by conducting the slump tests using the slump cone immediately after mixing the concrete. For concrete mix with a constant W/C of 0.25 and a constant content of superplasticizer for all mixes, For the concrete mix with 1.5% PVDC, the slump increased to 30 mm, to 45mm with 3% and 5% PVDC. In general, the slump increased when the quantity of polymer increased.

This means that the PVDC additive could slightly enhance the workability of the high performance concrete. This was because the polymer causes the high performance concrete to become more viscous and the particles of polymer which fill up the voids of the concrete will enhance the concrete slump. Figure 9 shows the slump measurements on the modified high performance concrete with different amounts of PVDC.

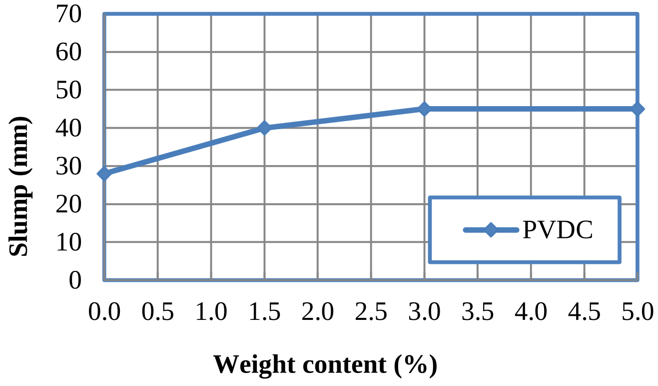

Fig. 9. Measured slump values for the HPC with different contents of PVDC

B. Unit Weight (Density)

The test results of the density for the HPC with different amount of SBR at 28 days are shown in Figure 10. For the PVDC modified high performance concrete, the densities of high performance concrete samples with different percentages of PVDC powder are slightly higher than that of the control mix.

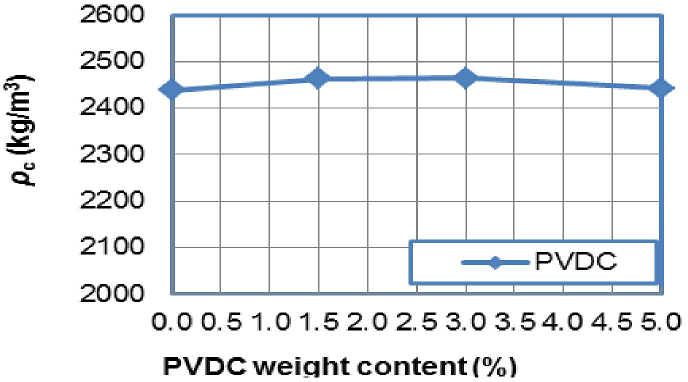

Fig. 10. Densities of the HPC with different contents of PVDC at 28 days

C. Compressive Strength

The results for compressive strength demonstrate the effect that is expected with the addition of different amounts of PVDC on the high performance concrete.

The compressive strength development of mixtures at 7, 28 and 90 days for different dosages of PVDC has been illustrated in figure 12. Fracture angles were often between 30º and 60º to the central vertical axis as showed in Figure 11.

The compressive strength of the HPC at 7 days decreased with the addition of PVDC. When the content of PVDC increased from 0.0% to 1.5%, the compressive strength decreased from 106.29 MPa to 101.25 MPa. When the addition of PVDC increased to 3%, the compressive strength slightly recovered back to 103.20 MPa. When the addition of PVDC increased 5%, the compressive strength dropped down to 93.20 MPa. At 28 days, the addition of 1.5%, 3% and 5% of PVDC to the mix increased the compression strength by 13.6%, 13.1% and 10.9%, respectively. The compressive strengths of the high performance concrete samples with different percentages of PVDC powder at the 90-day curing age were higher than that of the control mix. The additions of 1.5%, 3% and 5% PVDC to the mix increased the compression strength by 16.0%, 4.7% and 2.5% respectively.

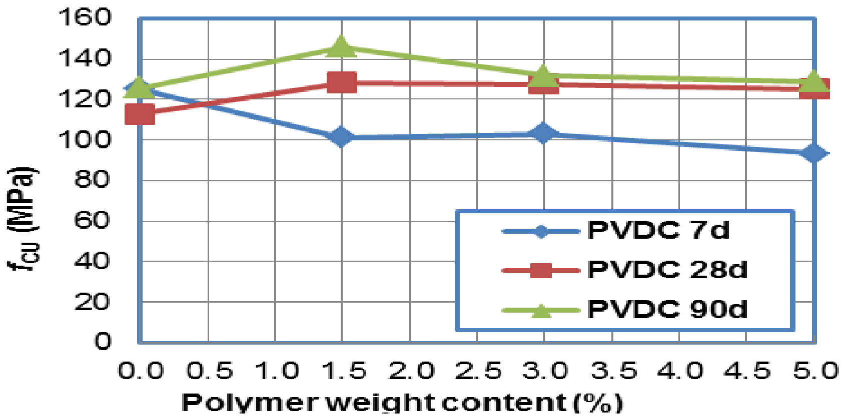

Fig. 12. Compressive strength of the HPC with different contents of PVDC at 7, 28 and 90 days

D. Splitting Tensile Strengths

It can be seen from Figure 13 that the tensile strength increased when the PVDC was added. The additions of 1.5%, 3% and 5% of PVDC resulted in increases in the splitting tensile strength of the high performance concrete by 35.6%, 41.5% and 40.1%, respectively. The most optimum content of PVDC powder in the mix was found to be 3% in weight, which produced the best performance, with 8.39 MPa.

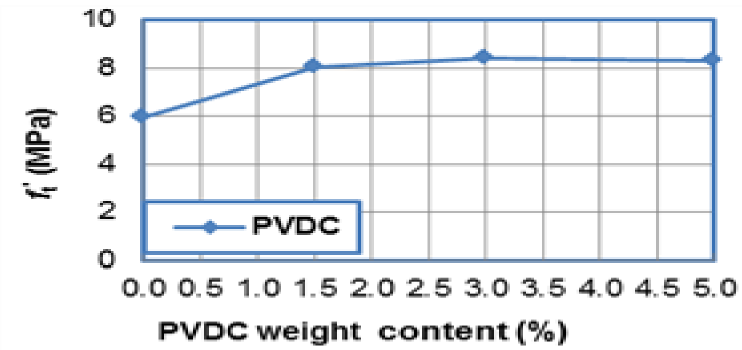

Fig. 13. Splitting tensile strength of the HPC with different contents of PVDC at 28 days

4. Conclusions

In this study, the strengthening and effects of PVDC 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 polymer was the Polyvinylidene Chloride (PVDC) with contents of 1.5%, 3% and 5% in weight of cement content. In general, the workability was enhanced by utilising PVDC. The slump values increased when the quantity of PVDC increased because the PVDC made the high performance concrete more viscous and the particles of polymers filling up the voids of the concrete would enhance the concrete slump. The density of the PVDC enhanced concrete slightly decreased with the increasing polymer because the densities of the adopted polymer materials were lighter. In particular at 28 days, The enhancements on the compressive strength were 13.6%, 13.1% and 10.9% for the high performance concrete with the addition of 1.5%, 3% and 5% PVDC. The additions of 1.5%, 3% and 5% of PVDC resulted in the increases of 35.6%, 41.5% and 40.1% in the tensile strength of the high performance concrete.

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