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Study on Gas Permeability of HPC Containing Binary and Ternary Pozzolanic Materials and Polypropylene Fibers

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ABSTRACT

Durability is one of the main factors in the rational design of hydraulic structures. Permeability of concrete is a major key for durability of concrete. Permeability is a microstructure property of concrete which indicates the ability of concrete to bypass a fluid with specific viscosity under a pressure gradient. It's found that measuring gas permeability coefficient of concrete is essential in studying the durability of concrete. The use of GGBS and SF in HPC is very usual. In this paper, the influence of GGBS addition on properties of concrete as compared with silica fume (SF) has been studied through measurement of compressive strength and gas permeability test.

INTRODUCTION

Durability has been of the main concern at the design and maintenance of marine structures [Neville 2000]. Concrete structures should have adequate durability to perform in accordance with its intended level of functionality and serviceability over an expected or predicted life cycle. It follows that durable concrete must be able to withstand the potentially deteriorative condition to which it can reasonably be expected to be exposed. Deterioration process in concrete structure, whether affecting the concrete itself, or more commonly causing reinforcement corrosion, are determined largely by the ability of the cover zone to resist the ingress of deleterious agents from the environment. Hence, concrete deterioration depends largely on the ease or difficulty with which flow of liquid or gas can migrate through the hardened concrete mass, referred as permeability. Consequently, measurement of permeability provides an indicator of the durability of the concrete so that permeability called as the key to durability [Neville 1995; Mehta and Monteiro 2005; Leeman and Romer 2005]. The positive effects of the use of silica fume on reduction of permeability have already been shown [Shekarchi et al. 1998].

It is important that the permeability of concrete should be kept low in order to protect the reinforcing steel bar contained within or if concrete is used for a water retaining structure. Controlling the permeability of concrete can be done by different ways such as water or gas permeability [Blogovic 2007; Mahoutian et al. 2007]. Permeability of concrete to oxygen is usually determined by a method developed by Cembureau [Kollek 1989]. Although other test methods including non-destructive Torrent method and South African oxygen permeability index (OPI) have been developed to evaluate gas permeability. All permeability methods applied on concrete samples lead qualitatively to the same trend of permeability coefficient [AFREM 1996].

Many researchers have applied silica fume (SF) to improve cement-based materials properties, and have achieved great successes. GGBS is a pozzolan material which can be used as a cementitious ingredient in both cement and concrete composites. This supplementary material improves many of the performance characteristics of the concrete, such as strength, workability and volume change properties [Babu and Kumar 2000]. Jianyong and Pei [1997] showed that GGBS improved long-term compressive strength of concrete. Generally, the early age strength of GGBS concretes is lower than the ordinary Portland cement concrete. However, when the curing period is extended, the strength increase is higher for the GGBS concretes. This is due to slow formation of C-S-H in the pozzolan reaction. GGBS is a low reactive material and improves workability in the fresh concrete compared with SF concrete [Juenger and Jennings, 2002]. However, in the recent years, the use of polypropylene fibers in concrete has been considered as a practical alternative to be used in controlling the plastic shrinkage and temperature cracks [Malisch 1986]. About the effects of these fibers on the gas permeability of HPCs, few studies have been done. In this paper, the gas permeability of HPC has been investigated in concretes containing SF, GGBS and PP.

The overall objective of this research was to investigate the efficiency of SF, GGBS and synergistic effect of these pozzolanic materials on the performance of concrete by comparing with control concrete. Then, the advantages and disadvantages of each pozzolanic materials in RC structures have been shown.

EXPERIMENTAL INVESTIGATION

Materials

Table 1 shows chemical composition of used cement, GGBS, and SF, respectively. Commercially available polypropylene fibers in 12mm fibrillated bundles were used in this study. These fibers separate into individual strands during mixing and disperse evenly throughout the concrete mix. Some of the properties of the polypropylene fibers are shown in table 2. The coarse aggregate was gravel with the maximum particle size of 16mm, the fine aggregate was graded silica sand with fineness modulus of 3.2. Water to binder ratio and total binder content for all mixtures were 0.38 and 420kg/m3, respectively.

Table1. Chemical Compositions (%) and Properties of Binding Materials

Binder	SiO_2	Al_2O_3	CaO	MgO	Fe_2O_3	SO_3	Na_2O	K_2O	Specific gravity
Cement	21.00	5.00	63.00	1.80	3.50	1.60	0.50	0.60	3.15
GGBS	35.50	10.00	36.50	9.50	0.70	1.86	0.50	0.53	2.86
SF	93.16	1.13	-	1.60	0.72	0.05	-	-	2.11

Table2. Some Properties of Polypropylene Fibers

Melting point	155-170˚C
Ignition point	600˚C
Tensile strength	600-700 MPa
Young's modulus	3.3 GPa
Thermal and Electrical conductivity	Low
Acid and Salt resistance	High

Mix proportioning of HPRCs

Seven groups of HPC mixtures were listed in Table 2. The type of pozzolanic materials and the content of fiber have been changed for each of HPC mixtures. Mixture R is plain concrete and marked as a reference concrete. In the Mixture R-SF, silica fume replaced cement by 7.5% of cement weight; In Mixture R-S, GGBS replaced cement by 25% of cement weight while in Mixture R-SF.S, 32.5% of cement was substituted by GGBS (25% of cement weight) and silica fume (7.5% of cement weight). Also, concrete mixtures (R-SF, R-S and R-SF.S) made-up with polypropylene fibers and marked as a R-F.SF, R-F.S and R-F.SF.S, respectively. The content of fiber used in mixtures was 1kg/m^3.

Table 3. Mix Proportioning of HPCs

Concrete	C_a (kg)	GGBS (kg)	SF (kg)	PP (kg)	SP (%)	CA_b (kg)	FA_c (kg)	W/B	Slump (mm)
R	420	-	-	-	0.5	793	1000	0.38	155
R-SF	390.5	-	29.5	-	0.5	793	988	0.38	140
R-F.SF	390.5	-	29.5	1	0.6	793	988	0.38	140
R-S	315	105	-	-	0.5	793	992	0.38	155
R-F.S	315	105	-	1	0.6	793	992	0.38	160
R-SF.S	285.5	105	29.5	-	0.6	793	980	0.38	180
R-F.SF.S	285.5	105	29.5	1	0.6	793	980	0.38	150

a) Cement b) Coarse aggregate c) Fine aggregate

Permeability test procedure

Compressive specimens were fabricated for each concrete mixture in accordance with ASTM C 192 and then were tested at 3, 7, 28 and 90 days according to ASTM C 39. In this paper, permeability of concrete to oxygen was determined by a method developed by Cembureau [Kollek 1989]. The underlying principle is the Hagen-Poiseuille relationship for laminar flow of a compressible fluid through a porous body with small capillaries under steady-state condition. The relationship proposed by Hagen-Poiseuille for determining specific permeability coefficient can be written as following:

$$K = \frac{2.Q.P_a.L.\eta}{A(P^2 - P_a^2)} \quad (m^2) \qquad (1)$$

Where :
Q = volume flow rate of the fluid (m^3/s)

A = cross-sectional area of the specimen (m^2)

L= thickness of the specimen in the direction of flow (m)

η = dynamic viscosity of the fluid at test temperature ($N.s/m^2$)

P=inlet pressure (absolute)(N/m^2)

Pa=outlet pressure, assumed in this test to be equal to atmospheric pressure (N/m^2)

By using oxygen as a fluid and standard reference specimen of 150mm diameter and 50mm thickness, the relationship simplified to:

$$K_{oxygen} = \frac{1.14 \times 10^{-4} Q.P_a}{(P^2 - P_a^2)} \qquad (2)$$

In this method a uniaxial gas flow between the two parallel surfaces of the test specimen is caused by a different absolute pressure of the test gas on both surfaces. The flow depends on the pressure difference, testing area, thickness and open porosity of the specimen and the viscosity of the test gas [Torrent 1992]. The essential elements and testing equipment consist of a gas supply, a pressure regulator with pressure gage, the testing cell, flow meter and a stop-watch [Kollek 1989]. The testing equipment and a detail of a testing cell are shown in Fig. 1. Based on this recommendation; first, the thickness and diameter of the specimen disc were measured by calculating the mean of five measurements of each dimension. After reading atmosphere pressure, Pa, the specimens were placed in the cell and the apparatus assembled.

For each specimen, five absolute inlet pressure stages in succession should be selected and applied in the test cell. After stabilization of flow rate at each pressure stage, the oxygen flow should be recorded by taking at least two reading for each pressure stage and evaluating the mean of the two flow rates. For calculating the gas permeability coefficient in each pressure stage K_i, the flow rate should be substituted in equation (2). Finally the oxygen permeability coefficient of the specimen, K_{oxygen}(K_g), would be obtained by evaluating the mean K from the five K_i values obtained for the five pressure stages.

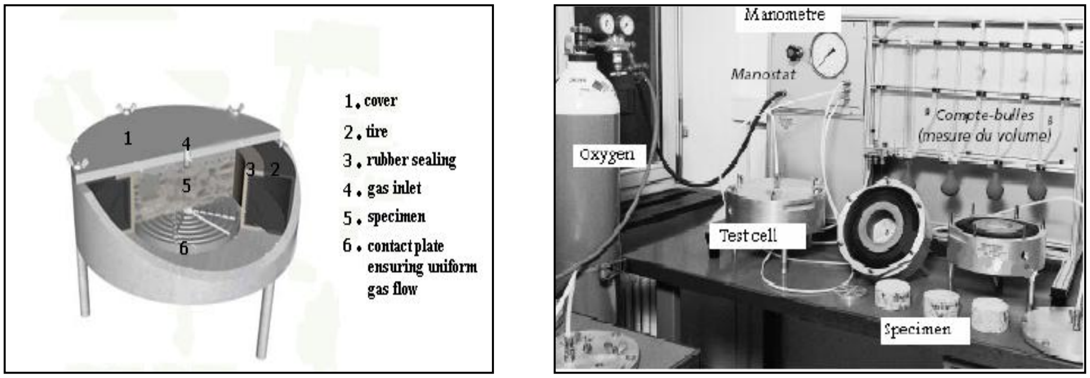

Fig. 1. Gas Permeability Meter and Detail of a Testing Cell

RESULTS AND DISCUSSIONS

Compressive strength

The experimental results of compressive strengths are listed in Fig. 2. As shown in this table, Concrete R-S and R-S.F acquired lower compressive strength with respect to other concretes at early ages (3 days). In the later ages, this concrete shows much higher strength due to delay pozzolanic reaction of GGBS. This shows that, initial rate of hydration of GGBS cements is slower than the Portland cements. It confirms the research don by Brandt (1995) that GGBS concrete needs more than 3 day curing for strength development. Moreover, ACI 308 (98) suggests 7 days of moist curing for blended cement concrete. Between 7 and 28 days, the GGBS concretes gained more compressive strength than the reference concrete.

After 3 and 7 days of curing, Concrete R-SF and R-SF.F have the highest compressive strength and this shows that in mixtures contain SF, increasing in compressive strength is more than mixtures without SF. Up to 28 and 90 days, all six blended concretes obtained greater compressive strength than Concrete R. Concrete R-SF.S and R-F.SF.S, especially, showed much higher strength values. It is worthwhile to note that after 28 days, Concrete mixtures without GGBS, have no significant increase in compressive strength. Instead, compressive strengths of blended concrete mixtures with GGBS (R-S and R-S.F) increased significantly. Concretes R-SF.S and R-F.SF.S with SF and GGBS, had the highest compressive strength of the 28 and 90 days. In the ternary system (Concrete R-SF.S and R-F.SF.S), compressive strength increased in the both short-term and long-term.

From the results, it is noticed that there is no improvement in the compressive strength of concretes by the inclusion of polypropylene fibers, some of the polypropylene fiber reinforcement concretes show a slight drop in compressive strength compared to same concrete without fibers. In general, the effecting of Fiber on compressive strength is negligible.

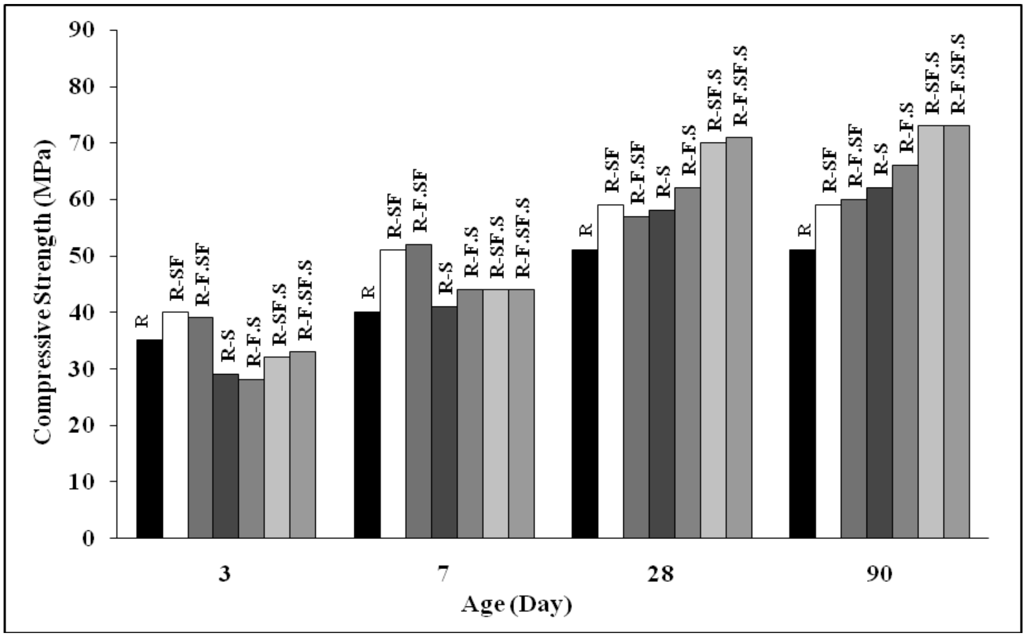

Fig. 2. Compressive Strength of Concrete Mixtures

Gas permeability

Fig. 3 presents the average results of gas permeability tests. In general, the permeability coefficients fell within the range 14E-17 – 38E-17, this value being at the middle of the range of values normally expected for structural concrete [Bakhashi et al. 2006]. From the results, it can be seen that coefficient of gas permeability decreases with use of pozzolanic materials especially in ternary pozzolanic concretes compared with reference concrete. In R-SF and R-F.SF Concretes. However, the reduction of permeability compared with R-S and R-F.S are 17 and 13 percent respectively, and decreasing compared with reference concrete are 63 and 31 percent. This shows that, SF has a positive effect on decreasing of permeability to GGBS. It seems that, SF reduces the interconnections among the pores in the paste.

Based on the results, polypropylene fibers increase gas permeability coefficient. To explain such increase in the gas permeability coefficient of polypropylene concretes, it may be assumed that permeability is determined more by matrix properties than the fibers [Miloud 2005]. In particular, the matrix-fiber interface has the largest content of pores and micro cracks that affects overall permeability. Also, it is very important to mention here that fibers act as ties between pores so that interconnections are created which allow gas flow to penetrate more easily inside the concrete structure [Brandt 1995; Husseyin et al. 1995; Bamforth 1987]. Reduction of the gas permeability coefficient in the concrete containing both SF and GGBS as pozzolanic materials compared to reference concrete is about 63 percent.

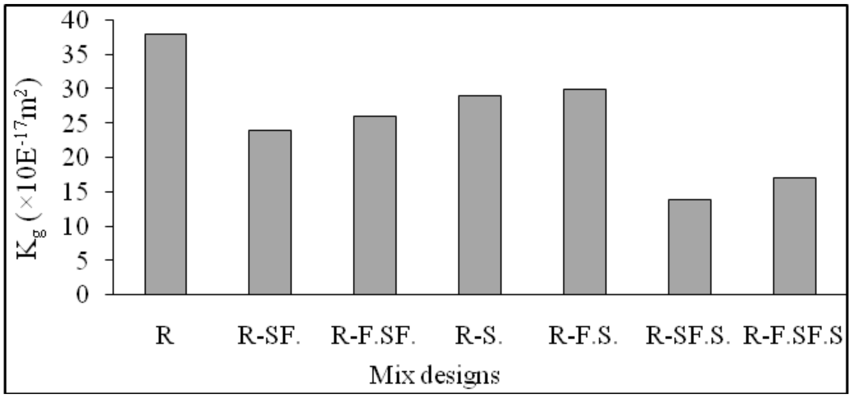

Fig.3. Gas Permeability of Concrete Mixtures

Fig. 4 shows comparison between the coefficient of gas permeability and compressive strength values at age of 28 days. In all of concretes containing the pozzolanic materials, increase in compressive strength and decrease in gas permeability have been observed compared to plain concrete. High compressive strength and low coefficient of gas permeability are both obtained for concrete containing SF and GGBS (R-SF.S and R-F.SF.S) with or without fibers. Values of compressive strength versus of gas permeability values are plotted in Fig.5. It can be seen from Fig. 5 that values of compressive strength have an appropriate correlation with gas permeability values. Subsequently, regression of these two series value is about 0.824 (R^2=0.824).

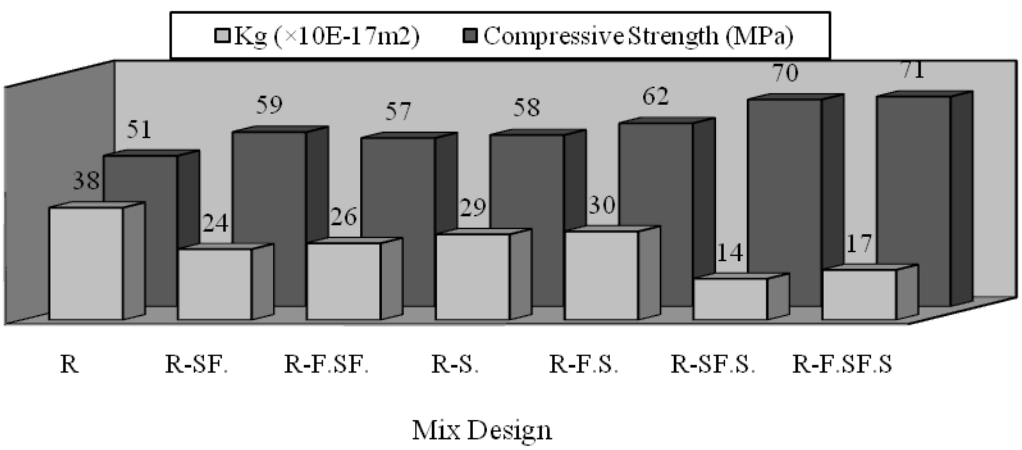

Fig.4. Comparison between the Coefficient of Gas Permeability and Compressive Strength

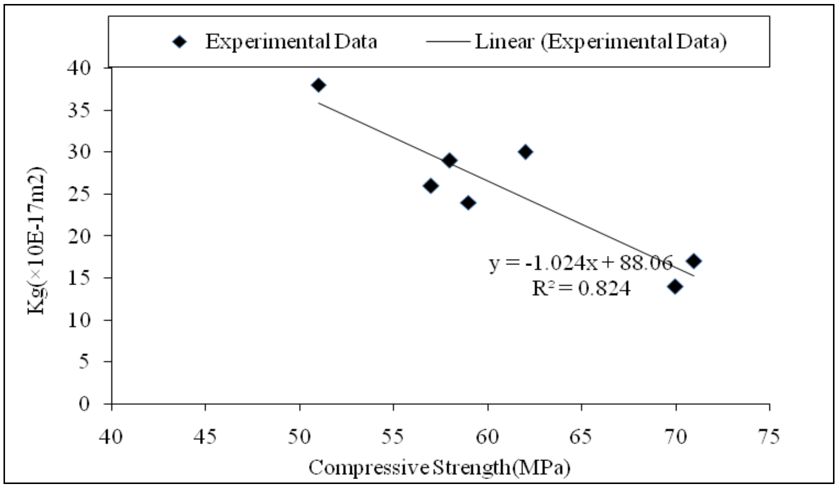

Fig.5. Correlation between the Coefficient of Gas Permeability and Compressive Strength

CONCLUSIONS

The following general conclusions can be drawn from the study provided in the paper:

- Concrete containing GGBS is highly influenced by the type of curing regime used at early ages. Curing for more than 3 days is necessary for the strength development of GGBS concrete. In fact, extending the curing time in concrete containing GGBS has a positive effect on increasing of compressive strength in later ages. When SF and GGBS were simultaneously used in concrete, positive synergistic effect on increasing compressive strength observed in both early and later ages.
- Compressive strength in reinforced concrete with polypropylene fibers with respect to concrete without fibers has not increased. Even, in some cases, the comporessive strength of concretes reinforced with fibers, has slightly decreased with respect to concretes without fibers.
- Coefficient of gas permeability is decreased by the use of pozzolanic materials, especially in SF concretes compared with reference concrete. Maximum reduction of gas permeability coefficient is related to ternary pozzolanic concretes.
    - Compressive strength and coefficient of gas permeability in concretes containing GGBS is more than concretes with SF. However, concrete that experienced high compressive strength merely don't have high coefficient of gas permeability.

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