Fracture Mechanics of Concrete and Concrete Structures -
High Performance, Fiber Reinforced Concrete, Special Loadings and Structural Applications- B. H. Oh, et al. (eds)

Comparative study of nano-SiO_2 and silica fume on gas permeability of high performance concrete (HPC)

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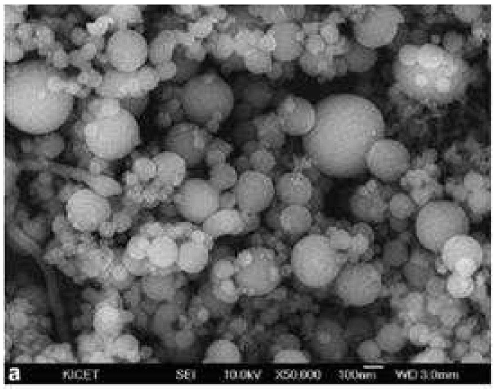
ABSTRACT: Permeability is a microstructure property of concrete which indicates the ability of concrete to bypass a fluid with specific viscosity under a pressure gradient. In this paper the influence of nano-SiO_2 (NS) addition on properties of concrete as compared with silica fume (SF) has been studied through measurement of compressive strength, electrical resistivity and gas permeability test. In the program the effect of NS was studied by replacing a part of SF with NS as a pozzolan in mix design and result were compared with control concrete. The results show that replacement of portion of SF with NS will improve the durability characteristic of HPC.

1 INSTRUCTIONS

Durability has been of the main concern at the stages of design and maintenance of concrete structures [1]. It is generally accepted that concrete durability to a large extent is governed by its resistance against the transport of aggressive elements into its pores [2]. The durability and mechanical properties of HPC are mainly dependent on the gradually refining structure of HPC and the gradually improving paste-aggregate interface incorporating additions and admixtures. Many researchers have applied silica fume (SF) to improve cement-based materials properties, and have achieved great successes. But the activity of SF at early ages is low according to the literature [3-7].

Recently, nanotechnology has attracted considerable scientific interest due to the new potential uses of nm scale. A new pozzolanic material produced synthetically, in form of water emulsion of ultra-fine amorphous colloidal silica, is available on the market and it appears to be potentially better than silica fume for the higher content of amorphous silica (>99%) and the reduced size of its spherical particles (1-50 nm) [8]. Therefore, it is supposed to the pozzolanic activity of nano-SiO_2 is more than that of silica fume. Scanning electron micrographs (SEM) of silica fume and nano-SiO_2 are shown in Figure 1 [9]. Permeability is a measure of the concrete's ability to resist penetration of water or other substance. 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 different ways such as water or gas permeability [10]. Permeability of concrete to oxygen is usually determined by a method developed by Cembureau. 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 [11]. In this research gas permeability and compression strength tests were performed on specimens of concrete to investigate the durability and mechanical properties of concrete containing nano-SiO combined with silica fume as compared with silica fume.



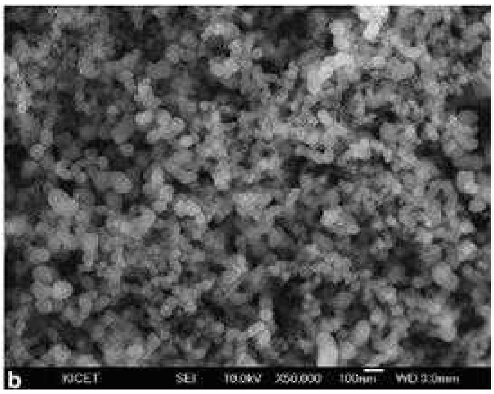


Figure 1. SEM photographs of materials: (a) silica fume (b) nano-SiO_2 [9].

2 SPECIMEN MANUFACTURE AND TEST PROCEDURE

For each mixture proportion, 3 numbers of 150 mm cubes and a cylindrical specimen, 150mm in diameter and 300mm in height which is cut in three discs after curing, prepared for the measurement of strength and gas permeability respectively. Compressive strengths of concrete specimens were measured after 28 days while gas permeability tests were carried out after 35 days. After the curing, specimens of permeability were dried in the oven (105±1°C) for 5 days. This preconditioning regime is recommended by Cembureau and is recognized as regime B [12]. Before permeability testing, each cylinder is cut into three discs with the thickness of 50mm suited for placing in the test cell. In the Cembureau method, 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:

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

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)

P_a=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 150 mm diameter and 50 mm thickness, the relationship simplified to:

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

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. The detail of gas permeability device is shown in Figure 2 [13,14].

The oxygen permeability coefficient of the specimen Koxygen would be obtained by evaluating the mean K from the five K_i values obtained for the five pressure stages.

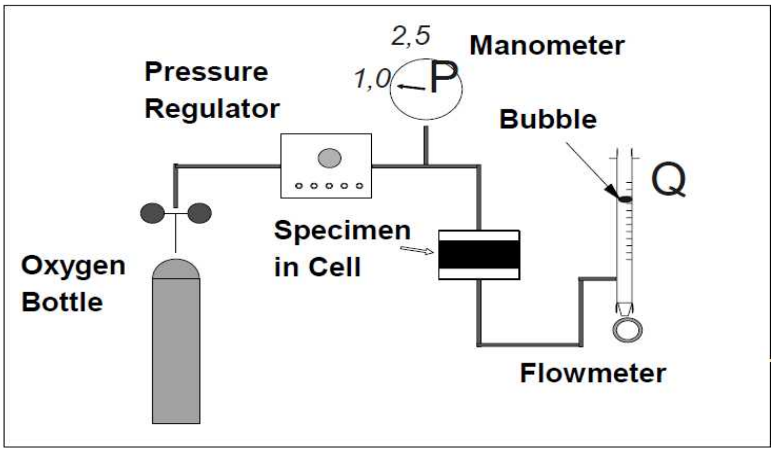


Figure 2. Details of gas permeability device [14].

3 MATERIALS

The cementitious materials used in this study were Portland cement type II. Table 1 shows the chemical analysis and the physical properties of the blended Portland cement. Crushed aggregates with maximum size of 19 mm were used. Polycarboxylate super- plasticizer was used in order to improve the workability of fresh material. Aggregate had specific gravity and absorption values of 2.59 and 3%, respectively. The fineness modulus of fine aggregates was 3.4. Silica fume (SF) obtained from Azna ferro-silicon alloy manufacture. The samples were prepared from a colloidal silica sol containing 15 wt% of solid material. The particle size was 5 nm with a specific surface area of 500 m^2/g. the colloidal silica sol was allowed to gel at 313 K for 48 h and later annealed for three weeks at seven different temperatures in the range 323-973 K, to ensure sample reproducibility and homogeneity.

Table 1. Chemical analysis and properties of cement.

Composition (%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	CO_2	Blaine fineness (m^2/g)
Cement	22.1	4.6	3.34	62.68	3.68	0.62	0.14	1.49	0.56	0.34

Table 2 shows the mixture concrete properties. According to Table 2, two concrete mixtures had been used that include: mix concrete containing Silica fume 7.5% (MSC) and mix concrete incorporating Silica fume 6% plus nano-SiO_2 1.5% (NSC).

Table 2 . Mix properties.

Mix Code	MSC	NSC
Cement (kg/m^3)	370	370
Silica Fume (kg/m^3)	30	24
Nano-SiO_2 (kg/m^3)	0	6
Corse aggregate (kg/m^3)	800	800
Fine aggregate (kg/m^3)	970	970
Water (kg/m^3)	180	180
Super plasticizer (%)	0.24	0.61
w/c	0.45	0.45
Slump (mm)	85	85

4 RESULTS AND DISCUSSION

4.1 *Electrical resistivity results*

In this investigation, the AC current method was applied on the saturated surface dried (SSD) specimens with 1.1 kHz frequency. Figure 3 shows the cell and system used to measure resistance of samples. After measuring the resistance, the resistivity of the concrete was derived from a simple equation:

$$\rho=(R\times A)/H \tag{3}$$

which ρ is the resistivity (kΩ· cm), R is the electrical resistance (kΩ), A is the surface area (cm^2) and H is the height of the slice (cm).

The average results of electrical resistance tests are shown in Table 3. As it is shown the electrical resistance of the sample NSC is more than sample MSC. Addition of nano-SiO_2 to silica fume concrete, leads to more compacted structures.

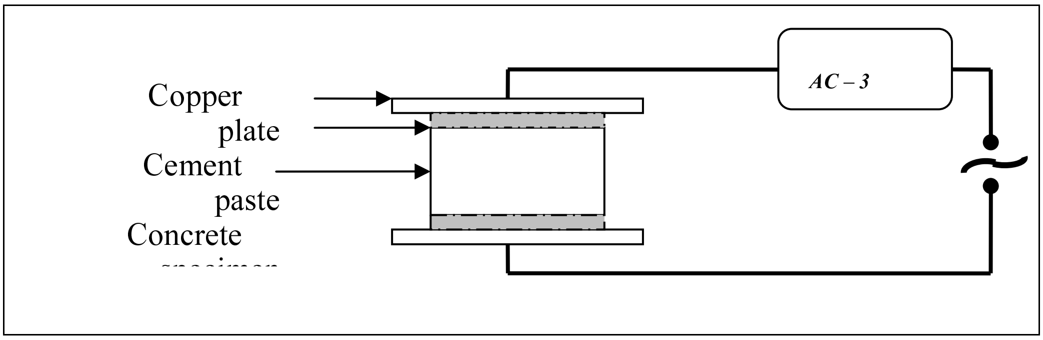


Figure 3. Electrical resistivity measuring instrument.

Table 3. Electrical resistivity of concrete samples.

Code	Electrical resistivity (KOhm.cm)
MSC	18.5
NSC	20.5

4.2 *Compressive strength results*

Figure 4 presents the compressive strengths of the tested specimens. As it is shown the compressive strength is approximately the same for both samples in all ages. It can be result of high reactivity of nano silica at the early age, but in later both of the pozzolans effect similarly in compressive strength.

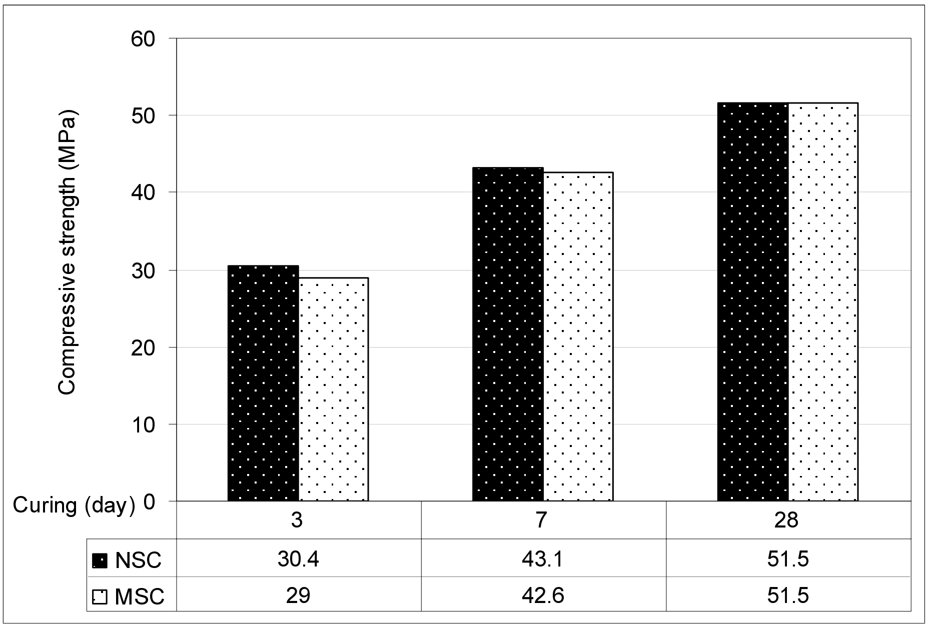


Figure 4. Compressive strength of samples.

4.3 *Gas permeability results*

The average results of gas permeability tests are summarized in Table 4. The NSC mixture showed higher resistance to gas permeability at 28-d age compare to the MSC mixture. Despite the result of compressive strength shows the same amount for the both pozzolans, the durability factor of concrete containing nano silica showed better performance. It seems that nano silica reduces the connections among the pores in the paste and also it can be consequence of strong bond between the paste and aggregates considering that there is no significant difference in mechanical strength.

Table 4. Coefficient of Gas Permeability of samples (m^2).

MSC	disc 1	2.37 E-16	average	2.9±0.5 E-16
	disc 2	2.96 E-16		
	disc 3	3.44 E-16		
NSC	disc 1	1.8 E-16	average	1.9±0.2 E-16
	disc 2	2.19 E-16		
	disc 3	1.78 E-16		

5 CONCLUSION

According to the results it can be concluded:

(1) Nano-SiO_2 pozzolan is more active in early age than silica fume due to the larger specific surface area and fineness.

(2) A durability characteristic in form of gas permeability is improved in concrete containing nano silica in comparison to concrete incorporating silica fume. Hence, it can be concluded that the microstructure of the nano-SiO_2 concrete is containing fewer porosity than that of the concrete incorporating Silica fume.

(3) As it is shown in compressive strength, it seems that nano silica activation is faster in early age than SF, but in the long term both samples have the same strength.

(4) The electrical resistivity of concrete increases by replacing nano-SiO_2 for cement. An electricity resistance test reveals that the microstructure of concrete with nano-SiO_2 is more uniform and compacted than that of concrete containing silica fume.

(5) These results can be outcome of absorption of the $Ca(OH)_2$ crystals by the Nano-SiO_2, and also reduction of the size and amount of the $Ca(OH)_2$. The nano-SiO_2 particles can fill the voids of the C-S-H gel structure and act as nucleus to tightly bond with C-S-H gel particles, making binding paste matrix denser, permeability properties of concrete are expected to be increased.

ACKNOWLEDGMENT

This study has been funded by Iranian Nanotechnology Initiative and authors of this paper thanks especially to Dr. M. Tadayon, representative of Iranian Nanotechnology Initiative, also continued regards to Construction Materials Institute at the University of Tehran is highly appreciated.

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