Effect of Nano-Silica Powder on the Durability Properties of High Performance Concrete

Yeong- Nain Sheen*, Ren-Yih Lin, Huang-Hsing Pan

The purpose of the study is to investigate the durability of high performance concrete containing nano-silica powder (NSHPC). The test variables are water-binder ratio of 0.32, and the nano-silica powder added to cement is 1.2%, 1.8% and 2.4% by weight. The results show that, by comparing with high performance concrete, electric resistivity of NSHPC is increased by 30% to 42% at the age of 28 days and chloride-ion permeability coefficient is always less than 100 coulombs. Analyzed by field emission scanning electron microscope (FE-SEM) pictures and X-ray diffraction, it can be shown that nano-silica powder as nano-scale particles is evenly distributed within the high performance concrete, which makes the concrete stronger and denser. NSHPC has proven to be excellent on durability.

1. Introduction

Nano-material is a new field in the global material research. Nanotechnology is referred to the technology in which at least one of its dimensions, length, width, or height, is controlled within 100 nm for its material structure and function. Nano-silica powder, a 99.9% pure SiO_2 material and one of the pozzolanic materials, is a new product of nanotechnology with an average particle diameter of 25 nm. Pozzolanic material is the material that contains silica oxide and aluminum oxide, and can react with calcium hydroxide in slow pozzolanic hydration reaction, producing cementation reaction similar to the cement hydration reaction [1-4]. Adding proper quantities of pozzolanic material into concrete can make the voids within the concrete finer, increase waterproof ability, decrease the diffusion coefficient of various ions, elevate the ability to resist erosion from sulfate, suppress alkali-aggregate reaction, and is helpful to improve concrete's long-term properties [1,5,6]. To improve concrete's quality and fulfill the needs for safety and durability, nano-silica powder is added to the paste to reduce the paste's voids and increase its strength and interface properties. The engineering properties of concrete are hence improved for better quality and durability [7, 8].

2. Experiment Program

2.1 Experiment Material

In this study, water-binder ratio of high performance concrete (W/B = 0.32) and the quantities of nano-silica powder added to cement (1.2%, 1.8%, 2.4% in weight ratio) are taken as the experimental variables. At the age of 3, 7, 28, 56, 91, and 120 days, the engineering properties of the high performance concrete is studied. Table1 lists the concrete's mix proportion, in which Type I Portland cement in accordance with CNS, fly ash (FA) with F class, and blast furnace slag powder were used. Table 2 lists the physical properties of the nano-silica powder

(SiO_2), Table 3 lists the basic properties of superplasticizer (SP), and Table 4 lists the properties of the coarse and fine aggregate that meet CNS requirements.

2.2 Test Procedure

The test procedure of this study includes the slump flow test for newly mixed concrete required by CNS 1176 and ASTM C143.The compression test on the concrete specimen is carried out according to CNS 1232 at the age of 3, 7, 28, 56, 91, and 120 days after the concrete has hardened. The chloride-ion permeability coefficient is measured at the 91-day concrete specimen according to ASTM C1202-91. Then, microstructure analysis is implemented for representative specimens using field emission scanning electron microscope (FE-SEM) and X-ray diffraction (XRD).

3. Results and Discussion

3.1 Microanalysis of Nano-Silica Powder

The nano-silica powder used in this study is in powder state before the separation process. Due to the large attraction force among particles and the large activity on the particle surfaces, the nano-silica powder agglomerated as a lump and hence enlarged the particle diameter, which hindered the original function of the nano-silica powder. In this study, pure water is employed as the main solution to separate the nano-silica powders. Moreover, separation agent up to 1% of the weight of nano-silica powder was added to form the solution. Under the dual action of the mechanical force and the separation agent, nano-silica powder is separated into particles of average diameter in nano scale. Figure 1 illustrates the SEM picture (100000 times) of the nano-silica powder, showing that the diameter of the nano-silica powder after separation is 25 nm. It is thus proved that after the proper process, the nano-silica powder can be effectively separated into particles bearing nano-scale dimensions.

3.2 NSHPC Micro Property Analysis

Figure 2 exhibits a micro picture of the mortar of nano-silica powder, it can be seen that the nano-silica powder with nano-scale particles distributes evenly in the mortar. Figure 3 to Figure 6 demonstrate the microstructure of NSHPC added with various quantities of nano-silica powder at the age of 7 days. In these figures, the microstructure of the concrete without nano-silica powder looks loose and a needle-like hydrated structure exists. The NSHPC added with 1.2% nano-silica powder exhibits that its microstructure is dense already at the age of 7 days. For adding a quantity up to 1.2%, the nano-silica powder can react sufficiently with the calcium hydroxide contained in the cement to produce C-S-H gel and hence the microstructure of the concrete is reinforced and the quality of the paste improved. As to adding 1.8% and 2.4%, the microstructure is even denser, as demonstrated in Figure 5 and Figure 6. As a concluding remark, nano-silica powder can effectively fill up the micro voids in the paste and undergoes a pozzolanic reaction with the paste to reinforce the microstructure properties of the concrete.

3.3 XRD Analysis

The X-ray diffraction analyses for NSHPC at the age of 7 days and 28 days are shown in Figure 7 and Figure 8. From the results, after adding nano-silica powder to the high performance concrete, the peak value of calcium hydroxide tends to decrease. As the nano-silica powder has very small particles, and very large surface area, the chance of hydration reaction with cement is hence increased, also the hydration reaction between nano-silica powder and cement becomes faster. Besides, nano-silica powder undergoes the pozzolanic reaction with calcium hydroxide, consuming calcium hydroxide and producing C-S-H gel, making the microstructure of high performance concrete even denser and stronger. Comparing Figure 7 and Figure 8, the peak value of calcium hydroxide without adding nano-silica powder tens to be weaker as the age increases, whereas the specimen added with nano-silica powder has no apparent change. The reason can be that nano-silica powder has very tiny particle diameter, the pozzolanic reaction between nano-silica powder and calcium hydroxide has carried out sufficiently at the age of 7 days and proper amount of calcium hydroxide has been consumed. As the result, the X-ray diffraction analysis of nano-silica powder at the age of 28 days does not show any apparent decrease for the peak value of calcium hydroxide.

3.4 Electric Resistivity and Chloride-ion Permeability Coefficient

The relation between NSHPC coefficient of permeability and the quantities of nano-silica powder added is shown in Figure 9. From this result, it is found that, compared with high performance concrete with no nano-silica powder, electric resistivity of NSHPC is increased by 30% to 42% at the age of 28 days depending on the quantities of nano-silica powder. The relation between coefficient of permeability and the quantities of nano-silica powder added is shown in Figure 10. At the age of 91 days, NSHPC has much lower Coulomb electricity than the concrete without nano-silica powder does. The chloride permeability coefficient is less than 100 coulombs, which can be considered negligible. Because of the pozzolanic reaction of the nano-silica powder, low density C-S-H gel is provided for the concrete to fill up the voids and that will decrease its porosity, and access between voids. Electricity passing through the concrete is greatly lowered. One can also see that the concrete's coefficient of permeability decreases with increasing quantity of nano-silica powder. The permeability is ranked in sequence as 0% > 1.2% > 1.8% > 2.4%. For concrete added with the pozzolanic material, nano-silica powder, the enlarged surface area does accelerate the pozzolanic reaction. Also because its fine powder can effectively fill up the voids, NSHPC turns out to be excellent in denseness, blocking the access between voids and decreasing the permeability.

4. Conclusions

1. Obtained from the micro property analysis, nano-silica powder can be distributed evenly as nano-scale particles in the mortar after the separation process.
2. Adding nano-silica powder to NSHPC makes the microstructure of mortar much denser.
3. Electric resistivity of NSHPC is increased by 30% to 42% at the age of 28 days.
4. The chloride-ion permeability coefficient of NSHPC is less than 100 coulombs.

Acknowledgement

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Table 1. Mixture proportions of NSHPC (kg/m^3)

W/B	Series No.	Coarse Agg.	Fine Agg.	Cement	FA	Slag	SiO_2	Mixing Water	SP
0.32	CS0	942	903	253	159	13	0	136	3.96
	CS1.2	942	903	253	159	13	3.04	136	4.26
	CS1.8	942	903	253	159	13	4.55	136	4.98
	CS2.4	942	903	253	159	13	6.07	136	4.85

Table 2. Properties of nano-silica powder

Average Particle Diameter (nm)	25
Specific Surface Area (m^2/g)	90 ± 20
SiO_2 Contents (wt%)	99.9
Loose Density (cm^3/g)	0.1~0.15

Table 3. Properties of superplasticizer

Color	Light Brown
Chloride Contents	Max.500 ppm
Ion	Negative Ion
PH Value	3.0 ± 1.0
Specific Weight	1.080 ± 0.020

Table 4. Physical properties of aggregate

Test Item	Coarse Agg.	Fine Agg.
Specific Weight (SSD)	2.63	2.61
Specific Weight (OD)	2.62	2.60
Water Absorption (%)	1.28	1.29
Max. Particle Diameter (mm)	19	—
Fineness Modulus (FM)	6.77	2.84
Unit Weight (kg/m^3)	1521	1656

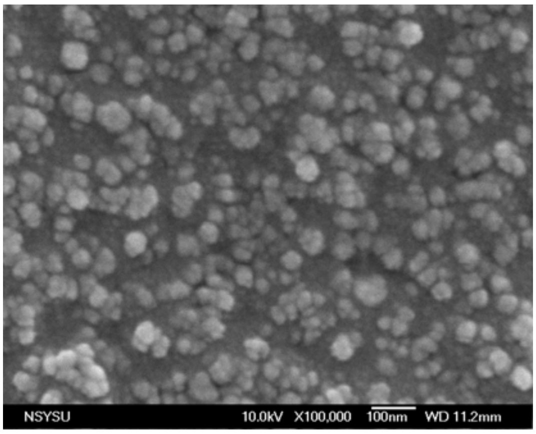

Figure 1. SEM Picture of nano-silica powder

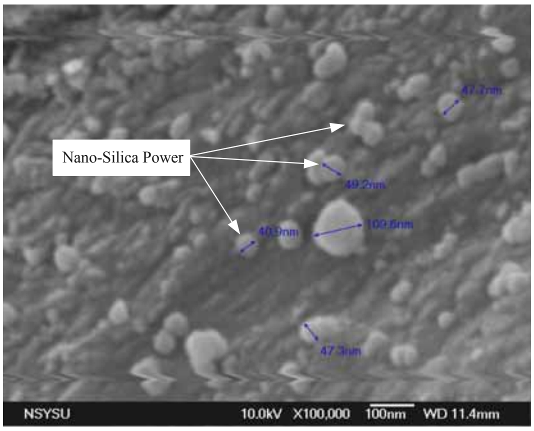

Figure 2. SEM in paste

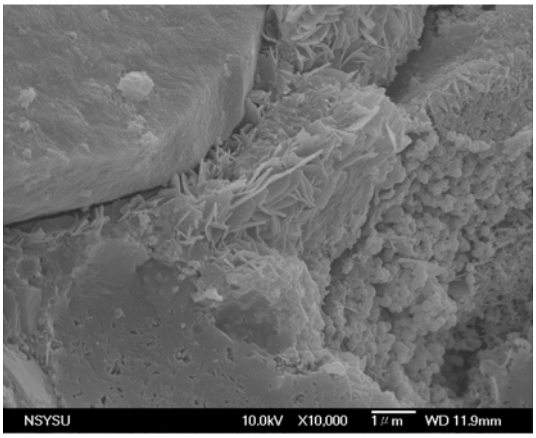

Figure 3. SEM in NSHPC (0%, 7 days)

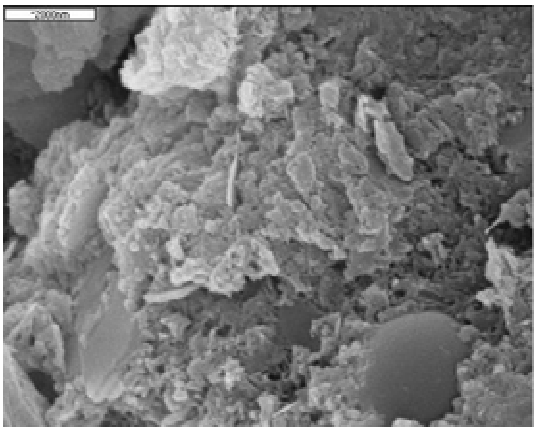

Figure 4. SEM in NSHPC (1.2%, 7 days)

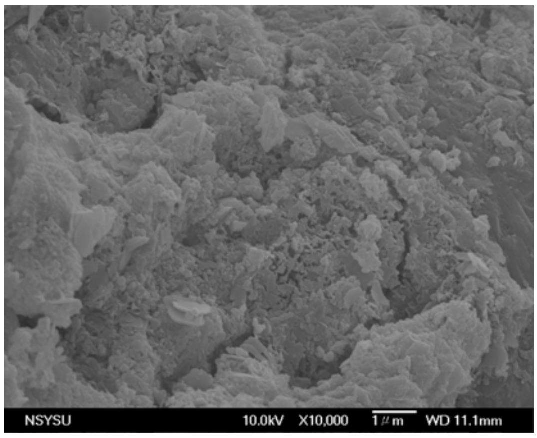

Figure 5. SEM in NSHPC (1.8%, 7 days)

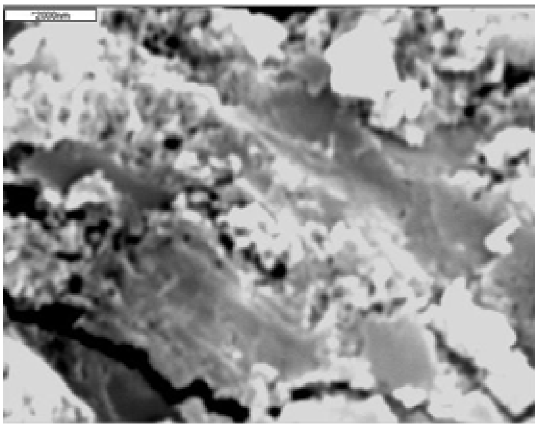

Figure 6. SEM in NSHPC (2.4%, 7 days)

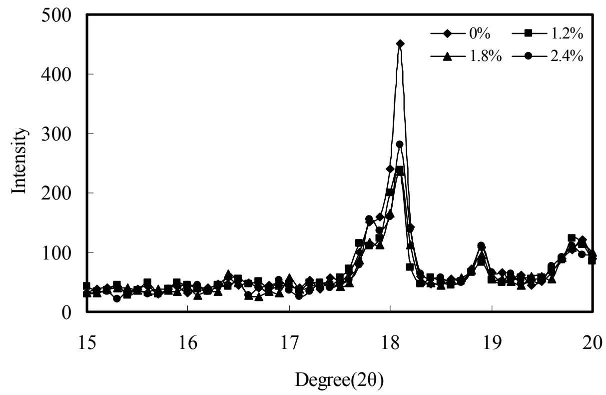

Figure 7. XRD analysis of calcium hydroxide in NSHPC (7 days)

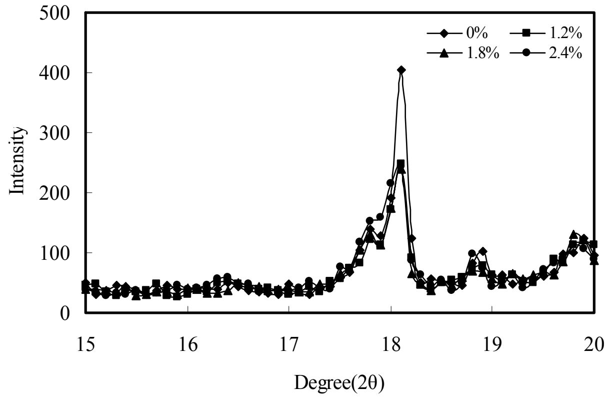

Figure 8. XRD analysis of calcium hydroxide in NSHPC (28 days)

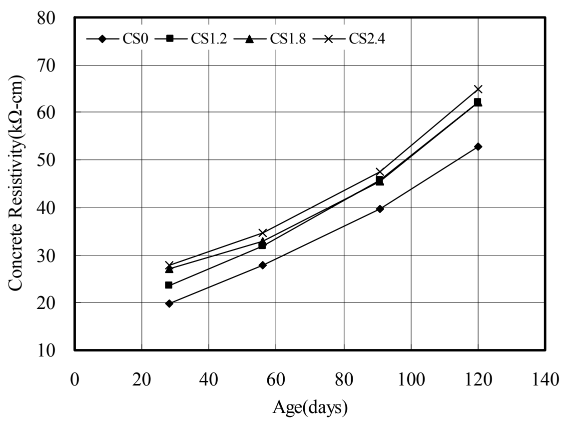

Figure 9. Electrics resistivity of NSHPC

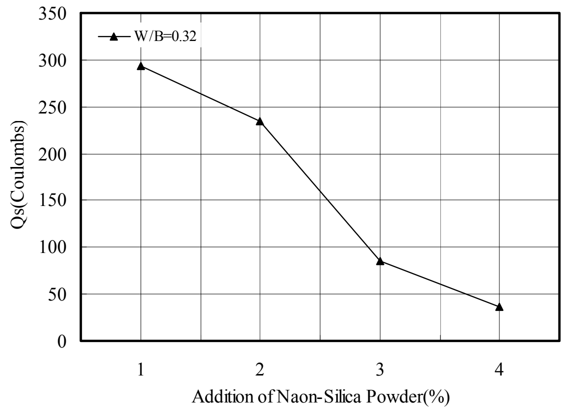

Figure 10. Nano-silica quantity and the Qs on NSHPC

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