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THE EFFECT OF VIETNAM'S NANO-SILICA ON MECHANICAL PROPERTIES OF HIGH-PERFORMANCE CONCRETE

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Abstract. The demand for High Performance Concrete (HPC) is steadily increasing with massive developments. Conventionally, it is possible to use industrial products such as silica fume (SF), fly ash, as supplementary cementitious materials (SCM), to enhance the attributes of HPC. In recent years, nano-silica (NS) is used as an additive in added mainly to fill up the deviation arises with the addition of SF for HPC. This study aims to optimize the proportion of NS (produced in Vietnam) in the mixture used for fabricating 70 MPa high-performance concrete. The SiO_2 powder with particle size from 10 to 15 nm were used for mixing. A series of compressive strength tests of HPC with nano-SiO_2 varied from 0 to 2.8 percent of total of all binders (0%, 1.2%, 2%, 2.8%), and the fixed percentage of silica fume at 8% were proposed. Results show compressive strength increases with the increase of nano-SiO_2, but this increase stops after reaching 2%. And at day 28 of the curing period, only concrete mixture containing of 8% silica fume and 2% nano-SiO_2, had the highest compressive strength.

Keywords: high performance concrete, nano silica, concrete mixture, compressive strength, optimize the proportion.

1. INTRODUCTION

Concrete technology has developed very rapidly. Several studies have related to high-performance concrete has been done. A problem to be solved in the high-performance concrete is how to strengthen the inter-surface zone between mortar and aggregate. Some additives commonly used to improve interface zone are silica fume, fly ash and slag. One of the new innovations in the development of material technology is nano-silica; an innovative product based on nanotechnology- is capable to performing at the accuracy less than 1μm or $1x10^{-9}$m. Because nanoparticles have a greater value of ratio between a surface area and a volume compared to similar particles with larger size.

Several researches related to the use of nanomaterials states that nanotechnologies can improve the compressive strength of concrete structure. Nittaya, et al [1] and Ozyildirim, et al [2] examined the effect of adding NS on the density of concrete. Furthermore, Forood Torabian Isfahani et al [3], M. Nili, et al [4] Valquiria S., et al [5], and Zhang, M. [6] studied the effects of the use of nano-silica on compressive strength of concrete. Lin DF, et al [7], and Björnström J [8] confirmed that the SiO_2 nanoparticles increased concrete strengths and enhanced its resistance to water absorption (WA). Mechanical properties, environmental resistance and durability of ordinary, high performance concrete can be improved using NS, studies by Xu S [9] and Wang XF, et al [10].

The nano materials can reduce the amount of water that filled the voids of the blending materials. For specimens cured in water, Givi AN, Rashid SA [11] found that 1% NS gave the maximum enhancement. The influence of NS on the concrete strengths tested at the 7th, 28th and 90th day was discussed by Nazari A, Riahi S [12]. In these experiments, cement content was partially substituted with 0%, 0.5%, 1%, 1.5% and 2% NS. They stated that, for specimens cured in water, the peak compressive strength was obtained at 1% NS, and specimens cured in saturated waterline showed compressive strength greater than that cured in water. Najigivi A, Khaloo A, Rashid SA [13] also studied the effects of NS on WA. They used 1%, 2%, 3%, 4% and 5% of Ns at the 2nd, 3rd and 28th day. The results showed that adding 4% NS gave the lowest percentage of WA then 5%, 3%, 2% and 1% NS follow it. A study of Nazari A, Riahi S [14] stated that in plain cement concretes, adding NS up to 4% reduced WA while Bahadori H, Hosseini P [15], Hosseini P, et al [16] reported 3%, and 2% by Najigivi A, et all [17].

This paper is aimed to evaluate the high-performance concrete properties casted with different proportion NS (produced in Vietnam). Basing on these above researches, the study set the proportion of nano-SiO_2. The influence of NS was found by a series of compressive strength test with nano-SiO_2 from 0 to 2.8 percent of total of all binders (0%, 1.2%, 2%, 2.8%), and the fixed percentage of silica fume at 8%, were introduced. About content of water, according to ACI 211.4R-08, for average compressive strength f'_{cr} = 82MPa, the maximum particle diameter is 9.5mm, the water cement ratio is 0.3. So, with the aim of expanding the research for self-compacting concrete, the series of test studied with 0.34 of water–cement ratios (w/c).

2. EXPERIMENT

2.1 Materials

a. Cement

Table 1. Chemical composition of NghiSon- Type I cement.

Chemical	C3S	C2S	C3A	C4AF
NghiSon PC40	52%	29%	6%	10%

Concrete cubes used PC40 NghiSon-Type I (ASTM C150/C150M-16 standard). The physical properties and chemical configuration of the concrete are listed in Table 1 as obtained from the manufacture sheet.

b. Aggregate

Coarse aggregate is 9.5mm in size (gradation test is met ASTM C33 standard, see Figure 1), 2.75 g/cm^3 in specific weight, and volume of the compacted state is 1620 kg/m^3.

Quartz sand originally from the golden river sand of TayNinh (Vietnam) with size from 0.1-4.75mm, with specific weight of 2.65 g/cm^3 and the volume of compacted state is 1540kg/m^3, Maximum air content r_c=36.0%. The material is met the Specification AASHTO T27 or ASTM C136 (see Figure 2).

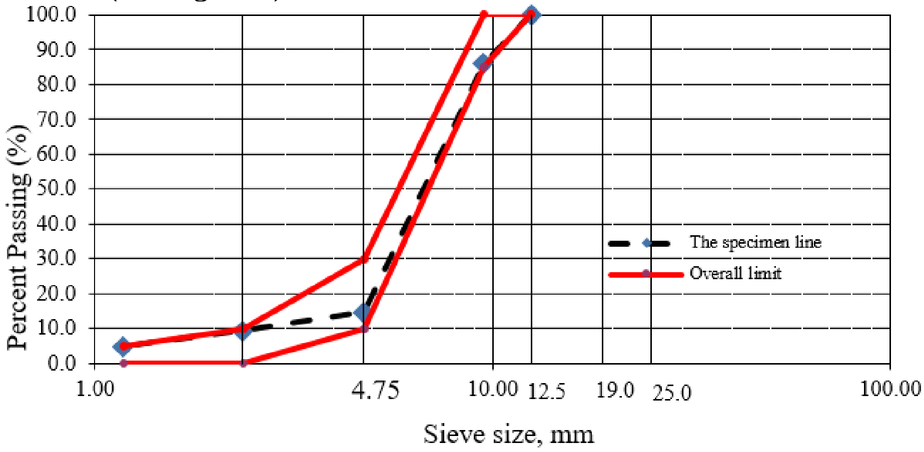

Figure 1 - Grading curves of coarse aggregate.

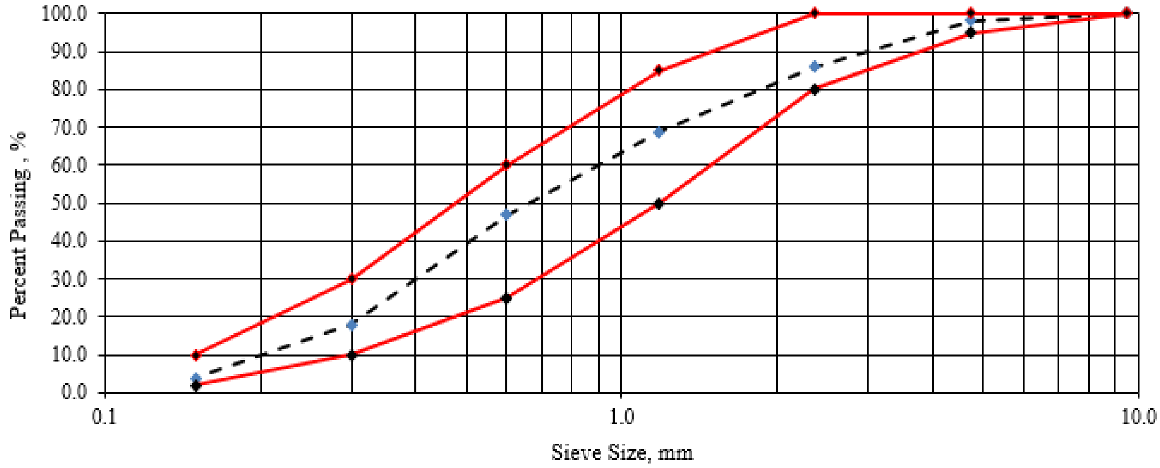

Figure 2. Grading curves of fine aggregates.

c. Chemical mixtures

Silica fume with specific gravity 2.2g/cm^3 used in the concrete mix is Sikactete PP1 of Sika Company. Admixture: Admixture used Sika Viscorete 3000-20M, the specifications is shown in Table 2.

Table 2. Chemical and physical characteristics of Sika Viscorete 3000-20M.

Characteristic	Value
Specific gravity at 25^{0}C	1.097 g/cm^3
pH index at 25^{0}C	5.06

d. Mineral additives

Nano-Silica: Nano-silica grain made from rice husk ash (from Mekong Delta- Vietnam). The obtained SiO_2 powders had monoclinic crystal system, large specific surface area ($258.3 m^2/g$), and particle size (10 to 15nm). EDX spectra of the silica nanoparticles is figured out in Figure 3; and Figure 4 is spectra of Nano silica SEM.

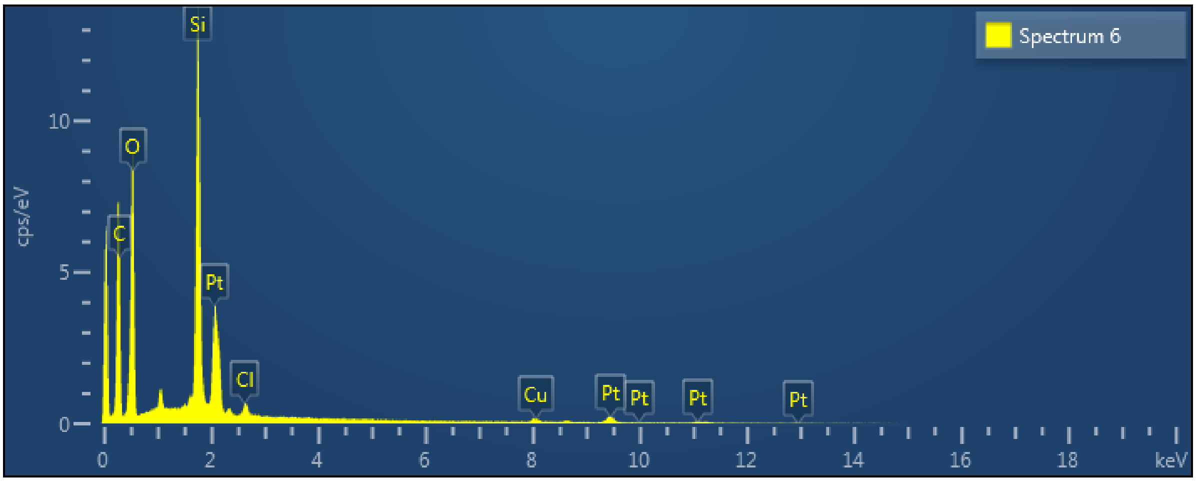

Figure 3. Nano silica EDX.

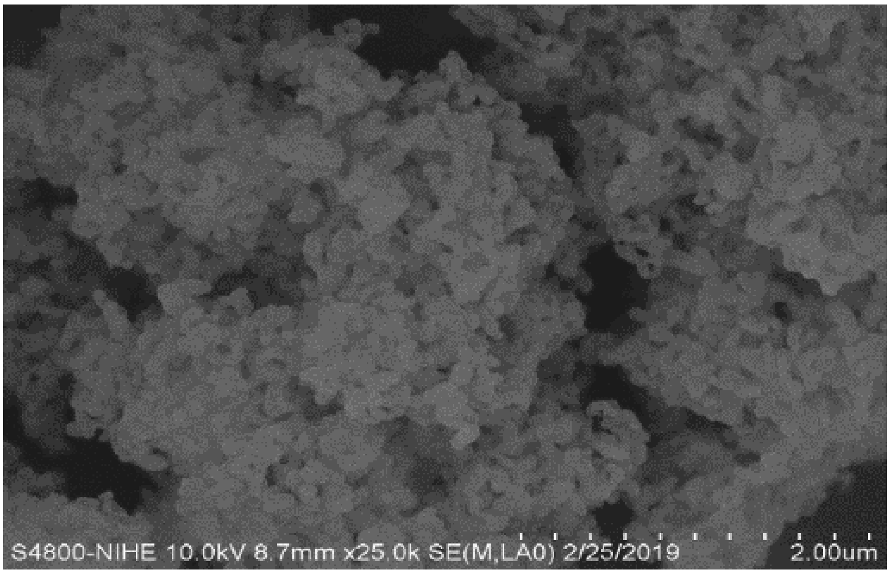

Figure 4. Nano silica SEM.

2.2 Concrete Mix Design

Method of calculation preliminary compositions of concrete mixture is applied in accordance to ACI 211.4R-08 (American). The compressive strength of concrete is determined by a 100x200 mm cylindrical concrete specimens. These cube samples are demolded after 24 hours later casting and placed in a 25^0C water curing tank until the experiments. The compressive strength HPC is measured at the ages of 7, 21 and 28 days

The concrete mix consists of nano-silica as a cement partial substitution material. Ratio of water and cement W/C is 0.30 and 0.34. For the experiments, nano-silica was added into the concrete mix as cement partial substitution of amount 0%, 1.2%, 2%, and 2.8% of all binders. Percentage of silica fume fixed at 8% and Admixture Sika Viscorete 3000-20M used

1.2kg per 100kg of Cement. Table 3, and Table 4 is about concrete mix with W/C = 0.34, and 0.3 respectively.

Table 3. Concrete mix with W/C = 0.34.

Mix	Cement (kg)	Silica fume (kg)	Nano-Silica (kg)	Sand (kg)	Coarse (kg)	Water (L)	Sika Viscorete (L)
C0.34-0NS	434.2	37.8	0	738	1053	160.6	5.7
C0.34-1.2NS	428.5	37.8	5.7	736	1053	160.6	5.7
C0.34-2NS	424.8	37.8	9.4	734	1053	160.6	5.7
C0.34-2.8NS	421	37.8	13.2	733	1053	160.6	5.7

Table 4. Concrete mix with W/C ratio 0.3.

Mix	Cement (kg)	Silica fume (kg)	Nano-Silica (kg)	Sand (kg)	Coarse (kg)	Water (L)	Sika Viscorete (L)
C0.3-0NS	492.2	42.8	0	681	1053	160.6	6.4
C0.3-1.2NS	485.8	42.8	6.4	679	1053	160.6	6.4
C0.3-2NS	481.5	42.8	10.7	677	1053	160.6	6.4
C0.3-2.8NS	477.2	42.8	15	676	1053	160.6	6.4

3. RESULT AND DISCUSSION

3.1 Slump of Concrete

This test method based on the jurisdiction of ASTM Committee C143/C142M. The slump changes with the nano content. The slump amount is reduced by replacing the used cement by the nano-particles. With water rate is 0.3, the drop varies from 10-14cm, and the water rate is 0.34, the drop varies from 16-20cm.

3.2 Tensile Strength

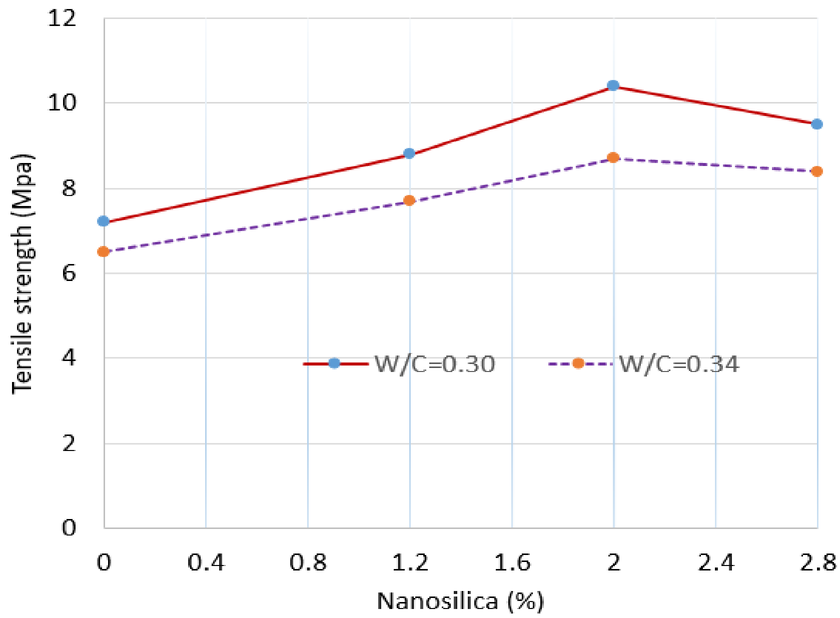

Figure 5. Concrete tensile strength of 2 Mix concrete at day 28.

This test method was under the jurisdiction of ASTM Committee C78/C78M. (Using simple beam with Third-Point Loading). Testing specimen is 400x100x100mm concrete girder and one mix concrete has 6 specimens. It is observed that nano-silica also effect to the tensile strength of concrete. Tensile strength increases with the percentage of nano-silica in a concrete (see Figure 5). And, it is found that the concrete with 2% of nano silica has the highest strength. Additionally, strength tends to increase with decrease in W/C ratios for each variation of silica fume. It means that, W/C = 0.3 nano-silica concrete is higher than strength of the W/C =0.34 concrete one.

3.3 Compressive Strength

This test method was followed by the jurisdiction of ASTM Committee C39/C39M. Testing specimen is 100x200mm concrete cylinders and one mix concrete has 6 specimens. **Error! Reference source not found.** and **Error! Reference source not found.** shows rate of compressive strength of mix concrete w/c =0.3, and w/c=0.34 respectively; with differences of nano-silica substitution 0%, 1.2%, 2%, and 2.8% of total binders.

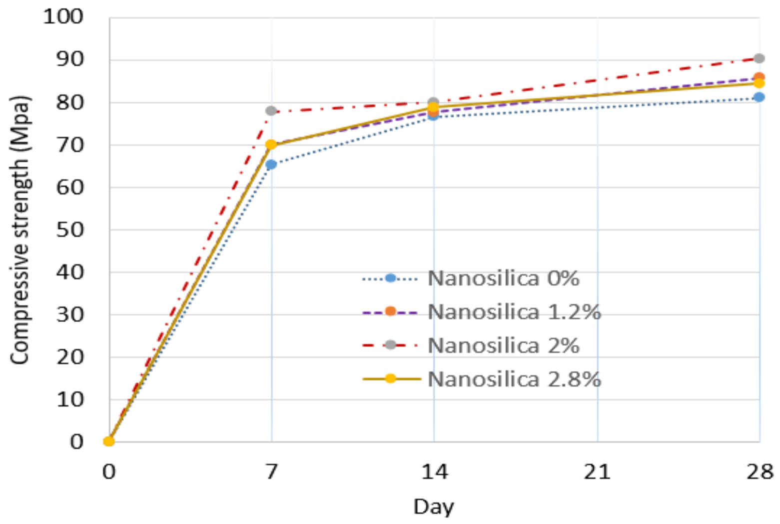

Figure 6. Development of concrete compressive strength of Mix concrete with W/C=0.30.

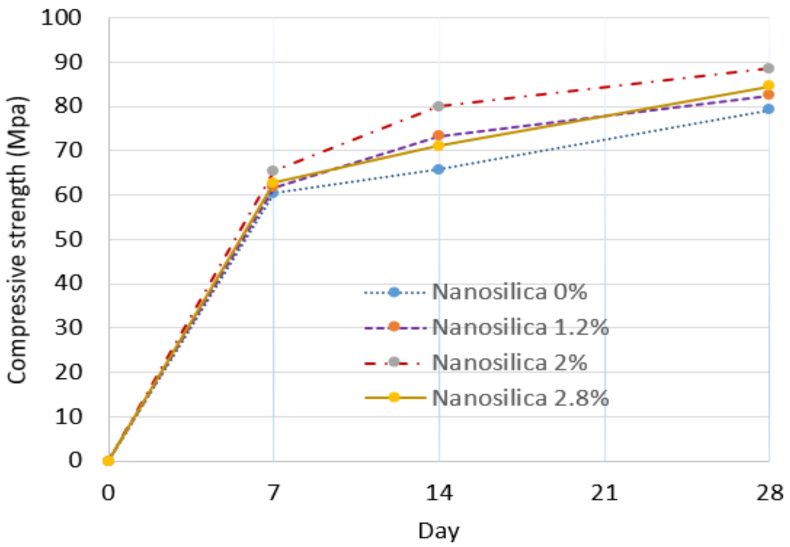

Figure 7. Development of concrete compressive strength of Mix concrete with W/C=0.34.

Concrete slump of mix concrete with w/c=0.30 was about 10-14 cm, with w/c = 0.34 was 16-20cm. Since, Nano-silica is a filler to enhance the density in micro, and an activator in the hydration reaction, it may state that nano-silica concrete has a rapid development in compressive strength compare to non-nano silica concrete. The addition of nano-silica is beneficial to the compressive strength of concrete. The compressive strength of nano-silica modified concrete increases with increased nano-SiO_2 content toward the threshold content. At day 28 of the curing period, only concrete mixture containing of 8% silica fume and 2% nano-SiO_2, had the highest compressive strength of 90.2Mpa. However, further addition of nano SiO_2 resulted in a decrease in the compressive strength of the concrete.

4. CONCLUSION

Mixture concrete used 2% nano-silica has the highest strength of compress and tensile. But, the strength of nano-silica concretes with W/C =0.3 is always higher than strength of the W/C =0.34 ones.

Mixture concrete with W/C=0.30, 2% nano-SiO_2 reached 90.2MPa at age 28 day. Although W/C= 0.34, mixture concrete with nano-SiO_2 has a compressive strength greater than 70MPa, but it is found that the slump of the concrete is high, and it is suitable with self-consolidating concrete. Based on the results of this experiment, interested parties should consider working with variables not exceeding optimum value of 2% nano-SiO_2.

There should be more in-depth experiments like scanning electron microscopy SEM to better understand the mechanism of calcium silicate hydrate (C-S-H), calcium hydroxide (C-H) and interfacial transition zone (ITZ).

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