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Effect of nano-silica on the properties and form mechanism of foamed concrete

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ABSTRACT

Foamed concrete is usually made of cement and fly ash, with H_2O_2 and $Fecl_3$ as foaming agent, and calcium stearate as foam stabilizer. Nano SiO_2, or nano-silica, can be used as an additive to change the properties of concrete. In this paper, the effect of nano-SiO_2 on the compressive strength of foamed concrete is investigated, as well as the additive mechanism is analyzed. Experimental results show that compressive strength at 7-th days can be improved up to 15%, and at 28-th days can be improved up to 18%, respectively through adding nano SiO_2. The improvement is explained as that nano-SiO_2 changes the microstructure and the interactions on the surface of foam to shorten the foaming time.

KEYWORDS

Foamed concrete; Nano SiO_2 ; Fly ash; H_2O_2; $Fecl_3$.

INTRODUCTION

Foamed concrete is a kind of porous concrete materials which is mainly made from cement, fly ash and blowing agents, with additives and through nature conservation process[3]. Because of its light-weight, material saving, green, good thermal insulation, fire resistance and equal-lifetime with building, and obtained easily, foamed concrete is popular used in construction industry. To solve its low strength problem, lots of study works are turned to strength improvement technology, especially focusing on the most wanted low density foamed concrete with density from 100 to 300 kg/m^3.

Nano-Silica, also written as Nano- SiO2, is widely used in construction industry as an important additive. It has been proved that nano-silica can be used as concrete additive to improve compressive and flexural strength based on its chemical and physical structural characters[5].

Two typical firming methods in use are chemical foaming and mechanical foaming[1], which will affect the chemical components and physical micro-structure in different ways, and then changes the strength.

In this paper, chemical method is used to made foaming concrete, to investigate the effect of nano-silica as additive on concrete strength during forming. The effect of is explained with that nano-silica changes chemical components in foam and enhances the compressive and stress strength. The experiment is described in section 1, and the result are listed and analyzed in section 2, then conclusions are formed in section 3.

EXPERIMENT

Materials

Materials used in experiments include silicate cement (42.5#, physical properties are shown in TABLE 1), fly ash (dry ash, level II, chemical compositions are shown in TABLE 2), naphthalene superplasticizer (NS), $Fecl_3$, H_2O_2 (27.5%), calcium stearate (CS), polypropylene fiber (PF, physical properties are shown in TABLE 3) and water. As the additive, nano-silica is also used, and its main technical parameters are shown in TABLE 4.

TABLE 1: Physical properties of the silicate cement (42.5#)

Type	Specific surface area /(m^2/g)	Setting Time		Grade	Compressive Strength/MPa			Flexural Strength /MPa		
		Initial Set /min	Final Set/h		1d	3d	7d	1d	3d	7d
silicate cement (42.5#)	≥350	≥25	≤3	42.5	34.5	42.5	50.3	6.5	7.0	7.5

TABLE 2: Chemical composition of fly ash (mass%)

Al_2O_3	SiO_2	CaO	Fe_2O_3	Na_2O+K_2O	TiO_2	others
45.4%	47.2%	1.9%	2.8%	0.46%	1.4%	0.84%

TABLE 3: Physical properties of polypropylene fiber

Diameters/mm	Tensile Strength /GPa	Elastic Modulus /GPa	Elongation at break /%	Fiber length /mm	Density /g/cm^3
20-200	0.5	5	20	2	0.9

TABLE 4: Parameters of nano SiO_2

Appearance	Purity /%	Average particle size/nm	Apparent density /g/L	PH	Specific surface area /m^2/g
white powder	99.5	30	40-60	5-7	200±10

Test piece preparation

A basic series of foamed concrete pieces are prepared, with density as 220 kg/m^3(C1)、230 kg/m^3(C2)、240 kg/m^3(C3)、250 kg/m^3(C4)、260 kg/m^3(C5). The mix proportion data are shown in TABLE 5. Based on the pieces, nano-silica is used as additive with mass content as 0.2%, to form the series of target pieces named as C1-1, C2-1, C3-1, C4-1 and C5-1 accordingly.

TABLE 5: Mix proportion of basic foamed concrete

Index	Density kg/m^3	Cement /g	Fly ash /g	CS /g	NS /g	PF /g	Water /g	Fecl$_3$/g	H_2O_2/g
C1	220	7300	1200	150	39	28	4300	15	300
C2	230	7300	1200	150	39	28	4300	13	275
C3	240	7300	1200	150	39	28	4300	12	260
C4	250	7300	1200	150	39	28	4300	10	235
C5	260	7300	1200	150	39	28	4300	8	220

It is extremely important to maintain the feeding sequence and mixing time. To avoid the agglomeration of nano-silica particles and to spread it evenly in cement paste, a feeding sequence is designed. First step, NS and nano-silica are dissolved in water to get a solution at temperature as 35 degree. Second step, powders of cement, fly ash, CS and PF are mixed in an high-speed mixer for 3-5 minutes. Third step, the solution is added into the mixed powder carefully in the mixer and keeps the machine running for 2 more minutes. Forth step, $FeCl_3$ and H_2O_2 are added and mixed for 30 seconds. Then the mixture is put into moulds. After 24 hours, the moulds are removed, and the final test pieces are cut into standard test pieces with 100mm×100mm×100mm. The test pieces are saved in Standard Curing Room (SCR), and tested at 7th and 28th day.

Test method

Apparent density are measured according to standard code GB/T 11970-1997 (The Test Methods of Density, Moisture Content, and Water absorption for gassed concrete).

Compressive strength is measured according to GB/T 11971-1997 (The Test Methods of Mechanical Properties for Gassed Concrete).

Surface morphology is reviewed under electron microscope of QUANTA-400.

EXPERIMENT RESULT

Main components in foaming concrete

Ordinary silicate cement and fly ash (dry ash level II) are the main components in foaming concrete. During the hydration process, Ca0, SiO_2, Al_2O_3, Fe_2O_3, C_3S, C_2S and C_3A are formed. The porous components are mainly formed through the formation of foam. In this experiment, H_2O_2 and $FeCl_3$ are used as foaming agent, and calcium stearate as foam stabilizer. H_2O_2 is a kind of weak acid with strong oxidation, and it can react chemically stable in the cement slurry to generate O2. Affected by $FeCl_3$, H_2O_2 will quickly release oxygen. The calcium stearate at certain amount will ensure the stability of foam. Experiments show that, the amount is very sensitive to result, such as surficient to cause collapse. The calcium stearate will ensure the form of small and uniform bubbles, and control the foaming time.

Nano-silica's effect and mechanism

(a) Characters of the nano-silica

In micro-silica, there are more metal oxides like Fe_2O_3 and Al_2O_3, and its content of SiO_2 is less than 70%. Comparing with micro-silica, Nano-silica has a much higher content more than 98%[6]. And the silica particles are smaller with diameter from 10 to 60 nm, higher specific surface area from 400 to 700 m^2/g. Because there are more dangling bonds in the surface Si atoms, the nano-silica is very unsaturated and high chemical activity to combine with other atoms to form stable bonds. Nano-silica has a special network structure as a three dimensional chain molecular structure, which will greatly improve the strength and toughness of material[2]. The structure will also change the molecular structure in cement slurry and form new three-dimensional chain molecule structures.

(b) Nano-silica's mechanism

Foamed concrete is a kind of low strength concrete with a large number of pores inside. And after being used for a period of time, the surface of foamed concrete is easy to crack with the formation of dry shrinkages, which is directly caused by the porosity. Under external forces such as gravity, wind and other loading, the crack extends fast and widely. Studies show that[4], the presence of nanoparticles can induce bridge-connection effect at the ends of cracks, which is the main reason for the enhanced mechanism of nano materials. In the experiment, by adding nano-silica in foamed concrete, the crack will stop growth when it meets nanoparticles in the tip. Because of bridge effect, more energy is needed, and so the crack slows down, and the foam concrete has a higher strength and lower drying shrinkage value.

Nano-silica's Effect on strength of foamed concrete

The strength of foamed concrete changes after the nano-silica of 0.2% is used as additive, and the result are shown in TABLE 6 and TABLE 7.

TABLE 6: Effect of nano-silica (0.2%) on compressive strength on foamed concrete, value of 7th day

Density	220kg/m^3	230kg/m^3	240kg/m^3	250kg/m^3	260kg/m^3
Without Nano-SiO_2	0.20	0.28	0.36	0.40	0.44
With Nano-SiO_2	0.24	0.32	0.41	0.43	0.47
Rate of increase	20%	14.3%	13.9%	7.5%	6.8%

TABLE 7: Effect of nano-silica (0.2%) on compressive strength on foamed concrete, value of 28th day

Density	220kg/m^3	230kg/m^3	240kg/m^3	250kg/m^3	260kg/m^3
Without Nano-SiO_2	0.22	0.32	0.4	0.43	0.47
With Nano-SiO_2	0.27	0.35	0.45	0.47	0.52
Rate of increase	22.7%	9.3%	12.5%	9.3%	10.6%

Data in the tables shows that, by using the nano-silica, the foamed concrete is enhanced, and its compressive strength values at 7th and 28th day increase obviously. The effect is also various with the concrete density. To the lowest density concrete of 220Kg/m^3, its compressive strength increase 20% at the 7th day value, and 22.7% at the 28th day value.

Nano-silica is a kind of non-stable material with big specific surface area and high activity. Its Pozzolanic Activity are high than the micro-silica. During the setting process, it reacts with the $Ca(OH)_2$ in the furry, fastens the composition of C-S-H gelatin, and finally changes the composition of cement furry. So the foamed concrete has a better compressive strength.

The amount of nano-silica is also high relative. In TABLE 8 and 9, the strength changes more obvious after nano-silica of 0.4% is used as additve. The strength value at 7th and 28th day increase with higher rate, and to the concrete with lower density the effect is much better. For example, to the lowest density concrete of 220Kg/m^3, its compressive strength increase 30% at the 7th day value, and 31.8% at the 28th day value.

TABLE 8: Effect of nano-silica (0.4%) on compressive strength on foamed concrete, value of 7th day

Density	220kg/m^3	230kg/m^3	240kg/m^3	250kg/m^3	260kg/m^3
Without Nano-SiO_2	0.20	0.28	0.36	0.40	0.44
With Nano-SiO_2	0.26	0.35	0.42	0.45	0.49
Rate of increase	30%	25%	19.4%	12.5%	11.4%

TABLE 9: Effect of nano-silica (0.4%) on compressive strength on foamed concrete, value of 28th day

Density	$220kg/m^3$	$230kg/m^3$	$240kg/m^3$	$250kg/m^3$	$260kg/m^3$
Without Nano-SiO_2	0.22	0.32	0.4	0.43	0.47
With Nano-SiO_2	0.29	0.38	0.46	0.49	0.55
Rate of increase	31.8%	18.8%	15%	14%	17%

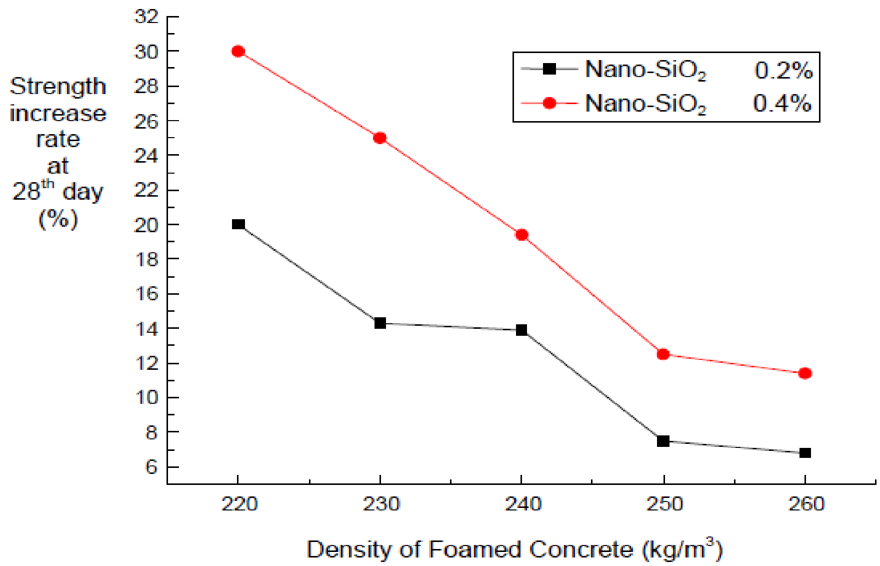

Figure 1: Enhance effect of nano-silica to foamed concrete, strength value at the 7th Day

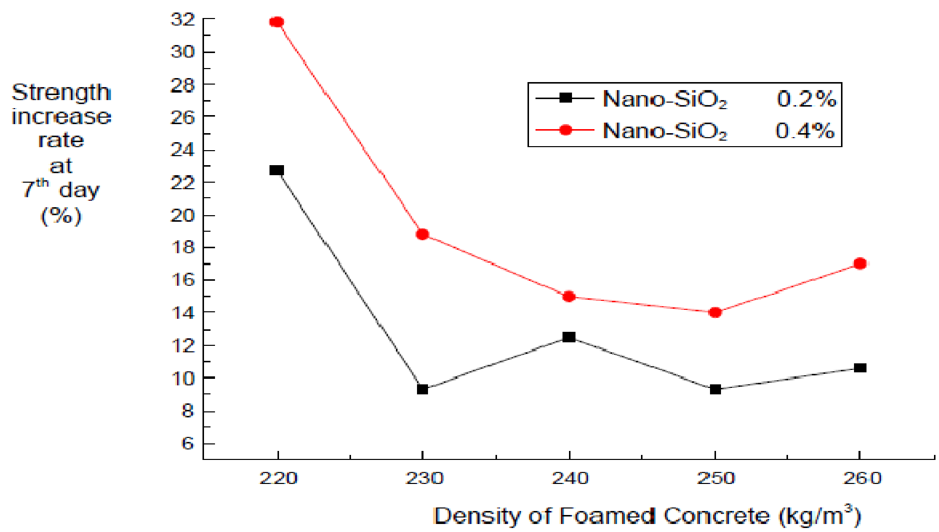

Figure 2: Enhance effect of nano-silica to foamed concrete, strength value at the 28th day

In Figure 1 and 2, nano-silica shows a higher effect on concrete compressive strength when more nano-silica is used, by the values at 7th and 28th day.

Nano-silica's effect in the foaming process

The volume of foamed concrete in mould is investigated. If the volume does not change in 5minutes, the concrete is defined as fully set, and the set time is recorded. The nano-silica used as additive can effectively reduce the foaming time. The reduce rate of setting time improves with the dosage of nano-silica. For example, the rate reaches 15% when the dosage is 0.5%, shown in Figure 3. During the process of gas bubble in slurry resisting the surface tension and viscous force and growing up, when liquid tension and viscous force are equilibrium with foam's gravity force, the foam is formed.

The foam now will not fall or rise up because of gravity, and will not expand or break because of the surface tension force. With the increase dosage of nano-silica, the foaming time reduces, which means there is shorter time to reach the equilibrium. Because of the bridge effect of the nano particles, the framework between foams are enhanced, and the foams are more stable.

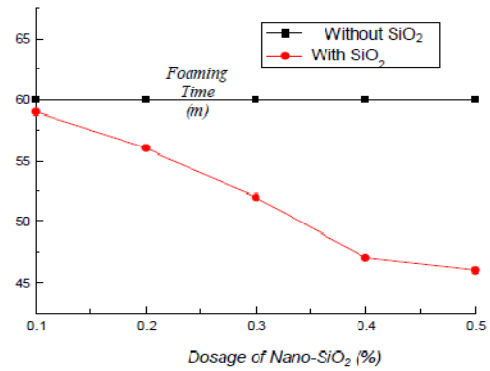

Figure 3: Impact of nano SiO_2 on foaming time

Nano-silica's effect on micro appearance

Hydration products from cement include $Ca(OH)_2$, C-S-H, $C_3A{\cdot}3CaSO_4{\cdot}32H_2O$ and other substances. While among them, $Ca(OH)_2$ will reduce the strength of the cement. Based on nano-silica's high activity and dispersivity, the nano-particles will react with $Ca(OH)_2$ quickly to form C-S-H gelatin. In Figure 4, the foamed concrete without nano-silica additive is shown under a SEM, where big amount of $Ca(OH)_2$ exists. After nano-silica is added, the $Ca(OH)_2$ are much rare in the concrete image in Figure 5. This is the main reason why the foamed concrete is more strengthen after nano-silica is used as additive.

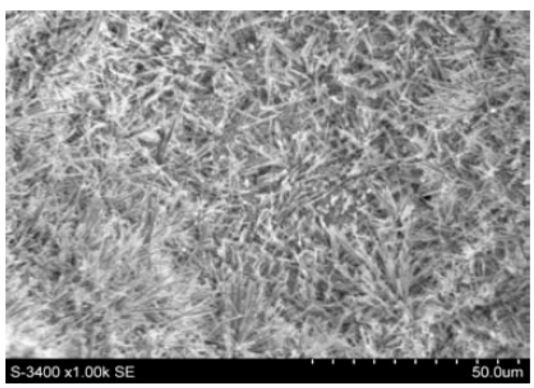

Figure 4: SEM image of foamed concrete without nano SiO_2

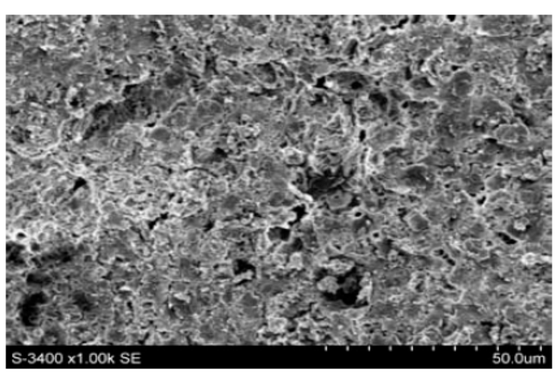

Figure 5: SEM image of foamed concrete with nano SiO_2

The experiment image proves that, nano-silica will reduce the foaming time and concrete density, thus improve the foaming ability. Nano-silica as an additve will change surface structure of foams and interactions between foams. In cement slurry, nano-silica reacts with paste and forms gelatin which will cover the surface of cement particles. The hydrations of cement will reacts on the surface of gelatin to form C-S-H gelatin, and nano-silica can boost this process.

CONCLUSION

After experiment and analysis, these conclusions are drawn,

1. To foamed concrete with lowest density as 220 Kg/m^3, nano-silica has more obvious effect, and concrete's compressive strength raise 15% at the 7^{th} day and 18% at the 28^{th} day.

2. During the setting process, nano-silica will react with the $Ca(OH)_2$ in slurry and boost the forming of C-S-H gelatin, to change the composition of cement slurry and to enhance the compressive strength of the target foamed concrete.

3. With increase of the dosage of nano-silica used as additive, the foaming time reduces obviously. To concrete with additive density at 0.5%, the foaming time reduces 15 minutes.

4. Nano-silica is easy to react with $Ca(OH)_2$ to form C-S-H gelatin in slurry because of its high activity and dispersive.

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