Properties of concrete incorporating silica fume and nano-SiO_2

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Abstract

The use of silica fume has been considered as a pozzolan for several years. Besides, doing research about nano and its application in concrete is increasing. The present study investigates the simultaneous use of nano-SiO_2 and silica fume in concrete. In order to such a purpose, silica fume in measures of 5 and 10 percent and nano-SiO_2 in measures of 0.5 and 1 percent were replaced with cement and totally eight mixture plans for doing the compressive strength and water absorption experiments. Finally, the results showed that using such materials improves the qualities of concrete. Using both 10% silica fume and 1% nano SiO_2, as a cement replacement, resulted in 42.2% increase in compressive strength in comparison to control sample. Furthermore, it was understood that the simultaneous use of these materials is more influential than their single use.

Keywords: Concrete, Silica fume, Nano-SiO_2, Compressive strength, Water absorption.

1. Introduction

Concrete, as a constructive material, has been used in construction industry for about two centuries. Approximately, the whole bulk of the concrete is used in one year is more than one ton apiece. Therefore, doing research about using modern technologies in production concrete is of great importance. Reducing the necessary amount of Portland cement without reducing the performance of concrete is significant for big projects that require a large amount of cement. Furthermore, Portland cement clinker production consumes large amounts of energy and has a notable environmental impact. For instance, 1.7 tones raw materials is needed to produce 1 ton clinker which leads to emission of greenhouse and other gases into the atmosphere (Meyer, 2009). Approximately 850 kg of CO_2 is emitted per ton of clinker produced (Gartner, 2004). Hence, pozzolan and cementitious materials play an important role in concrete production. Previous studies show that silica fume, as an active pozzolan, cuts down cement consumption and increases the durability and strength of concrete (Mazloom et al., 2004; Bhanja & Sengupta, 2002). Besides, various combinations of a pozzolan and silica fume were used to produce high strength concrete (Shang, 2000). On the other hand, the usage of nano-SiO_2 in concrete has been increasing in recent years. The positive effects of using nano-SiO_2 on the mechanical properties of concrete and cement mortar have been shown by recent studies (Tao, 2005; Byung et al., 2007; Li et al., 2004; Qing et al., 2007, Byung et al., 2008; Wan et al., 2007). Moreover, the mechanical properties of concrete were significantly improved with the use of nano-SiO_2 and pozzolan together (Li, 2004; Heidari & Tavakoli, 2013). However, no comprehensive study has yet done in which the use of silica fume and nano-SiO_2 Simultaneously. Therefore, in this experimental study, the effects of using simultaneous nano-SiO_2 and silica fume were studied by using 0.5 and 1 percent nano-SiO_2 and 5 and 10 percent pozzolan.

2. Materials

2.1 Cement

Cement used here is Type II Portland cement, their physical properties and chemical compositions shown in Table 1.

Table 1. *Properties of cement*

Chemical properties	Percent
SiO2	21.8
Al2O3	5.1
Fe2O3	3.9
CaO	64.8
MgO	≤1.7
CL	≤0.03
SO3	≤2.0
L.O.I	≤1.3

Physical properties	Value
Initial Setting	95 (min)
Final Setting,(min)	150 (min)
Fineness(blain)	≥2900 (cm2/g)
Autoclave expansion	≤0.15(percent)
3 Days Compressive strength	≥190 (Mpa)
7 Days Compressive strength	≥320 (Mpa)
28 Days Compressive strength	≥490 (Mpa)

2.2 Aggregate

The fine aggregate and the coarse aggregate used in the concrete were crushed limestone aggregates. The water absorption, particle size distribution, density and fineness modulus of the aggregates were specified following the tests methods described in ASTM and are shown in Table 2.

Table 2. *Physical and mechanical properties of aggregates*

Property	Fine aggregate	Coarse aggregate
Specific gravity	2.6	2.55
Fineness modules	3.1	-
Water absorption in percent	2	0.2
Maximum size in millimetre	-	25
Bulk density (kg/m^3)	1750	1597
Abrasion value in percent	-	26.43

2.3 Nano-silica

A cement paste is compound of small grains of hydrated calcium silicate gels, nano-sized particular pores, capillary pores, and large crystals of hydrated products. Thus, there should be room for nano-phase materials to fill the pores of the cement paste (Qing , 2001). Amorphous nano-scale silica, which is the main component of a pozzolan, reacts with calcium hydroxides formed by the hydration of calcium silicates. The rate of the pozzolanic reaction is coWWmmensurate with the value of the Blaine fineness (Qing et al., 2007). Thus, nano-SiO_2 was bought from WACKER chemical company (figure 1-a), and its main properties are shown in Table 3.

Fig. 1. *a) Nano SiO_2 b) silicafume*

Table 3. *Properties of nano-SiO2*

Properties	Characteristics
Surface area (m2/g)	200±30
SiO_2 content (percent)	>99.8
Tamped bulk density (g/l)	Approx. 40
Moisture (percent)	<1.5
Loss on ignition (percent)	<1.5
PH value (4% dispersion in water)	3.8 – 4.3
Al2O3 content (percent)	<0.05
Fe2O3 content (percent)	<0.005
TiO2 content (percent)	<0.003

2.4 Water-reducing admixture

In order to gain a consistency defined by slump values of between 4 and 5.5 cm, a superplasticiser was used, which guarantees compatibility with the cement and the mineral admixture used. The superplasticiser used is based on polymer dispersions. The properties of the superplasticiser used in the study were a pH of 7, a dark brown color, and a specific gravity (kg/Lit) of 1.19. the superplasticiser was purchase from NAMI KARAN chemical company.

2.5 Silica fume

The silica fume was in powder form with an average of 93% silicon dioxide (figure 1-b). The chemical composition and some physical characteristics of these materials are given in Table 4.

Table 4. *Properties of silica fume*

Chemical properties	Percent
SiO2	93.3
Al2O3	1.1
Fe2O3	0.85
CaO	1.2
MgO	1.1
Na_2O	0. 3
SO3	0.7
MgO	1.1
K_2O	0.7

Physical properties	Value
Colour	Gray
SiO_2 content (percent)	< 90
Moisture (percent)	< 3
Loss on ignition (percent)	< 2.5
Surface area (m2/g)	15 – 30
Particle size (μm)	< 1
Specific gravity (gr/cm^3)	2.2

3. Mix proportion

Concrete mixtures using different mix proportions and several combinations of silica fume and nano-SiO_2 were initially performed. Eight concrete mixes were optimised and used in the current study. Mixes contained 0.5 and 1 percent nano-SiO_2 and different proportions of silica fume (5 and 10 percent) by weight of cement. The details of these mixtures are given in Table 5.

The mixture is designed according to ACI-211-89 and concrete mixtures were mixed in accordance with ASTM C 192, in a 120 liter drum mixer. And workability of the fresh concrete was measured with a standard slump cone, Slump test Fulfilled according to ASTM C 143-90. Instantly after mixing, a slump of between 40 and 55 mm was obtained. The superplasticiser admixture was used in various amounts to maintain the workability of the fresh concrete.

Nano-particles and silica fume are not easy to distribute uniformly due to their high surface energy. Therefore, particles were stirred in water, and then they were added to the mixture.

Casting, compaction, and curing were accomplished according to ASTM C 192 -81. For each mix, cubic samples were tested to determine the compressive strengths at 7, 28 and 56 days of curing. The compressive strength for each mixture was obtained from an average of three cubic specimens. A 2000-kN capacity uniaxial compressive testing machine was used to test the specimens. The water absorption test according to ASTM C

642 was conducted at the end of the 42th day. The cube specimen was dried in an oven at a temperature of 110ºC for 48 h. After removing the specimen from the oven, it as allowed to cool in a desiccator and weighed. The specimen was then submerged in water for 72 h and the saturated surface dry (SSD) weight of the specimen was measured. Percentage of water absorption is the ratio of the difference between the weight of SSD sample after immersion and the weight of oven-dry sample to the weight of oven-dry sample.

4. Results and discussion

The findings of silica fume and Nano SiO_2 substitution as cement are shown in table 6. The average results obtained from the sample compression tests, broken at 7, 28 and 56 days, are shown in Fig 2. The compressive strength developed in concretes containing nano-SiO_2 and silica fume particles was higher than that of the control sample in every case. Although, nano-SiO_2 is used in modicum amounts in concrete, its impact is somehow similar to silica fume with high consumption measures. This fact, in turn, indicates the high pozzolanic activity of nano-SiO_2. The simultaneous impact of nano-SiO_2 and silica fume is more than that of each one. It can be due to either the size of particles that given the different grading of nano-SiO_2 and silica fume fills up all the concrete pores and results a condensed concrete, and the simultaneous pozzolanic influence of the two materials, adjacent to each other, which shows a better result. The most compressive strength was related to the samples possessing 10 percent of silica fume and 1 percent of nano-SiO_2 (CM10N1) in which about 42.2 percent of increase had in its strength. The pozzolanic impact of nano-SiO_2 on the compressive strength was more effective at early curing ages (7 days); while the pozzolanic properties of silica fume is more vivid in 28 day curing age. Which in turn causes the defect of concrete in all ages to be completely covered in the case of simultaneous use of the two materials.

The water absorption test was performed on all mixtures; the results on the 42th day of curing are shown in Fig. 2.

Figure 2 illustrates that adding nano-SiO_2 and silica fume to concrete leads to much lower water absorption compared to control concrete. The first cause of the decrease in the water absorption is the packing effect of small nano-SiO2 and silica fume acting as a filler to fill the interstitial spaces inside the skeleton of the hardened microstructure of concrete to increase its density. The second cause is the pozzolanic effect, which combines glass-like silicon elements in nano-SiO_2 and silica fume with the lime elements of calcium oxide and hydroxide in cement to increase the bonding strength and solid volume, resulting in a higher compressive strength and lower water absorption capacity of the concrete.

Because of high specific surface and extremely water absorption of nano SiO2 and silica fume, Slump values seem to decrease when using higher percentages of them, but these values were controlled by superplasticiser and all samples had a plastic consistency.

Table 5. *Concrete mixture proportions*

Properties	Mixture Name								
	C	CM5	CM10	CN0.5	CN1	CM5N0.5	CM10N0.5	CM5N1	CM10N1
Cement, (kg/m3)	320	304	288	318.4	315.2	302.4	286.4	300.8	284.8
Silica fume, (kg/m3)	0	16	32	0	0	16	32	16	32
Nano-SiO2, (kg/m3)	0	0	0	1.6	3.2	1.6	1.6	3.2	3.2
Water, (kg/m3)	160	160	160	160	160	160	160	160	160
W/C	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Sand, (kg/m3)	840	840	840	840	840	840	840	840	840
Coarse aggregate, (kg/m3)	1040	1040	1040	1040	1040	1040	1040	1040	1040
Superplasticiser, (%)	0.1	0.5	0.8	0.9	1.5	1.5	1.8	2.1	2.4

Table 6. *Physical and mechanical properties of concrete mixes*

Sample	Slump (mm)	Specific Wight (kg/m^3)	Water absorption (%)	Compressive strength (MPa)		
				7 days	28 days	56 days
C	5.5	2443	4.88	24.9	35.1	37.2
CM5	5	2447	4.61	26.7	41.5	44
CM10	5	2451	4.55	25.7	44.3	47.1
CN0.5	5	2444	4.67	30.4	38.2	40.4
CN1	4.5	2446	4.58	32.1	41.4	43.9
CM5N0.5	4.5	2450	4.4	32.7	45.7	48.6
CM5N1	4	2455	4.15	31.8	49.1	52.2
CM10N0.5	4	2457	4.07	34.8	48.7	51.5
CM10N1	4	2460	4.01	33.1	49.3	52.9

Fig. 2. *Compressive strength*

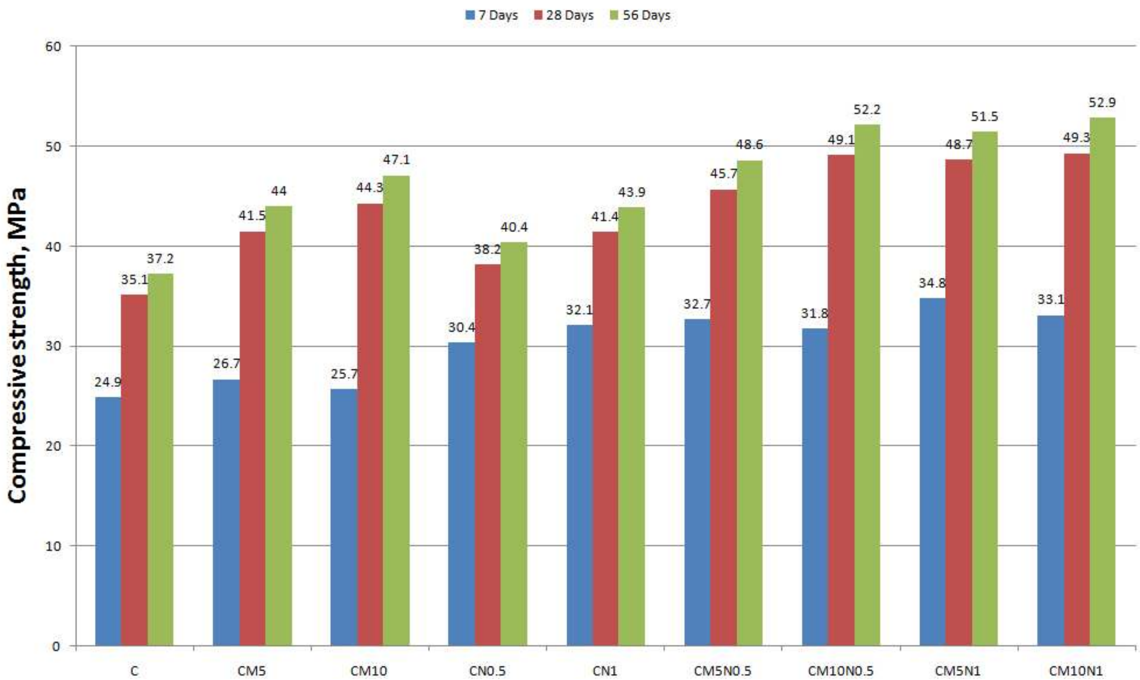
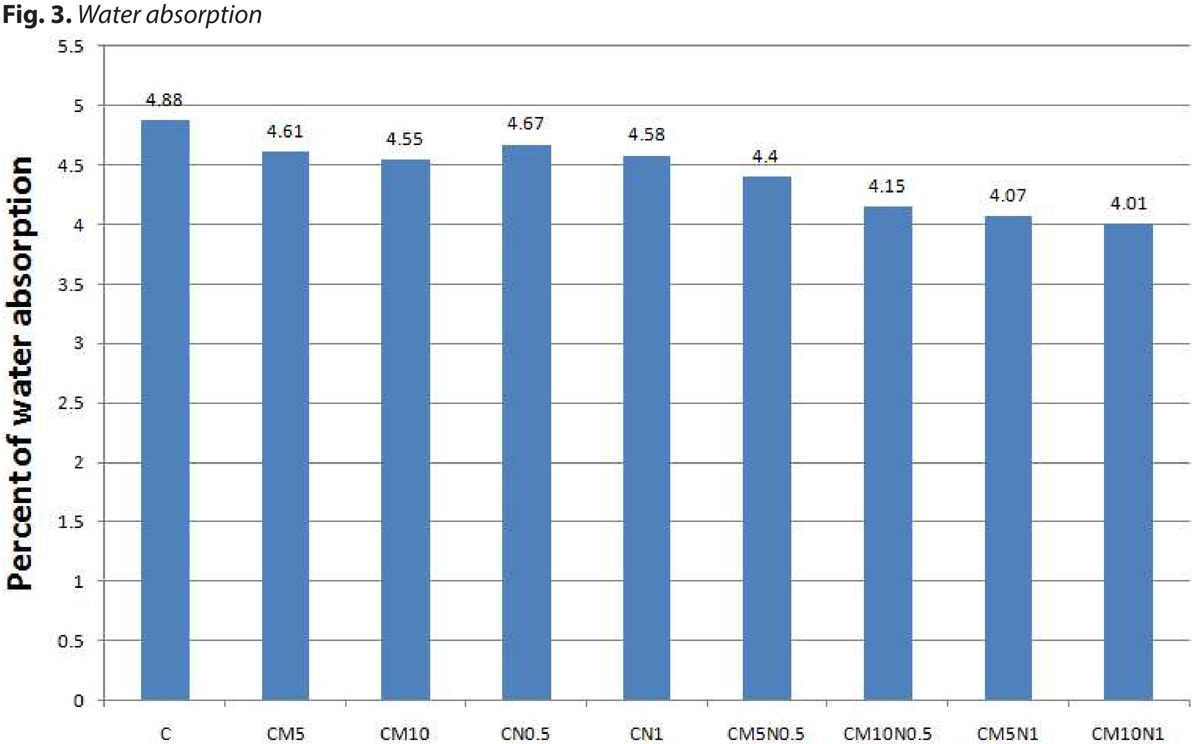


Fig. 3. *Water absorption*



5. Conclusions

The combination of silica fume with nano-SiO2 as a replacement for cement has been investigated in this study. The silica fume was used in quantities of 5 and 10 percent and nano-SiO_2 was 0.5 and 1 percent of the cement. The following conclusions can be drawn from the study:

- Silica fume and nano-SiO_2 can lead to the improvement of concrete strength. Moreover, given the less water absorption as a result of using these two materials, it can be maintained that these materials enhance the concrete durability in the long term.
- Nano-SiO_2 in low amounts can exert positive and desirable impacts on concrete. Therefore, the necessity to do further studies is strongly felt.
- the simultaneous use of silica fume and nano-SiO_2 increase noticeably the strength and durability of concrete compared with their single use, besides, in view of the two materials, influence process in the case of their simultaneous use in concrete, all defects of concrete in all ages will be covered and caused them to strengthen each other.

6. References

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