Research Article

The influence of silica fume, nano silica and mixing method on the strength and durability of concrete

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Abstract
The present work was accomplished to investigate silica fume (SF) and nano silica (NS) effects on the compressive strength (f_{cu28}) of concrete made by cement contents (CC) of 300, 400, 500 and 600 kg/m^3. Two NS types having purity of 89% (Type I) and 99% (Type II) were partially replaced CC by the percentages of 1.5% and 3%. The influence of replacing cement by 5% and 10% SF was also studied. Nano silica was mixed by two techniques, mechanically and by ultrasonic device. The influence of SF, NS and CC on f_{cu28} and water absorption (WA) was found. The obtained results indicated that f_{cu28} increased and WA% reduced by replacing part of CC by either NS or SF. For both of NS types, the enhancement ratio in f_{cu28} was higher when replacing cement by 1.5% NS compared to replacement ratio of 3% and both ratios recorded greater values of compressive strength when compared to that without NS. At 1.5% NS ratio, f_{cu28} increased by about 14.81% for type I and by 41.33 for type II while at 3% NS, the enhancement ratios were 5.86% for type I and 35.46 for type II respectively. Mixing Type I NS by ultrasonic mixing method recorded higher values for f_{cu28} as compared to those recorded by the mechanical method.

Keywords Nano silica · Silica fume · Concrete · Compressive strength · Water absorption · Ultrasonic

1 Introduction

Concrete is considered the most familiar construction materials around the world. The recent advance in concrete industry is to reduce cement content by using supplementary cementitious materials (SCMs). Adding the SCMs such as silica fume (SF), micro-silica (MS), slag or fly ash (FA) to concrete can improve its properties. Regarding to the physical and chemical effect of MS, the use of MS in concrete effectively improved its short and long term properties [1, 2].

Nowadays, utilization of mineral additives such as SF or FA has increased due to improvements in rheological, mechanical, durability and because of environmental concerns [3, 4]. When compared with type I OPC, SF shows particle two orders finer and highly pozzolanic reactive chemistry. However, the micro-level currently fails to provide enough visions into building materials so, Nano scale gaining increasing attention. The SiO_2 nanoparticles increased concrete strengths [5] and enhanced its resistance to WA [6]. Also, leakage of calcium related to concrete degradation is measured by the utilization of SiO_2 [7]. Nano silica (SiO_2) also accelerates the hydration of C_3S owing to extremely reactive surface of the nanoparticles [8]. Mechanical properties, Environmental resistance and durability of ordinary, geopolymer concrete and high performance concrete can be improved using NS [9–12].

The mechanical properties of basalt fiber reinforced mortar incorporating Silica fume was studied [13]. Silica fume (5%, 10%, and 15%) and basalt fiber (1%, 1.5%) contents was used. the obtained results indicated that, for basalt fiber specimens containing 0%, 1%, 1.5%, adding 5% SF leads to increase the compressive strength up to 23%, 37% and 12%, respectively. Also, adding 10% SF

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to 0% basalt fiber specimens increased the compressive strength of up to 40% and 20% compared to control and 5% SF respectively. For non-basalt fiber specimens, 15% silica fume obtained the higher strength.

The results obtained from [14] assured that Regardless of the W/CM ratio, concrete age or the replacement level, SF mixes have always exhibited a higher pozzolanic strength activity index compared to MK mixes. Moreover, The test results reported in [15] indicated that the replacement of cement by 0.5% NS and 0.75% NS increased the compressive strength by 14.2% and 20.5% for 7 days, 8.7% and 24.4% for 28 days and 8% and 18.1% for 90 days respectively over that of the control mix. Otherwise the strength decreased for specimens incorporating 1.5% NS, due to the agglomeration occurred by NS.

The mechanical strengths of concretes increased when adding NS. For specimens cured in water, 1% NS gave the maximum enhancement [16]. The influence of NS on the concrete strengths tested at 7, 28 and 90 days was discussed [17, 18]. In these works, cement content was partially substituted with 0%, 0.5%, 1%, 1.5% and 2% NS. They found that, for specimens cured in water, the peak compressive strength was obtained at 1% NS while specimens cured in saturated waterline showed compressive strength greater than that cured in water. The optimum amount of NS provided the peak strengths was 4% as illustrated in [19]. Zhang and Li [20] verified a growth in the compressive strength with adding NS. Also, concrete strength containing 1% NS was greater than that incorporating 3% NS. In the other hand, the combined of MS and NS addition increased the concrete compressive strength and elastic modulus than using NS or MS only. Moreover, the cementing efficiency factor of NS is significantly higher than that of MS [21].

Adding of NS by 1%, 2%, 3%, 4% and 5% and their effects on the WA% of SCC tested at 2, 3 and 28 days was studied [19]. The results displayed that adding 4% NS gave the lowest percentage of WA then 5%, 3%, 2% and 1% NS follow it. Some authors [19] showed that in plain cement concretes, adding NS up to 4% reduced WA while others reported 3% [22, 23] and 2% [16, 24].

From the previous studied related to the use of silica fume and nano silica it was assured that, Silica fume belongs to the category of highly pozzolanic materials as it consists of silica in non-crystalline form with particles of a high specific surface, and thus exhibits great pozzolanic activity [25]. Also nano silica acts as the micro-filler of the cement particles. The Nano materials can reduce the amount of water that filled the voids of the blending materials [26].

From the above researches, the effect of SF and NS for different cement contents, NS purity, time of curing and mixing technique on the concrete properties are still limited. In This paper is aimed to evaluate the concrete properties casted with different cement contents incorporating SCMs in micro scale and nano-scale. Cement contents of 300, 400, 500 and 600 kg/m^3 were used. Two NS types having purity of 89% (Type I) and 99% (Type II) are partially replaced cement content by the percentages of 1.5% and 3%. The influence of replacing cement by 5% and 10% SF was also studied. Nano silica was mixed by two techniques, mechanically and by ultrasonic device to study the effect of mixing techniques on the compressive strength. The influence of SF, NS and CC on water absorption (WA) was found.

2 Experimentation

In this paper, the properties measured were compressive strength and WA for 180 cubes tested at 28 or 56 days. Four values of CCs, 300, 400, 500 and 600 kg/m^3, were studied. The cement was partially replaced by two percentages of NS, 1.5% and 3%. NS was mixed by either mechanical method or ultrasonic method. The effect of replacing cement by 5% or 10% SF was also investigated. Superplasticizer was used for consistency adjustment. Trial mixes were prepared on the different investigated mixes to find the appropriate quantity of superplasticizer required for every mix to keep its slump value within the designed range of 80–100 mm.

2.1 Materials

Concrete cubes were casted using Ordinary Portland Cement (OPC) having a grade CEM I 42.5 N (BS EN 197-1/2000). Highly effective water-reducing agent (Sikament-163, supplied by Sika Egypt for construction chemicals) with synthetic type dispersion base and density equal 1.2 kg/l (ASTM C-494 Type A&F and BS 5075-3) was used. Two percentages of cement content (5 and 10%) were replaced by SF. The physical properties and chemical configuration of SF are listed in Table 1 as obtained from the manufacture sheet. Two kinds of Nano-SiO_2 (Type I and Type II) in powder form were examined in this study. The first type (Type I) was commercial. The second type of NS (Type II) was prepared in the Chemical Department, Faculty of Science, Zagazig University. Physical properties of Type I and Type II NS are found in Table 1. Natural sand and local natural dolomite of 14 mm NMS were used as fine and coarse aggregate respectively. Physical properties of aggregate are reported in Table 1. The grading of sand and dolomite were adjusted to follow the ACI recommendation as shown in Fig. 1.

Table 1 Properties of SF, NS and aggregate

Silica fume		
Property		Value
Specific surface area (cm^2/g)		2.73×10^3
Particle size (μm)		0.15
Bulk density (g/cm^3)		0.66
Specific gravity		2.15
Moisture		0.6%
Loss on ignition L.O.I		3.4%
Total silica content SiO_2		> 88.9%
Available alkali like Na_2O		< 0.5%
Free CaO		< 0.1%
Free SI		0.14%
Free Cl%		0.02%
H_2O		0.85%
Accelerated pozzolanic activity (7 days)		117
Nano silica		
Properties	Type I	Type II
Appearance	Powder form	Powder form
Colour	(White)	(White)
Particle size	≈ 18 nm	≈ 18 nm
Density (25 °C)	2.2–2.6 g/mL	2.2–2.6 g/mL
Molecular	SiO_2	SiO_2
Purity	89.0%	99.0%
Aggregate		
Properties	Sand	Dolomite
Specific gravity (Gs)	2.57	2.63
Compacted density (g/cm^3)	1.73	1.72
Loss density (g/cm^3)	1.581	1.54
Void%	32.6%	34.0%
Angularity no.	–	≈ 2

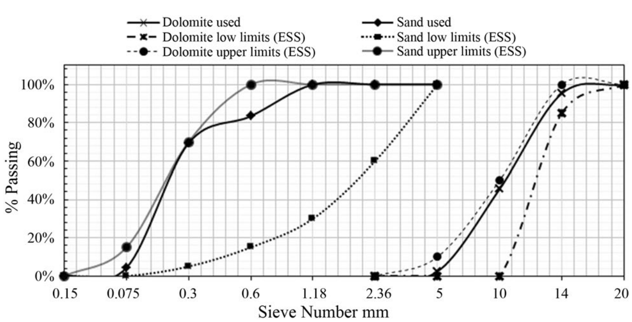

Fig. 1 Grading curves of the used aggregates

2.2 Mix design and mixing procedures

The design of all mixtures was achieved to follow ACI method. Required quantities for concrete constituents' materials to produce a cubic meter for each mix are scheduled in Table 2.

The legend of specimen refers to content of CM (3 for 300 kg/m^3 and 4 for 400 kg/m^3 and so) followed by NS percent (N-%) then SF percent (S-%) and in ultrasonic method the samples names tailed by letter (U). The mixtures code for second type of NS samples tailed by letter (T). For example: (5N3.0S0T) is the code for samples containing cementitious materials = 500 kg/m^3, NS = 3.0%, SF = 0 and T is the code for NS type II.

Drum mixer was used in order to mix concrete constituents and NS mechanically (mechanical method). Coarse aggregate, sand, cement and NS were mixed during 2 min in dry form. Then 50% of mixing water enclosing the total quantity of SP was combined and mixed till 3 min. After that, about 1 min rest was allowed and finally the remaining water was added inside the mixture and mixed during

Table 2 Materials required producing 1 m³ from different investigated mixes

Mix code	Materials (kg/m³)						
	CC	Dolomite	Sand	Water content	NS	SF	SP
3N0.0S00	300	1020	716	212	Nil	0	0
3N0.0S05	285					15	0
3N0.0S10	270					30	0
4N0.0S00	400		635			0	0
4N0.0S05	380					20	0.68
4N0.0S10	360					40	1.32
5N0.0S00	500		544			0	1.35
5N0.0S05	475					25	1.45
5N0.0S10	450					50	2.15
6N0.0S00	600		472			0	1.36
6N0.0S05	570					30	2.16
6N0.0S10	540					60	2.64
3N1.5S00	295.5		716		4.5	Nil	0.25
3N3.0S00	291				9.0		0.25
4N1.5S00	394		635		6.0		0.28
4N3.0S00	388				12.0		0.28
5N1.5S00	492.5		544		7.5		0.66
5N3.0S00	485				15		0.66
6N1.5S00	591		472		9.0		1.20
6N3.0S00	582				18		1.20
4N1.5S0U	394		635		6.0		0.28
4N3.0S0U	388				12.0		0.28
5N1.5S0U	492.5		544		7.5		0.66
5N3.0S0U	485				15		0.66
6N1.5S0U	591		472		9.0		1.20
6N3.0S0U	582				18		1.20
4N1.5S0T	394		635		6.0		0.28
4N3.0S0T	388				12.0		0.28
5N1.5S0T	492.5		544		7.5		0.66
5N3.0S0T	485				15		0.66
6N1.5S0T	591		472		9.0		1.20
6N3.0S0T	582				18		1.20

Table 3 Technical data for used sonotrode

Sonotrode	Micro Tip S7
Max. submerged depth (mm)	90
Tip diameter (mm)	7
Max. amplitude (μm)	175
Acoustic power density (W/cm²)	300

1 min. For mixing by ultrasonic method, NS with half mixing water was mixed using Hielscher ultrasonic UP200 mixer with 90-W power input for 5 min at ¾ cycles and for 5 min at 1 cycle. The technical data for the used sonotrode is listed Tables 3.

The slump test was conducted according to BS 1881-102. It is clear that the measured slump values for all investigated mixes are within the range from 80 to 100 mm. The fresh concrete was cast in cubes of 100 mm side length and stored at room temperature till 24 h. After being de-molded the cubes were cured using water at 20 ± 1 °C for 28 days. The concrete samples were removed from curing tank at the specified testing age and any deposits on the specimens faces were removed before testing.

2.3 Test procedures for hardened concrete

Cube specimens 100 mm side length was prepared to evaluate the compressive strength (BS 1881-116). The cured cubes were tested after 28 and 56 days of curing (Three cubes for each mix). Also, WA test was performed at 28 days according to ASTM C 642-06 by draying cube samples in oven at a temperature of 100–110 °C for 24 h and then weighted (W_1). After that, the samples were immersed inside water for 48 h followed by drying their surface and then weighted again (W_2). The WA% was implemented as follows:

$$WA\% = \left(\left(W_2 - W_1\right)/W_1\right) * 100$$

3 Results and discussion

The compression test results measured at 28 and 56 days (f_{cu28} and f_{cu56}) and WA test results measured at 28 days for the cubes are found in Table 4.

3.1 Fresh properties of NS concrete

In general, all slump values are ranged between 80 and 100 mm for all investigated mixes. As NS percentage increases, the superplasticizer dosage was increased to regulate the slump of mixture. The results are agreed with those reported in [6, 27, 28]. It is detected that mixes containing high content of SF required also high SP dosages. The high demand of superplasticizer with the concrete containing SF may be accredited to its very fine particle that acts as micro-filler of the cement particles. This may lessen the water that fill the blending materials voids and thus causes some of the SP being absorbed on its surface [29, 30].

Table 4 Slump test, compressive strength and water absorption results

Mix code	Cementations material, CM (kg/m^3)			f_{cu28} (MPa)	Enhancement (%)	f_{cu56} (MPa)	f_{cu56}/f_{cu28} * 100	WA%
	CC	SF	NS					
3N0.0S00	300	0	0	27.00	–	31.00	114.81	6.21
3N0.0S05	285	15		32.00	18.52	33.00	122.22	6.08
3N0.0S10	270	30		31.00	14.81	32.17	119.15	5.28
3N1.5S00	295.5	0	4.5	31.00	14.81	33.00	122.22	5.15
3N3.0S00	291		9.0	28.00	3.70	32.00	118.52	4.48
4N0.0S00	400	0	0	34.67	–	38.00	109.60	4.67
4N0.0S05	380	20		40.00	15.37	46.67	134.61	4.49
4N0.0S10	360	40		38.33	10.56	45.00	129.80	4.21
4N1.5S00	394	0	6.0	38.00	9.60	40.00	115.37	3.85
4N3.0S00	388		12.0	35.50	2.39	38.50	111.05	3.34
4N1.5S0U	394		6.0	40.00	15.37			
4N3.0S0U	388		12	36.70	5.86			
4N1.5S0T	394		6.0	49.00	41.33			
4N3.0S0T	388		12	47.00	35.56			
5N0.0S00	500	0	0	47.50	–	51.00	107.37	3.57
5N0.0S05	475	25		53.00	11.58	55.67	117.20	3.14
5N0.0S10	450	50		51.33	8.06	54.00	113.68	3.53
5N1.5S00	492.5	0	7.5	50.80	6.95	53.50	112.63	3.19
5N3.0S00	485		15	48.50	2.11	51.50	108.42	3.02
5N1.5S0U	492.5		7.5	51.00	7.37			
5N3.0S0U	485		15	50.00	5.26			
5N1.5S0T	492.5		7.5	55.50	16.84			
5N3.0S0T	485		15	53.00	11.58			
6N0.0S00	0	0	0	52.70	–	56.00	106.26	3.34
6N0.0S05	570	30		58.00	10.06	60.67	115.12	3.05
6N0.0S10	540	60		56.00	6.26	58.00	110.06	3.26
6N1.5S00	591	0	9.0	55.00	4.36	58.67	111.33	2.87
6N3.0S00	582		18.0	53.70	1.90	56.50	107.21	2.55
6N1.5S0U	591		9.0	56.50	7.21			
6N3.0S0U	582		18	55.00	4.36			
6N1.5S0T	591		9.0	60.00	13.85			
6N3.0S0T	582		18	59.00	11.95			

$$\text{Enhancement}\% = \frac{f_{cu}\ \textit{with CMs} - f_{cu28}\ \textit{without CMs}}{f_{cu28}\ \textit{without CMs}} \times 100$$

3.2 Compressive strength results

3.2.1 Concrete incorporating SF and Type I NS

The effect of CC on the compressive strength measured at 28 and 56 days (f_{cu28} and f_{cu56}) is cleared in Fig. 2. The figure illustrates that f_{cu28} increased by about 28.4% with increasing CC from 300 to 400 kg/m^3. The enhancement in f_{cu28} with increasing CC to 500 kg/m^3 is 37% compared to concrete with CC of 400 kg/m^3. By increasing CC from 500 to 600 kg/m^3, f_{cu28} enhanced by about 11% (Fig. 2a). At 56 days, f_{cu56} increased as the cement content increased (Fig. 2b). The ultimate improvement in f_{cu56} was about 14.81% recoded at cement content of 300 kg/m^3 as the testing age increased from 28 days to 56 days. The concrete strength improvement ratio increased as testing age increased while it decreased when CC increased (see Table 4).

Figure 3 shows SF effects on f_{cu28} and f_{cu56} of concrete made with CMs of 300, 400, 500 and 600 kg/m^3 respectively. In general, it is clear that, replacement of CC by SF enhanced f_{cu28} for different CMs contents (see Fig. 3a). The maximum enhancement was observed at SF% equals 5%, after that f_{cu28} decreased but still greater than that of the control mix (SF = 0). Silica fume increases the concrete properties by two ways: first, its small particles act as filler for the spaces between cement and aggregates particles. Second, SF reacts with CH to produce a greater solid volume of C–S–H gel, tends to an additional reduction in capillary porosity during hydration [31, 32]. Herein, the maximum f_{cu28} was recorded for concrete having 5% SF partially replaced instead of CC. This result is matched with Nili and Ehsani [33]. Also, Youm et al. [34] found that 3.5% SF gave the maximum f_{cu28} compared to 7% SF for both normal and light-weight aggregate concretes. For concrete incorporating SF and tested after 56 days, f_{cu56} increased in a similar manner to that of f_{cu28} (Fig. 3b) but with higher enhancement ratios than those of f_{cu28}. A high improvement ratio of f_{cu56} was 34.61% at CMs of 400 kg/m^3 (Cubes 4N0.0S05, SF = 5%). The enhancement ratio of f_{cu56} increased as the CMs (Cement + SF) increased from 300 to 400 kg/m^3 then decreased after words (see Table 4).

Figure 4 shows the impact of Type I NS (1.5% and 3%) on f_{cu28} and f_{cu56} for concrete made with different CCs (300, 400, 500, 600 kg/m^3). The figure clearly indicate that spare of cement by 1.5% NS enhanced f_{cu28} at the different CCs.

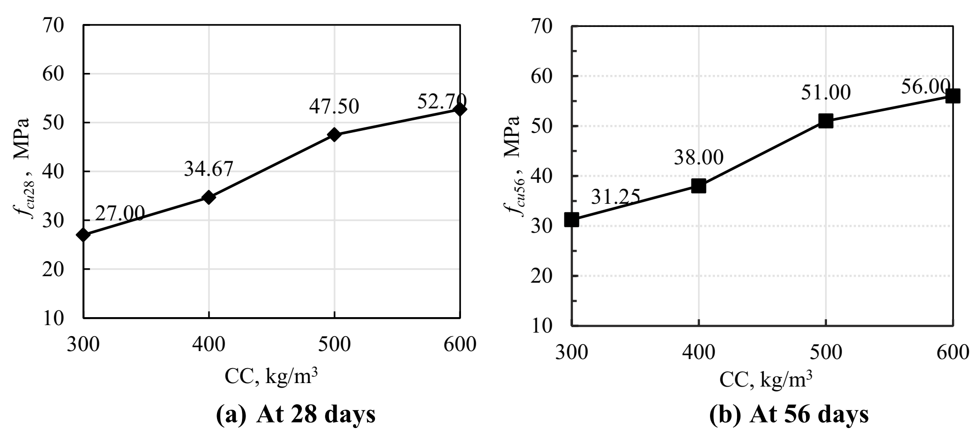

Fig. 2 Effect of CC on f_{cu28} and f_{cu56}

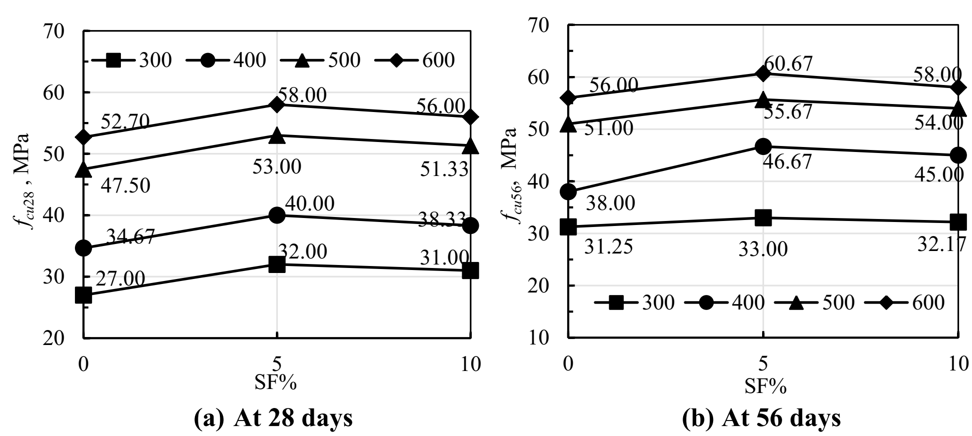

Fig. 3 Effect of SF% on concrete strength with different CMs

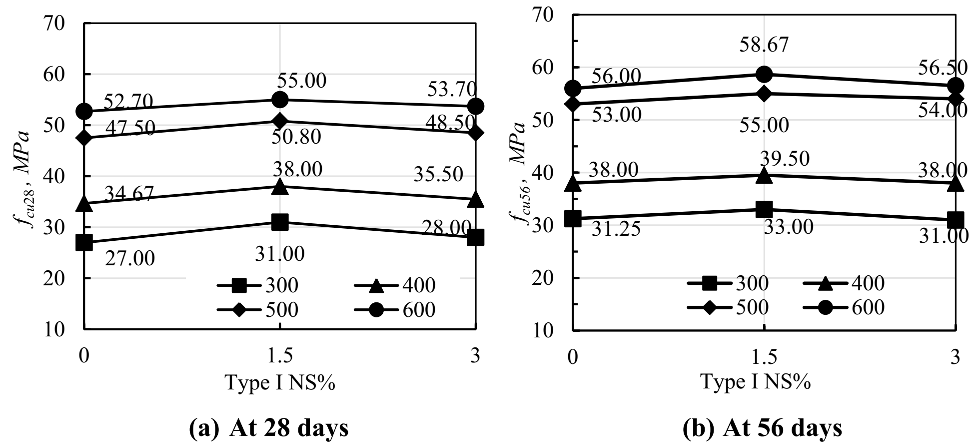

Fig. 4 Effect of Type I NS on concrete strength concrete strength with different CMs

This can be attributed to the reaction of silica with calcium hydroxide (pozzolanic reaction) resulted from cement hydration besides the formation of C–S–H gel. Also, the high specific surface of NS enables it to make very well [7, 8, 11].

On increasing NS from 1.5 to 3%, f_{cu28} decreased but it still greater than the control mix compressive strength (NS = 0), (Fig. 3a). Givi et al. [35] recorded a rise in concrete strength with adding NS till 1.5% replacement and after that it decreased. This was explained as follows: as the quantity of SiO_2 nano-particles added to the mix is greater than that needed to syndicate with the liberated lime through the hydration process, the extra silica, which does not contribute to concrete strength, replaces portion of the CMs materials and thus decreased the strength. When the NS percentage is large, the weak zone in concrete increases then f_{cu} decreases. This decrease is owing to the agglomeration and defects generated in dispersion of NS particles [8, 11].

The 56 days compressive strength, f_{cu56}, of concrete incorporating type I NS increased in a similar manner to that of f_{cu28} (Fig. 3b) with higher improvement ratios than those of f_{cu28}. A high improvement ratio of f_{cu56}/f_{cu28} of about 22.22% was recorded for concrete containing CMs of 300 kg/m^3 (Cubes 3N1.5S00, NS = 1.5%). The improvement ratio of f_{cu56} reduced as the CMs (Cement + NS) increased (see Table 4).

3.2.2 Concrete incorporating Type II NS

This type was included to investigate its influence on the concrete strength having CMs of 400, 500 and 600 kg/m^3 and tested 28 days later. As shown in Fig. 5, the maximum value for f_{cu28} was attained at 1.5% NS partially added instead of CC. As the NS ratio increased to 3%, f_{cu28} decreased but still greater than f_{cu28} of control mix (NS = 0) for the different CCs. Based on the results illustrated in Figs. 4 and 6, a comparison between f_{cu28} of concrete

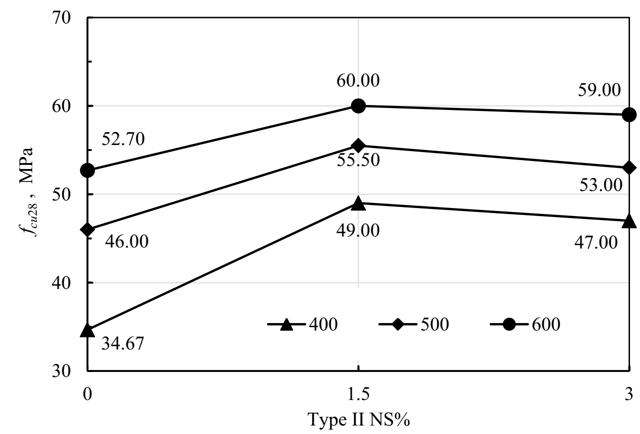

Fig. 5 Effect of Type II NS% on f_{cu28} of concrete made with different CMs

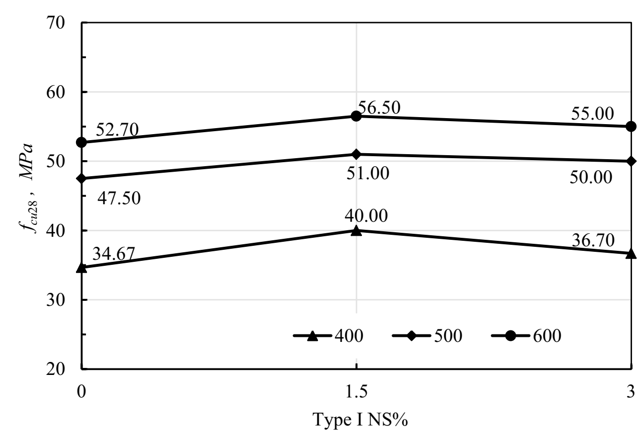

Fig. 6 Effect of CMs on f_{cu28} of concrete containing Type I NS% mixed by ultrasonic method

mixes containing 1.5% and 3% NS for Type I and Type II NS will be held. From the figures, it is clear that Type II NS (high purity) showed greater values of f_{cu28} for all NS%

investigated. For example at CMs equals 400 kg/m^3, with the utilization of Type II NS, f_{cu28} was 29% and 32% higher than those of Type I NS at NS equals 1.5% and 3% respectively. These percentages of enhancement in f_{cu28} with the usage of Type II NS decreased to about 9.5% as the CMs increased to 500 and 600 kg/m^3. The purity of silica in Type II NS is around 99% (wt%) leads to increasing f_{cu28}.

3.2.3 Influence of mixing method for NS

In this section, the results concerning to ultrasonic technique effects to disperse Type I NS in water were assessed and likened to traditional method. This mixing method was applied on concrete mixes having CMs of 400, 500 and 600 kg/m^3 and tested 28 days later. Figure 6 shows Type I NS effects (1.5% and 3%) mixed by ultrasonic method on f_{cu28}. The maximum f_{cu28} was recorded at 1.5% NS. After increasing NS amount to 3%, f_{cu28} decreased but still greater than the control mix strength at the different CCs. However, NS have great surface area with high surface energies; agglomeration would appear at high ratios of the added powder, which prevents uniform distribution of NS particles within the mortar [36].

The mixing effects by mechanical and ultra-sonication on f_{cu28} of concrete containing 1.5% and 3% Type I NS partially added instead of CC at different CMs can be compared using the results reported in the two figures (Figs. 4a, 6). It is clear that the ultrasonic mixing method does not show a significant improvement on f_{cu28} for different CMs (maximum of about 5%). As stated above, owing to their extremely small particle sizes, NS particles formed agglomeration easily and uniform dispersion is hampered. This result agreed with that reported in [36]. It was found that f_{cu28} of sonicated mortars reduced by 5–10% compared to mortars prepared by mechanical mixing.

3.3 Water absorption

Figure 7 shows CC effects (300, 400, 500 and 600 kg/m^3) on WA% of concrete at SF = 0 and NS = 0 tested 28 days later. It is clear that with increasing CC, WA% decreased with a decreasing rate. Using 400 kg/m^3 CC in concrete decreased WA% by about 24.8% compared to concrete containing 300 kg/m^3 CC. By increasing CC to 500 kg/m^3, WA% decreased by about 23.6% compared to 400 kg/m^3 CC. Rising CC from 500 to 600 kg/m^3 decreased WA from 3.57 to 3.34 with reduction percentage of about 6.4%.

The SF partially replaced CC and their effect on WA% is demonstrated in Fig. 8. Silica fume improved concrete resistance for WA as its clear from the figure. This is because SF has finer particles and creates concrete further denser [28]. In general, SF decreasing pore size thus reduced WA [37]. The highest reduction in WA% for concrete containing

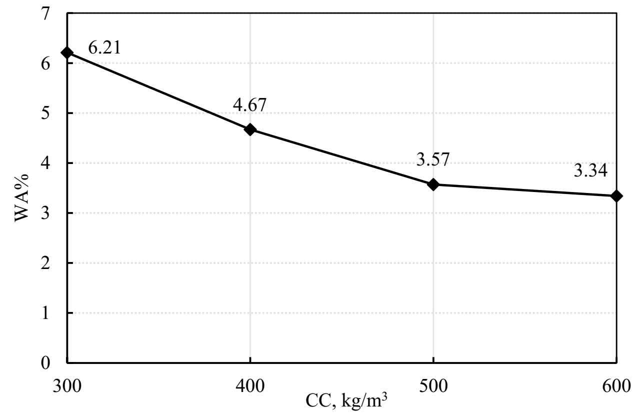

Fig. 7 Effect of CCs on WA% of concrete without SCMs

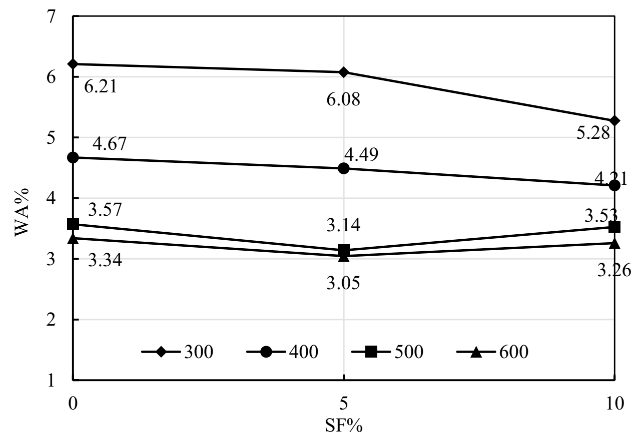

Fig. 8 Effect of SF% on WA% of concretes containing different CMs

300 and 400 kg/m^3 was recorded at 10% SF. After rising CM to 500 and 600 kg/m^3, the highest reduction in WA% was observed at 5% SF. This may be owing to agglomeration which appears at high ratios of SF, which prevents uniform distribution of particles within the matrix.

Figure 9 shows the type I NS effect (1.5% and 3.0%) on WA% of concrete made with different CCs at 28 days. Using NS in general improved concrete resistance to WA. As particles of NS were finer than cement particles it fills the cement paste spaces and replace amount of CH by C–S–H leading to upgrading the interface of structure. Therefore, the permeability of the concrete would decreased by Nano particles reducing the pores at Nano level [38].

From Fig. 9, it is clear that, the reduction in WA increases as NS increases to 3%. This may be because NS can plays as a nucleus to tightly bond with C–S–H gel particles. Thus, the concrete durability during long-term may be increased as NS improved the hydration stability [39]. They stated that with increasing NS till 4%, the total specific pore volumes of concretes decreased, and the voids diameters of

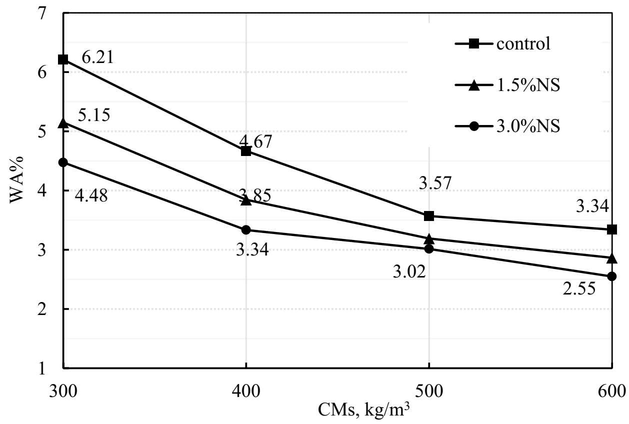

Fig. 9 Effect of type I NS% on WA% of concretes at different CMs content

concrete becomes smaller. As reported in [40], increasing content of NS, the voids inside concrete is decreased. The space among nanoparticles reduces with increasing content of nanoparticles. Owing to the those limited spaces among particles, the growth of $Ca(OH)_2$ crystal decreased thus decreasing the cement paste shrinkage.

4 Conclusion

In this paper, the strength and WA of concrete were studied. Concrete casted with cement contents, 300, 400, 500 and 600 kg/m^3 were studied. The effect of SF with two percentages (5% and 10%) and two types of NS with two percentages (1.5% and 3%) as partially replacement materials instead of cement was also studied. Two methods (mechanical method and ultrasonic method) were chosen to mix the NS. The results of the present experimental work support the following conclusions:

1. Concrete mixes containing higher SF content tended to require high amounts of SP. As the NS amount increased, the required amount of SP increased to regulate the slump of mixture.
2. When the CC was partially substituted by 5% SF, f_{cu28} of concrete at different CCs was enhanced to maximum (18.52% over that without NS). On increasing this ratio to 10%, f_{cu28} decreased compared to that at 5% SF but it is still greater than the concrete strength without SF. An extreme improvement ratio of f_{cu56} was 34.61% at CMs of 400 kg/m^3 (SF = 5%). The improvement ratio f_{cu56} increased as the CMs (Cement +SF) increased from 300 to 400 kg/m^3 and after that it decreased.
3. The concrete strength increased as NS exists. The full improvement ratio in f_{cu28} was obtained at 1.5% NS (14.81% for type I and 41.33 for type II over that without NS). As this ratio increased to 3%, the enhancement ratio decreased but still higher than the concrete strength without NS (5.86% for type I and 35.46 for type II over that without NS). For f_{cu56} of concrete incorporating type I NS, A determined improvement ratio of f_{cu56} was 22.22% at CMs of 300 kg/m^3. The improvement ratio of f_{cu56} reduced as the CMs increased.
4. Mixing NS by ultrasonic method improved f_{cu28} by about 3.46% and 5.77% when compared with the mechanical technique for the two Type I NS dosages of 1.5% and 3% respectively.
5. Water absorptions of concrete reduced as Type I NS or SF exists. The highest reduction in WA for concrete containing CMs of 300 and 400 kg/m^3 was recorded at 10% SF. Increasing CMs to 500 and 600 kg/m^3, the highest reduction in WA was recorded at 5% SF. Moreover, using Type I NS in concrete by 1.5% and 3.0% instead of cement enhanced concrete resistance to WA and the percentage reduction increased by increasing NS to 3%.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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