E3S Web of Conferences **184**, 01076 (2020) https://doi.org/10.1051/e3sconf/202018401076
ICMED 2020

Performance evaluation of nano-silica concrete

Kakara S J Kumar[1], *M V* Seshagiri Rao[2], *V Srinivasa* Reddy[3], *S* Shrihari[4]

[1]Research Scholar of Civil Engineering, JNTUH CEH, Hyderabad.
[2]Ex-Professor, JNTUH CEH and Professor, CVR College of Engineering, Hyderabad
[3]Professor, Department of Civil Engineering, GRIET, Hyderabad. Email id: vempada@gmail.com
[4] Professor, Department of Civil Engineering, VJIT, Hyderabad.

Abstract. In this paper, the study of the influence of nano-silica (nano-SiO_2) on the properties of the interface between CSH gel and cement particles and its effect on nano-mechanical properties of the products at the interface zone was examined. In this paper M50 grade SCC mixes were developed using 5% micro-silica and various percentages of 0.5%, 1.0% and 1.5% nano-SiO_2. For 1.0% nano-SiO_2 addition to M50 grade SCC mix, the compressive strength is maximum. Similarly concrete quality using non-destructive techniques, water absorbtion capacity and porosity are also assessed.

1 Introduction

Concrete is a composite material consisting of many phases in micro and macro scale level. It is strong due to the heterogeneous nature acquired due to (1) interfacial transition zone between aggregate and matrix, (2) interaction between sand and paste matrix and (3) collaboration among CSH gel, large crystals of $Ca(OH)_2$, unhydrated cement particles and pores formed due to high w/c ratio. Interface between coarse aggregate, fine aggregate and cement paste is understood well with micro observational studies but the phase between the unhydrated cement grains and CSH gel was not been explored effectively especially in concretes with high w/c ratio due to availability of high amount of unhydrated cement particles. To enable a uniform distribution of nano-SiO_2 in paste, colloidal nano-SiO_2 (CNS) was used instead of nano-SiO_2 powder. The SiO_2 content of CNS was larger than 99% by weight, and the pH value was 11.

2 Micro-silica and Nano-silica

Nanosilica demonstration that presence of nanoparticles in cement increases the CSH gel chain length thereby increasing the stiffness of CSH. This highly stiff CSH prevents calcium leaching mechanism improving the durability of concrete.

Micro-silica and nano-silica conforms to IS 15388:2003. Micro-silica and nano-silica falls under category of Silica fume. The tables below physical and chemical properties of micro-silica and nano-silica. Silica fume is available in the form of micro-silica and nano-silica. Micro-silica is about 100 times smaller than cement size whereas nano-silica is about 1000 times smaller than cement.

Table 1. Physical Characteristics of Colloidal Nanosilica

Property	Value
Average Particle size(nm)	21
Density(g/cm3)	2.3
Molar Mass(g/mol)	59.30
Melting Point(◦c)	1620
Boiling Point(◦c)	2325
Specific gravity(g/cm3)	1.11
Specific Surface(m2/g)	139
Active nano silica content	35-40%
pH	9.3-9.6
Texture	Milky White Liquid

Table 2. Chemical Composition of Nanosilica

Oxides	SiO2	C	MgO	CaO	Al2O3	FeO	TiO2	L.O.I
% by Weight	99.90	-	-	-	-	-	-	2.9

Table 3. Physical properties of Microsilica

S.No	Property	Limits	Value
1	>45 micron	Maximum 10%	0.55
2	Pozzolanic Activity Index	Minimum 105%	134
3	Sp. Surface	Min.15m2/g	19.5
4	Bulk Density	500-700 kg/m3	630

Table 4. Chemical properties of Microsilica

S.No	Property	Limits	Value
1	SiO2	Min.85.0%	90.5
2	Moisture Content	Max.3.0%	0.63
3	Loss of Ignition	Max.6.0%	1.24

Micro-silica mainly acts as a filler densely packing the voids created by the CSH gel and un-hydrated cement particles. Due to the presence of high reactive silica in micro-silica which reacts with calcium hydroxide to form additional hydrates which adds to the strength and stiffness of the concrete. Nano-silica has higher pozzolanic reactivity than micro-silica and also helps in lowering the water demand and reduces the capillary pores due to improved particle packing and developed intermolecular forces which may make concrete little stiff to work with. Due to addition of micro-silica there is decrease in setting times of the cement paste this reduction is observed more when nano-silica is used.
The objective of the present work is to evaluate performance of nano-silica in self-compacting concrete (SCC) of M50 grade. Nan Su mix design principles are adopted to arrive at the quantities required for M50 grade SCC.

3 Effect of dosage of nano-SiO_2

To quantify the amount of nano-SiO_2 to be used in concrete, it is admixed with cement mortar cubes and tested for compressive strength. The amount of Nano-SiO_2 added are 0.5%, 1.0% and 1.5% by weight of the cement.

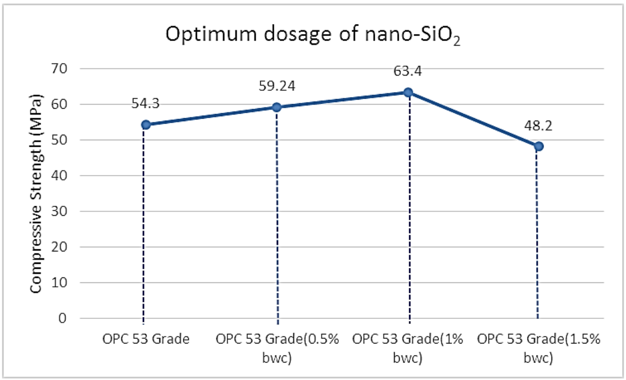

Fig. 1. Optimum dosage of nano-SiO_2

For 1% addition of nano-SiO_2 by weight of cement, the strengths obtained in cement mortar cubes is maximum so for further examinations this is considered as the optimum percentage of nano-SiO_2 is adopted.

4 Effect of nano-SiO_2 on setting times

Table below presents the effect of nano-SiO_2 on setting times of cement mortars. With the addition of nano-SiO_2 to the cement decreases the setting times.

5 Consistency

A flow table test was conducted as per IS 5512-1983 to determine the flow for the nano-SiO_2 admixed mortars.

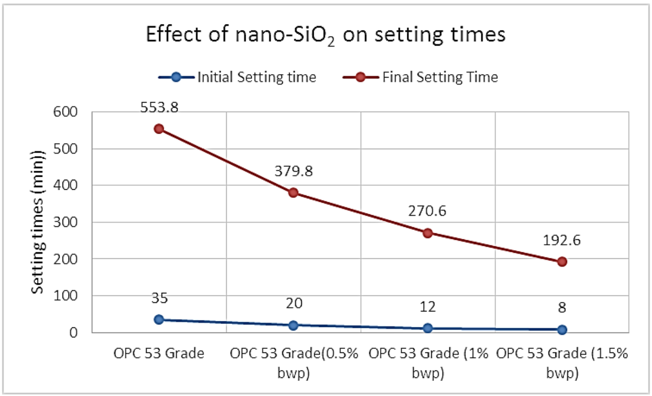

Fig. 2. Effect of nano-SiO_2 on setting times

 https://doi.org/10.1051/e3sconf/202018401076

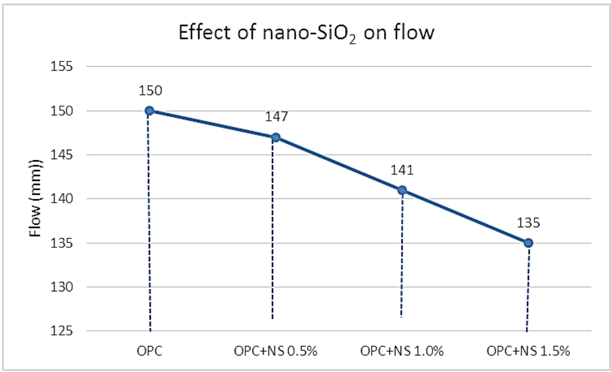

Fig. 3. Effect of nano-SiO_2 on flow

As the percentage of nano-SiO_2 was increased in mortar specimens there is a gradual increase in consistency was noted due to improved homogeneity of the cement matrix in nano-SiO_2 admixed cementitous materials. The initial setting time of nano-SiO_2 mixed samples drastically decreased due to the ultra-fine size of nano silica particles.

6 Mix quantities

Super plasticizers and mix quantities are revised subjected to satisfaction of flow properties as per EFNARC Guidelines. 5% Microsilica is added to attain the desired compressive strength.
Based on the Nan-Su mix design the quantities that are obtained for M50 grade is listed below:

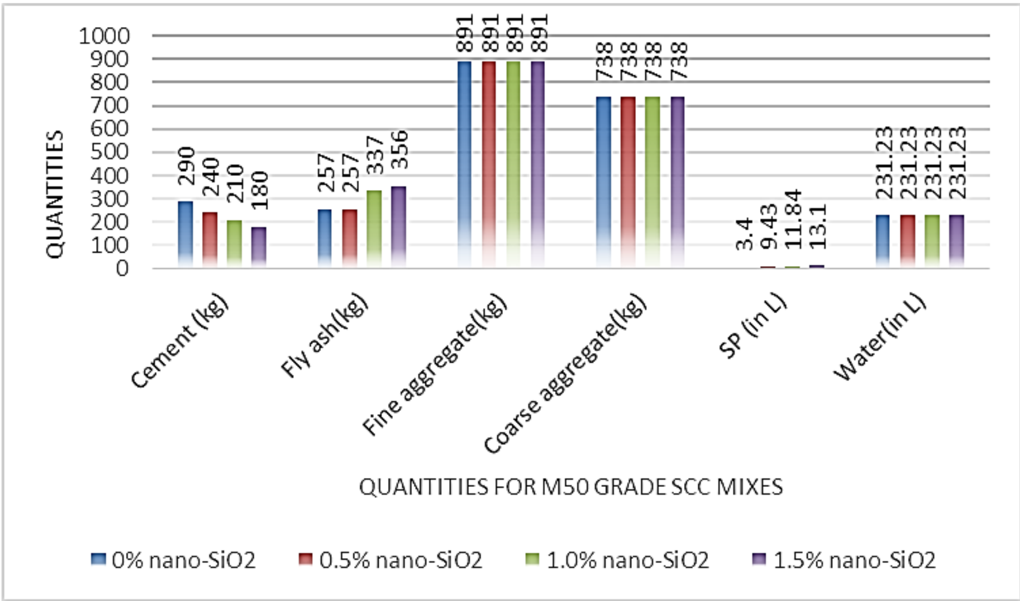

Fig. 4. Effect of nano-SiO_2 on flow consistency

7 Fresh properties on SCC as per EFNARC guidelines

The following table presents the various workability tests based on EFNARC guidelines

Table 5. Fresh properties on SCC as per EFNARC guidelines

Workability Tests	0% Nano-SiO_2	0.5% Nano-SiO_2	1.0% Nano-SiO_2	1.5% Nano-SiO_2
Slump flow (mm)	635	657	653	630
J ring(mm)	3.1	5.2	5.3	4.2
V funnel(Sec)	8.3	11	9	5.3
L box	0.98	0.82	0.82	0.81

8 Compressive strengths of nano-SiO_2 SCC mixes

The following table presents the compressive strengths of nano-SiO_2 SCC mixes mixed with various dosages of nano-silica. Compressive strength found to be more for 1.0% addition of nano-SiO_2. The percentage of nano silica is restricted to 1% due to workability issues. This seems to be controlled by the particle size distribution and the high specific surface area of nano-SiO_2 in the presence of poly-carboxylate (PCE based) superplasticizer. With a further increase in nano-SiO_2 content, the pozzolanic reaction and the resulting hydrated products formation increases, but along also increases the micro-cracking caused by the self-desiccation effect, resulting in harmfully disturbing its strength development.

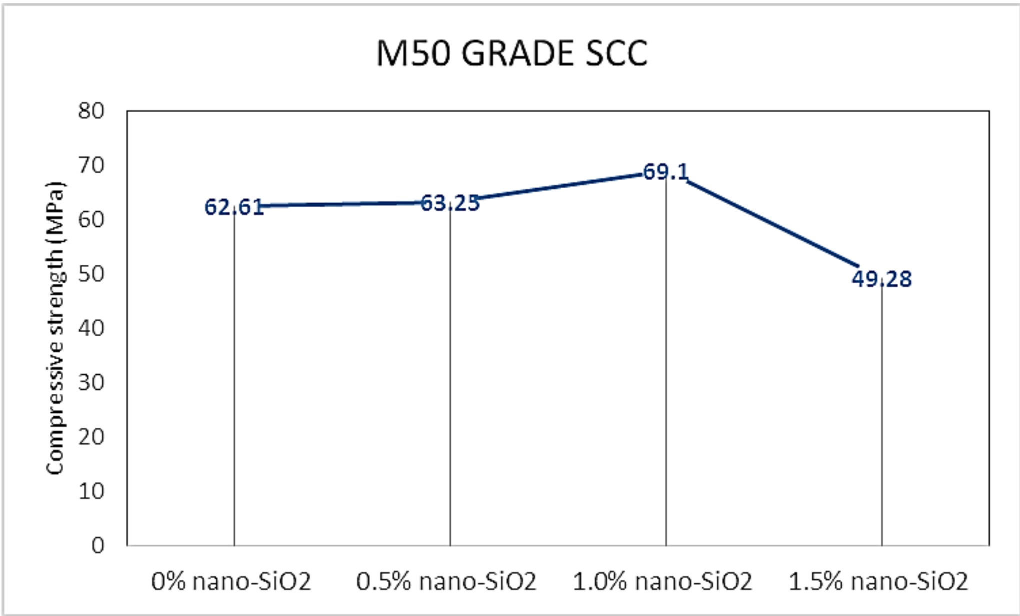

Fig. 4. Effect of nano-SiO_2 on compressive strength

9 Rebound hammer and Ultrasonic pulse velocity tests

Fly ash has very low initial pozzolanic reactivity, but this activity considerably amplified after incorporating a small percentage of nano-SiO_2. The use of fly ash creates a highly porous structure at early days of curing but inclusion of nano-SiO_2 creates a more condensed microstructures, even during early ages of 1-3 days due to positive effect of nucleation of nano-silica. The following table presents the quality of M50 grade SCC made with 1.0% addition of nano-SiO_2 based on combined rebound hammer and ultrasonic pulse velocity tests.

Table 6. Rebound hammer and Ultrasonic Pulse Velocity Tests
Combined Rebound hammer and Ultrasonic Pulse Velocity values

	M50 grade reference SC				M50 grade nano-silica based SCC			
Age in days	Mean Rebound Number	Mean Pulse Velocity km/sec	Compressive Strength (f ck) N/mm2	Quality of Concrete	Mean Rebound Number	Mean Pulse Velocity km/sec	Compressive Strength (f ck) N/mm2	Quality of Concrete
28	41	4.89	62.61	Excellent	48	5.22	74.21	Excellent
60	43	4.92	69.26	Excellent	51	5.36	82.92	Excellent
90	44	4.99	73.59	Excellent	53	5.41	88.63	Excellent

Rebound numbers obtained indicate the superior surface hardness than reference SCC and also the USPV measurements were greater than 4.5km/sec which denotes that nano-silica based SCC is classified as excellent concretes in terms of strength and durability point of view due to improved pore structure of concrete.

10 Water absorbtion capacity and porosity

Usage of nano-silica will accelerate the hydration process resulting in additional hydration products due reaction with portlandite formed during 1-3 days of curing. So the microstructure of concrete is densified due to both filler and pozzolanic effect particularly at the interface between aggregate and cement paste and between unhydrated cement grains and hydrated products forming a homogeneous and uniform structure. Distribution of pores are refined and their size is reduced drastically. The pozzolanic activity of nano-SiO2 is superior to that of micro-silica because nano-silica consumes more CH crystals reducing the size and orientation of CH crystals at the interface.

Figure below presents the water absorbtion capacity and porosity of M50 grade SCC made with 1.0% addition of nano-SiO_2.

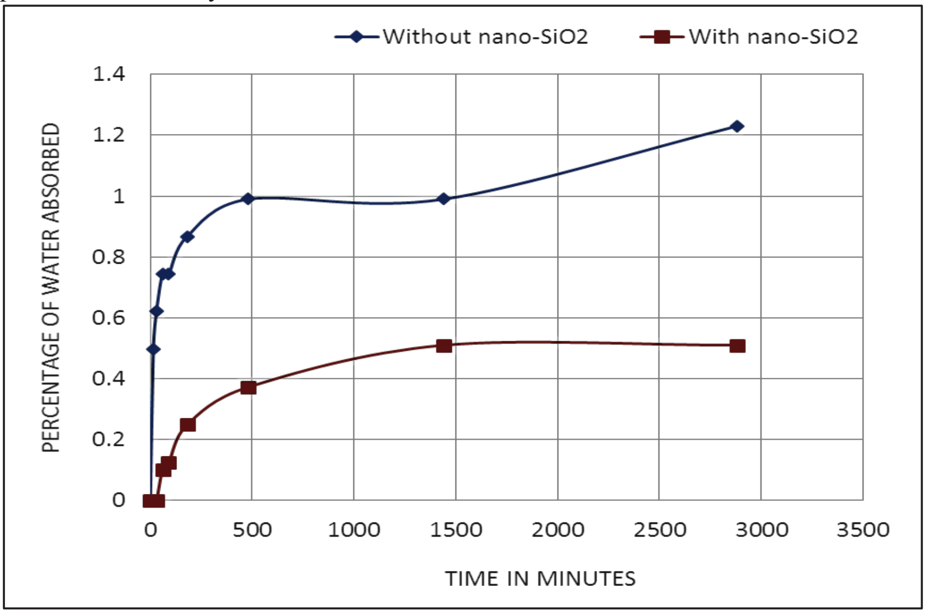

Fig. 5. Water absorbtion capacity and Porosity

Table 7. Permeation properties of Nano-SiO_2 mixed M50 grade SCC mix

Parameter	0% Nano-SiO_2	1.0% Nano-SiO_2
Water absorption capacity (%)	1.03	0.498
Volume of permeable voids (%)	2.655	0.32
Apparent porosity (%)	4.347	0.98

11 Cost Involved

Table 7 presents the costs involved in the development of Nano-SiO_2 mixed M50 grade SCC.

Cost of Nano-SiO_2 mixed M50 grade SCC mix

	M50 SCC	Cost Rs	M50 SCC with 1% Nano-SiO2	Cost Rs
Cement (kg/m3)	290	1885	210	1365
fly ash(kg/m3)	257	514	257	514
Microsilica (kg/m3)	27.4	602.8	--	--
Nanosilica(kg/m3)	--	--	5.5	550
Fine aggregate (kg/m3)	891	1603.8	891	1603.8
Coarse aggregate (kg/m3)	738	516.6	738	516.6
Water (L)	231.23	0	231.23	0
Superplasticizer (L)	3.4	136	11.8	473.6
	Cost of M50 SCC	**5258.20**	Cost of nano-SiO_2 mixed M50 grade SCC	**5183.00**

Cement - Rs 6.5/kg; Fly ash- Rs 2/kg; Microsilica- Rs 22/kg; Nano-silica- Rs 100/kg; River Sand- Rs 1.8/kg; Coarse aggregate- Rs 0.70/kg; Water- Rs 0/kg; Superplasticizer- Rs 40/kg (Based on available market prices)

12 Conclusions

The following conclusions are established based on the test results obtained-

1. The optimum percentage of Nano-silica to be used in M50 grade SCC is determined to be 1% by weight of total powder.
2. Due to addition of nano-silica, the initial and final setting times of Nano-silica based cementitious materials are observed to be reduced.
3. Due to enhanced pore refinement due to Nano-silica, the compressive strength for 1% Nano-silica based SCC is nearly 30% more than that of plain SCC mix in 28 days.
4. The addition of Nano silica improves the hydrated structure of concrete by modifying the concrete pore structure by plugging the voids /or the nano pores within cement–sand matrix by nano-silica particles. The nano particles act as a filler to improve the density of concrete, which leads to the porosity of concrete reduced considerably.
5. Nano particles can not only act as an activator to accelerate cement hydration due to their high activity, but also makes the size of calcium hydroxide crystal smaller. Nano-SiO_2 will absorb the calcium hydroxide crystals, and reduce the size and amount of the calcium hydroxide crystals, thus making the dense interfacial transition zone between the aggregates and binder paste matrix. This enhances the compressive strength due to rapid consumption of calcium hydroxide which formed during the hydration of cement especially at the early age due to high reactivity of nano-silica.

References

1. Said, A. M., Zeidan, M. S., Bassuoni, M. T., & Tian, Y. (2012). Properties of concrete incorporating nano-silica. Construction and Building Materials, 36, 838-844.
2. Mondal, Paramita, Surendra P. Shah, Laurence D. Marks, and Juan J. Gaitero. "Comparative study of the effects of microsilica and nanosilica in concrete." Transportation Research Record 2141, no. 1 (2010): 6-9.
3. Nili, M., A. Ehsani, and K. Shabani. "Influence of nano-SiO2 and micro-silica on concrete performance." In Proceedings Second International Conference on Sustainable Construction Materials and Technologies, pp. 1-5. 2010.
4. Du, Hongjian, Suhuan Du, and Xuemei Liu. "Durability performances of concrete with nano-silica." Construction and building materials 73 (2014): 705-712.
5. Quercia, G., and H. J. H. Brouwers. "Application of nano-silica (nS) in concrete mixtures." In 8th fib International Ph. D. Symposium in Civil Engineering. Lyngby, vol. 20, no. 1, pp. 431-436. 2010.
6. Tummala Suresh Kumar, Kosaraju Satyanarayana, Materials Today: Proceeding, 26 (2), 3228-3233, (2020).
7. Maheswaran, S., B. Bhuvaneshwari, G. S. Palani, R. Nagesh, and S. Kalaiselvam. "An overview on the influence of nano silica in concrete and a research initiative." Research Journal of Recent Sciences, ISSN2277 (2013): 2502.