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Assessment of the effect of Nano-SiO_2 on physical and mechanical properties of self-compacting concrete containing rice husk ash

A. Sadrmomtazi[1*], A. Barzegar[2]

[1,2]*Department of Civil Engineering, University of Guilan, P.O. Box 3756, Rasht, Iran*

[1*]*Corresponding Author*, Tel.:+98 131 727 0725, Fax: +98 131 727 0725, *E-mail address*: sadrmomtazi@yahoo.com
[2]Tel:+98 911 325 0675, *E-mail address*: civileng.2008@yahoo.com

ABSTRACT
In recent years, nanotechnology has attracted considerable scientific interest due to the new potential uses of particles in nanometer scale. This paper presents the results of experimental investigation on the effect of nano-sio2 on properties of self-compacting concrete with and without rice husk ash (RHA). Accordingly all the mixtures were designed with the constant water/binder ratio of 0.43 and a total binder content of 450 kg/m^3. Fresh properties of the SCCs were tested for slump flow diameter, L-box height ratio, and V-funnel flow time. Furthermore, the hardened properties of the concretes including compressive and flexural strength at 7, 28 and 60 days were determined. Also water absorption values and drying shrinkage of specimens were measured. The results show that the inclusion of Nano-SiO_2 in SCC improves the physical and mechanical properties and unfavorable effect of RHA on shrinkage of these concretes.

Key words: Self Compacting Concrete, Nano-SiO_2, Rice Husk Ash, Mechanical Strength, Shrinkage

INTRODUCTION

Due to Nano scale size of particles and very high pozzolanic activity, Nano-particles show unique physical and chemical properties; that help us to fabricate new building materials with some outstanding properties [Lau]. [Li G] found that Nano-SiO2 by filling the pores between large fly ash and cement particles at Nanoscale, could significantly increase the compressive strength of concretes containing large volume fly ash, at early age and improve pore size distribution. Moreover it has been found that when the Nano-SiO_2 particles uniformly disperse in the paste due to their high activity generate a large number of nucleation sites for the precipitation of the hydration products which accelerate cement hydration[Li Hui]. Nano-silica decreased the setting time of mortar when compared with silica fume (SF) [Qing] and reduced bleeding water and segregation, while improving the cohesiveness of the mixtures in the fresh state [Collepardi]. Rice husk ash (RHA) as the rice waste material is a by-product of the rice milling process. It is not just a cheap alternative but a well burn and a well-ground RHA with most of its silica in an amorphous form and with enough specific surface is active and can improve the strength and durability of concrete [Yu]. Published reports regarding the effect of Nano-SiO_2 on characteristics of self-compacting concrete (SCC) are scarce. Accordingly in latter research Nano-SiO_2 particles were incorporated into SCC with and without RHA and properties of these composites were investigated.

MATERIALS PROPERTIES

Cement. In this research ordinary Portland cement type I was applied with specific surface 3415 cm2/g and specific gravity 3.15gr/cm^3. Chemical composition of ordinary cement is reported in Table 1.

Table 1. Chemical composition raw material

materials	SiO_2	AL_2O_3	Fe_2O_3	CaO	MgO	SO_3	L.O.I
Cement	21	4.6	3.2	64.5	2	2.9	1.5
RH	92.1	0.41	0.21	0.41	0.45	-	-

Rice husk ash. Rice husk ash (RHA) as the rice waste material is a by-product of the rice milling process. When subjected to combustion, almost 20% of the husk becomes ash with a porous cellular structure, a high specific surface (50–100 m2/g) and high silica content [Gemma]. Also, RHA can improve the strength and durability of concrete. RHA used in this experiment contained 92.1% SiO_2 with average size of 15.83 µm and specific gravity 2.09 gr/cm^3. Chemical ingredients of RHA were given in Table 1.

Fine aggregate. The fine aggregates consisted of river sand with maximum size of 4.75 mm, with a modulus of fineness 2.97; normal grading. Specific gravity was 2.52, and absorption capacity was 1.4%.

Coarse aggregate. Coarse aggregate is from river gravel with a maximum size of 12.5 mm and normal continuous grading. The specific gravity of the coarse aggregates was 2.7, absorption value was 1.01%. The sieve analyses of the fine and coarse aggregates are confirmed to ASTM-C33.

Nano-SiO_2. A cement paste is composed of small grains of hydrated calcium silicate gels, Nano-sized individual pores, capillary pores, and large crystals of hydrated products. Therefore, for filling the pores of the cement paste, there should be room for Nano-scale materials [Byung-Wan]. The Nano-SiO_2 used was of liquid form with 99.9% SiO2, a particle size of 50 nm, density of 1.03 g/cm ^{3} and PH value of 10.

Superplasticizer. A modified polycarboxylate based superplasticizer with a relative density of 1.055±0.01g/cm³ was incorporated into all mixes. The content was adjusted for each mix to ensure that the slump flow diameter would fix.

MIX PROPORTIONS

Details of mix proportions for concretes containing rice husk ash and Nano-SiO_2 are given in Table 2 in which the mixtures were designated according to the type of cementitious materials included.

Table 2. Concrete mix quantities (kg/m^3)

Mix ID.	W/B[a]	Water	PC	RH	Gravel	Sand	Nano-SiO_2	SP
Control SCC	0.43	195	450	-	770	850	-	8
RH	0.43	195	360	90	770	850	-	10.7
NSRH	0.43	195	346.5	90	770	850	13.5	12.1
NS	0.43	195	418.5	-	770	850	31.5	10.2

a: Binder (The sum of cement, rice husk ash and Nano-sio2)

The water–binder ratio was 0.43 and the total binder content was 450 kg/m3, where the binder weight was considered the total weight of cement, RHA and Nano-SiO_2. The slump flow diameter of all mixtures was kept constant at about 69 ±2 cm by using the superplasticizer at varying amounts. The amount of RHA substitute in concrete was 20% by weight of cement. The replacement contents of cement by Nano-sio_2 particles for concrete with and without rice husk ash were 3% and 7% weight of cement, respectively [Sadrmomtazi].

TEST PROCEDURE

Nano-particles due to their high surface energy are not easy to disperse uniformly. Accordingly, mixing sequence was as follows:

- The superplastisizer was dissolved in water and then the Nanoparticles were added and stirred at high speed.

- the sand and gravel were place in the mixer and start the mixer.
- Then the cementitious materials were added to the mixer and stirred for 1 min.
- The mixing water was slowly added and mixed for 2 min.
- Mixing was continued for 5 min; the mixer stopped for 3 min, and then continued mixing for an additional 2 min.

Upon completion of mixing, place the fresh concrete into the molds to form the cubes of size 10×10×10 cm for all mixing proportion for compressive strength and water absorption tests and prisms of size 10×10×45 cm for flexural strength and shrinkage tests. After 24 hours, the specimens were demoulded and cured in water with 22±2°C until required for testing.

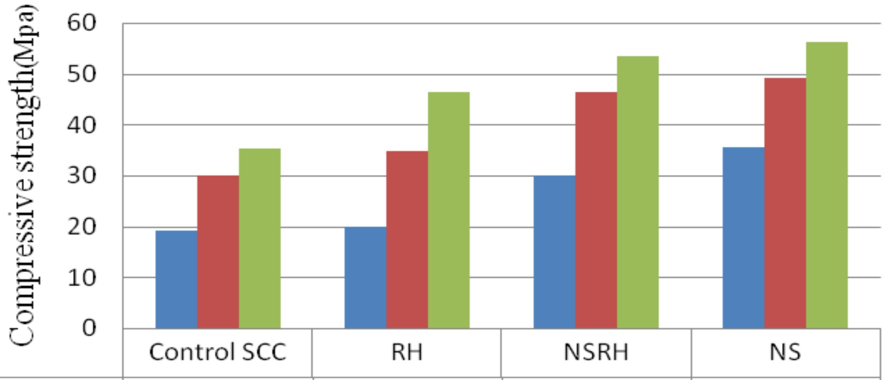
For the evaluation of fluidity of mixes, the testing for slump flow (cm), time required to flow through V-funnel (s) and filling height ratio of L-box test has been conducted immediately after the mixing of the concrete, according to the procedure recommended by EFNARC committee [EFNARC]. The results of workability tests are given in Table 3. Incorporating RHA or Nano-SiO_2 in concrete generally made the samples more viscous. But in performing the workability tests, the authors did not observe any segregation or blockage.

Table 3. The results of workability and water absorption tests

Mix ID.	Slump flow D(cm)	L-box H_2/H_1	V-funnel flow time(s)	Water absorption (%)
Control SCC	71	0.93	4.50	6.20
RH	69	0.90	6.70	5.33
NSRH	67	0.86	9.40	4.31
NS	69	0.87	7.80	3.82

RESULTS AND DISCUSSIONS

Compressive strength. The Compressive strengths after 7, 28 and 60 days are shown in Fig. 1. It can be seen that the compressive strength was developed in concretes containing Nano-SiO_2 particles in every case higher than the specimens of without that. The difference in the strength development of the mixtures can be imputed to pozzolanic reaction. By addition of Nano-SiO_2, the increment percentages of compressive strength in control SCC are about 86%, from 19.1 to 35.6 Mpa, at 7 days, 64%, from 30 to 49.2 Mpa, at 28 days and about 58%, from 35.4 to 56.1 Mpa, at 60 days. Whereas, compared with RH mix, the strengths of NSRH mix increased by 51%, 34% and 15% at ages of 7 day, 28 days and 60 days, respectively. According to the results above, it is concluded that the addition of Nano-SiO_2 has a greater effect on strength of control SCC than SCC containing RHA. Also, it can be observed that the Nano-SiO_2 particles are more beneficial in providing strengthening than rice husk ash. Strength enhancement of Nano-SiO_2 can be attributed to reduction in the content of $Ca(OH)_2$ which has not any cementing property and production of hydrated calcium silicate (CSH) that plays a vital role in mechanical properties of concrete. Therefore, in this procedure, the Nano-SiO_2 admixture can be

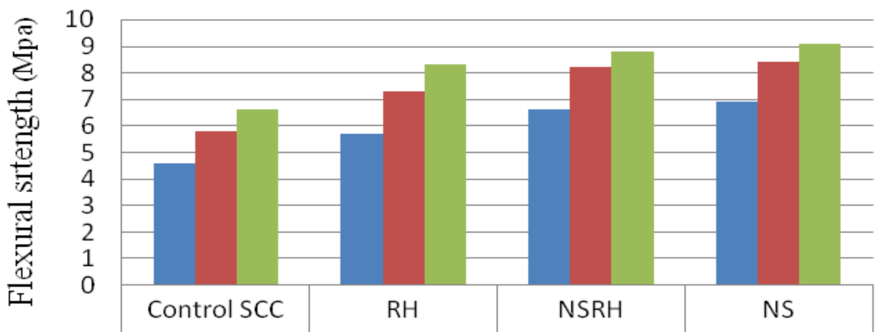


	Control SCC	RH	NSRH	NS
7 days	19.1	19.9	30	35.6
28 days	30	34.8	46.5	49.2
60 days	35.4	46.5	53.5	56.1

Fig.1. Compressive strength of all mixes

filled among the cement particles to make hardened concrete compact and to improve the interface structure and performance [Byung-Wan]. Compared with the results of RH mix, the early age compressive strength of rice husk ash was significantly increased when 3% Nano-SiO_2 was added. Fig. 1 shows that the addition of 3% Nano-SiO_2 increased the 7-day compressive strength by about 51%. It also increased the strength at the later ages. This indicates that NSRH can achieve adequate early compressive strength while maintaining a high long-term strength. Also, the NS mix, 63% of the 60-day compressive strength has obtained at the age of 7 days.

Flexural strength. Fig. 2 shows the strength gain of the concretes between 7 and 60 days. Similarly to the compressive strengths of samples, the flexural strengths of all



	Control SCC	RH	NSRH	NS
7 days	4.6	5.7	6.6	6.9
28 days	5.8	7.3	8.2	8.4
60 days	6.6	8.3	8.8	9.1

Fig.2. Flexural strength of all mixes

specimens containing 7% Nano-sio$_2$ (NS mix) were obviously higher than other mixtures. So that, at the ages of 7, 28 and 60 days flexural strengths of NS mix were, respectively, 6.9, 8.4 and 9.1 Mpa and were, respectively, 21%, 15% and 10% higher than that of RH mix, and 4.5%, 2.4% and 3.4% higher than that of NSRH mix. Both Nano-SiO$_2$ and RH belong to pozzolanic materials, however results showed that the pozzolanic activity of Nano-SiO$_2$ was much greater than that of RH. A possible reason for this observation could be nucleation effect. Nano-SiO$_2$ due to its high specific surface serves additional nucleation sites for precipitation of the hydration products whereby chemical reactions are accelerated [Isaia]. Moreover it has been suggested that the surface of pozzolan can adsorb many Ca^{+2} ions and that lowering of the concentration of the calcium ions accelerates the rate of dissolution of C_3 S that increases the rate of hydration [Zelic]. Owing to the higher specific surface of Nano particles they adsorb more Ca^{+2} ions and accelerate the rate of hydration more effectively.

Drying shrinkage. Shrinkage is a common phenomenon generally encountered in almost every cementitious product due to contraction of total mass upon loss of moisture. It is sometimes accompanied by development of cracks especially in such members whose surface area to volume ratio is large [Rao]. These cracks serve as conduits for salt and water. The saline solution comes in contact with reinforcing steel and promotes corrosion. Corrosion causes expansion of steel and inevitably pop-outs occur in the concrete cover, Thereby reducing the strength and service life of the concrete [Toutanji Houssam]. In Fig. 3, drying shrinkage of all mixtures is plotted against time. The specimens were cured in temperature of 27±3 $^{\circ}C$ and the relative humidity 70%. The strains were taken using a length comparator with a precision of 2μm and at the ages of 3, 7, 14, 21, 28, 35 and 42 days.

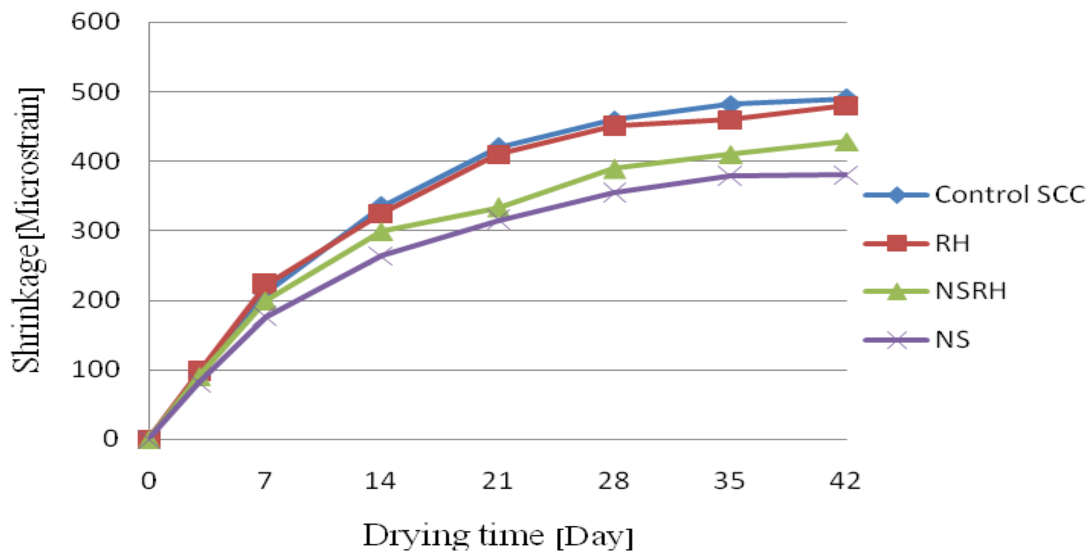


Fig.3. Drying shrinkage of all mixes versus time

As seen in Fig. 3 that the shrinkage values yielded approximately comparable values at early ages of drying period. However, an obvious distinction was observed for different concretes after about seven days. Considering the shrinkage values revealed that NS mix and Control SCC experienced the lowest and highest shrinkage strain. Also, from the results, it can be seen the shrinkage values of RH mix have insignificant difference with Control SCC. The use of Nano-SiO_2 within RH mix decreases its drying shrinkage values. For example, at 42 days, the shrinkage strain of RH mix was 0.048% in comparison with 0.0428% for NSRH mix.

Water absorption. The water absorption values of samples at the curing age of 28 days were listed in Table 3. The absorption characteristics indirectly represent the porosity through an understanding of the permeable pore volume and its connectivity [Tanaka]. The test results summarized in Table 3 clearly show that the inclusion of Nano-SiO_2 and rice husk ash in specimens can improve considerably the resistance of water penetration of concrete. So that, the absorption amount of mixture RH decreased by 5.33% compared to 6.2% for the Control SCC. Also, the incorporation of Nano-SiO_2 in Control SCC and RH mixes reduced the water absorption from 6.2% to 3.82% and from 5.33% to 4.31%, respectively. This impenetrability increase can be attributed to two attendant phenomena:
1. Nano-SiO_2 particles generate a large number of nucleation sites for hydration products and induce a more homogenous distribution of C-S-H and hence less pore structure [Ji Tao].
2. Nano-SiO_2 particles block the passages connecting capillary pores and water channels in cement paste [Benachour].

CONCLUSIONS

This study experimentally evaluated the influence of Nano-SiO_2 on physical and mechanical properties of self-compacting concrete with and without rice husk ash. The following conclusions can be drawn from this study:

- Incorporating RHA or Nano-SiO_2 in concrete generally made the samples more viscous. Therefore, for decrement of viscosity should applied more superplasticizer amounts.
- The results show that the inclusion of Nano-SiO_2 in concrete mixture makes cement paste thicker and accelerates the cement hydration process and mainly affects short-term strength of concrete.
- Nano-SiO_2 additive by filling pores lead to a densification of the concrete internal structure and considerable increment in compressive and flexural strength of Control SCC and RH mixes.
- Using of Nano-SiO_2 reduced significantly the drying shrinkage of the SCCs. But the shrinkage values of RH mix had little difference with Control SCC. The Nano-SiO_2 additive improves unfavorable effect of rice hush ash on concrete shrinkage.

- After 28 days, the least and most value of absorption belongs to NS mix by 3.82% and Control SCC by 6.2%, respectively. So the Nano-SiO_2 particles are more effective in reduction of permeability than that of RHA.
- Adding of Nano-SiO_2 particles improves the physical and mechanical properties of self-compacting concrete.

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