BRCORP
TECHNOLOGY | INNOVATION | INDUSTRY

International Journal of
Advanced Structures and Geotechnical Engineering
ISSN 2319-5347, Vol. 03, No. 02, April 2014

Optimization of fully replacement of natural sand by M-sand in high performance concrete with nanosilica

A. JAYARAMAN, V. SENTHIL KUMAR
Department of Civil Engineering Bannari Amman Institute of Technology, Sathamangalam, Tamil Nadu, India
Email: jayaraman.cvl@gmail.com

Abstract: In recent days the demand for river sand is increasing due to its lesser availability. Hence the practice of replacing river sand with M-Sand is taking a tremendous growth. It is also inferred from the literature that replacement of normal sand with M-Sand produces no appreciable increase in compressive strength due to the variation in the pore size of concrete at micro level. This paper presents the optimization of fully replacement of manufactured sand by natural sand with nano silica in high performance concrete. The ordinary Portland cement is partially replaced with nano-silica by 0.75% and natural sand is fully replaced with manufactured sand. The studies reveal that the increase in percentage of partial replacement of nano silica increased the compressive, tensile and flexural strength of concrete.

Keywords: *Compressive Strength, Flexural Strength, Manufacturing Sand, Nano Silica, Tensile Strength*

I. Introduction:

The huge quantity of concrete is consumed by construction industry all over the world. In India, the conventional concrete is produced using natural sand from river beds as fine aggregate. Decreasing natural resources poses the environmental problem and hence government restriction on sand quarrying resulted in scarcity and significant increase in its cost. Normally particles are not present in river sand up to required quantity. Digging sand, from river bed in excess quantity is hazardous to environment. The deep pits dug in the river bed, affects the ground water level. In order to fulfill the requirement of fine aggregate, some alternative material must be found. The cheapest and the easiest way of getting substitute for natural sand is obtained from limestone quarries, lateritic sand and crushing natural stone quarries is known as manufactured sand. Concrete made with limestone filler as replacement of natural sand in concrete can attain more or less same compressive strength, tensile strength, permeability, modulus of rupture and lower degree of shrinkage as the control concrete [(1)]. Concrete using various combinations of lateritic sand and quarry dust as complete replacement for conventional river sand. The result is found better workability and high compressive strength [(2)]. Concrete is the most commonly used material for construction and their design consumes almost the total cement production in the world. The use of large quantities of cement produces increasing CO_2 emissions, and as a consequence the green house effect. A method to reduce the cement content in concrete mixes is the use of silica fines. One of the silica fines with high potential as cement replacement and as concrete additive is nano-silica (nS). However, the commercial nS are synthesized in a rather complex way, resulting in high purity and complex processes that make them non-feasible for the construction industry. It includes the nS production process, their addition effect and their application in concrete. The 6% microsilica and 1.5% nanosilica as partial replacements of cement, improved compressive strength and electrical resistance and also diminished capillary absorption of the concrete specimens seriously [(3)]. Nano Silica is one such nano material which has shown to enhance the overall high performance of concrete. Incorporation of nano silica at smaller volume fractions has shown to result in higher compressive and flexural strengths at early ages, improved hydration characteristics and reduced porosity and water absorption when compared with conventional cementitious materials. The impacts of other nano materials such as CNTs, nano TiO_2, nano Al_2O_3 and nano TiO on concrete are also promising. While nano materials acts as fillers and provide nucleation sites for cement hydration, nano SiO_2 also acts as a pozzolanic material, increasing the amount of stiff CSH within the hydrated cement paste, resulting an improved microstructure .The concrete produced with 10% micro- SiO_2 and 2% nano- SiO_2 show higher degree of quality in their compressive strength, less water absorption and more electrical resistance in comparison with the others [(4)]. The ordinary Portland cement is partially replaced with silica fume and natural sand is replaced with manufactured sand by four proportions. The results indicated that there is an increase in the compressive and flexural strength[(5)]. Coarse aggregate is replaced with a nanofly ash. The work ability and compressive strength of concrete compared with that of normal concrete with nanofly ash is found to be stronger than normal conventional concrete[(6)].

II. Experimental investigation:

A. Materials

1 Cement: Portland pozzolanic cement 53 grade conforming to IS 8112 – 1989, and specific gravity of cement is found to be 3.15. The properties of cement given in Table 1

Table I - Properties of Cement

Physical properties of cement		
Fineness, m^2/kg	314	Minimum 300
Initial setting time (minutes)	110	Minimum 30
Final setting time(minutes)	160	Maximum 600
Standard consistency	26.4	-
Soundness, Le Chatelier, mm	1.0	Maximum 10
Mechanical properties of cement (Compressive strength, Mpa)		
3-days	23	Minimum 16
7-days	30	Minimum 22
28-days	40	Minimum 33
Chemical properties of cement		
Component	**Results (%)**	**Requirements of IS:1489**
SiO_2	21.8	-
$A1_2O_3$	4.8	-
Fe_2O_3	3.8	-
CaO	63.3	-
SO_3	2.04	Maximum 3
MgO_3	0.91	Maximum 6
Na_2O	0.21	-
K_2O	0.46	-
CI	0.06	Maximum 0.1
$P2O_5$	<0.05	-
Loss of ignition	1.36	Maximum 5
Insoluble residue	17.96	-

2 Fine aggregate: Locally available river sand having bulk density 1762 kg /m^3 is used and the specific gravity 2.73 and fineness modulus of river sand is 3.01

3 Manufactured sand: M-Sand is replaced is fully replacement of river sand .It is collected from BAG Groups Coimbatore, India. The bulk density of manufactured Sand 1460 kg/m^2 and the specific gravity 2.43 and fineness modulus of rive Sand is 2.8

Table 2 - Sieve analysis of River sand & M – Sand

IS sieve designation	**River sand % Passing**	**M- sand % Passing**
4.75 mm	99.43	98.1
2.36mm	95.84	98.23
1.18mm	66.27	43.35
600nm	47.27	29.6
300um	30	23
150um	9.27	5.3

4 Course aggregate: Considering all the above aspects, blue granite crushed stone aggregate of 12.5mm as maximum size and of typical particle shape "average and cubic" are used as the course aggregate for the present investigation. The aggregates are tested as per the procedure given in BIS: 2386- The bulk density of coarse aggregate 1660 kg/m2 and the specific gravity 2.83 and fineness modulus of coarse aggregate 6.73

5 Nano - silica: The nano silica is fully replaced for cement. Steel Authority of India has provided necessary facilities to produce annually about 3000 tons of nano silica at their Bhadravathi Complex. In India, However, the nano silica of International quality is marketed by Elkem Metallury (P) Ltd.,

B. Physical Properties of Nano silica

1 Specific gravity: The specific gravity of typical Nano silica is about 0.13 as compared to 3.15 for ordinary Portland cement. Depending on its chemical composition the specific gravity of Nano silica varies from 0.13 to 0.14

2 Particle Size: Most of the Nano silica particles are extremely fine with particle size less than or equal to 1 nano and with an average diameter of about 0.1 nano, about 100 times smaller than average cement particle.

3 Specific Surface Area: The specific surface of Nano -silica ranges from about 200 m^2 / g to 300 m^2 / g, as against 230 to 300 m^2/kg that of cement.

4 Specific Surface Area: The Chemical composition of Nano silica is given below. Nano silica of its extreme fineness and high Nano silica content is a highly effective pozzolanic material. Nano silica reacts pozzolanically with the calcium hydroxide during the hydration of cement to form the stable cementitious compound Calcium Silicate Hydrate (C-S-H).

Table 3- Chemical Composition of Nano – Silica

Chemical component	**% by weight**
$Si\ O_2$	95.3
$Al_2\ O_3$	0.65
$Fe_2\ O_3$	0.28
Ca O	0.27
Mg O	0.41
K_2 O	0.77
Na_2 O	0.26

III. Experimental Procedure:

The mix ratio is prepared for M30 grade concrete for both conventional sand and also M-Sand. The Cube size of (150 x 150 x 150) mm Specimen is prepared for compressive strength. The cylinder of height 30 cm and 15 cm diameter is prepared for tensile strength. The specimens are tested for 7 days, 14 days and 28 days with each proportion of nano silica and M-Sand mix. Totally there are 27 cubes and 27 cylinders are casted. The specimen size of (70x10x10) cm is used for flexural strength test. For durability test mortar specimen is prepared in a mix ratio of 1:3, the cube size of (50 x50 x 50) mm is prepared for water absorption test, and for RCPT a concrete disc of size 85 mm diameters and 50 mm

thickness. The specimen is tested 28 days totally for 9 cubs and 9 cylinders. All the specimens are demoulded after 24 hours, and curing is done in water for 7 days, 14 days and 28 days. The Scanning Electron Microscope (SEM) is used to determine the particle size of Nano –silica. Figure1.A Shows the SEM picture of NC Concrete, Figure1.B SEM picture of M-Sand Concrete and Figure1.C SEM picture of M-Sand with 0.75% of Nano-silica.

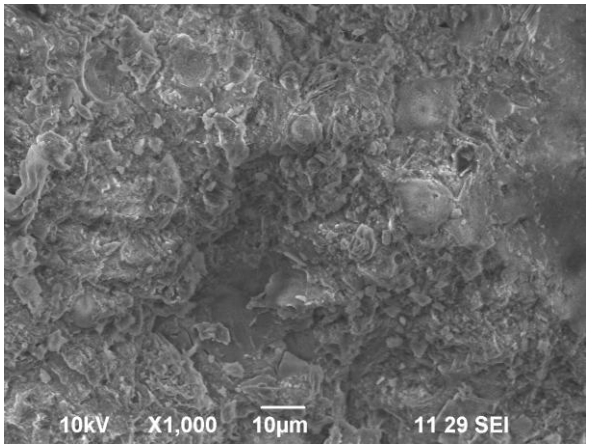

Fig 1.A Sem picture of normal concrete

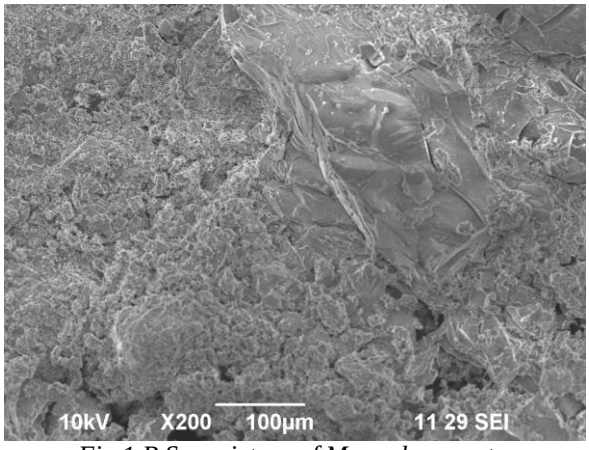

Fig 1.B Sem picture of M-sand concrete

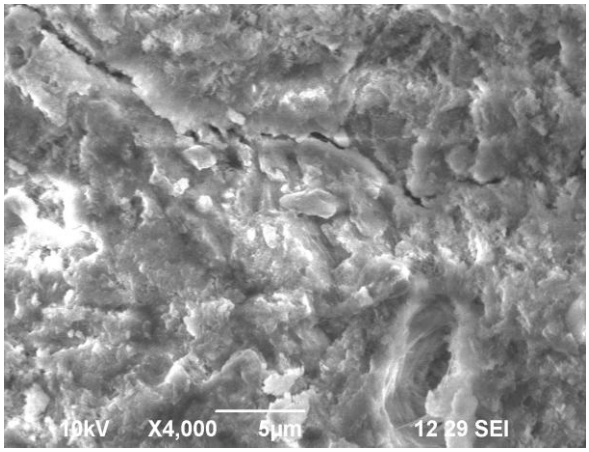

Fig 1.c M-sand with 0.75% nano silica concrete

IV. Result and Discussion:

The Compressive and tensile strength of concrete are presented in table 4 and 5

A. Compressive strength of concrete

Table. 4 - Compressive Strength of Concrete

S. No	**Type of mix**	**7 Days Strength N /mm^2**	**14 Days Strength N /mm^2**	**28 Days Strength N /mm^2**
1	Conventional mix	24.14	27.26	37.43
2	M –Sand Mix	24.30	24.96	27.41
3	M–Sand +0.75% Nano-silica	22.10	30.04	43.11

The test is carried out conforming to IS 516 -1959 to obtain compressive strength of concrete at the 7days, 14 days and 28 days. The cubes are tested using 400 tonne capacity HELICO compressive testing machine (CTM) .The results are presented in Fig.2

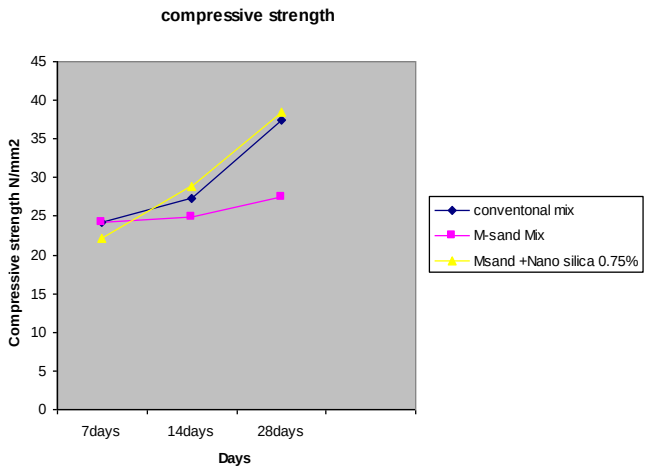

Fig.2 Compressive Strength of Concrete

The 7days compressive strength of M-Sand with 0.75% nano silica concrete 15% of compressive strength is reduced when compared to the normal river sand and M-Sand concrete. The compressive strength of normal river sand and M-Sand concrete is more or less same. The 14 days compressive strength of M-Sand with 0.75% nano silica concrete are found to be 10.42% and 20.35% more than the normal river sand concrete and M-Sand concrete. The 28 days compressive strength of M-Sand with 0.75% nano silica concrete are found to be 15.15% and 57.27% more than the normal river sand concrete and M-Sand concrete. Results of this test are show in table .4

B.Tensile strength of concrete

Table. 5 - Tensile Strength of Concrete

S. No	Type of mix	7 Days Strength N /mm^2	14 Days Strength N /mm^2	28 Days Strength N /mm^2
1	Conventional mix	2.35	2.46	2.78
2	M –Sand Mix	2.1	2.32	2.65
3	M–Sand +0.75% Nano-silica	3.14	3.23	3.52

The test is carried out conforming to IS 516 -1959 to obtain tensile strength of concrete at the 7 days, 14 days and 28 days. The cylinders are tested using 400 tonne capacity HELICO compressive testing machine (CTM) .The results are presented in Fig.3

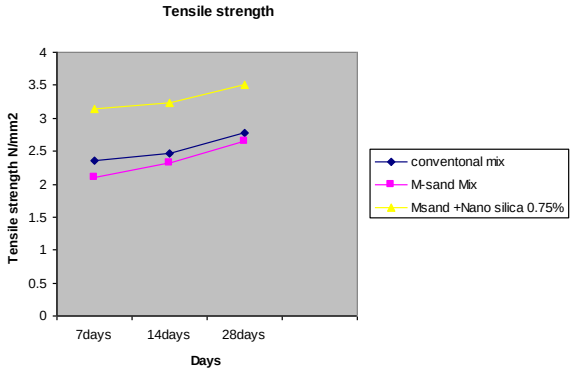

Fig 3 compressive strength of concrete

7days tensile strength of M-Sand with 0.75% nano-silica concrete are found to be 33.61% and 49.35% more than the normal river sand and M-Sand concrete. The 14 days tensile strength of M-Sand with 0.75% nano-silica concrete is found to be 31.22% and 39.35% more than the Normal river sand concrete and M-Sand concrete. The 28 days compressive strength of M-Sand with 0.75% nano-silica concrete is found to be 26.69% and 32.27% more than the normal river sand concrete and M-Sand concrete. Results of this test are show in table .5

C.Flexural strength of concrete

The test is carried out conforming to IS 516 -1959 to obtain tensile strength of concrete at the 7days, and 28 days are tested using loading frame 750 kN. The results are presented in Fig.4 The 7days flexural strength of M-Sand with 0.5% nano silica concrete and conventional concrete 18.75 % and 10.52% of flexural strength is increased when compared to the M-Sand concrete. The flexural strength of normal river sand and M-Sand with 0.5% nano silica concrete is more or less same. The 28 days flexural strength of M-Sand with 0.5% nano silica concrete are found to be 10.89% and 25.84% more than the normal river sand concrete and M-Sand concrete. Results of this test are show in table .6

Table. 6 - Flexural Strength of Concrete

S. No	Type of mix	7Days Strength N /mm^2	28 Days Strength N /mm^2
1	Conventional mix	6.2	10.1
2	M –Sand Mix	5.7	9.7
3	M–Sand +0.75% Nano-silica	6.75	11.2

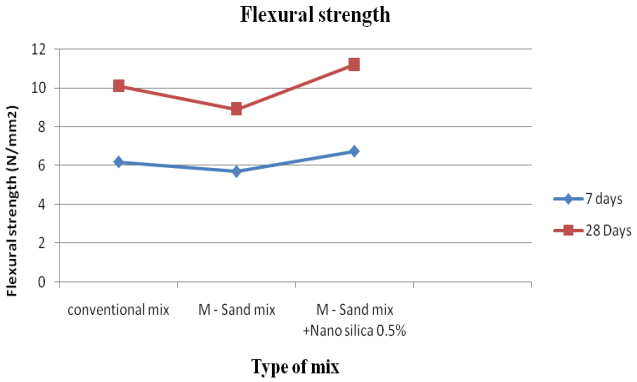

Fig 4 Flexural strength of concrete

D.Rapid chloride penetration test

This test is conducted as per ASTM C1202-09. Concrete disc of size 85 mm diameters and 50 mm thickness average value of three samples. The specimens are carried at different stages, allowed to cure for 28 days and then they are subjected to RCPT test by impressing a voltage of 60v. The permeability of M –Sand mix is very high when compared to the conventional mix. The M- sand with 0.75% nano-silica is to be 25.50% and 66.90% found to less than normal river sand and M- Sand concrete. There is a significant improvement in the durability of concrete because of high pozzolanic nature of the nano-silica and its void filling ability. The concrete with fully replacement of natural sand by M-Sand and partially replacement of 0.75% cement with nano-silica the RCPT values show in table 7.

Table. 7 - RCPT Value (Columbs)

S. No	Type of mix	RCPT value (columbs)
1	Conventional mix	662.5
2	M –Sand Mix	831.86
3	M–Sand +0.75% Nano-silica	275.28

Table. 8 - The Conditions of Columns Penetrability

Columbs Penetrability	**Chloride Ion**
>4000	High
2000-4000	Moderate
1000-2000	Low
100-1000	Very Low
<100	Negligible

Formula for RCPT = 900 x $\{I_0+(2I_1/30)+(2I_2/60)+.....+(I_n/360)\}$

E. Water absorption test

This test is done as per procedure given in ASTM C 642-97 by oven-drying method. For this test 50mm x 50mm x 50mm cubes are cast. After 24 hours of remolding, the specimens are kept immersed in water. At the end of 28 days, the specimens are taken from the curing tank and air-dried to remove the surface moisture then taken the initial weight (W1) is taken. The final weight (W2) is taken to the specimens are dried in an oven at a temperature of $100+10^o$ C for 48 hrs, and allowed to cool at room temperature. Results of this test are show in table .9

Table. 9 - Water Absorptions Test

Type of mix	**Water absorptions percents**
Normal mix	4.35
M-Sand mix	5.2
(M-Sand + 0.75% nano silica)	3.91

Conventional concrete specimen resulted to decrease of the water absorption and permeability of the concrete when compare to M-Sand mix. The effect of nano silica in reducing the permeability of conventional mix and M-Sand mix

% of Water absorption

% of water absorption = [(W2 – W1)/W1] x 100

Where,

W1 = weight of oven dried sample in air.

W2 = weight of surface dry sample in air after immersion in water.

The constituents are weighted and the material is mixed by hand mixing. The mixes are compacted using table vibration. The water binder ratio (W/B) adopted is 0.375 concrete and mortar. The specimens are demoulded after 24h, cured in water for 7, 14 and 28 days and then tested for its compressive, tensile and durability test as per indian standards. There is a significant improvement in the strength of concrete because of high pozzolanic nature of the nano silica and its void filling ablity.

V. Conclusions:

Addition of nano-Silica leads to a significance increase in the characteristic strength and durability of concrete. Replacement of cement with 0.75% of nanosilica gives more strength than the M-sand mix and also the durability has been increased compared to the M-Sand Mix. The self weight of the Nano mix is lighter than the M-sand and the conventional mix. The workability decreases with the addition of Nano-Silica compared to the conventional mix and the M-Sand mix.The penetration level of chlorides and acids are less in Nano concrete compared to that of conventional and M-Sand mix.

References:

[1] Joseph O. Ukpata, Maurice E.Ephraim and GodwinA. Akeke.(2012). "Compressive strength of Concrete using Lateritic Sand and Quarry Dust as Fine Aggregate."Arpn Journal of Engineering and Applied Sciences, Junuary 2012.Volume 7,No.1.

[2] K. Ganesan, K. Rajagopal, K. Thangavel,(2008). " Rice husk ash blended cement: Assessment of optimal level of replacement for strength and permeability properties of concrete." Constr. Build. Mater., **22** (8) (2008) pp.1675-1683.

[3] M.R.F.Goncalves, C.P.Bergmann,(2012). " Thermal insulators made with rice husk ashes Production and correlation between properties and microstructure." Constr. Build. Mater. 21 (2007) pp.2059-2065.

[4] Mohammad Reza Zamani Abyaneh, Seyed Mahdi Mousavi, Alireza Mehran, Seyed Mohammad, Mahdi Hoseini, Soroosh Naderi, Farhad Mesbah Irandoost,(2013). "Effects of Nano silica on Permeability of concrete and steel Bars Reinforcement Corrosion."Australian Journal of Basic and Applied Science,7(2):464-467, 2013.

[5] Prince Arulraj.G, Jemimah Carmichael.M,(2011). "Effect of Nano –Flyash on Concrete." International Jouranal of civil and structural Engineering ,November 2011.Volume 2, No 2, 2011.

[6] Rana Burhan Abdurrahman Alshahway, (2011). "Effect of Partial Replacement of Sand with Limestone Filler on some properties of Normal Concrete."*A1*-Rafidain Engineering ,June 2011.Volume19 No.3

[7] T.Shanmugapriya, R.N.Uma,(2012)."Optimation of Partial Replacement of M-Sand by Natural sand in High Performance Concrete With Silica Fume." International Jouranal of Engineering Sciences & Emerging Technologies, June 2012.Volume 2, pp:73.-80 IJESET.

[8] V.Saraswathy and Ha-Won Song,(2007). "Corrosion performance of rice husk ash blended concrete."Constr. Build. Mater. **1** (8) (2007), pp.1779-1784.