www.sphinxsai.com

ChemTech

International Journal of ChemTech Research
CODEN (USA): IJCRGG ISSN : 0974-4290
Vol.6, No.4, pp 2521-2528, July-Aug 2014

Influence of Nano slag on micro-structure, capillary suction and voids of high strength concrete

Sharmila P[1] and Dhinakaran.G[2]*

[1]School of Civil Engineering, SASTRA University, Thanjavur 613401, India.
[2]Centre for Advanced Research in Environment, School of Civil Engineering, SASTRA University, Thanjavur 613401, India.

***Corres. author: gd@civil.sastra.edu**
Tel: 919944082810 Fax: 914362 264120

Abstract: This study investigates the effect of nano-sized ground granulated blast furnace slag (GGBFS) as a partial substitute to cement on modification of micro-structure, capillary suction (sorptivity) and voids of high strength concrete. Disposal of waste product from steel industries becomes a huge threat and created an environmental concern. The GGBFS collected in the present work was subjected to grinding for two and half hours using planetary ball mill to reduce the size to a nano scale. Reduction in particle size was ensured by particle size analyzer. The sample was later used as a partial substitute to cement in three different percentages namely 5, 10 and 15. A high strength concrete mix with a characteristic compressive strength of 50 MPa was selected for the present study. Both sorptivity and voids tests were performed as per ASTM standards Test results showed that replacement of cement with nano sized slag improves the performance of concrete by modifying the micro structure and found that concrete with 10% of nano sized slag yielded best performance in terms of offering resistance to capillary suction and reduction in volume of voids.
Keywords: Nano sized slag, particle size analyzer, scanning electron microscopy, voids and capillary suction.

Introduction

Construction industry consumes a huge volume of concrete every year and it is expected it may reach a billion tones soon [1]. Portland cement is the most expensive component in a concrete mix. There is a very familiar statement about the manufacture of cement stating that every ton of Portland cement production releases a similar amount of carbon dioxide as a byproduct which affects the environment and it is also true. So to protect the environment from being polluted by the carbon dioxide released by the cement industries and to meet the rising demand in the world economically without affecting the strength characteristics of concrete mineral admixtures are used as supplementary cementing materials.

The concrete has to be modified with pozzolanic and cementitious materials for a long standing infra structure development. These are generally classified under the term mineral admixtures. Ground Granulated Blast Furnace Slag, Fly ash, Silica Fume, Rice husk ash are some of the examples of mineral admixtures. In this work GGBFS has been used as the mineral admixture.

GGBFS due to its high content of Silica and Alumina in an amorphous state shows pozzolanic behavior similar to that of natural pozzolans such as flyash and silica fume [2]. GGBS can be been used as an ingredient in cement as a mineral admixture or as a component of blended cement to encourage the reuse of by-products from industries. The use of GGBFS in concrete increases the workability, reduces bleeding of fresh concrete or mortar, improves strength, reduces heat of hydration, reduces permeability and porosity, and reduces the alkali silica [3]. In recent years finer particles are being used in construction industry. Several works were performed on incorporating nano particles into concrete specimens as mineral admixtures to improve physical and mechanical properties. Many researchers were focused their research on nano SiO_2, nano Al_2O_3, nano Fe_2O_3 and Zinc-iron oxide nano particles as mineral admixtures in concrete [4-10]. Also the use of nano sized mineral admixtures were also studied on self compacting concrete using SiO_2, Fe_2O_3, ZnO_2 and TiO_2 [11-16].

In addition the effects of several types of nano particles on properties of concrete specimens which are cured in different curing media were investigated in several works. It was observed from the literatures that the use of nano particles in concrete improves the mechanical properties of the specimen in addition to the improvement in microstructure of the concrete specimen.

Significance of the present research

Though nano particles play a major role in increasing the compressive strength of concrete, improving microstructure and pore structure of concrete specimen the cost of manufacturing nano sized particles is very high which limits their use liberally. The aim of this study is to investigate the physical and permeability characteristics of concrete incorporating ground slag of nano size as a partial replacement for Ordinary Portland Cement

Experimental Investigations

Material Used

The cement used was ordinary Portland cement of grade 43 having a specific gravity of 3.16. The chemical composition of the cement is presented in Table 1. The *Slag* was supplied from steel industries in Salem, Tamil Nadu, India and its specific gravity was 2.4. The chemical composition of Slag is given in Table 1. Raw Slag can be used as replacement for cement from 5% to 70 % depending upon the requirement. The same slag can be used effectively when it is converted to nano size. This would improve the performance of the slag as the surface area increases. In the present work the reduction in size of the raw slag was achieved by the use of planetary ball mill shown in Fig.1. The size reduction was achieved by loading raw slag of 17.15 microns into planetary ball mill and ground for 2½ hours. The reduction in size was verified using Particle Size Analyzer and was found to be 370 nm after grinding (size has been reduced to around 45 times than original value).

Table 1: Chemical composition of Cement and GGBFS

Formula	Concentration (%)	
	Cement	GGBFS
CaO	68.05	34.85
SiO_2	25.91	34.01
Al_2O_3	5.85	16.62
MgO	0.07	9.11
Fe_2O_3	0.12	1.71
SO_3	-	1.55
TiO_2	-	0.69
Na_2O	-	0.48
K_2O	-	0.46
MnO	-	0.27
BaO	-	0.10
P_2O_5	-	0.04
SrO	-	0.04
Cl	-	0.03
ZrO_2	-	0.03
As_2O_3	-	37 ppm

River sand was used as fine aggregate. The fineness modulus (FM) of the fine aggregate is 3.17 and it belongs to coarse sand category which can be used for concrete mixing. The specific gravity of the fine aggregate was noted as 2.63. Aggregate passing through 16 mm sieve and retained on 12.5 mm sieve was used as coarse aggregate in the concrete mixture. The specific gravity of the coarse aggregate was noted as 2.65. A commonly available super plasticizer CONPLAST SP 430 from FOSROC Company was used through this study to obtain the workable concrete mix. In the present work a high strength concrete grade to obtain a characteristic compressive strength of 50 MPa was adopted. The design mix ratio arrived was 1:1.04:2.13 (Cement: Fine aggregate: Coarse aggregate). Water cement ratio was taken as 0.33.

Specimen details

Specimens of size 100 mm (diameter) with 50 mm (height) were cast to study the durability characteristics by voids, water absorption and capillary suction. The specimens were prepared by partially replacing cement in the concrete mix in 5%, 10 and 15% of nano slag. In addition control concrete specimens were also cast in which no partial replacement was done.

Sorptivity Test

This test method is used to determine the rate of absorption (sorptivity) of water by hydraulic cement concrete by measuring the increase in the mass of a specimen resulting from absorption of water as a function of time when only one surface of the specimen is exposed to water. Resistance against capillary suction of concrete was measured through Sorptivity test as per ASTM standard [17]. Specimens of 100 mm diameter and 50 mm height cylinders were prepared by cutting the top and bottom of the 100 mm x 200 mm cylindrical concrete. The specimen was placed in the environmental chamber at a temperature of 50°C for 3 days. After the 3 days, it was placed inside a sealable container. Then the specimen was kept at 23°C for at least 15 days before the start of the absorption procedure. Specimen was removed from the storage container and mass of the conditioned specimen was recorded to the nearest 0.01 g before sealing of side surfaces. The side surface and end of each specimen was sealed with a suitable sealing material (epoxy resin). Then the specimen was tested according to ASTM standards.

Test for voids in hardened concrete

This test method used to determine density, percent absorption, and percent voids in hardened concrete and was conducted as per ASTM standard [18]. The individual portions may be pieces of cylinders, cores, or beams of any desired shape or size, except that the volume of each portion shall be not less than 350 cm^3 and each portion shall be free from observable cracks, fissures, or shattered edges. The specimen was kept in an oven at a temperature of 110°C for not less than 24 h. After removing each specimen from the oven, it was cooled in dry air to a temperature of 20 to 25 °C and mass was determined. Let it be *A*. The specimen was immersed water at approximately 21°C for not less than 48 h. Then it was weighed in water. Let it be B. Then the specimen was boiled in tap water for 5 h. After that it has been cooled for not less than 14 h to a final temperature of 20 to 25°C. Let it be C. Finally specimen was suspended into water and the mass was determined. Let it be D.

Absorption after immersion = $[(B-A)/A]x100$

Absorption after immersion and boiling = $[(C-A)/A]x100$

Bulk density, dry = g_1 = $[A/(C-D)]x\ \rho$

Bulk density after immersion = $[B/(C-D)]x\ \rho$

Bulk density after immersion and boiling = $[C/(C-D)]x\ \rho$

Apparent density = g_2 = $[A/(A-D)]x\ \rho$

Volume of permeable pore space (voids) = $[(g_2-g_1)/g_2]\ x100$

where:

A = mass of oven-dried sample in air, g
B = mass of surface-dry sample in air after immersion, g
C = mass of surface-dry sample in air after immersion and boiling, g
D = apparent mass of sample in water after immersion and boiling, g

g_1 = bulk density, dry, g/cc and
g_2 = apparent density, g/cc
ρ = density of water = 1000 g/m^3 = 1 g/cc.

Results and Discussions

Characterization of Micro Silica

Particle size analysis (PSA) of slag in unground and ground state (nano slag) used in the present work was done by using Particle size analyzer and the results are shown in Figures 1 & 2. It was understood that most of the particles fell under the size of 17 micron meter and this was about 4 times smaller than the cement particles used (average size of cement particles was around 60 µm or 60000 nm). Hence addition of slag can very well fill the voids available in the cement and will modify the micro-structure, which will be beneficial in terms of durability characteristics. Moreover the size of slag has been reduced to 370 nm after two and half hours of grinding in a planetary ball mill, which is 45 times less than the slag of unground state.

Microstructure of micro-silica used for the present work was analyzed by Scanning Electron Microscopy (SEM) to understand its morphology and the results are shown in Figure 3a, 3b and 3c for understanding the micro structure of concrete with 5, 10 and 15% of nano slag. The SEM images clearly explain the microstructure gets modified due to the addition of nano slag and for 15% nano slag due to agglomeration the size of particles becomes large. However the process of grinding did not affect the sphericity of particles.It was also observed that sizes of particles were reduced to considerable percentage due to the effect of grinding. SEM images witnessed the above statement.

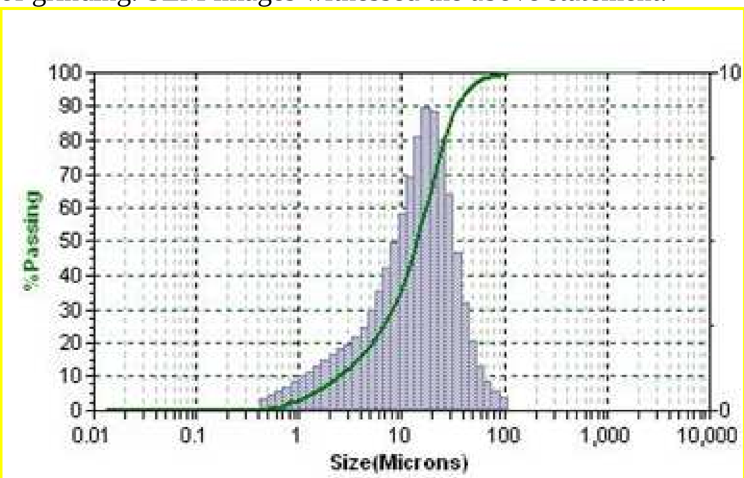


Figure 1: Particle size distribution of slag using particle size analyzer (17.15 µm)

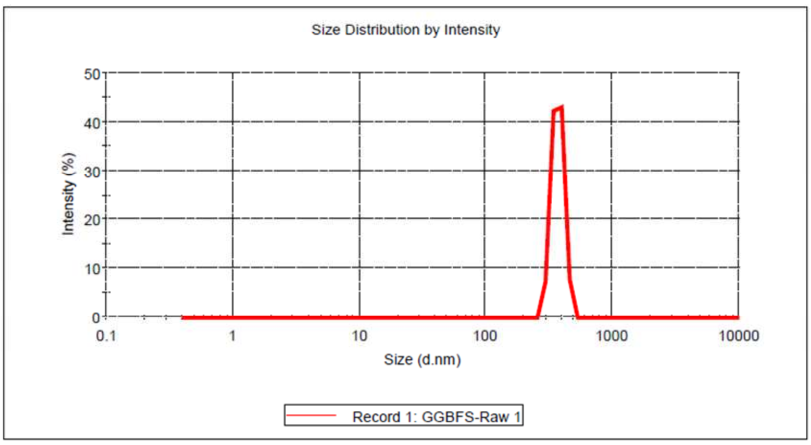


Figure 2 : Particle size distribution of slag after grinding (370.8 nm)

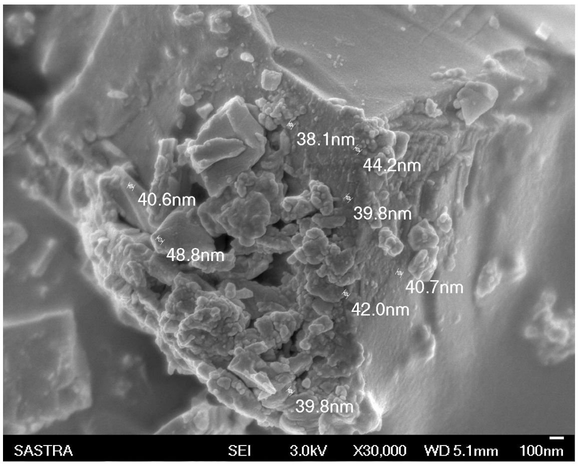


Figure 3 a : SEM image of concrete modified with 5% nano slag

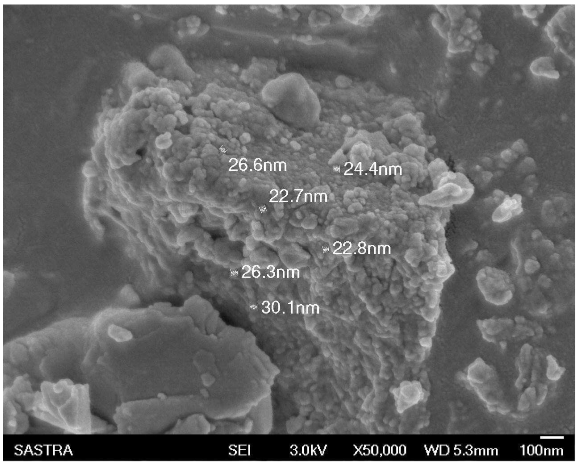


Figure 3 b : SEM image of concrete modified with 10% nano slag

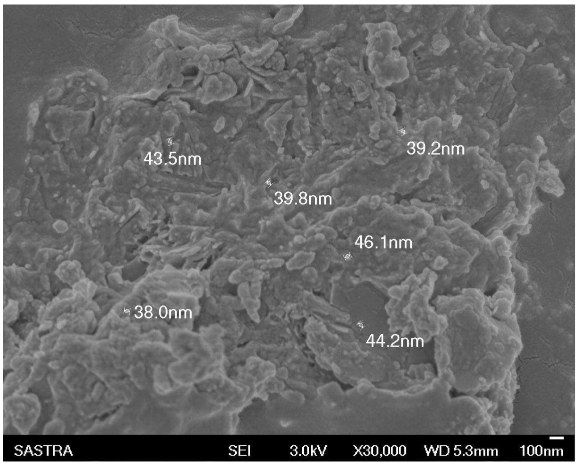


Figure 3 c : SEM image of concrete modified with 15% nano slag

Effect of nano slag in resisting permeability

The resistance against capillary suction due to the addition of nano slag was studied by conducting sorptivity test. The sorptivity values were plotted with respect to time elapsed. It is understood that the initial absorption by capillary suction for control concrete was found to be 0.0016 mm (average of first 6 hours sorption values). These values for concrete with 5%, 10% and 15% nano slag were 0.0014 mm, 0.0010 mm and 0.0012 mm respectively (refer Figure 4). From the results it was understood that for all the percentages of addition of nano slag concrete the sorption values were found to be less than control concrete and the maximum reduction was observed in concrete with 10% nano slag. For the concrete with 15% nano slag there was a reverse trend with 10% and was less than the value of control concrete. In a similar way the values of secondary absorption by capillary suction were calculated from average of 6 hours to 9 days. The capillary suction for control concrete was found to be 0.003 mm and these values for concrete with 5%, 10% and 15% nano slag were 0.0027 mm, 0.0020 mm and 0.0024 mm respectively. Here again concrete with nano slag exhibited better performance in terms resistance. Similar trend as observed in initial absorption was seen here also. It was inferred from the results of initial absorption that a maximum reduction of 46%, 50% and 41% were observed in concrete with 5%, 10% and 15% nano slag respectively in comparison with control concrete. These values for secondary absorption were found to be 32%, 44% and 36% for concrete with 5%, 10% and 15% nano slag respectively in comparison with control concrete (refer Figure 5). Comparing initial sorption and secondary sorption, sorption at the initial stage was found to be more aggressive irrespective of concrete whether it is made up of control or with nano slag. The R^2 values of control concrete and concrete with 5%, 10% and 15% nano slag were found to be 0.96, 0.90, 0.94 and 0.95 respectively. Since all the values of R^2 were exceeding 0.9, the goodness of fit was found to be well matching.

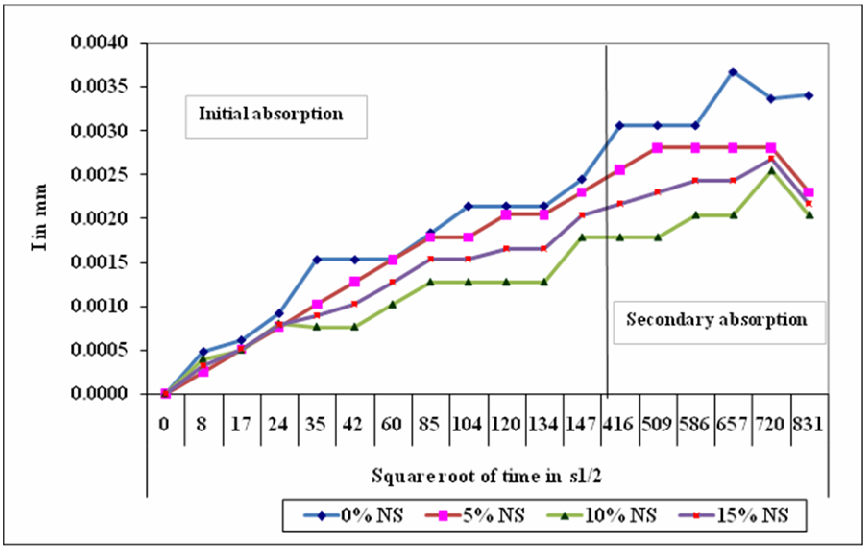


Figure 4 : Effect of nano slag on sorptivity of concrete

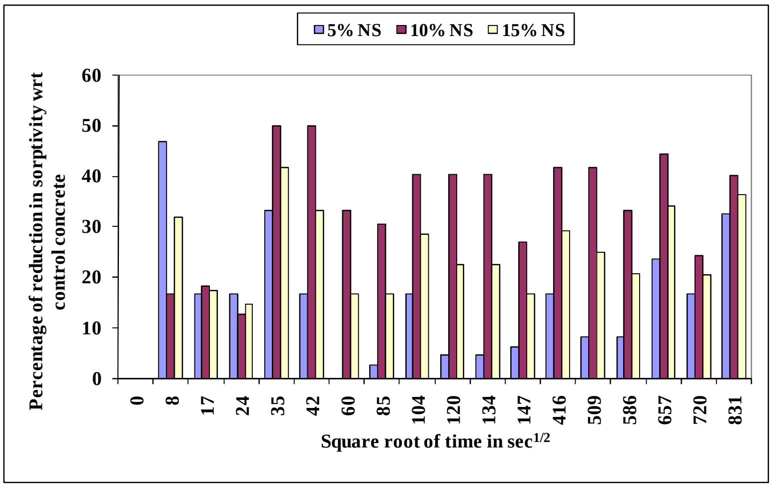


Figure 5 : Effect of nano slag on percentage reduction in sorptivity wrt control concrete

Effect of nano slag in water absorption and voids in hardened concrete

The resistance against water absorption, density and voids in hardened concrete due to the addition of nano slag was studied by conducting a standard test. The water absorption values were calculated as per the standard procedure and the values were 5.04% for control concrete, 4.43%, 4.20% and 4.76% for concrete with 5, 10 and 15% of nano slag respectively. The amount of water absorption was found to be higher for control concrete and deceases due to the addition of nano slag in concrete. Increase in percentage of nano slag from 5 to 10 % decreases water absorption and further increase of nano slag to 15% have shown a reverse trend. However the amount of water absorption of concrete with 15% nano slag was less than that of control concrete. The rate of reduction in water absorption in nano slag concrete were found to be 12, 17 and 6% respectively for concrete with 5,10 and 15% of nano slag with respect to control concrete. Hence it was evident that addition of nano slag served as micro filler in the voids or pores of concrete and modified the micro structure resulted a denser concrete. Similar trend also followed in apparent density also. The volume of voids in control concrete was found to be 9.2%. These values for concrete with 5, 10 and 15% nano slag were found to be 7.9, 7.2 and 8.3% respectively.

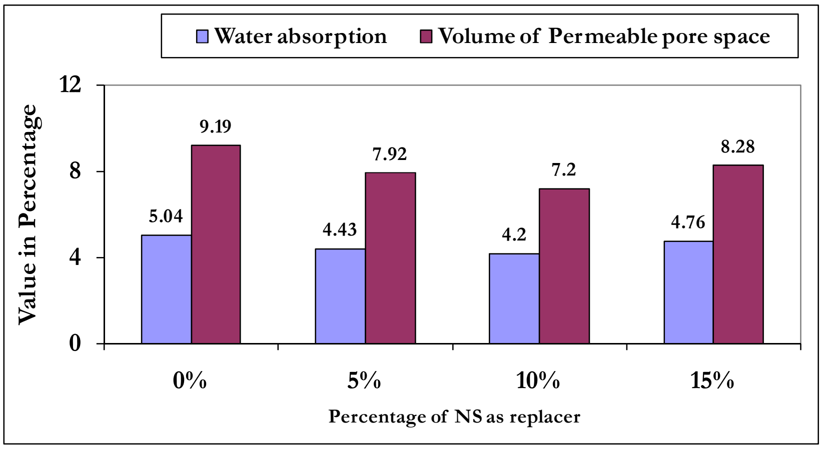


Figure 6 Effect of nano slag on water absorption and voids in hardened concrete

Conclusions

From the detailed experimental investigations carried out on high strength concrete added with nano slag to understand its effect on micro structure, capillary suction and voids the following conclusions were arrived:

- Addition of nano slag modified the microstructure irrespective of its percentage as replacer to cement and concrete have become denser.
- Nano slag based concrete offered better resistance to capillary suction both in case of initial absorption and secondary absorption. Maximum reduction in sorptivity of 50% and 44% were observed in concrete with 10% nano slag in terms of initial and secondary absorption respectively.
- In the case of concrete with 5, 10 and 15% nano slag, the water absorption was reduced to an extent of 12, 17 and 6% and voids were reduced to 14, 22 and 10% than control concrete.
- Among three different percentages of nano slag used, concrete with 10% yielded better results and found to be optimum in terms of improvement in microstructure, resistance to capillary suction and reduction in volume of voids in hardened concrete.

Acknowledgements

The authors whole heartedly thank the Vice-Chancellor of SASTRA University for having given permission and for the continuous support and encouragement given throughout this research work.

References

1. Pathak, P.P. (2009). “Inclusion of Portland and Pozzolana (fly ash waste) Cement in specifications”. Indian Highways, 37(4), 23-29.
2. Atis, C.D., and Bilim,C. (2007). Wet and dry cured compressive strength of concrete containing ground granulated blast-furnace slag”. Building and Environment, 42, 3060-3065.
3. Aldea, C.M., Young, F., Wang, K., and Shah, S.P. (2000). “Effects of curing on properties of concrete slag replacement”. Cement & Concrete Research, 30 (3), 465-472.
4. Li, H., Xiao, H.G., and Ou, J.P. (2004). “A study on mechanical and pressure-sensitive properties of cement mortar with nano phase material”. Cement & Concrete Research, 30 (3), 435-438.

5. Qing, Y., Zhang, Z., Kong, D., and Chen, R. (2007). "Influence of nano-SiO_2 addition on properties of hardened cement paste as compared with silica fume". Construction Building Materials, 21(3), 539-545.
6. Jo, B.W., Kim, C.H., and Tae, G.H. (2007a). "Characteristics of cement mortar with nano-SiO_2 particles". Construction Building Materials, 21(6), 1351-1355.
7. Jo, B.W., Kim, C.H., and Tae, G.H. (2007b). "Investigations on the development of powder concrete with Nano-SiO_2 Particles". KSCE Journal of Civil Engineering, 11(1), 37-42.
8. Li, Z., Wang, H., Yang, S.H., and Wang, M. (2006). "Investigations on the preparation and mechanical properties of the nano-alumina reinforced cement composite". Material Letters, 60(2), 356-359.
9. Lin, D.F, Lin, K.L., Chang, W.C., Luo, H.L., Cai, M.Q. (2007). "Improvements of nano-SiO2 on sludge/flyash mortar". Waste Management, 28 (6), 1081-1087.
10. Lin, K.L., Chang, W.C., Lin, D.F., Luo, H.F., and Tsai, M.C. (2008). "Effects of nano-SiO_2 and different ash particles sizes on sludge ash –cement mortar". Journal of Environmental management, 88 (4), 708-714.
11. Ali Nazari and Shadi Riahi.(2010). "The effects of TiO_2 nano particles on water permeability and thermal and mechanical properties of high strength self-compacting concrete". Material Science and Engineering, 7(5), 528 (2), 756-763.
12. Ali Nazari and Shadi Riahi. (2011a). "The effects of TiO_2 nano particles on physical, thermal and mechanical properties of concrete using ground granulated blast furnace slag as binder". Materials Science and Engineering, 528, 2085-2092.
13. Ali Nazari and Shadi Riahi. (2011b). "The role of SiO_2 nano particles and ground granulated blast furnace slag admixture on physical, thermal and mechanical properties of self compacting concrete". Materials Science and Engineering, 528, 2149-2157.
14. Ali Nazari and Shadi Riahi (2012a). "The effects of SiO_2 nano particles on physical and mechanical properties of high strength compacting concrete". Composites Part B: Engineering, 42(3), 756-763.
15. Ali Nazari and Shadi Riahi. (2012b). "The effects of ZnO_2 nano particles on split tensile strength of self compacting concrete". Journal of Experimental nano Science, 7(5), 491-512.
16. Shadi Riahi and Ali Nazari. (2011). "Physical, mechanical and thermal properties of concrete in different curingntaining ZnO_2 nano particles". Energy and buildings, 43 (8), 1977-1984.
17. ASTM C1585 (2013), "Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes", ASTM International, West Conshohocken, PA, 2011.
18. ASTM C642 (2013), "Standard Test Method for Density, Absorption, and Voids in Hardened Concrete", ASTM International, West Conshohocken, PA, 19428-2959.

****

Journal's Page:

International Journal of ChemTech Research

(Oldest & Original)

CODEN (USA): IJCRGG, ISSN: 0974-4290 [www.sphinxsai.com]

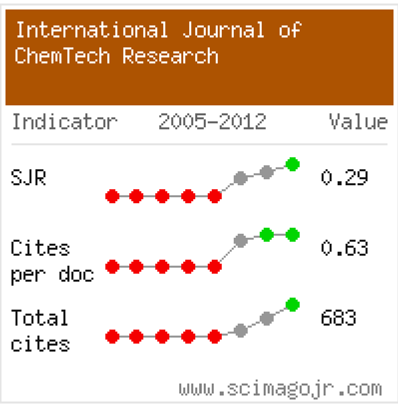
Journal's url= http://sphinxsai.com/frameijchemtech.html

Subject area:

This Journal publishes the Research/Review papers from all branches of Chemistry, Chemical Engineering and applied sub - disciplines like Synthetic Chemistry, Analytical Chemistry, Environmental Chemistry, Biochemistry, Polymer Chemistry, Chemical Engineering, Chemical Technology, Petroleum Chemistry, and Agricultural Chemistry, Biotechnology, Nanotechnology Pharmaceutical, Biological activities of Synthetic Drugs, *etc*.

Find more by clicking on Elsevier- SCOPUS SITE....AS BELOW.....

http://www.scimagojr.com/journalrank.php?area=1500&category=1501&country=IN&year=2011&order=cd&min=0&min_type=cd



Link = http://www.scimagojr.com/journalsearch.php?q=19700175055&tip=sid&clean=0

USE OF COMPLETE PUBLISHED PAPERS, SEARCH ON Journal's website for scientific information is FREE OF COST.
For paper search, use of References, Cites, use of contents etc in-
International Journal of ChemTech Research,

Please log on to - www.sphinxsai.com

*****