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Nano Alumina Based High Strength Concrete

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***Abstract:** Very recently, the world of nano technology has initiated to fabricate new materials owing to the demand for their use in enhancing the properties of different materials in general and, materials used in the construction industry in particular.*
In this study, the results of an exhaustive experimental analysis, on the use of nano alumina with cement powder to enhance the grade and strength of concrete has been undertaken. The influence of the nano alumina in concrete with different proportions has been studied to assess mechanical properties of concrete with reference to normal concrete. The test results indicate that the use of nano alumina in concrete has enhanced the mechanical properties of hardened concrete. This nano alumina based high strength concrete (HSC) has an enhanced compressive strength of 64.17 N/mm^2 (MPa) after 28 days, which is a significant improvement over normal concrete. All the mixes having nano alumina in different proportions gave better results as compared to normal conventional concrete mix. The Rebound Hammer, Ultrasonic Pulse Velocity, SEM and TEM analysis further validate the above findings.

***Keywords:** SEM, TEM, Nano Alumina, High Strength Concrete (HSC).*

I. INTRODUCTION

Over the past ten years, the construction technology has undergone some massive changes. The major thrust is to modernize the various techniques involved in construction and at the same time to use alternate construction materials. Research has been in progress to evaluate both short and long term mechanical characteristics of cementitious composites and has found importance throughout the world [1, 2]. Thus, we can now find many new different forms of additives being used, besides the conventional ones which focus to enhance the mechanical & physico-chemical properties of the conventional concrete. The new concrete using nano materials, has improved crack arrest mechanism, is more durable and shows a better creep-shrinkage pattern in its performance. In the recent past, one can come across very important studies, which show the application of nano-technology in concrete production. The surface area of nano-sized particle is considerably large as compared to its volume. This increased surface area provides for increased chemical activity. Hence nano- engineering and nano alteration of cementitious material is very crucial and important since its inception stage as far as bulk production and the use of concrete is concerned. Limited research is available which deals with the modification of cement in nano size particles and their noteworthy effect as nano-binders for concrete. [3, 4].

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Thus, nanotechnology is emerging as a promising field in which a lot of research can be done and which when applied in the field of construction will definitely with the use of optimum material resources bring a revolution in the material and construction technology. The use of nano-technology is also found to be vital for sustainable development in construction industry.
Thus, Nano technology finds its application not only in improving the performance of cementitious matrix but also in the sustainable development of cementitious matrix and research in this area would always be a path breaking activity [6].Recent studies have covered the application of cement hydration products at the nano scale using the nanostructures to enhance the strength of cementitious matrix [4, 7, 8]. A number of nano additives such as nano cement, silica fume, nano silica fumes, fly ash and nano fly ash in varying proportions were mixed with cement matrix by a number of researchers and their influence was studied to compare engineering properties to that of conventional cement matrix. Study shows that there is a remarkable improvement in the properties of cementitious matrix when compared with cement matrix. [9, 10].The amalgamation and assemblage of some unconventional materials at nano scale offers the development of fresh additives in cement such as nano particles, super plasticizers or nano reinforcements. As of now, work on nano particles involves the use of nano TiO2 [1, 2, 15, 21] and nano SiO2 [1, 11–20]. Studies on the use of nano Fe2O3, nano Al2O3 [22] and nano clay is limited [23, 24].
Nano SiO_2 is more effective in improving the strength and other engineering properties than the silica fume [13, 20]. Upon the addition of 10 % SiO_2 along with dispersing agents, it was observed that the compressive strength of concrete cube at 28 days increased by 26%, compared to only a 10% increase with the addition of 15% silica fume [25].
Nano Al_2O_3 helps to increase the modulus of elasticity. A dosage of only 5%, increases the value of modulus of elasticity upto 143 %. However it had limited effect on the compressive strength [22], whereas no other significant changes have been reported. Nano Al_2O_3 finds its use in many industries such as steel manufacturing, petroleum and gas, medicine, optics aerospace etc. The gas and petroleum industry commonly uses Al_2O_3 as a catalyst as the particles of Al_2O_3 are very pure. It is evident that the size of each cement particle is responsible for giving the compressive strength to concrete. Also, the modulus of elasticity, setting time, workability and water absorption depend on the amount of cementitious materials used. From experiments it has been clearly shown that with the use of nano materials the behavior of cementitious materials is greatly altered. This observation has encouraged researchers to study on the properties of various kinds of nano materials in concrete and cement mortars.

Comparing the results, it has been observed that the nano materials enhance and improve the compressive strength of concrete. There are some researches on the partial replacement of cement by nano particles in concrete or cement-based materials such a nano silicate (nano SiO_2), Carbon Nano Tubes, nano iron (nano Fe_2O_3) and nano-titanium oxide (nano TiO_2).

Besides, some improvements have been reported by replacement of cement with nano- Al_2O_3 in concrete. Nazari et al. investigated the compressive strength and workability of concrete by partial replacement of cement with nano-phase Al_2O_3 particles [29]. They also found nano- Al_2O_3 as a replacement of cement improves the compressive strength of concrete but decreases its workability.

II. MATERIALS AND EXPERIMENTAL PROGRAMME

To study the effect of nano-alumina on concrete matrix, nano sized alumina (nano-Al_2O_3) in different proportions was used in M50 grade concrete matrix to test its strength. Total sixty (60) concrete cubes samples were casted and were tabulated with the specific designation assigned to it. Various tests were performed on the hardened concrete cubes to ascertain the mechanical properties of the new nano alumina based concrete. A detail of the work plan is given in the Table A shown below. Other construction materials used in the mix are cement, fine aggregate, coarse aggregate and super plasticizer. A study of cement was performed with the help of SEM (Scanning Electron Microscope). SEM images show the morphological properties and particle size of cement (Figure 1). The nano-alumina was also studied under Transmission Electron Microscope (TEM) and Figure 2 shows the morphology and nano size of alumina. Finally cement concrete blocks were casted and their strength was measured as per the recommendation of the relevant IS (Indian Standard) Code of Practices.

Table A: Work Plan for Compressive Strength Test on M50 grade Concrete Matrix

Target Strength= M50 grade Concrete		
Cube Designation	Al_2O_3 (% Dosage of weight of the cement used)	Tests Performed on Hardened Concrete
A0	Alumina 0%	1. Compressive Strength in Normal Environment
A0.5	Alumina 0.5%	2. Compressive Strength in Aggressive Environment (Water with 4% NaCl)
A1	Alumina 1%	3. Rebound Hammer Test
A1.5	Alumina 1.5%	4. Ultrasonic Pulse Velocity Test (UPV)

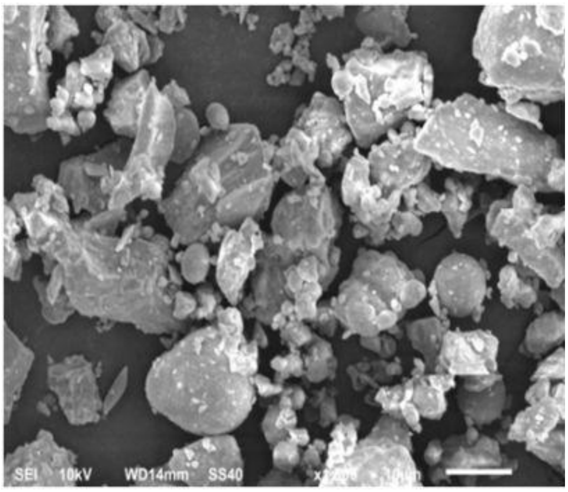


Fig. 1: SEM image showing morphology and particle size of the cement

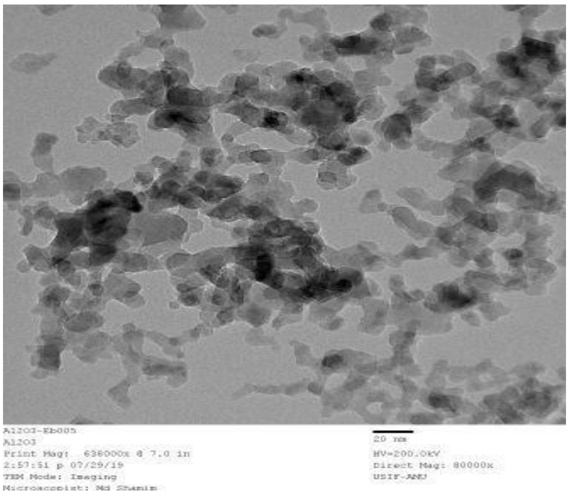


Fig. 2: TEM image showing morphology and particle size of nano alumina (Al_2O_3)

Cement

Table 1: Properties of Cements

S. No.	Type of Cement	Normal Consistency	Initial Setting Time (minutes)	Final Setting Time (minutes)
1	Normal Cement (ACC 43 OPC)	28.50%	61	294

ACC 43 grade Ordinary Portland cement was used. The physical properties of cement were investigated in the concrete laboratory as shown in Table 1.

Fine Aggregate

Locally available Badarpur sand was used. Lumps of clay and other foreign and deleterious matter were separated and screened out from the sand and it was later washed with water and then air dried. The grading and fineness modulus of the sand are given in Table .

Table 2: Sieve analysis of FA (fine aggregate)

S. No.	IS: Sieve Designation	Weight Retained (g)	Cumulative Weight Retained (g)	% Cumulative Weight Retained
1.	4.75 mm	Nil	0	0
2.	2.36 mm	20	20	1
3.	1.18 mm	235	255	12.75
4.	600 micron	560	815	40.75
5	300 micron	1102	1917	95.85
6.	150 micron	83	2000	100.00

Fineness Modulus = $\frac{250.35}{100}$ = 2.5035

Nano Alumina	Unit	Typical Value
Specific Surface Area (BET)	m^2/g	100 $\pm$ 15
Average primary particle size Tamped density* According to DIN EN ISO 787/11, August, 1983	nm g/l	13 approx. 50
Moisture* Two hours at 105^{0}C	wt. %	$\leq$ 5.0
Ignition Loss Two hours at 1000^{0}C, based on material Dried for 2 hours at 105^{0}C	wt. %	$\leq$ 3.0
pH in 4 % dispersion		4.5 – 5.5
Al_2O_3 - content Based on ignited material	wt. %	$\geq$ 99.8
Sieve residue (by Mocker 45 µm) According To DIN EN ISO 787/18, April, 1984	wt. %	$\leq$ 0.050

Coarse Aggregate (CA)

Coarse aggregate of locally available quartzite were used in the mix.

2.1 Compressive Strength Test of HSC in Normal Environment

In order to evaluate the performance of the material and their mix, the concrete cubes of size 150×150×150 mm size were cast in the laboratory (Figure 3). In total 24 concrete cubes samples were cast and specific designations were assigned to them. The constituent materials used for concrete cubes were cement, coarse aggregate, fine aggregate, water, super plasticizer and nano additive (nano-alumina). Potable water was used for the preparation of matrix. The grade of the concrete was taken as M50 high strength grade concrete. After casting of the specimens, the cubes were taken out from the moulds after 24 hours and cured for specified 7 and 28 days in the water curing tank (Figure 4). The cubes were tested under the compression testing machine (Figure 5) up to failure to ascertain their crushing strength. The compressive strength of concrete cubes is given in Table 4. As can be seen, the concrete cubes incorporating the nano material exhibit excellent strength both at 7 and 28 days. Thus the material system can definitely be relied upon for the intended application.

Fig. 3: Casting of Concrete Cubes

Fig. 4: Curing of Concrete Cubes

Table 4: Compressive Strength Test of HSC in Normal Environment

Cube Designation	Al_2O_3 (% Dosage)	7 days (MPa)	28 days (MPa)
A0	0 %	32.68	50.53
A0.5	0.5 %	35.33	55.06
A1	1 %	40.01	61.14
A1.5	1.5 %	43.29	64.17

Fig. 5: Testing of Concrete Cube

2.2 Compressive Strength Test of HSC in Aggressive Environment (Water with 4 % NaCl)

To investigate the performance of the material and their mix in the aggressive environment the concrete cubes of size 150×150×150 mm size were cast in the laboratory. In total 12 concrete cubes samples were cast and specific designations were assigned to them. The constituent materials used for concrete cubes were cement, coarse aggregate, fine aggregate, water, super plasticizer and nano additive (nano- alumina). Potable water was used for the preparation of matrix. The grade of the concrete was taken as M50 high strength grade concrete. After casting of the specimens, the cubes were taken out from the moulds after 24 hours and cured in salt solution (4% NaCl solution by weight of water) for specified 28 days in the water curing tank. After curing the cubes were tested for the compressive strength in the CTM (compression testing machine) up to failure to ascertain their crushing strength. The compressive strength of concrete cubes obtained is given in Table 5. As can be seen, the concrete cubes incorporating the nano material exhibit better strength at 28 days even if it was kept in aggressive environment.

Table 5: Compressive Strength Test of HSC in Aggressive Environment (Water with 4% NaCl)

Cube Designation	Al_2O_3 (% Dosage)	28 days (MPa)
A0S	0 %	42.88
A0.5S	0.5 %	43.95
A1S	1 %	45.45
A1.5S	1.5 %	47.16

2.3 Compressive Strength Test of HSC using Schmidt Rebound Hammer (NDT- Non Destructive Testing)

The concrete cubes of size 150×150×150 mm size were cast in the laboratory. In total 12 concrete cubes samples were cast and specific designations were assigned to them. The grade of the concrete was taken as M50 high strength grade concrete. After casting of the specimens, the cubes were taken out from the moulds after 24 hours and cured for specified 28 days in the water curing tank. The cubes were tested with Schmidt Rebound Hammer (Figure 6) and different readings of compressive strength on each faces were recorded and tabulated in the Table 6.The compressive strength of concrete cubes as reported by the Rebound Hammer test (NDT) matches with the standard concrete test performed earlier in compression machine.

Table 6: Compressive Strength Test of HSC using Schmidt Rebound Hammer

Mix Designation	Al_2O_3 (% Dosage)	Rebound Hammer Number
A0	0%	47
A0.5	0.50%	50
A1	1%	55
A1.5	1.50%	57

Fig. 6: Schmidt Rebound Hammer Test

2.4 Compressive Strength Test of HSC via UPV (Ultrasonic Pulse Velocity)

The concrete cubes of size 150×150×150 mm size were cast in the laboratory. In total 12 concrete cubes samples were cast and specific designations were assigned to them. The grade of the concrete was taken as M50 high strength grade concrete. After casting of the specimens, the cubes were taken out from the moulds after 24 hours and cured for specified 28 days in the water curing tank. The cubes were tested with UPV (Figure 7) and the readings on each faces were recorded and were tabulated in Table 7.

The quality and the grade of concrete cubes as reported by the Compressive Strength Test and Schmidt Rebound Hammer test (NDT) validates the UPV test.

Table 7: Compressive Strength Test of HSC via UPV (Ultrasonic Pulse Velocity)

Mix Designation	Al_2O_3 (% Dosage)	Average Pulse Velocity (km/sec)	Concrete Quality Grading
A0	0%	4.15	Good
A0.5	0.50%	4.32	Good
A1	1%	4.65	Excellent
A1.5	1.50%	4.79	Excellent

Fig. 7: Ultrasonic Pulse Velocity Test

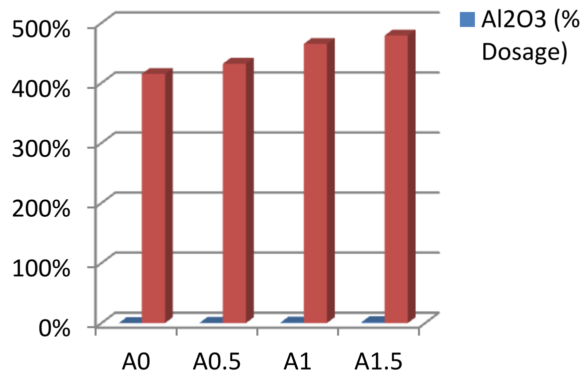
III. RESULTS AND DISCUSSION

A discussion on these test results is presented here with a view to draw qualitative as well as the quantitative conclusions. The results obtained from compressive tests on concrete cubes samples are given in Tables 4 to 7 above. These results have also been graphically presented in Figures 8, 9 and10 below.

3.1 Compressive Strength Test of HSC in Normal Environment

Results of 24 nos. concrete cube specimen of size 150 mm are given in the Table 4 above. The graphs show the variation mainly where the nano materials are used. The variations are discussed in detail below. In Figure 8 below, the compressive strength of concrete cube having nano alumina for 7 and 28 days is more than the compressive strength of normal concrete cube. The percentage increase in the compressive strength of nano alumina concrete with the normal concrete at 28 days is 9, 21 and 27 % respectively. The reason for gain in the strength at different stages is due to the nano particles (nano-alumina), which causes larger surface area of alumina to come in contact with the cement and water.

Moreover the voids will be less and hence the strength increases as the cracks need space or void to propagate through.



3.2 Compressive Strength Test of HSC in Aggressive Environment (Water with 4% NaCl)

Results of 12 nos. concrete cube specimen of size 150 mm are given in the Table 5 above. The graphs show the variation, where the nano materials are used. In Figure 9 below, the compressive strength of concrete cube having nano alumina for twenty eight (28) days is more than the compressive strength of normal concrete cube. The percentage increase in the compressive strength of nano alumina concrete with the normal concrete in aggressive environment at 28 days is 2.5, 6 and 10 % respectively. It was also concluded that the nano alumina based concrete performs better even in the aggressive environment.

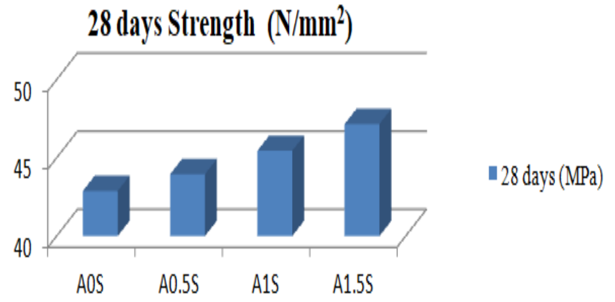


Fig. 9: Graph Showing Compressive Strength of Concrete Cube under Aggressive Environment (4% NaCl solution)

3.3 Compressive Strength Test of HSC using Schmidt Rebound Hammer

Results of 12 nos. concrete cube specimen of size 150 mm are given in the Table 6 above. The graphs show the variation, where the nano materials are used. As can be seen in Figure 10 below, the Schmidt Rebound Hammer Number of concrete cube having nano alumina for 28 days is more than the Schmidt Rebound Hammer Number of normal concrete cube. The percentage variation in the crushing strength and the Schmidt Rebound Hammer Number is 7, 9.2, 10 and 11.2 % respectively. These Percentage values are within the acceptable limits of the clause 7.1.5 of IS: 13311 (Part-II) - 1992.

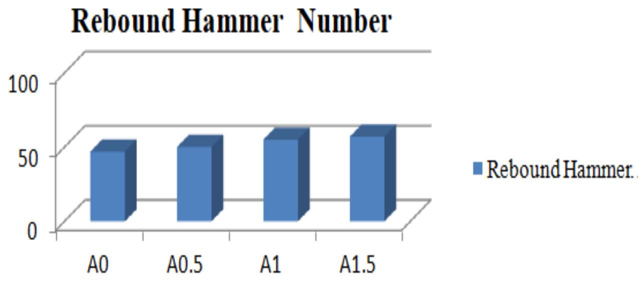


Fig. 10: Graph Showing Rebound Hammer Number

3.4 Compressive Strength Test of HSC via UPV (Ultrasonic Pulse Velocity)

Results of 12 nos. concrete cube specimen of size 150 mm are given in the Table 7 above. The average UPV values of A0, A0.5, A1 and A1.5 are 4.15, 4.32, 4.65 and 4.79 km/sec respectively. As per Table 2 of clause 7.1.1 of IS: 13311 (Part-I) – 1992, A0 and A0.5 lies in the good quality grade concrete whereas, A1 and A1.5 lies under the excellent quality grade concrete.

3.5 Cracking Pattern of Concrete Cubes Tested under Compression

From the Figure 11 shown below, it is clear that concrete cube having nano-alumina (A1) show aggregate failure instead of bond failure in the cube, whereas in the concrete cube without any nano particle (A0) (Figure 12) show the detachment of the aggregate with the cement matrix which results in bond failure instead of aggregate failure.

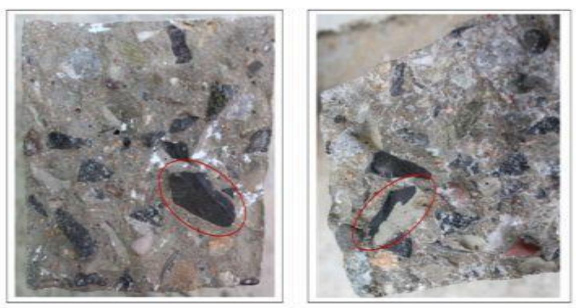


Fig. 11: Aggregate Failure in nano-alumina based Concrete Cube

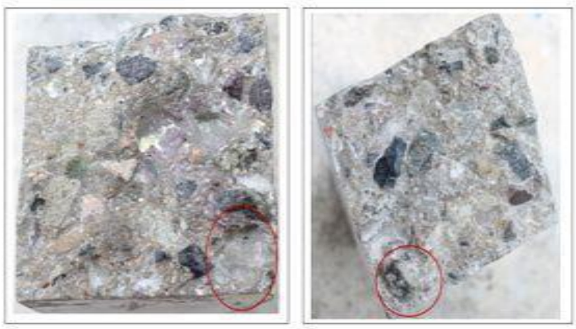


Fig. 12: Bond Failure in normal Concrete Cube

IV. CONCLUSIONS

The above experimental study gives the following conclusions. It is observed that all the properties of concrete matrix are enhanced with the increment of nano additives. The nano particles have tendency to fill the gaps in between the grains of cement and reduce the CaOH content resulting in the formation of CSH (calcium silicate hydrate) bond which further improves the interface structure of the concrete. The gain in strength at different stages can be ascribed to the fineness of nano alumina which causes larger surface area of alumina to come in contact with the water and cement and hence generation of denser micro fabric, limiting the number and size of voids thereby increase strength. The maximum strength is gained by the matrix which is having nano alumina in concrete was found to have significant increase in compressive strength of concrete matrix at seven and twenty eight days of curing. All different concrete mixes having nano alumina with different percentages give strength in the range of 55.06 to 64.17 MPa which are more than the normal concrete mix (50.53 MPa). The mix containing merely 1.5% nano- alumina has given 64.17 MPa, 28 days compressive strength. An increase up to 27% has been observed for concrete cube having nano alumina (64.17 MPa) as compared to the normal concrete (50.53 MPa).The nano alumina based concrete performs better even in the aggressive environment.The Schmidt Rebound Hammer and UPV tests validates the result, that concrete having nano alumina is more effective for surface hardness as well as concrete quality grading as compared to normal concrete. Due to presence of nano particles (nano-alumina) in the concrete matrix enhances the density of the concrete, which results in decreasing the cracking pattern within internal concrete matrix and hence it results in higher UPV value as compared to normal conventional concrete. It is clear that concrete cube having nano-alumina show aggregate failure instead of bond failure in the cube, whereas in the concrete cube without any nano particle (nano alumina) show the detachment of the aggregate with the cement matrix which results in bond failure instead of aggregate.

REFERENCES

1. Sanchez F, Sobolev K. Nanotechnology in concrete – a review. Constr Build Mater 2010; 24(11):2060–71.
2. Zhang R, Cheng X, Hou P, Ye Z. Influences of nano-TiO2 on the properties of cement-based materials: Hydration and drying shrinkage. Constr Build Mater 2015; 81:35-41.
3. Lee SJ, Kriven WM. Synthesis and hydration study of Portland cement components prepared by the organic steric entrapment method. Mater Struct 2005; 38(1):87–92.
4. Sobolev K, Ferrada-Gutiérrez M. How nanotechnology can change the concrete world: part 2. Am Ceram Soc Bull 2005; 84(11):16–9.
5. Feynman R. There's plenty of room at the bottom (reprint from speech given at annual meeting of the American Physical Society). Eng. Sci 1960; 23:22–36.
6. Bartos PJM. Nanotechnology in construction: a roadmap for development. In: Bittnar Z, Bartos PJM, Nemecek J, Smilauer V, Zeman J, editors. Nanotechnology in construction: proceedings of the NICOM3 (3rd international symposium on nanotechnology in construction). Prague, Czech Republic; 2009. p. 15–26.
7. Scrivener KL, Kirkpatrick RJ. Innovation in use and research on cementitious material. Cem Concr Res 2008; 38(2):128–36.
8. Sobolev K, Shah SP. SP-254 Nanotechnology of concrete: recent developments and future perspectives. Detroit: American Concrete Institute; 2008.
9. Minet J, Abramson S, Bresson B, Franceschini A, Van Damme H, Lequeux N. Organic calcium silicate hydrate hybrids: a new approach to cement based nano composites. J Mater Chem 2006; 16: 1379–83.
10. Bjornstrom J, Martinelli A, Matic A, Borjesson L, Panas I. Accelerating effects of colloidal nano-silica for beneficial calcium–silicate–hydrate formation in cement. Chem Phys Lett 2004; 392(1–3):242–8.
11. Bjornstrom J, Martinelli A, Matic A, Borjesson L, Panas I. Accelerating effects of colloidal nano-silica for beneficial calcium–silicate–hydrate formation in cement. Chem Phys Lett 2004; 392(1–3):242–8.
12. Ji T. Preliminary study on the water permeability and microstructure of concrete incorporating nano-SiO2. Cem Concr Res 2005; 35(10):1943–7.
13. Jo B-W, Kim C-H, Tae G-h, Park J-B. Characteristics of cement mortar with nano-SiO2 particles. Construct Build Mater 2007; 21(6):1351–5.
14. Li H, Xiao H-g, Ou J-p. A study on mechanical and pressure-sensitive properties of cement mortar with nano phase materials. Cem Concr Res 2004; 34(3):435–8.
15. Li H, Zhang M-h, Ou J-p. Abrasion resistance of concrete containing nano particles for pavement. Wear 2006; 260(11–12):1262–6.
16. Qing Y, Zenan Z, Deyu K, Rongshen C. Influence of nano-SiO2 addition on properties of hardened cement paste as compared with silica fume. Construct Build Mater 2007; 21(3):539–45.
17. Lin KL, Chang WC, Lin DF, Luo HL, Tsai MC. Effects of nano-SiO2 and different ash particle sizes on sludge ash–cement mortar. J Environ Manage 2008; 88(4):708–14.
18. Lin DF, Lin KL, Chang WC, Luo HL, Cai MQ. Improvements of nano-SiO2 on sludge/fly ash mortar. Waste Manage 2008; 28(6):1081–7.
19. Sobolev K, Flores I, Torres-Martinez LM, Valdez PL, Zarazua E, Cuellar EL. Engineering of SiO2 nano particles for optimal performance in nano cement based materials. In: Bittnar Z, Bartos PJM, Nemecek J, Smilauer V, Zeman J, editors. Nanotechnology in construction: proceedings of the NICOM3 (3rd international symposium on nanotechnology in construction). Prague, Czech Republic; 2009. p. 139–48.
20. Qing Y, Zenan Z, Li S, Rongshen C. A comparative study on the pozzolanic activity between nano-SiO2 and silica fume. J Wuhan UnivTechnol – Mater Sci Ed 2008; 21(3):153–7.
21. Li H, Zhang M-h, Ou J-p. Flexural fatigue performance of concrete containing nano-particles for pavement. Int J Fatig 2007; 29(7):1292–301.
22. Li Z, Wang H, He S, Lu Y, Wang M. Investigations on the preparation and mechanical properties of the nano-alumina reinforced cement composite. Mater Lett 2006; 60(3):356–9.
23. Chang T-P, Shih J-Y, Yang K-M, Hsiao T-C. Material properties of Portland cement paste with nano-montmorillonite. J Mater Sci 2007; 42(17):7478–87.
24. Kuo W-Y, Huang J-S, Lin C-H. Effects of organo-modified montmorillonite on strengths and permeability of cement mortars. Cem Concr Res 2006; 36(5):886–95.
25. Li H, Xiao H-g, Yuan J, Ou J. Microstructure of cement mortar with nano particles. Compos B Eng 2004; 35(2):185–9.
26. Li Z, Wang H, He S, Lu Y, Wang M. (2006). "Investigations on the preparation and mechanical properties of the nano alumina reinforced cement composite". Mater Lett. 60 (3). 356–9.
27. IS: 13311 (Part-I) - 1992, "Indian Standard for Method of Test for Ultrasonic Pulse Velocity Test", BIS, New Delhi, 1992.
28. IS: 13311 (Part-II) - 1992, "Indian Standard for Method of Test for Rebound Hammer", BIS, New Delhi, 1992.
29. IS: 516-1959, "Indian Standard for Method of Test for Strength of Concrete", BIS, New Delhi, 1959.

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