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A COMPREHENSIVE OVERVIEW ON PERFORMANCE OF NANO SILICA CONCRETE

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Abstract

This paper provides an overall review of the literature on the influence of Nano-Silica in concrete and its applications for sustainable development. Limited work has so far been done incorporating Nano silica (NS) in concrete. This review presents the influence of Nano silica in concrete, its pore filling effect and its pozzolanic activity with cement towards improvement of mechanical properties and durability aspects.

Keywords: Nano Silica; Mortar; Concrete; Strength; Durability.

1. Introduction

Concrete is a composite material composed of cement, fine aggregate, coarse aggregate and water. Often, additives and reinforcements are included in the mixture to achieve the desired physical properties. When these ingredients are mixed together, they form a fluid mass that is easily molded into any desired shape. Concrete has relatively high compressive strength, but significantly lower tensile strength and as such is usually reinforced with materials that are strong in tension (often steel). The elasticity of concrete is relatively constant at low stress levels but starts decreasing at higher stress levels as matrix cracks develop. Concrete has a very low coefficient of thermal expansion and as it matures concrete shrinks. All concrete structures will crack to some extent due to shrinkage and tension. Concrete which is subjected to forces for long-duration is prone to creep. In very high-strength concrete mixtures (greater than 70 MPa) the crushing strength of the aggregate can be a limiting factor to the ultimate compressive strength.

Nano technology is an interesting but emerging field of study which is under constant evolution offering a very wide scope of research activity. Normally, if the particle size ranges between 1nm to100 nm, they are generally called as nano-particles or materials. The fineness can reach up to molecular level (1 nm –100 nm), by special processing techniques. As the fineness increases, the surface area increases, which increases the 'reactivity' of the material. Nano-cement was produced in a high energy ball grinding mill and was used as a partial replacement to cement. Application of nano-cement in concrete can lead to significant improvements in the strength and life of concrete. The mechanical behaviour of concrete materials depends to a great extent on structural elements and phenomena which are effective on a micro- and nano- scale. The ability to target material modification at the nano-structural level promises to deliver the optimization of material behaviour and performance needed to significantly improve the mechanical performance, volume, etc. Nano composites are produced by adding nano-particles to a material in order to improve the properties of material.

Concrete is a material most widely used in construction industry. As already mentioned, it is a composite material in which mineral or chemical admixtures are added. The materials such as nano-silica, nano fly ash and nano metakaolin are being added to cement. There are also a limited number of investigations dealing with the manufacture of nano-cement. The use of finer particles (higher surface area) has advantages in terms of filling the cement matrix and densifying the structure thereby resulting in higher strength and faster chemical reactions i.e. hydration. Nano-cement particles can accelerate cement hydration due to their high activity. Similarly, the incorporation of nano-particles can fill pores more effectively to enhance the overall strength and durability.

2. Literature Review

Recently nano technology is considered for usage in many applications and it has also received increased attention as a building materials. Particularly use of NS in cement and concrete production. However, there is a limited work done on concrete dealing about the mechanism by which NS affects the flow properties, setting times, consistency, workability and mechanical properties. Due to the high specific surface area of nano material sized colloidal nano silica (CNS) particles, they posses high reactive siliceous material. However, it has not been established whether the more rapid hydration of cement in the presence of NS is due to its chemical reactivity upon dissolution.

Bjorn et al. has stated that the mechanical behaviour of concrete materials affects to a great extent on the strength of structural elements and phenomena which are effective on a micro- and nano- scale. The ability to target material modification at the nano- structural level promises to deliver the optimization of material behaviour and the performance needed to improve significantly the mechanical performance, volume change properties, durability and sustainability of concrete. Mohamed Heikal et al. presented the effect of NS on physicochemical, compressive and flexural strengths. Different mixes were made with various amounts of NS, OPC and granulated blast-furnace slag

(GBFS) and hydrated for 1, 3, 7, 28 and 90 days. The cement was replaced up to 60% with GBFS and up to 6% with NS. The hydration behaviour was followed by estimation of free lime (FL) and combined water content at different curing ages. The required water for standard consistency, setting times and compressive strength were also determined. The required water for standard consistency and setting times increases with NS content due to the presence of 1% of super plasticizer. As the NS content increases the values of both FL and pH decrease. The compressive and flexural strengths of cement mortars containing NS are higher than those of control OPC mix. As the NS content increases above 40% GBFS and 4% NS, compressive and flexural strengths of OPC–GBFS–NS blends decrease but still more than those of the control samples. Tanakorn Phoo-ngernkham et al. presented the effect of adding nano-SiO_2 and nano-Al_2O_3 on the properties of high calcium fly ash geopolymer pastes. Nano-particles were added to fly ash at the dosages of 0%, 1%, 2%, and 3% by weight. The alkaline liquid/binder ratio of 0.60 and curing at ambient temperature of 23°C were used in all mixtures. The results showed that the use of nano-SiO_2 as additive to fly ash results in the decrease of the setting time, while the addition of nano-Al_2O_3 results in only a slight reduction in setting time. Adding 1–2% nano- particles could improve compressive strength, flexural strength and elastic modulus of pastes due to the formation of additional calcium silicate hydrate (CSH) or calcium alumina silicate hydrate (CASH) and sodium alumina silicate hydrate (NASH) or geopolymer gel in geo-polymer matrix. In addition, the additions of both nano-SiO_2 and nano-Al_2O_3 enhance the shear bond strength between concrete substrate and geopolymer.

Nima Farzadnia et al. focused on the chemical composition, micro structural changes and residual mechanical properties of high strength mortars with presence of 1%, 2% and 3% nano Titania at elevated temperatures. X-Ray Diffraction (XRD), Scanning Electron Microscopy (SEM) analysis and gas permeability tests were conducted to investigate the chemical composition and micro- structural changes of mortars after being exposed to elevated temperatures up to 1000 °C. The residual compressive strength, energy absorption per unit volume and relative elastic modulus were also obtained. Addition of nano Titania increased residual compressive strength up to 14% and enhanced elastic modulus and energy absorption of mortars at temperatures up to 600 °C.

Morteza Bastami et al. studied about effect of elevated temperature on high strength concrete (HSC) modified with NS and on its compressive and tensile strengths, spalling, and mass loss. This research studied the effect of elevated temperature on the compressive and tensile strength, spalling and mass loss of HSC modified with NS. Six sample mixtures containing varying amounts of NS and two samples without NS were considered in the experimental program. The mechanical properties of the modified HSC were measured by heating 150 mm dia x 300 mm height sample cylinders of concrete to 400°, 600° and 800°C at a rate of 20°C/min. The obtained results demonstrate that NS efficiently used in HSC can improve its mechanical properties at elevated temperature. The results show that the presence of NS increased residual compressive and tensile strengths. The spalling and mass losses were decreased as the penetrability increased. Byung Wan Jo et al. investigated the effectiveness of the chemically synthesized nano cement in controlling physical and mechanical performances of concrete. In this investigation, concrete samples were fabricated using variable amounts of aggregates and alkali activator content with respect to weight of nano cement. Based on the analysis of mechanical properties, it was assessed that chemically synthesized cement was able to produce compressive strength of 43 MPa after 14 days curing instead of 28 days with an optimized amount of aggregates as well as alkali activator content. Finally, a model has been proposed to explain the overall performances of nano cement based concrete. Bjorn strom et al. explained about the hydration process of tricalcium silicate (C_3S) cement and established the accelerative effects of colloidal silica and role of water during hydration. From this study, it was observed that CNS accelerate dissolution of C_3S phase, thereby renders the rapid formation of C-S-H phase. If the nano particles are integrated with cement based materials, the new materials might posses some outstanding properties. NS can react with Calcium Hydroxide (CH) crystals, which are arranged in the interfacial transition zone (ITZ) between hardened cement paste and aggregates and produce C-S-H gel. Thus, the size and amount of CH crystals are significantly decreased and the early age strength of hardened cement paste in increased.

Ye Qing et al. found that the setting times and consistency for silica fume (SF) and NS incorporated concrete were different, but NS makes the cement paste thicker and accelerated cement hydration. Compare to SF concrete, NS showed improved compressive and bond strength.

Jo et al. studied the properties of cement mortar with NS particles and reported on the importance of NS addition towards strength characteristics, hydration progress and calorimetric investigations. Observations were also made from the heat of hydration values, which depicted the amount of CH formed by the addition of NS that could increase the amount of heat evolved during setting and hardening of the cement. Gaitero et al. have explained about the reduced calcium leaching behaviour of cement paste by the addition of NS and revealed that the calcium leaching was a degradation process that consisted in the progressive dissolution of the cement paste as a consequence of the migration of Ca^{2+} ions to the aggressive solution. The results obtained showed that NS increases the strength of the cement paste by about 30%. Sololev et al. reported the roles of nano particles of silica act as fillers in the voids or empty spaces. The well dispersed NS act as a nucleation or crystallization centers of the hydrated products, thereby increasing the hydration rate, that is NS assisted towards the formation of smaller size CH crystals and homogeneous clusters of C-S-H composition. Moreover, they found that NS improved the structure of the transition zone between aggregates and the paste. The drawback in using NS in concrete is self - desiccation due to increased surface area and it will lead to shrinkage at high concentration and thereby produces cracks in concrete.

Khanzadi et al. reported the influence of NS particles on the mechanical properties and durability of concrete through measurement of compressive and tensile strengths, water absorption and the depth of chloride penetration. It was observed that the compressive and tensile strengths increased in presence of nano SiO_2, which indicates the pozzolanic activity of NS improvement in ITZ. Also water absorption, capillary absorption and distribution of chloride ion test results indicate that the nano-silica concrete has better permeability resistance than the normal concrete. With advent of supplementary cementitious materials and other siliceous and aluminous materials, today's concrete technology has achieved enormous potential applications, by the way of reduction in cement consumption, enhanced properties and reduced carbon foot print. In concrete, for example, the micro silica fume works in the form of chemical reaction with CH form more C-S-H gel at final stage and also fill the voids and pores in the fresh and hardened cement paste, thereby increasing the concrete's density. Some researchers found that the addition of 1 kg of SF permits a reduction of 4 kg of cement, and this can be more if NS is used.

Lin et al. observed the effect of NS addition on permeability and compressive strength of fly ash (FA) cement mortar with NS. From the pore analysis study, it was reported that the relative permeability and pore sizes of concrete were decreased, whereas the compressive strength increased by adding 3% NS.

Li et al. demonstrated the effect of addition of NS in high volume FA concrete (more of CaO content) and the results compared and reported that the pozzolanic activity of FA based concrete with NS were increased considerably and found that decrements in permeability of concrete gained high strength in the early and later stage.

Yazdi et al. investigated the effect of NS on high volume fly ash concrete (HFC), and reported that due to the low pozzolanic reactions of fly ash, early strength of HFC reduced considerably, but with the addition of NS promoted the pozzolanic activity reaction which enabled the enhancement of strength of HFC, especially in the early ages.

Mastafa Jalal et al. reported about the mechanical, rheological, durability and micro structural properties of high performance self-compacting concrete (HPSCC) containing silica of micro and nano size blended NS and SF. The addition of NS alone up to 2% weight of cement enhanced both the compressive and split strengths by about 62% and

25% respectively, whereas 2% NS blended with 10% SF with control concrete, there was an additional strength improvement of 9% and 8% respectively. They described that the enhancement of strength was not only because of pore filling effect, but also by the accelerated cement hydration due to their higher reactivity of NS. Moreover, the water and capillary absorption results revealed significant decrease by the addition of blended NS and SF for the binder content.

Stefanidou, et al. reported that the addition of NS tends to primarily increase the mechanical response and caused 20-25% strength improvement. At the same time, with the addition of 1% super plasticizers reduced the water demand and the strength increase varied from 30% to 35%. Impressive changes were also recorded in the structure of nano-modified samples as the calcium silicate crystal size is larger in samples with high NS content and micro structure observation also recorded a denser structure in nano- modified samples.

3. Influence on Mechanical Properties

Li et al. conducted experiments using NS and the results showed that with 5% replacement of cement by NS (mean size 15±5 nm), 7 and 28-days compressive strength of mortars were increased by 20% and 17% respectively. With the experimental analysis, it was proved that the compressive and flexural strengths of the cement mortars with nano-silica is higher than that of the plain cement mortar with the same water to binder ratio.

Abdullah et al. conducted experimental investigation on the effect of NS on the compressive strength, split tensile strength and modulus of elasticity of low quality lime stone coarse aggregate concrete. His results indicated that incorporation of NS enhanced the compressive strength and split tensile strength of all concretes especially that of the low quality limestone coarse aggregates. Bhanja et al. showed that the compressive and tensile strengths increased with silica fume incorporation, and the results indicated that the optimum replacement percentage is not constant but depends on the w/c ratio of the mix. They also found that compared with split tensile strengths, flexural strengths have exhibited greater improvements. Jo et al. has showed experimentally that the compressive strengths of mortars with NS were all higher than those of mortars containing SF at 7 and 28 days. It was demonstrated that the NS is more valuable in enhancing strength compared to SF. The addition of NS and SF enhances mechanical properties of cement-based materials. Givi et al. investigated that there are effects of size of NS on compressive, flexural and tensile strengths of binary blended concrete. It was found that the cement could be advantageously replaced by NS up to maximum limit of 2% with average particle sizes of 15 and 80 nm. Although the optimal replacement level of NS particles for 15 and 80 nm size were gained at 1% and 1.5% respectively.

4. Influence on Durability Properties

Ji et al. have explained about the water absorption, capillary absorption and distribution of chloride ion tests which indicated that the NS concrete has better permeability resistance than the normal concretes.

Zhang et al. have observed that the weight loss of mortar did not follow a linear regression model and the mortars with NS showed higher values than SF. With 7 days the shrinkage increased 80%, while at 28 days it increased 54%. The chloride permeability of concrete containing nano- particles (TiO_2 and SiO_2) for pavement was compared with that of plain concrete, concrete containing polypropylene (PP) fibres and concrete containing both nano-TiO_2 and PP fibres. Quercia et al. have addressed the characterization of six different amorphous silica samples with respect to their application in cement paste. It was determined that the addition of 0.5 to 4.0% NS to the cement paste reduced the water demand without the use of super plasticizers.

Stefanidou nad Papayianni et al. have conducted experimental test, results of which indicated that the addition of nano- particles refines the pore structure of concrete and enhances the resistance to chloride penetration of concrete. The NS addition decreased the apparent density and increased the air content in the mortars. It was investigated that the addition of 1% super plasticizers reduced the water demand and the strength increase varied from 30% to 35%.

5. Conclusions

From the elaborate review of literature, the influence of NS in cement paste, cement mortar and cement concrete and the reasons for the same have led to the following conclusions:

- The improvement in the mechanical properties due to the incorporation of NS due to (i) its pore filing effect (ii) Pozzolanic reactions.
- The nano size materials reduce the pore size making the concrete denser and accounts for increase in durability.
- The dense packing also helps in restricting the entry of unwanted substances such as air, water and other chemicals into the concrete thereby increasing the durability of concrete.
- The reason for the increase in concrete strength with increase in NS content is that it acts as activator to promote the hydration and also to improve the microstructure of cement paste if nano-particles were uniformly dispersed. The strength is enhanced with nano-SiO_2 addition, especially at early stages, and the pozzolanic activity of NS is much greater than that of SF.
- It was observed that nano-silica-blended concretes have higher strength as compared to non-blended concretes. Strength is higher at all ages for nano-silica-blended concretes.

- Most of the research works are limited to cement pastes and mortars, with only a few researchers having worked extensively on mechanical properties and permeability of the concrete incorporating NS.
- Durability properties still need to be investigated further on the acid resistance and sulphate resistance.

However, there is a gap available for further research towards the fruitful application of NS for construction.

From above discussion it clear that there is a wider scope for the researchers to carry out their research using NS either in colloidal or powder form incorporating the various pozzolanic materials available. Also these otherwise waste materials have a serious problem in their disposal. Hence advantageously using them in concrete would pave way for sustainability.

References

1. Ksenija Jankovic., Srboljub Stankovic., Dragan Bojovic., Marko Stojanovic., Lana Antic., The influence of nano-silica and barite aggregate on properties of ultra high performance concrete, *Constr. Build Mater.,* 126 (2016) 147–156.
2. Zhenhai Xu., Zonghui Zhou., Peng Du., Xin Cheng.,Effects of nano-silica on hydration properties of tricalcium silicate, *Constr. Build Mater.,* 125 (2016), 1169–1177.
3. N-M. Barkoula., C. Ioannou., D.G. Aggelis., T.E. Matikas., Optimization of nano-silica's addition in cement mortars and assessment of the failure process using acoustic emission monitoring, *Constr. Build Mater.,* 125 (2016), 546 – 552.
4. Ye Qing, Zenan Z., Deyu K. and Ch. Rongshen, Influence of nano-SiO_2 addition on properties of hardened cement paste as compared with silica fume, *Constr. Build Mater.,* 21(2007), 539–545.
5. Jo Byung-Wan, Kim Chang-Hyun, Lim Jae-Hoon, Characteristics of cement mortar with nano-SiO_2 particles, *ACI Mat. Jl.,* 104(4) (2007), 404-407.
6. Gaitero J.J., Campillo I. and Guerrero A., Reduction of the calcium leaching rate of cement paste by addition of silica nano particles, *Cem. and Con. Res.,* 38(2008), 1112–1118.
7. Sololev K., Engineering of Silica nano particles for optimal performance in nano cement based materials: Nano Technology in Construction, Proceedings of the NICOM3, *Prague,* (2009) 139-148.
8. Khanzadi M, Mohsen Tadayon , Hamed Sepehri and Mohammad Sepehri, Influence of Nano-Silica Particles on Mechanical Properties and Permeability of Concrete, Second Intl. Conf. on Sustainable Construction Materials and Technologies, June 28-30, Universita Politecnica delle Marche, Ancona, Italy, (2010).

9. Senff L., Hotza D., Repette W.L., Ferreira V.M. and Labrincha J.A., Mortars with nano-SiO_2 and micro-SiO_2 investigated by experimental design”, *Constr. Build Mater.*, doi:10.1016/j.conbuildmat. (2010) 2010.01.012.

10. Senff L., Labrincha J.A., Ferreira V.M., Hotza D. and Repette W.L, Effect of nanosilica on rheology and fresh properties of cement pastes and mortars, *Constr. Build Mater.*, 23, (2009) 2487–2491.

11. Lin K.L., Chang W.C., Lin D.F., Luo H.L and Tsai M.C, Effects of nano-SiO_2 and different ash particle sizes on sludge ash–cement mortar, *Jl. of Environ. Manage.*, 88 (2008), 708–714.

12. Li G., Properties of high-volume fly ash concrete incorporating nano-SiO_2, *Cem. and Con. Res.*, 34(2004), 1043–1049.

13. Lin D.F., Lin K.L., Chang W.C., Luo H.L and Cai M.Q., Improvements of nano SiO_2 on sludge/fly ash mortar, Waste *Management*, 28(6) (2008), 1081-1087.

14. Yazdi A.D., Sohrabi M.R., Ghasemi M.R., Mohammad Danesh-Yazdi, Investigation of Nano-SiO_2 Effects on High-Volume Fly Ash Concrete, 1st International Conference on Concrete Technology, Iran (2009).

15. Sadrmomtazi A., Barzegar A., Assessment of the effect of Nano-SiO_2 on physical and mechanical properties of self-compacting concrete containing rice husk ash, Second Intl. Conf. on Sustainable Construction Materials and Technologies, June 28-30, Universita Politecnica delle Marche, Ancona, Italy (2010).

16. Nazari A. and Riahia S., Splitting tensile strength of concrete using ground granulated blast furnace slag and SiO_2 nanoparticles as binder, *Energy and Buildings*, 43(4) (2011), 864-872.

17. Byung Wan Jo, Chang Hyun Kim, and Jae Hoon Lim, Investigations on the Development of Powder Concrete with Nano-SiO_2 Particles, *KSCE Journal*, 11(1) (2007), 37-42.

18. Min-Hong Zhang, Jahidul Islam and Sulapha Peethemparan, Use of nano silica to increase early strength and reduce setting time of concretes with high volumes of slag, *Cem. and Con. Compo.*, 34(2012), 650-662.

19. Min-Hong Zhang, Jahidul Islam, Use of nano silica to reduce setting time and increase early strength of concretes with high volumes of fly ash or slag, *Constr. Build Mater.*, 29(2012), 573–580.

20. Mastafa Jalal, Esmaeel Mansouri, Mohammad Aharifipour, Ali Reza Pouladkhan, Mechanical, rheological, durability and micro structural properties of high performance self compacting concrete containing SiO_2 micro and nanoparticles, *Materials and Design*, 34(2012), 389-400.

21. Hou P et al., Modification effects of colloidal nano SiO_2 on cement hydration and its gel property, *Composites: Part B*, http://dx.doi.org/10.10.16/j.compositesb. 2012.05.056, (2012).

22. Stefanidou M., Papayanni I., Influence of nano- SiO2 on the Portland cement pastes, *Composites : Part B*, 43 (2012), 2706-2710.

23. Berra M., Carassiti F., Mangialardi T., Paolini A.E., Sebastini M., Effect of nanosilica addition on workability and compressive strength of Portland cement pastes, *Constr. Build Mater.*, 35(2012), 666-675.

24. Kontoleontos F., Tsakiridis P.E., Marinos A., Kaloidas V., Katsioti M., Influence of colloidal nano silica on ultrafine cement hydration: Physiochemical and micro-structural characterization, *Constr. Build Mater.*, 35(2012), 347-360.

25. Feldman R.F., Sereda P.J., A model for hydrated Portland cement paste as deduced from sorption-length change and mechanical properties, *Materials and Structures*, 6(1968), 509-519.

26. Mohamed Heikal., A.I. Ali., M.N. Ismail., S. Awad N.S. Ibrahim., Behavior of composite cement pastes containing silica nano-particles at elevated temperature, *Constr. Build Mater.,* 70(2014), 339–350.

27. Sanchez F. and Sobolev K., Nano Technology in concrete - a review, *Constr. Build Mater.*, 24(2010),2060-71.

28. Bjornstrom J., Martinelli A., Matic A., Borjesson L. and I. Panas, Accelerating effects of colloidal nano-silica for beneficial calcium–silicate–hydrate formation in cement, *Chemical Physics Letters,* 392 (2004), 242–248

29. Ji T., Preliminary study on the water permeability and microstructure of concrete incorporating nano-SiO_2, *Cem. and Con. Res.,* 35(2005), 1943–1947.

30. Aitcin, P. C. Hershey, P.A. and Pinsonneault, Effect of the addition of condensed silica fume on the compressive strength of mortars and concrete, *American Ceramic Society*, 22 (1981), 286-290.

31. Berra M., Carassiti F., Mangialardi T., Paolini A.E., Sebastiani M.), Effects of nanosilica addition on workability and compressive strength of Portland cement pastes. *Constr. Build Mater.*, 35(2012), 666–675.

32. Bhanja S., Sengupta B., Influence of silica fume on the tensile strength of concrete. *Cem and Con Res.,* 35(2005), 743–747.

33. Campillo I, Dolado JS, Porro A, High performance nano-structured materials for construction. In: Bartos PJM, Hughes JJ, Trtik P, Zhu W, editors. *Proceedings of the 1st international symposium on nanotechnology in construction, Paisley, UK* (2003), 215-25.

34. Diab A.M., Awad A.E.M., Elyamany H.E., Elmoaty M.A., Guidelines in compressive strength assessment of concrete modified with silica fume due to magnesium sulphate attack. *Constr. Build Mate.*, 36(2012), 311–318.

35. Givi A.N., Rashid S.A., Aziz F.N.A., Salleh M.A.M., Experimental investigation of the size effects of Silica nano-particles on the mechanical properties of binary blended concrete. *Composites:* Part B 41(2010), 673–677.

36. Hosseinpourpia , A. Varshoee, M. Soltani P. Hosseini, H. Ziaei Tabari, Production of waste bio-fiber cement-based composites reinforced with nano-SiO_2 particles as a substitute for asbestos cement composites, *Constr. Build Mate.,* 31(2012), 105–111.

37. Heidari A., Tavakoli D., A study of the mechanical properties of ground ceramic powder concrete incorporating nano-Silica particles, *Constr. Build Mate.*, 38(2013),255–264.

38. IWGN, National Science and Technology Council, Committee on Technology, Interagency Working Group on Nanoscience, Engineering and Technology (IWGN), Nanotechnology: Shaping the world Atom by Atom.

39. Kyoung-Min Kim, Young-Sun Heo, , Suk-Pyo Kang, Jun Lee, Effect of sodium silicate- and ethyl silicate-based nano-silica on pore structure of cement composites, *Cem and Con. Res.,* 49(2014), 84–91.

40. Mohamed Heikal, A.I. Ali, M.N. Ismail, S. Awad, N.S. Ibrahim, Behavior of composite cement pastes containing silica nano-particles at elevated temperature, *Constr Build Mate.,*70(2014), 339–350.

41. Nima Farzadnia, Hossein Noorvand, Abdirahman Mohamed Yasin, Farah Nora A. Aziz, The effect of nano silica on short term drying shrinkage of POFA cement mortars, *Constr Build Mate.,*95 (2015), 636–646.

42. Prasad AS, Santanam D, Krishna Rao SV. Effect of micro silica on high strength concrete, National conference-emerging trends in concrete construction, CBIT, Hyderabad, India(2003).

43. Pacheco-Torgal, Jalali S., Nanotechnology: advantages and drawbacks in the field of building material, *Constr. Build Mate.*, 25(2011), 582–90.

44. Qing Y., Zenan Z., Deyu K., Rongshen C., Influence of nano-silica addition on properties of hardened cement paste as compared with silica fume. *Constr. Build Mate., 2(2007),* 539–545.

45. Quercia G., Hüsken G., Brouwers H.J.H., Water demand of amorphous nano silica and its impact on the workability of cement paste. *Cem and Con. Res.,* 42(2012), 344–357.

46. Roddy, Craig. W., Duncan O.K., Well Treatment Compositions and Methods Utilizing Nano- Particles. United States, patent No. 02777116 A1(2008)

47. U. Said A.M., Zeidan M.S., Bassuoni M.T. and Tian Y., Properties of concrete incorporating nano-silica. *Constr. Build Mate.*, 36(2012), 838–844.

48. Scrivener KL, Kirkpatrick RJ, Innovation in use and research on cementitious material. *Cem and Con. Res.*, 38(2) (2008), 128–136.
49. Siegel, R.W., Hu, E. and Roco, M.C, Nanostructure science and technology: a worldwide study; IWGN, September 1999.
50. Stefanidou M., Papayianni I, Influence of nano-Silica on the Portland cement pastes. *Composites: Part B*, 43(2012), 2706–2710.
51. Tanyildizi H., Coskun A, Performance of lightweight concrete with silica fume after high temperature. *Constr. Build Mate.*, 22(2008), 2124–2129.
52. Zapata L.E., Portela G., Suárez O.M., Carrasquillo O, Rheological performance and compressive strength of super-plasticized cementitious mixtures with micro/nano-Silica additions. *Constr. Build Mate., 41(2013),* 708–716.
53. Zhang M.H., Li H, Pore structure and chloride permeability of concrete containing nanoparticles for pavement. *Constr. Build Mate., 25*(2011), 608–616.
54. Zhang M.H., Islam J., Peethamparan S. Use of nano-silica to increase early strength and reduce setting time of concretes with high volumes of slag. *Cem and Con Comp.,* 34(2012), 650–662.