Effect of nano silica on the performance of cementitious grout for ground modification

Rajendiran Vadivel \(^1\) and V.K Stalin \(^2\)

\(^i\) Research Scholar, Department of Civil Engineering, CEG, Anna University, Chennai - 600025, India.
\(^ii\) Professor, Department of Civil Engineering, CEG, Anna University, Chennai - 600025, India.

ABSTRACT

Growing infrastructure development gives rise to new advancements in construction industry. Nanotechnology contributes to the construction industry development by improvements made in the engineering properties of construction materials from the micro to the macro level as nano-composites. Cement plays a vital role in geotechnical applications as a chief material for wide range of ground modification techniques. Grouting is one of the techniques extensively applied to enhance advantageously the properties of different soil profiles and grain size with good reports of improved performance. This paper discusses the performance study made on a neat cementitious grout incorporated with nanosilica (nSiO\(_2\)). This study has been performed on the grout with a w/c ratio 1.20 at 0\%, 0.10\%, 0.50\%, 1.0\%, 1.50\% of nanosilica dosage to cement content. Various rheological properties of the grout were studied along with permeation grouting onto a coarse sand column. It has been found that the nano silica enriched cementitious grout results in higher groutability, flowability with controlled bleedability with higher efficiency; reduced permeability and remarkable changes in the compressive strength.

**Keywords:** Cementitious grout, rheology, bleedability, compressive strength, nano-composite grout, nano silica, permeability, permeation grouting.

1 INTRODUCTION

Booming growth of developments in infrastructure, requirements for urban area development with land constraints gives rise to geotechnical engineering challenges for optimum utilization in problematic soils. Proactive designing for the ground modification challenges the geotechnical engineers to apply a wide range of stabilization techniques. Grouting provides technical solutions for a wide range of ground modification works with variable grain size. Major advances in the development of new modified grouts, leading to a better understanding of fluid and set properties and ability to control them have been reported (Bruce et al 1997).

Grouting is one of the techniques widely applied in the construction industry for ease of applicability and repairing as a ground modification technique applicable for various profiles of soil as well as various grain sizes of problematic underlying soil profiles. Its application for different grain sizes has been reported (Stalin and Saranya. 2009).

In Geotechnical works, problematic sub soils such as different loose soil and marine clay profiles impact and present difficulties in the execution of works over them. Jet grouting covers all grain sizes of soils and provides a curtain and a substantial layer for working above them. Large volumes of neat cement grouts are pumped under high pressure to stabilize ground. Large quantities of cement are used generally to produce the sacrificial substantial layer and strutting action. Grout mix with existing soil forms a soilcrete, which can perform with an increased bearing capacity and exhibits strength to resist (Vadivel 2006).

Nanotechnology influences the world intensely to enter into an in-depth study over various properties of materials. The evolution impacts on molecular and atomic levels that exhibits different phenomenon of various properties of the materials at macro level. The revolution was initiated by physicist Richard P.Feynmen in his noble lecture given at California Institute of Technology in the year 1959 “There is Plenty of room at the bottom” (Feynman 1960). Development of application of nanotechnology was expanded and enlarged in various field of science and technology. Application of nanotechnology is wide spread in the last few decades in various field of engineering and technology. The nanotechnology studies applied at atomic level were achieved early in chemistry, in molecular and atomic level studies. Subsequently, biological studies on application on drug delivery system and studies on DNA structures and in physics with various nano level approaches.

http://doi.org/10.3208/jgssp.OTH-32
Exercise of nanotechnology in the construction industry is an innovative approach breaking the conventional techniques and applying new ones. Production of nano-composites incorporating nanomaterials, which exhibit novel properties are being attempted. Nanotechnology with its potential for development, advancement of categorization and eventual prediction and control of properties of materials at a sub-micron level is the need of the hour. Applications of Nanotechnology are expected to be much more efficient and effective in the use of basic resources for economical and environmentally sustainable products with improved engineering material properties.

2 STUDY

This study focuses on a neat cementitious grout in the enhancement of its engineering properties by incorporating nanosilica (nSiO$_2$) as additive/filler in cement replacement techniques which provide wide property variations compared to conventional processes.

Cement is a larger contributor worldwide in the construction industry as well as carbon footprint. As a green initiative, development of techniques to come out with new composites to reduce the cement consumption substantially with enhanced properties is necessary.

2.1 Cementitious grouts and grouting techniques

Cement is a widely applied grouting material along with various other grouting materials. Application of cementitious grout in due course of novelty of its enrichment of applied soil properties reaps with engineering parameters. Cementitious Grouts, compound mixture of assigned water cement ration(w/c ratio) along with additives or fillers, admixtures such as retarders, activators etc., The governing control parameters of a grout are as minimal bleed potential, viscosity, agglomeration, rheology, stable, durability, strength characteristics.

Studies carried out in the cement grout by various researchers, (Hously, 1990) discussed in brief about the cement grout along with various application and types of cement grout as well as applicability of the same.(Nonveiller,1989) Grouting has a wide application in modern civil engineering such as to connect distinct structural elements in a homogeneous structure by injecting the seams between them with grout compounds, to fix reinforcing cables in precast and pre-stressed concrete structures, to lift and erect leaning structures and buildings, for rehabilitation and reinforcement of old defective masonry or historical buildings and many other applications(Bruce and Chuaqui et al 2003) High Mobility Grout (HMG) with low viscosity and driven a logic and principle involved along with various properties. Various properties such as Viscosity, setting time, bleed, compressive and flexural strengths and resistance of the grout to sulfate attack have been studied.(Akbulut and Saglam,W. et al 2002) studied the effect of w/c ratio in predicting the groutability.

Groutability increased on increasing w/c ratio but the increase in w/c ratio resulted in the increase in permeability of the grouted soil and decreased the strength.(Anagnostopoulos, et al.,2004) grouting is a process by means of which grout is injected into voids, fissures, cavities in soil or rock formations in order to improve the properties, specifically to reduce permeability, to increase strength or to lessen the deformability of the formations. The compressive strength and permeability characteristics of the grout is a property that relates directly to the efficiency of cementitious grout as well as effectiveness of groutability.

A high performance, non-shrinkable cement grout should be used to achieved excellent result in post tensioned concrete. A common problem associated with the grouting of bonded post tensioning tendons is the segregation of water from the grout mixture. There are two forms of bleeding in one form, water rises to top of the duct and the heavier cement and aggregates settle to the bottom due to difference in unit weights. In the other form, when the tendons are made up of strands, bleeding is due to the filtering action of the strands, but solid particles do not (Reynolds et al, 2008).

Grouting technique is a tailor made systematic process made based on the laboratory trial and error method with optimal parameter achievements, for particular activity or work area which planned according to the requirement where it is to be and how? The primary area starts with design of grouts with well-known properties; this can be achieved by conducting grout mix design.

The grout must satisfy basic parameters such as Flowability or pumpability said to be High Mobility Grout (HMG), Rheological properties. High Mobility Grout using cement stated if the fluid properties of the grout change in an uncontrolled or unpredictable manner with time it is therefore not possible to properly control or analyses the injection process. With the exception of a thixotropic grout, it is typically desirable for a grout to maintain a constant viscosity for a period of time equal to the injection time and then for its viscosity to increase rapidly until initial set is reached. Thixotropic grouts have a low viscosity while being in turbulent motion (being sheared during injection) and much higher viscosity when no shear is applied. This property is beneficial when injecting grouts into open voids because the grout can be placed where it is desired without it flowing away after pumping ceases. For HMG, these properties include bleed, segregation, resistance to pressure filtration, control of particle agglomeration, anti-washout characteristics, rheology, evolution of cohesion and viscosity(Bruce, et al 1990, 1997)and (Chuaqui and Bruce, 2003).
The viscosity of a grout at a given age is typically indexed with a Marsh Funnel for grouts ASTM C-939 states; Water has a “Marsh time” of 26+/−0.50 seconds per 946ml (1 US quart). When the Marsh time is in the range of 35 to 50 seconds said to be low viscosity. A Correlation exists between apparent viscosity and true viscosity of the fluid (Deere, 1992).

Jet grouting, the process of ground improvement by employing high pressure jet to erode soil strata underneath. The technology popularized in world by mid-1970’s and the application of high pressure jet by pumping cement grout through a small nozzle located on bottom of drill rod(Schafer, et al, 1997) Cement grouts are said to be particulate grouts and also called as suspension grout. Solutions of chemical based grouts contain homogenous mixture of two substances. The micro fines exist with suspended particle diameter less than 10µm; chemicals with particle size around 10 to 15nm are developed (USACE, 1995). Jet grouting into marine clay reaps an enhancement of engineering properties of the medium, a wide application of JGP to enrich the mechanical properties of the marine clay, a cement grout of water cement ratio of 1:1 was made into marine clay and provided subsurface barrier (Vadivel,2006).

2.2 Nanosilica on engineering properties cementitious material

The mechanical properties of mortars with nSiO$_2$ and found demonstrate an increase in compressive strength of mortars with developed nanoparticles at early stages of hardening followed by the strength reduction at later age (vs. the reference). Addition of super plasticizer was proposed to overcome this obstacle. Super plasticized mortars with selected nSiO$_2$ demonstrated a 15-20% increase of compressive strength, reaching up to 144.8 MPa at 90-day age. Mechano-chemical activation was found to be effective method to improve the strength of cement-based materials. It was proposed that this process is governed by the solid state interaction between the organic modifiers and cement. During this process the surface of cement particles attaches the functional groups introduced from the modifiers; so the organomineral nano-layers or nano-grids are formed on the surface of cement. The developed high-performance cements demonstrate the 28-day compressive strength at the range of 93 - 115 MPa, which is higher than 72 - 89 MPa (Sobolev,2006).

2.3 Cementitious grout – nano Silica (nSCG)

Laboratory experimental study has been made on the neat cement grout and nano silica incorporated cementitious grout. Test has been made on a sand column made up of coarse sand of size > 2.36mm. Keeping water cement ratio as constant at 1:1.2 along with variation in nSiO$_2$ at 0.00% (neat cement grout / control reference), 0.10%, 0.50%, 1.0% and 1.50%.

Testing on Grout mix exhibit the basic rheological parameter of viscosity, groutability, flowability, bleedability, initial and final setting time, shear strength. Over the cement grouted sand column, permeability, compressive strength.

2.5 Groutability of cementitious grout

Groutability (N) of cementitious grout has been carried out with empirical groutability ratio. $N = D_{15}/d_{85}$ and $N_c=D_{10}/d_{90}$ evaluating the penetrability of cement $N$; 41>24 and $N_c$; 30>11.

3 MATERIAL AND ITS PROPERTIES

3.1 Cement

Cement used for the study was Ordinary Portland Cement (OPC) confirming to grade 53, BIS:12269-1987. Fineness of 295m$^2$/kg, Setting time initial of 185min, final of 285min. Silicates C$_3$S and C$_2$S are the most important compounds and are mainly responsible for the strength of the cement paste. They constitute the bulk of the composition. C$_3$A and C$_4$AF do not contribute much to the strength. In the manufacturing process they facilitate combination of lime and silica, and act as a flux.

3.2 Sand

Coarse Sand used for the testing was sieved in accordance to BIS:2720(part4)-1985, retained materials at 2.36mm, water washed to remove fines in the sand has been taken and its specific gravity 2.64, with permeability of $K_{27}$ 13.76x10$^{-7}$cm/sec.

3.3 Nano-SiO$_2$(nS)

Colloidal silica is an aqueous suspension with presence of nano silica. The particles can range in size from 2 to 100 nanometers, although the particle size is fairly constant in a given suspension. In dilute solutions, colloidal silica has a density and viscosity similar to water. Colloidal silica is attractive as a potential grouting material because it has long, controllable gel times and excellent durability characteristics. It is also chemically and biologically inert and nontoxic. The nano silica used for study where commercially available colloidal silica “Cemsyn”.

Table 1 Extent of Chemical Compound in Cement

| S.No | Compound | Composition % |
|------|----------|---------------|
| 1    | C$_3$S   | 48-52 %       |
| 2    | C$_2$S   | 22-26 %       |
| 3    | C$_3$A   | 6-10 %        |
| 4    | C$_4$AF  | 13-16 %       |
| 5    | Free lime| 1-2 %         |
Table 2 Properties of nSiO$_2$

| Property                        | Value  |
|--------------------------------|--------|
| Conforming to CAS              | 7631-86-9 |
| % of active nSiO$_2$ (%wt/wt)  | 30%    |
| pH                             | 10     |
| Specific Gravity (g/cc)        | 1.40   |
| Molecular mass                 | 60.08  |
| Viscosity                      | 12 sec |

Fig 1. (a) SEM and (b) EDS analysis of nano Silica

Fig 2. (a), (b) Cementitious Grout Testing Process

Fig 3. Bleedability of Cementitious Grout
4 GREEN INITIATIVES

4.1 Green Nanotechnology

Development of green nanotechnology tends to be clean technologies, "to minimize potential impact to environmental and human health risks associated with the manufacture and use of nanotechnology products, and to encourage replacement of existing products with new nano-products that are more contribute environmentally friendly throughout their lifecycle.

Green nanotechnology has two goals: Producing nano-composite and products without harming the environment or human health, and Producing nano-composite that provide solutions to environmental problems. It uses existing principles of green chemistry and green engineering to make nanomaterial and nano-composite without toxic ingredients, at low temperatures using less energy and renewable inputs wherever possible, and using lifecycle thinking in all design and engineering stages.

In addition to making nano-composite and products with less impact to the environment, green nanotechnology also means using nanotechnology to make current manufacturing processes for non-nano materials and products more environmentally friendly.

For example, nano-composite carbon filter for water may filter harmful pathogens not minerals, nano scale membranes can help separate desired chemical reaction products from waste materials. Nano scale catalysts can make chemical reactions more efficient and less wasteful.

Initiative, there is a future study possibilities to reduce consumption of cement, as there is an incremental increase in strength, groutability, increase in flowability and reduction in bleedability.

5 RESULT AND DISCUSSIONS

5.1 Fresh Grout Properties

Cementitious grout after mixing various properties studied.

Bleeding test was measured in accordance with ASTM C940 over the trial of mixing, it has been noticed that the bleeding potential was rapidly down with increase in colloidal nano silica. The Neat cement grout found to be unstable and high bleedability noticed whereas the nanosilica incorporated grout shown that reduction in bleedability at addition of nS 0.10% efficient by 33% simultaneously 0.50% at 38%, 1.00% at 50% and 1.50% at 72% with reference to control.

The rheology of cementitious grout, viscosity of the grout was tested in accordance to API practice 13B-1 with marsh cone, flown of 946ml of grout passes thru 4.76mm nozzle, time taken for grout to flow where taken. CG takes 31 sec and in nSCG found less than that of neat cement grout, Indicates the nano acts a n viscosity modifying agent and incorporated grout is flowable with high yields high pressure and mobility. Specific gravity of the grout was measured in accordance to API practice 13B-1 with mud balance, the grout shown slightly lesser than neat cement grout.

Gel strength of the grout was measured in accordance with API practice 13B-1 with shear-o-meter. It has been noticed that the grout within 60 min after mixing has shown 20% (refer fig.3) lesser than neat cement grout. Setting time was studied by vicat needle apparatus; it has shown that nano silica incorporated grout has extended initial setting time against neat cement grout.

5.2 Engineering Properties

Permeability test was conducted over the grouted coarse sand sample exhibits $k_p = 10^{-6}$ to $10^{-7}$ shown that the water penetration into the nano cementitious grouted specimen was more impermeable than that of neat cement grout.

Compressive strength of the grouted specimen was shown that there is a differential enhancement of 1.60 times than that of neat cement grout.

6 CONCLUSIONS

In accordance with the above results and review of influence of nanotechnology by incorporation of nanosilica into concrete and geotechnical field. The assessment of colloidal nanosilica in cement grout used for grouting, where there is a possibilities for reduction in consumption of cement by optimal utilization for ground modifications, the high carbon footprint producer worldwide.

Nanosilica added cementitious grout shows enhancement of engineering properties as well as the fresh mixed grout properties.
Nanosilica (nS) acts as a viscosity modifying agent and as a substantial bleedability controller with increase in % of nS enlist. The compressive strength characteristics are increase with nS.

Nanosilica (nSiO$_2$) reacts at cement hydration process at C-S-H crystallization interface. Provided strong bonding and reduced permeability potential. It may give raise to reduction of size of grouting requirement substantially in like manner may reduce cement consumption. Towards green initiative, the cement consumption may reduce consequently, carbon footprint.

ACKNOWLEDGEMENT

The study is the part of research work carried out by author under guidance of Professor Dr. V.K. Stalin in Division of Soil Mechanics and Foundation Engineering, Department of Civil Engineering, Anna University.

REFERENCES

1) Feynman R., (1960) 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.
2) Hously, A.C., (1990), “Construction and Design of Cement grout”, John Wiley & Sons Inc.,
3) Bruce, D.A., G.S. Littlejohn, and A. Naudts. (1997). “Grouting Materials for Ground Treatment: A Practitioner’s Guide,” Grouting – Compaction, Remediation, and Testing, Proc. of Sessions Sponsored by the Grouting Committee of the Geo-Institute of the American Society of Civil Engineers, Logan UT, Ed. by C.Vipulanandan, Geotechnical Special Publication No. 66, July 16-18, pp. 306-334.
4) Chuquii, M. and D.A. Bruce. (2003). "Mix Design and Quality Control Procedures for High Mobility Cement Based Grouts." Grouting and Ground Treatment, Proceedings of the Third International Conference, Geotechnical Special Publication No. 120. Edited by L.F. Johnsen, D.A. Bruce, and M.J. Byłe, American Society of Civil Engineers, New Orleans, LA, February 10-12, pp. 1153-1168.
5) Deere, D.U.L.,(1982): “Cement-Bentonite grouting for Dams,” Proceedings of the ASCE Specialty Conference in Grouting and Geotechnical Engineering, New Orleans, Louisiana, pp 279-300.
6) Rajendiran Vadivel (2006), Ground Improvement using Jet Grout Pile for tunnelling in soft marine clay, Proc. of the Indian Geotech. Int’l Con., India, pp 905-908.
7) Rajendiran Vadivel and Stalin.V.K., (2013), Performance assessment of cement grout by incorporating nanomaterials, Proc. of the Adv. Nanomaterials and Emerging Engineering Technologies (ICANMET), Int’l Conf., India, pp 706-712.
8) Schafer, V. et al (eds.) (1997)“Ground Improvement, Ground reinforcement, Ground treatments 1987-1997” ASCE, 113-125 pp.
9) Sobolev.K., et al.(2006): Development of nano-SiO$_2$ based admixtures for high-performance cement-based materials. Progress report, CONACYT, Mexico
10) Sobolev.K., and others (2006) “Nanomaterials and Nanotechnology for High-Performance Cement Composites”,Proceedings of ACI Session on “Nanotechnology of Concrete: Recent Developments and Future Perspectives” November 7, 2006, Denver, USA
11) F. Sanchez, Sobolev.K., et al.,(2010) Nanotechnology in concrete- A Review, Construction and Building Materials 24; 2060–2071
12) Stalin.V.K., Saranya.K., (2009) “Tree Root Grouting Method of Soil Improvement – A New Approach”, Geotide, IGC 2009, Guntur, India.
13) Roco, M.C., Williams, R.S., Alivisatos, P. (Eds.),(1999) Vision for Nanotechnology R&D in the Next Decade, IWGN Report on Nanotechnology Research Directions, National Science and Technology Council, Committee on Technology.
14) USACE 1995 U.S. Army Corps of Engineers, Chemical Grouting-pdf” publication no. EM1110-1-3500, Available http://www.usace.army.mil/inet/usace-docus/eng-manual/ce cw.htm (Accessed on 01.06.2013)