DOI:10.21276/sjeat.2016.1.3.1

Saudi Journal of Engineering and Technology
Scholars Middle East Publishers
Dubai, United Arab Emirates
Website: http://scholarsmepub.com/

ISSN 2415-6272 (Print)
ISSN 2415-6264 (Online)

Research Article

The Effects of Using Nanomaterials to Improvement Soft Soils

Zaid Hameed Majeed[1*], Mohd Raihan Taha[2]
[1]Lecture, Department of civil engineering, college of Engineering, University of Babylon, Babil, Iraq
[2]Professor & Director, Institute for Environment and Development (LESTARI),Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, MALAYSIA, and Professor, Dept of Civil & Structural Engineering, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia

***Corresponding Author:**
Zaid Hameed Majeed
Email: zaidalhaswan@yahoo.com

Abstract: Tests were conducted to investigate the influence of using nanomaterials in the modification and stabilization of soft soil. The soft soils were collected from two different sites and treated with three nanomaterials (nano-copper, nano-alumina, and nano-magnesium). Nanomaterials were added in small amount (≤ 1.0%) by dry weight of the soil. Laboratory tests to determine the compaction characteristics and unconfined compressive strength were performed. Results of the investigation showed significant improvement in maximum dry density, and unconfined compressive strength. The improvement is dependent on the type of nanomaterials. The unconfined compressive strength and maximum dry density increased as the nanomaterials content increased until reach a percentage after which the strength will be decrease. Nanomaterial contents in excess of the optimum content cause agglomeration of particles that adversely affects the mechanical properties of the soils. In general, the addition of finer particles such as nanomaterials, even at low doses, could enhance the geotechnical properties of soil. Also considering the possible negative environmental effects of chemical addition to soils, the possibilities of using nanomaterials as stabilizing agents of soft soils this combined admixture is intended to reduce the cost and promote a more environment-friendly and sustainable stabilizing agent.
Keywords: Soil stabilization, soft soil, nanomaterials, unconfined compressive strength, SEM.

INTRODUCTION

Soft soils can usually be found in areas with high water content. At natural water contents approaching that of the liquid limit the soil experiences high settlement potential and low shear strength. Thus, for construction to take place on such soils, a stable foundation should bepreparedandachieved to satisfy preconstruction and post construction bearing capacity and settlement criteria.

Construction on soft soils in many civil engineering projects has prompted the introduction of many approaches for soil improvement particularly stabilisation. According to Kolias *et al.* [1] soil stabilisation is a traditional strategy used to enhance soils to fulfil the specifications of different kinds of projects. A number of studies have focused on stabilising soft soils using various additives. Traditionally, materials such as cement, lime and mineral additives such as fly ash, silica fume, and rice husk ash have been used in the past for improving soils[2].

Nanotechnology revolves around the creation and application of a varied collection of NM i.e. nanomaterials. This basically encompasses NP i.e. nano-particles along with nano objects. NM are known to be 100 nm lower in terms of their dimension whereas nano objects fall two dimensions lower than the same.

At the micro scale, most of the properties remain approximately the same as those for bulk materials. The decrease of one or more geometric dimensions down to the nano scale completely modifies the behaviour of the material[3]. Thus, at the nano scale, a higher ratio of surface to volume and a higher cation exchange capacity exists. Nanoparticles interact very actively with other particles and solutions, and very minute amounts may lead to considerable effects on the physical and chemical properties of a material. Gravitational force at the nano scale can be disregarded. Instead, electromagnetic forces are dominant[4].

During the recent years, there has been a great deal of interest in nanoparticles due to the many technological applications also attempt was made for rapid, low cost and eco-friendly green approach for nanoparticles. These useful features of the biosynthesized nanoparticles may benefit in agriculture, biomedical, and engineering sector [5].

This paper presents the results of a systematic investigation on the effects of the addition of nanomaterials on soft soil on their compaction characteristics and unconfined compressive strength.

MATERIALS AND METHODS

Soft soil samples were collected from two sites in Malaysia. Specifically, soils1 (S1) and 2(S2) were obtained from Transkrian, in the State of Penang and Banting, in Selangor, Malaysia, respectively. All samples were disturbed soils collected from 0.5 m to 1.0 m below the ground surface. They were collected from the bottom of the borrow pit through excavation by hand shovels. Table 1 shows the index properties, grain size fractions, classification of the soils used in the present study. The specific gravity of soil S1 is quite low due to its high organic content compared to soil S2. Thus, soil S1 is classified as organic (OL). The soils are also quite acidic which is very typical for soils in the tropical climates.

Soil samples were compacted at maximum dry and optimum moisture content using the standard compaction test method before and after adding the nanomaterials (i.e., nanoCuO, nanoAl2O3, and nanoMgO). The standard Proctor compaction test was carried out to determine the moisture content-dry density relationship according to ASTM D 698 specifications.

Compacted specimens were obtained by inserting tubes with a diameter of 38 mm into the soil using a compression machine. Specimens were extracted from these tubes by an extruder, and then cut into 89 mm long specimens. All specimens were tested immediately after preparation using a test conducted according to ASTM (D2166-65).

Table 1:Physical and chemical properties of the soft soils

Characteristic	Standard	Value and description	
		S1	S2
Organic content (%)	ASTM D 2974	12.17	1.31
Specific gravity	ASTM D 854	2.42	2.75
pH	ASTM D4972	3.24	4.25
Clay fraction (%)	ASTM D 422	29.8	36.2
Silt fraction (%)	ASTM D 422	31.3	31.3
Sand fraction (%)	ASTM D 422	38.9	32.5
Liquid limit index (%)	BS 1377 part 2 1990	46.35	50.61
Plasticity index (%)	BS 1377 part 2 1990	18.25	25.61
Linear shrinkage (%)	BS 1377 part 2 1990	11.07	8.24
Unified soil classification (USCS)	ASTM D 2488	OL	CH
Optimum water content (%)	ASTM D 698	21.60	24.80
Maximum dry unit weight (kN/m^3)	ASTM D 698	14.44	15.68

The Table 2 below illustrates some of the main characteristics of the nanomaterials which are used in this study. It is apparent from this table that the a nano-copper oxide with a purity of 99.99%, nano-alumina (Al_2O_3) powder with a purity of 99.99%, and a nano-magnesium oxide with a purity of 99.9%, all of which were supplied by Inframat Advanced Materials, Manchester, CT, USA. Moreover, it can be seen that the nano-copper powder has the largest specific gravity of 6.40 with an average particle diameter is about 100 nm. Meanwhile, the specific gravity of nano-alumina and nano-magnesium were 3.60 and the average particle diameter is ranged from 20 to 50 nanometre.

Table 2: Properties of the nanomaterials used in this study

Property	Nano CuO	Nano Al_2O_3	Nano MgO
Formula	CuO	Al_2O_3	MgO
Specific gravity	6.40	3.60	3.60
Average particle size (nm)	100	20-50	25-30
Surface area (m^2/g)	>150	>50	N/A
Purity (%)	99.99	99.99	99.90
Appearance	Black powder	White	White

RESULTS AND DISCUSSION

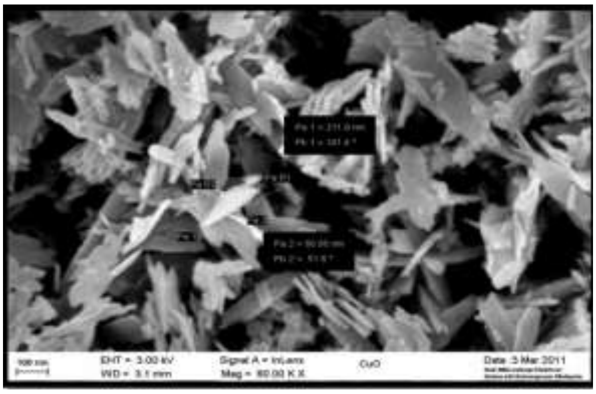
Figure 1 show the nanomaterials used in the study under SEM. The relationships between the maximum dry density and optimum water content of different nanomaterials (i.e., nanoCuO, nanoAl_2O_3, and nanoMgO) are shown in Figure 2and 3. These figuresshow that increasing nanomaterial contents were associated with decreasing optimum water content and increasing maximum dry density for all soils except S1. The decrease in moisture content is related to the tendency of nanomaterials to absorb water from moist soil, as described previously. Moreover, the addition of nanomaterials powder decreases the optimum water content in soil due to the high surface area of nanomaterials particles[3]. Also the decrease in water content results in a decrease in number of voids in soil matrix[6].

The increase in the maximum dry density is possibly due to the particle densities of nanomaterials which are greater than the particle density of the natural soils. Furthermore, the nanomaterials particles reduced the porosity by filling the space between soil particles and bonded the particles together. For soil sample S1, the nanomaterials added to the soil increased both the maximum dry density and the optimum water content. An increase in the maximum dry density generally indicates soil improvement in terms of soil strength. In addition, this is in line with Das and Sobhan [7] who mentioned that the factors that affect compaction included the particle size and specific gravity of the soil and the stabiliser. The increase in optimum moisture content is attributed to the additional water held within the flocculent soil structure due to the excess water absorbed, resulting from the porous nature of the soil. The essence of this additional water can be justified by the presence of organic material in the soil.

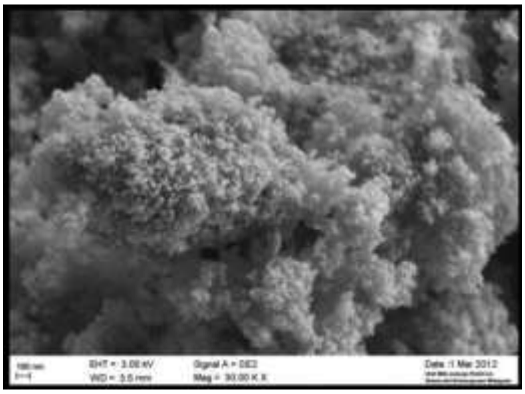
The unconfined compressive strength of specimens with different percentages of nanomaterials is shown in Figure 4. Increasing the amounts of nanomaterialsled's to an increase in the unconfined compressive strength. A general trend of increasing unconfined compressive strength with increasing nanomaterials content was observed as shown in Figure 4.

The results indicate that the maximum shear strength it's obtained from soil treated with nano-copper. Soil to which nano-copper had been added showed hardening and improved strength compared with soil specimens that contain other nanomaterial additives. That may due to the heights specific gravity for the nano-copper compared to the other nanomaterials.

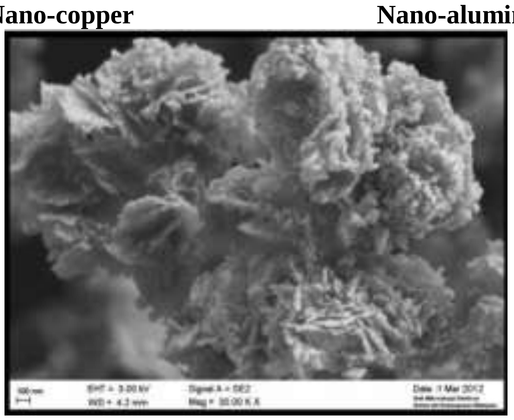
However, beyond the optimum nanomaterial content, further increasing the nanomaterial contents only slightly affected the unconfined compressive strength. For example, the results show that an increase of 662.7% in the compressive strength of soil sample S2, which represents an increase from 43 kPa for the control soil (i.e., the soil without the nanomaterial) to 328 kPa for the soil with 0.7% nano-copper, meanwhile the increase of 532% in compressive strength of 1% nano-copper. That significant increases in the soil compressive strength were also obtained using the other nanomaterials considered in this study (i.e., nano-alumina, and nano-magnesium) at less than 1% nanomaterial content.



Nano-copper



Nano-alumin



Nano-magnesium

Fig-1: The nanomaterials used in the study under SEM

The increase in the unconfined compressive strength, as previously mentioned is attributed to the chemical reaction between nanomaterials and fine-grained soil. Figure 5 (a) Illustrates a micrograph of S2 soil sample treated and stabilized with 0.1% nano-alumina (optimum alumina content). The micrograph illustrates the formation of ettringite (rod-like crystals) and filling the pore spaces. These crystals also attached the nanoparticles and soil particles together subsequently possibly led to the overall increase in the strength of the whole matrix. Figure 5 (b) Illustrates a micrograph of S2 soil sample treated and stabilized with 0.3% nano-magnesium and the micrograph shows the growth of ettringite crystals on the surface of clay-relics and nano-magnesium particles nucleated with ettringite crystals.

As shown in Figure 5 (a and b), the soil-nano-nanomaterials mixtures micrographs illustrate the new phase consists of an interlocking network of needle like crystals. After that, bridges are formed between adjacent soil particles. These interlocking networks of needle like crystals have grown into the interstices to form a continuous network. That will be explained in terms of improvement of strength of soil.

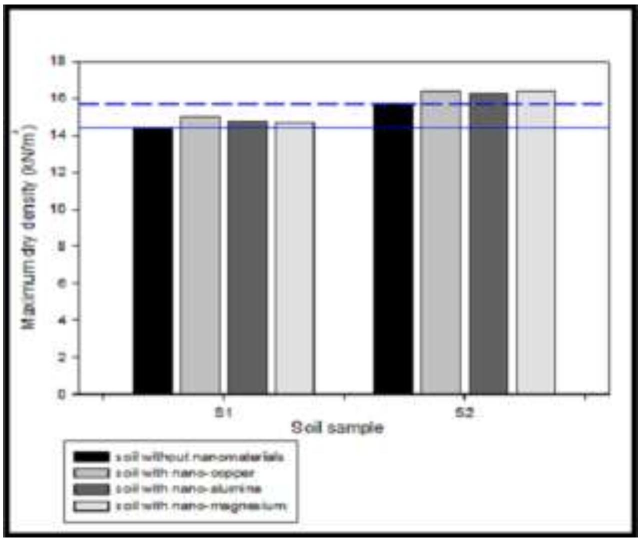


Fig-2: The effect of nanomaterials on the maximum dry density, □$_{d(max)}$

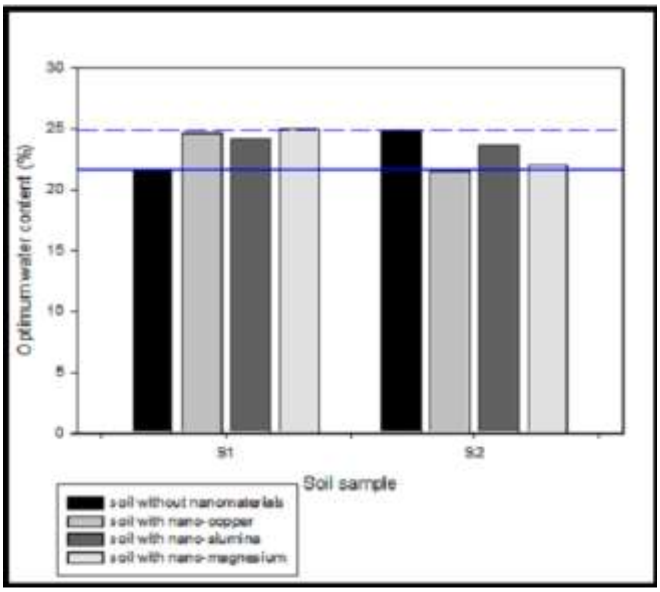


Fig-3: The effect of nanomaterials on the optimum water content, w_{opt}

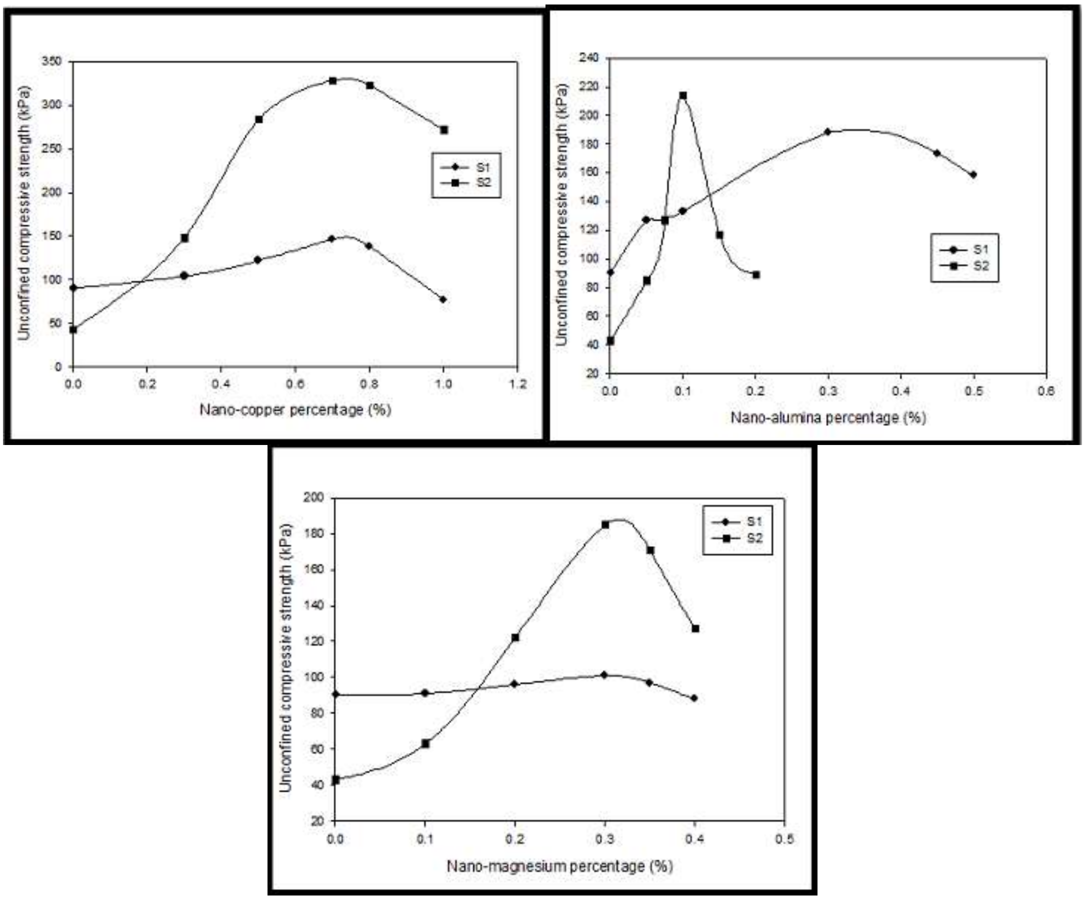


Fig-4: The effect of nanomaterials on the unconfined compressive strength, UCS

The increase of nanomaterial more than the optimum limit may possibly result from agglomeration in nanomaterial particles which in turn cause an increase in the void ratio then decrease in density and increase in water content there was evidence of particles agglomeration which in turn affected the mechanical properties of soils negatively.

Agglomeration is a natural phenomenon which involves the sticking of particles to one another or to solid surfaces causing size enlargement. According to Ferkel and Hellmig[8], the agglomeration of nano scaled powders increases the amount of necks between particles and therefore decreases the soil density.

These are shown in Fig 6 in which the SEM photos show soil sample S1 which was mixed with 0.8% nano-copper (Figure 6 (a)) and 1.0 % nano-copper with S2 (Figure 6 (b)). The nano-copper particles agglomerated when the nano-copper content was increased more than the optimum nanomaterials content (0.7% nano-copper content). Note that all photos were taken at same magnification (25000 KX).

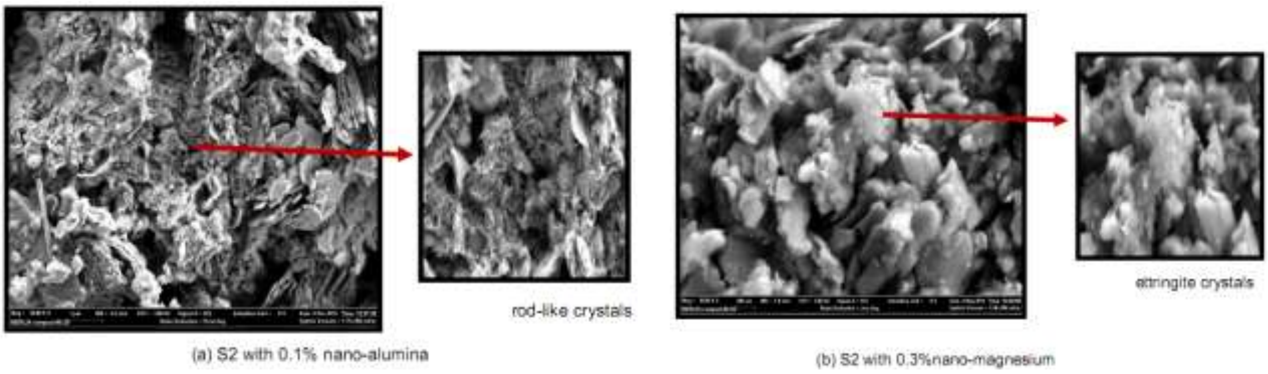
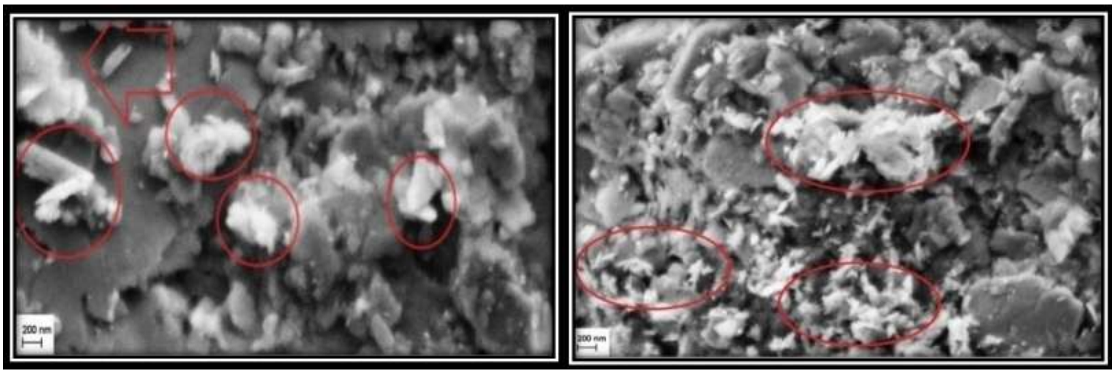


Fig-5: SEM-micrograph of the chemical action of nanomaterials

CONCLUSION

This investigation was conducted to study the effect of addition of three nanomaterials (i.e., nanoCuO, nanoAl2O3, and nanoMgO) on some geotechnical properties soft soil. The dry unit weight, moisture content, and compressive strength of the soil were determined. The dry density increased with increasing nanomaterial percentage and the unconfined compressive strength of the soil increased with nanomaterial addition. On the other hand, the moisture contents of the soil mixtures decreased with increasing nanomaterial percentage. In addition, when the nanomaterial content exceeded the optimum amounts, there was evidence of particles agglomeration which in turn affected the mechanical properties of soils negatively. In general, the addition of a small amount of nanomaterials, i.e. not more than 1%, leads to enhancement of soil geotechnical properties by increasing the compressive strength and durability for all tested soils. These results show that nanomaterials can be used to improve soil strength and other soil properties. However, further research is required to fully examine its suitability to provide cost effective materials for soil improvement.



(a) S1 with 0.8 % nano-copper **(b) S2with 1% nano-copper**

Fig-6: Agglomeration of nano-copper beyond its optimum content

ACKNOWLEDGEMENTS

The authors would like to acknowledge the technical staff of the Soil Mechanics Lab in the Faculty of Engineering of Universiti Kebangsaan Malaysia for their assistance in the experimental work.

REFERENCES

1. Kolias, S., Kasselouri-Rigopoulou, V. & Karahalios, A. (2005). Stabilisation of clayey soils with high calcium fly ash and cement. *Cement and Concrete Composites* 27(2): 301-313.
2. Al-Rawas, A. A. & Goosen, M. F. A. (2006). Expansive soils: Recent advances in characterization and treatment, Taylor & Francis, London,
3. Taha, M. R.& Taha, O. M. (2013). Crack control of landfill liner and cap materials using nano-alumina powder, in Manassero et al. eds., *Coupled Phenomenain Environmental Geotechnics*, 459-463.
4. Mercier, J. P., Zambelli, G. & Kurz, W. (2002). Introduction to materials science. *Elsevie*r, Paris, 461 pp.
5. Kajbafvala, A., Li, M., Bahmanpour, H., Maneshian, M. H. & Kauffmann, A. (2013). Nano/Microstructured materials, Rapid, low-cost, and eco-friendly synthesis methods. *Journal of Nanoparticles* 2013(3), Article ID 530170, 3 pp.
6. Bowles, J. E. (1992). Engineering properties of soils and their measurement. 4th Ed, McGraw-Hill, New York, 480 pp.
7. Das, B. M. and Sobhan, K. (2013). Principles of geotechnical engineering. Cengage Learning, Stamford, CT, USA, 768 pp.
8. Ferkel, H. & Hellmig, R. J. (1999). Effect of Nanopowder Deagglomeration on the Densities of Nanocrystalline Ceramic Green Bodies and Their Sintering Behaviour. *Nanostructured Materials* 11(5): 617-622.