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**Research Article**

# Stabilization of Soft Soil Using Nanomaterials

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**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 sites and treated with three nanomaterial types (nano-copper, nano-clay and nano-magnesium). Nanomaterials were added in small amount (≤1.0%) by dry weight of the soil. Laboratory tests to determine the Atterberg limits, linear shrinkage, compaction characteristics and unconfined compressive strength were performed. Results of the investigation showed significant improvement in maximum dry density, plasticity index, linear shrinkage 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. Thus, the addition of finer particles such as nanomaterials, even at low doses, could enhance the properties of soil.

**Keywords:** Consistency limit, nanomaterials, soft soil, soil stabilization, unconfined compressive strength

## INTRODUCTION

Soft soils can usually be found in areas with high water content, namely, approaching that of the liquid limit, which results in high settlement potential with low shear strength. Thus, a stable state should be achieved to satisfy preconstruction and post construction settlement and to ensure stable strength and deformation.

Construction on soft soils in many civil engineering projects has prompted the introduction of many approaches for soil improvement particularly stabilization. According to Kolias *et al*. (2005) 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 stabilizing soft soils using various additives. Traditionally materials such as cement, lime and mineral additives such as fly ash, silica fume and rice husk ash were used for improving soils (Al-Rawas and Goosen, 2006).

Nanotechnology revolves around the creation of a varied collection of Nanomaterials (NM). This basically encompasses Nano-Particles (NP) 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. The idea of nanotechnology was first introduced in the year 1959 in a lecture delivered by Feynman (1960) which was titled "there's plenty of room at the bottom". It is important to note though that at that time the term 'nanotechnology' did not exist yet. It was years later that this technology made a rapid and significant progress in the sciences.

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. 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 (Mercier *et al*., 2002).

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 (Kajbafvala *et al*., 2013). This study presents the results of a systematic investigation on the effects of the addition of nanomaterials on soft soil on their linear shrinkage, plasticity limit, compaction characteristics and unconfined compressive strength.

## MATERIALS AND METHODS

Soil samples were collected from two sites in Malaysia. Specifically, Soils 1 (S1) and Soil 2 (S2)

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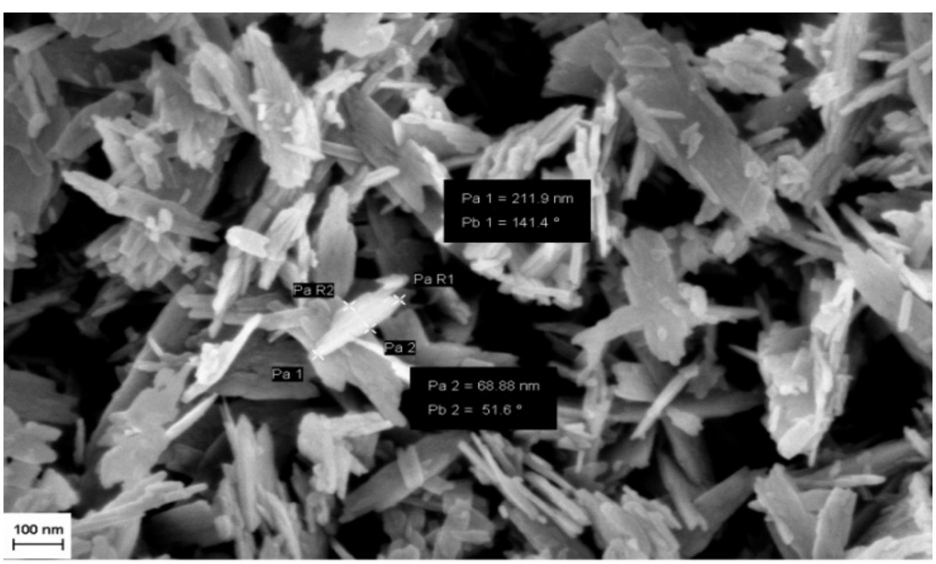
were obtained from Penang and Banting, respectively. All samples were disturbed soils collected from 0.5 to 1.0 m below the ground surface. They were collected from the bottom of the borrow pit through excavation by hand shovels. Table 1 shows the index properties, grain size fractions and classification of the soils used in the present study.

Three nanomaterials were used i.e., nano CuO, nano MgO and nano clay. Figure 1 show the nanomaterials used in the study under FESEM analysis. Soil samples were compacted at maximum dry density and optimum moisture content using the standard compaction test method before and after nanomaterials addition. The standard proctor compaction test was carried out to determine the moisture content-dry density relationship according to American Society for Testing and Materials specifications (ASTM D 698).

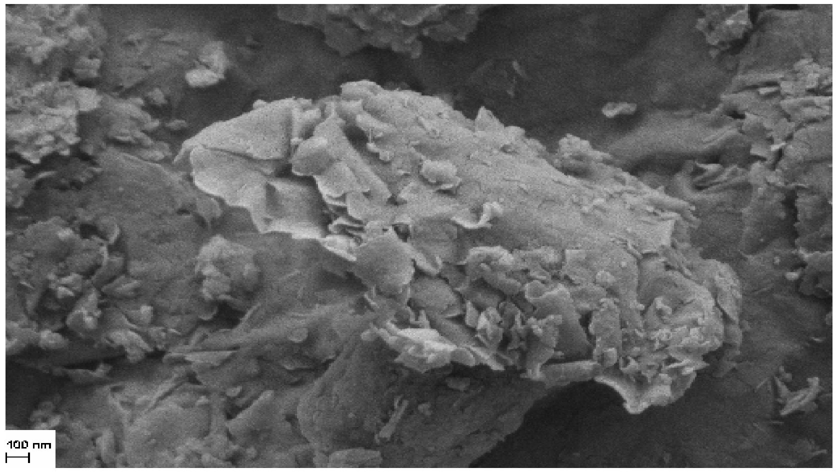
The liquid limit test was conducted using the cone penetrometer method apparatus according to British Standards (BS, 1377-part 2-90). The plastic limit test was conducted according to BS (1377-part 2-90). These tests were carried out to investigate the effects of nanomaterial addition on consistency limits. 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.

Table 1: Physical and chemical properties of the soils

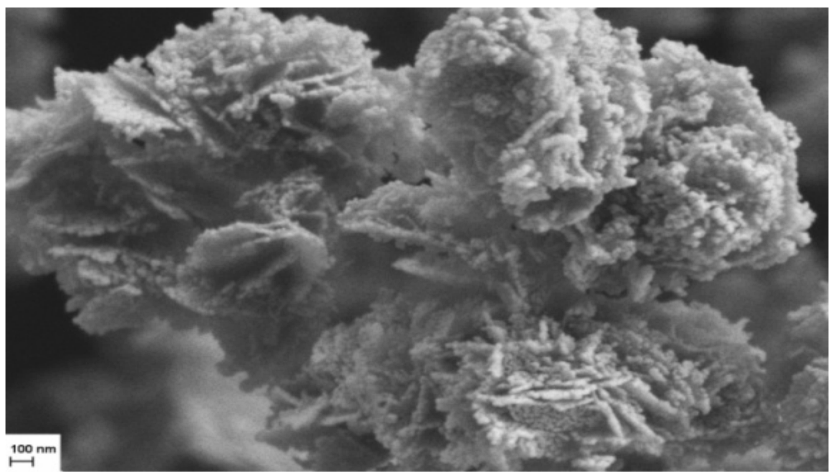
| Characteristic | Standard | Value and description S1 | S2 |
|---|---|---|---|
| Organic content (%) | ASTM D 2974 | 12.17 | 1.31 |
| Specific gravity | ASTM D 854 | 2.42 | 2.75 |
| pH | ASTM D 4972 | 3.24 | 4.25 |
| Clay fraction (%) | ASTM D 422 | 29.80 | 36.20 |
| Silt fraction (%) | ASTM D 422 | 31.30 | 31.30 |
| Sand fraction (%) | ASTM D 422 | 38.90 | 32.50 |
| 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 |
| Chemical composition | | | |
| $SiO_2$ (%) | | 61.72 | 57.03 |
| $Al_2O_3$ (%) | | 17.53 | 23.63 |
| $Fe_2O_3$ (%) | | 3.61 | 7.33 |
| MgO (%) | | 1.16 | 0.73 |
| CaO (%) | | 0.06 | 0.04 |
| $TiO_2$ (%) | | 0.89 | 1.80 |
| $Na_2O$ (%) | | 0.40 | 0.31 |
| $K_2O$ (%) | | 2.92 | 2.51 |
| Others | | 11.71 | 5.31 |




(a) Nano-copper




(b) Nano-clay




(c) Nano-magnesium

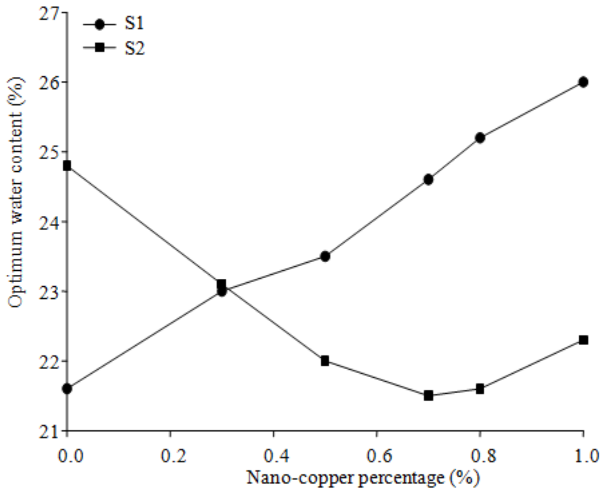
Fig. 1: The nanomaterials used in the study under SEM

These specimens were used to perform unconfined compression test immediately after preparation. This test was done according to ASTM (D2166-65).

## RESULTS AND DISCUSSION

The relationships between the maximum dry density and optimum water content with different nanomaterials (i.e., nano CuO, nano MgO and nano clay) are shown in Fig. 2 and 3. For S1, Figure 2 showed that the optimum water contents increased with increase the nanomaterials contents. In contrast, the optimum water content of S2 decreased along the contents of nanomaterials. The decrease in moisture content is related to the tendency of nanomaterials to absorb water from moist soil. Moreover, the addition of nanomaterials powder decreases the optimum water content in soil due to the high surface area of nanomaterials particles (Taha and Taha, 2013). Also the decrease in water content results in a decrease in the volume of voids in soil matrix (Bowles, 1992).

For S1 and S2, the results of maximum dry density (Fig. 3) revealed that it increased with increase the dosages of nanomaterilas. The increase in the maximum dry density is possibly due to the particle densities of nanomaterials which are greater than the particle density of natural soil. 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 (2010) who mentioned that the factors that affect compaction included the particle size and specific gravity of the soil and the stabilizer. The increase in optimum moisture content is attributed to the additional

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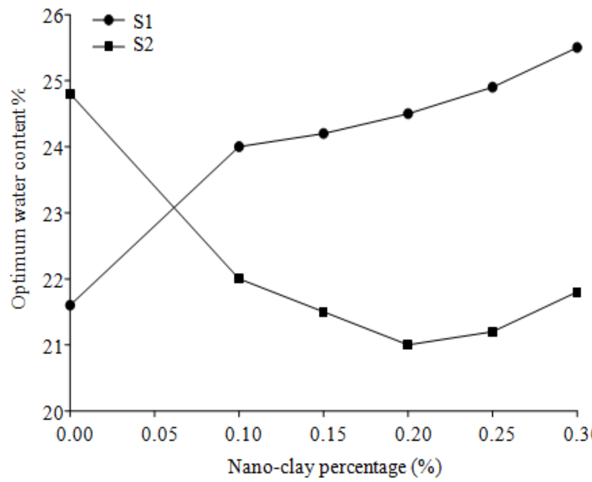


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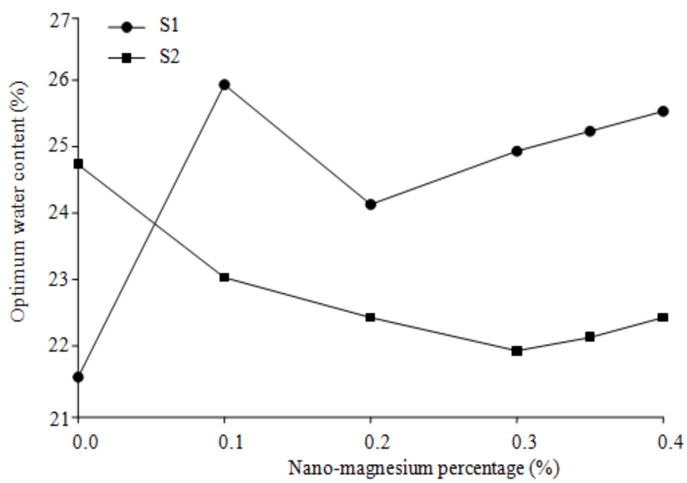


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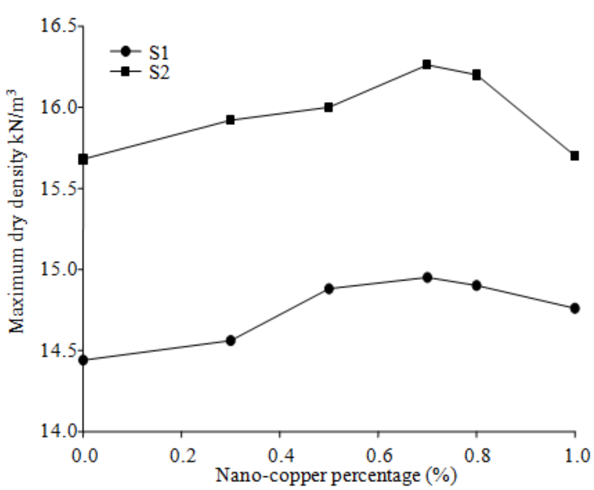
Fig. 2: Effect of different nanomaterials on the optimum water contents for S1 and S2

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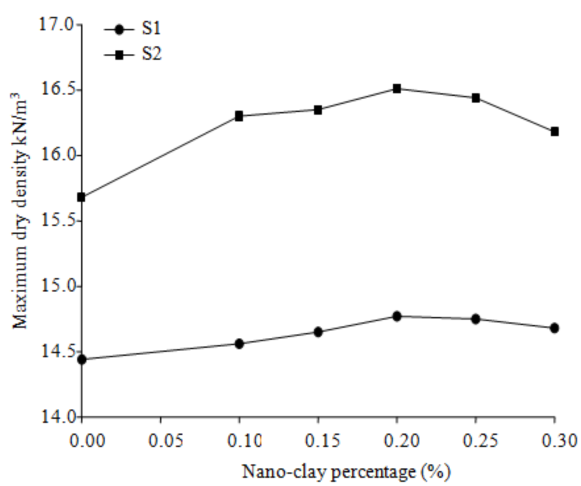


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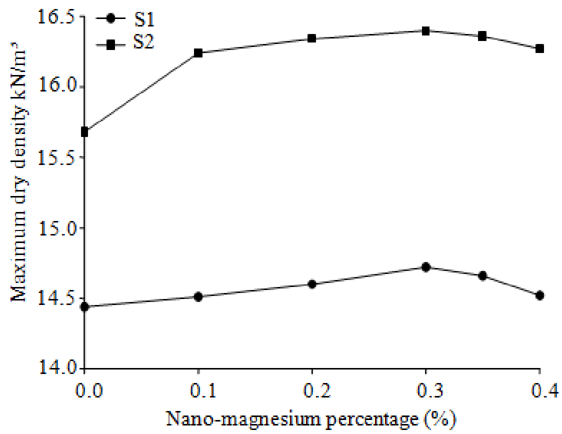


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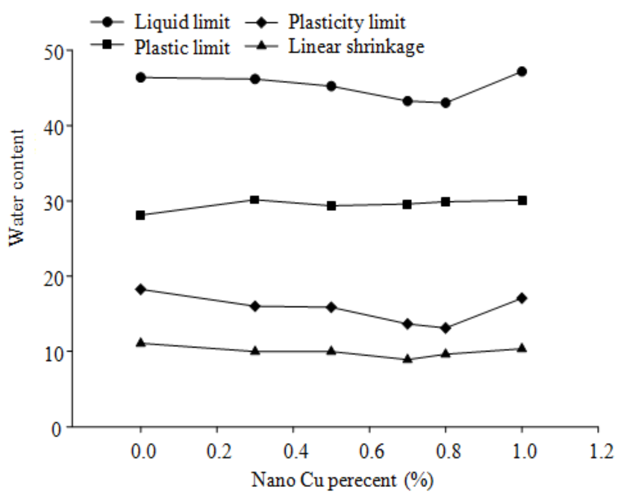
Fig. 3: Effect of different nanomaterials on the maximum dry density

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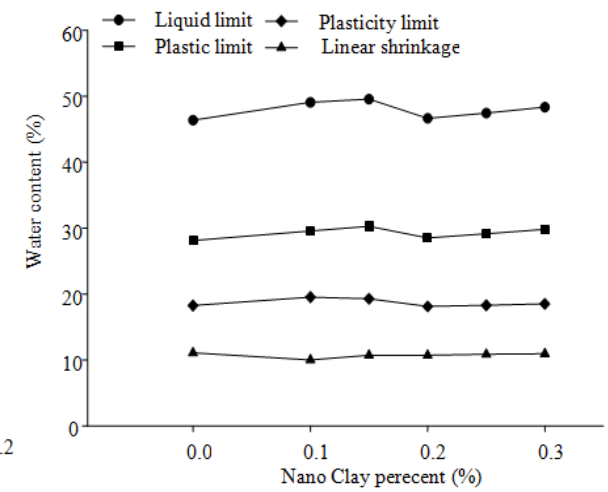


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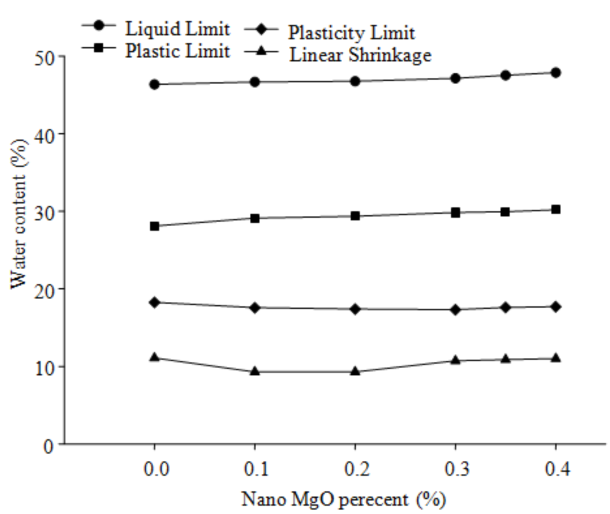


(c)

Fig. 4: Effect of different nanomaterials and water content on engineering properties of the soil

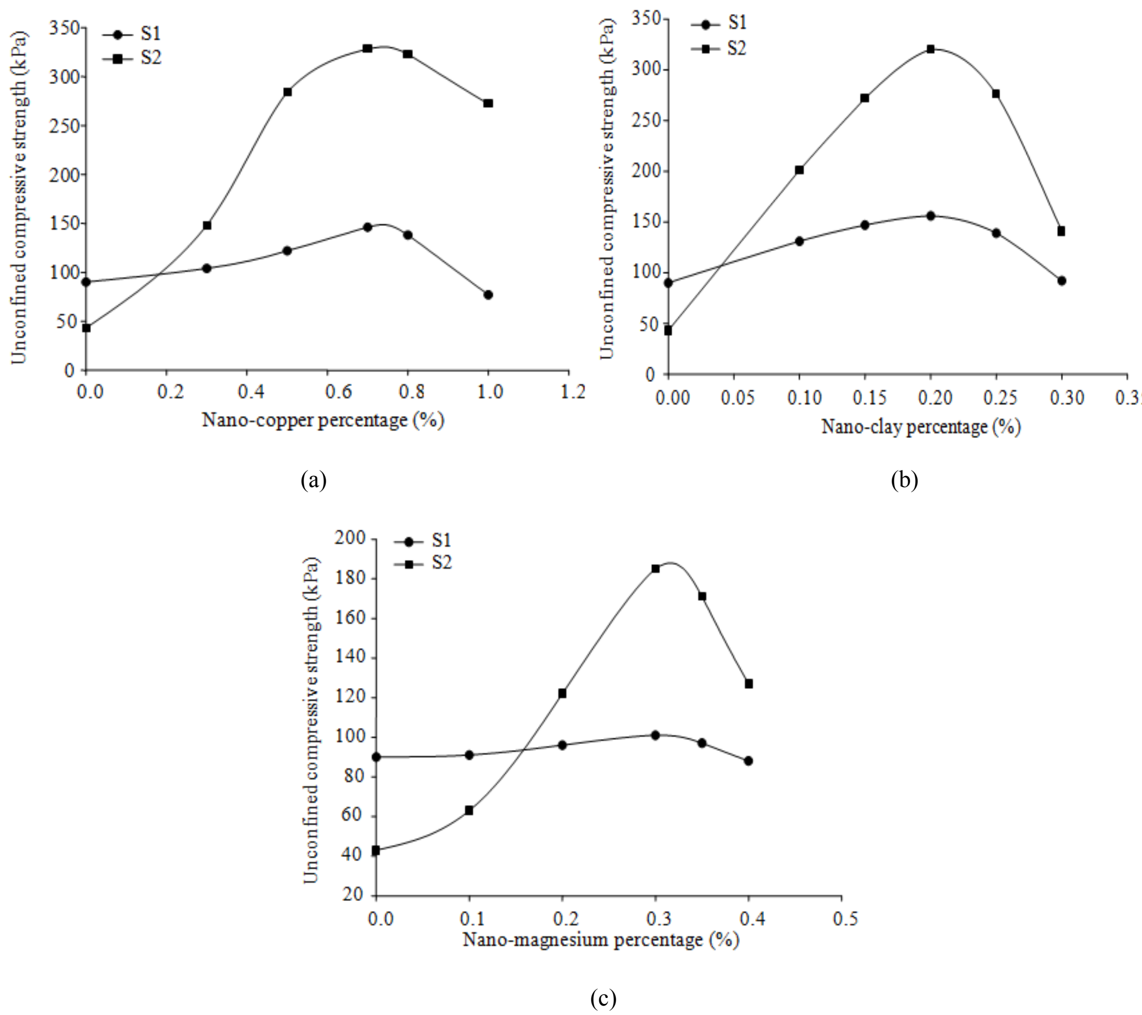


Fig. 5: Effect of different nanomaterials percentage and unconfined compressive strength

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. Moreover 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.

Figure 4 shows the effect of nanomaterial contents on the Atterberg limits. The liquid limit, plastic limit, plasticity index and linear shrinkage decreased as the nanomaterial content increased. Reductions in the plasticity indices are indicators of soil improvement. Thus, addition of fine particles, such as nanomaterials, to soil, even at low doses, can enhance its properties (Taha, 2009).

The unconfined compressive strength of specimens with different percentages of nanomaterials is shown in Fig. 5.

Generally, increasing the amounts of nanomaterials induced an increase in the unconfined compressive strength. The results indicate that the maximum shear strength was obtained from soil treated with nano clay. Soil to which nano clay had been added showed hardening and improved strength compared with soil specimens that contained other nanomaterial additives.

## CONCLUSION

This investigation was conducted to study the effect of addition of three nanomaterials (i.e., nano CuO, nano MgO and nano clay) on the geotechnical properties of soft soil. The liquid limit, plastic limit, linear shrinkage, compaction parameters and shear strength of the soil were determined. Addition of each of the nanomaterials decreased the liquid limit, plastic limit, plasticity index and linear shrinkage of the soil. The dry density increased with increasing nanomaterial percentage. On the other hand, the optimum moisture contents of the soil-nanomaterials mixtures decreased with increase dosages of nanomaterial. In addition, when the nanomaterial percentage exceeded the optimum contents, there was evidence of particles agglomeration which in turn affected the mechanical properties of soils negatively. As well, the compressive strength of the soil increased with nanomaterial addition. Moreover, 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 for all tested soils. These results can help researchers further improve soil strength and other soil properties.

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