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# Performance of Soil Stabilized with Carbon Nanomaterials

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The use of nanomaterials to stabilize soil is a developing research area in geotechnical engineering. In this study, the use of carbon nanotube was compared to carbon nanofiber for possible applications in soil stabilization. Fundamental properties such as Atterberg's limits and compaction characteristics were first explored. Then the hydraulic conductivities of the soil-nanomaterial reinforcement were determined. The maximum amounts of the nanomaterial used is 0.2 % by dry weight of the soil. Both nanomaterials increased the specific gravity, dry densities and pH values slightly. Furthermore, the hydraulic conductivity decreases for samples with carbon nanotube and greater decrease was obtained for samples with carbon nanofiber. These results indicated that small amounts of nanomaterials used can provide measurable changes in the soil behavior. Thus, the nanomaterials used in this study can be further considered as potential soil stabilization materials.

## 1. Introduction

Soil stabilization has been one of the recommended methods to improve subgrade soils. For example, compacted clays with low hydraulic conductivity are commonly used as a waste containment material. An important property of compacted clay is desiccation cracking as it will cause cracks in soil liners consequently reducing the sealing effect of the containment system dramatically. It was found that hydraulic conductivity increases about three orders of magnitude due to desiccation cracking (Sadek et al., 2007). Some studies have considered soil additives (lime, sand, and cement) to increase the soil strength and resistance to cracking (Omidi et al., 1996a, Firoozi et al., 2015). However, lime or cement did not sufficiently address desiccation cracking and the high permeability of clayey soils with high water contents.

## 2. Literature review

Nanomaterials refer to materials in which at least one of its dimension is between 1 to 100 nm. The principle distinction between a nanomaterial and a bigger scale material is the bigger surface area of the nanomaterial which allows for an extensive substance reactivity and/or a change in the physical properties of the material (Majeed et al., 2014, Taha et al., 2018). These properties have been utilized in most technical fields of knowledge such as electronics, computer science, manufacturing, medicine, etc. for a sometime now. These vast, fast and up-to-date use of nanotechnology is due to the logical meeting of science, material science, science and design streams (Liu et al., 2012). Thus, the developments in nanotechnology must be tapped by geotechnical engineers to improve and enhance our common material, i.e. soil strength (Alsharef et al., 2016).
Nanocarbon (NC) fibres are primarily used in industrial sectors such as electronics, automotive, aeronautics, sports, marine, and concrete. NC is also a promising advanced material in the construction industry. NC fibres, especially carbon nanotubes (CNT) and carbon nanofibres (CNF) have promising material properties such as high tensile strength, elastic modulus, hardness and electrical properties (Taha et al., 2018). The history of carbon nanofibres goes back more than a century. This study aimed to examine the influence of a type of carbon nanotube i.e. a multiwalled carbon nanotube (CNT) on the physical properties of soil. Another nanomaterial within the same carbon family, i.e. a carbon nanofiber (CNF) will be used as comparison. These nanomaterials are now readily available in the market, with good quality products and relatively inexpensive. The soil used is a local Malaysian sedimentary residual soil which is found in abundance in Malaysia and in

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the tropics. The parameters investigated in this study included specific gravity, pH, optimum water content, Atterberg's limits, hydraulic conductivity and maximum dry density.

## 3. Methods and materials

The soil used in this study is a sedimentary residual soil. This soil is obtained from Bangi, Malaysia and designated as UKM soil. The physical and chemical properties of the soil are shown in Table 1. The soil was classified as clayey sand (CL) in line with the Unified Soil Classification System (USCS). The UKM soil Sieve analysis and particle size distribution is shown in the Figure 1.

*Table 1: Basic properties of UKM soil*

| Properties | Value |
|---|---|
| Specific gravity | 2.604 |
| % Passing no 200 sieves | 45.39 |
| Clay content, (<2 µm) (%) | 23 |
| Soil classification (USCS) | CL |
| Main chemical composition: | 62.07 |
| $SiO_2$ (%) | 29.46 |
| $Al_2O_3$ (%) | 5.7 |
| $Fe_2O_3$ (% | |
| Organic matter (%) | 4.2 |

Two types of nanocarbons, a multiwall carbon nanotube (CNT) and a carbon nanofiber (CNF), were selected. The proportions used in experiments were 0.05, 0.075, 0.1, and 0.2 % by dry weight of the soil. The properties of CNT and CNF are listed in Tables 2 and 3.

The utilization of electrometric technique (BS 1377: part 3: 1990: Clause 9) in this study to regulate pH value of soil suspension in water. This technique required a soil-water ratio of 1:2.5 obtainable via passing 30 g soil through a 2 mm sieve in addition to 75ml distilled water used to weaken it for no less than 8 h.

The specific gravity test was conducted on control soil via a mini 50 ml capacity pycnometer and took three samples to determine each soil type utilizing a specific gravity value. The experiment was carried out in compliance with the technique suggested by BS: 1377, part 2:1990, Clause 8.3.

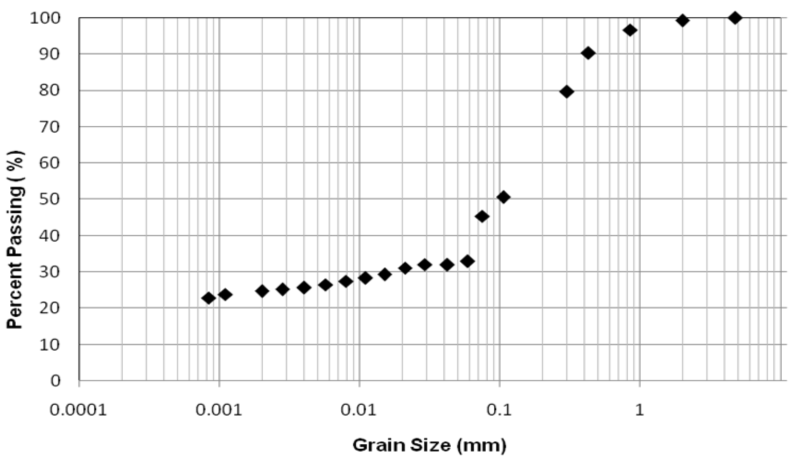


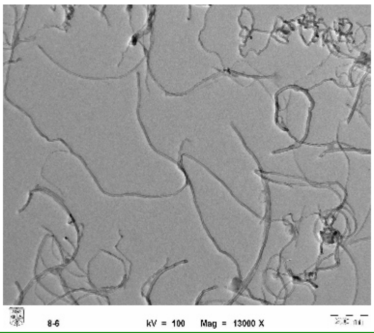
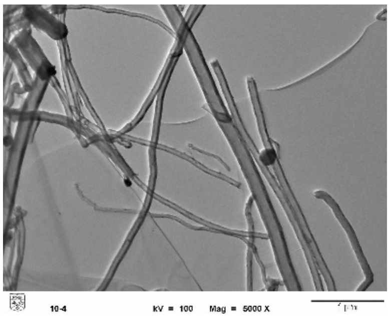

*Figure 1: Grain size distribution of the UKM soil*

The Atterberg's limits (i.e. the liquid limit, the plastic limit, and the plasticity index) of each of the natural and treated soil samples were determined in accordance with BS 1377, part 2, (1990). The plasticity index was calculated as the difference between the water contents at the liquid and plastic limits.

The normal Proctor test was carried out for both natural soil and soil-nanomaterials mixtures to decide the compaction parameters. The BS 1377- 4:1990 standard was used as these tests' base. In the test, the soil was compressed in a mould with a 1,000 $cm^3$ volume. The compacted soil was oven dried and using a rubber hammer, smashed finely until it passed the U.S. 0.425 mm. Using a spray bottle containing tap water, the soil was moistened and stirred with a trowel throughout mixing ensuring an even water dispersal. Soil was later packed in plastic bags and hydration is permitted for a minimum of 24 h in advance of compaction. Three equal layers compressed using 27 blows each.

For the hydraulic conductivity experiment, the soil compaction was consistent with the regular experiment methodology (BS1377: part 4:1990 Clause 3.4). At optimum water content, cylinder-shaped specimens with 70 mm diameter and 35 mm high were fixed from the compacted blends through regular compaction dynamism. Therefore, hydraulic conductivity was decided succeeding ASTM D5084, i.e. with malleable membrane device. Permeable stones and filter paper were placed counter to the ends of the samples to dispense permeated de-aired water through whole sample end area. Once sampling was set in the test cell, water filled the cell and the specimen was soaked with the application of pressures steadily from both directions, with pressures from the bottom and cell adjoining the sample forcing water entering and saturating the sample up to the back pressure reached 215 kPa, a permeation gradation of more than 98 % was given. Inlet and outlet burettes readings were noted after completion of the saturation until the measured hydraulic conductivity.

*Table 2. Properties of CNT (Graphistrength C100) and CNF ((PR-19-XT-LHT)*

| Property | CNT (Graphistrength C100) | CNF (PR-19-XT-LHT) |
|---|---|---|
| Diameter Avg (nm) | 10-15 | 200 |
| Length Avg (µm) | 1-10 | 50-200 |
| Carbon purity (%) | >95 | >98 |
| Apparent density (kg/m3) | 50-150 | 30-300 |
| Relative density (g/ml) at 25oC | 2.1 | 2-2.1 |
| Aspect ratio (length/diameter) | 600-700 | 1,300-1,500 |
| Applications | Reinforcements | Mechanical and electrical |
| Transmission electron microscopy (TEM) images |   |   |

## 4. Results and findings

### 4.1 Specific gravity

Specific gravity test results for soil-nanomaterial mixtures are shown in Figure 1a. Nanomaterial content of 0 indicated test with pure soil. The results showed the specific gravity reduced from 2.604 to 2.53 and 2.542, respectively, for CNT and CNF. This result is to be expected due to the low specific gravity of the nanomaterials, i.e. about 2.1. Although the number of nanomaterials is very small (maximum 0.2 %), the reduction in specific gravity of the mixture is noticeable. CNT is actually similar to a kaolinite family mineral, i.e. halloysite due to its tubular morphology. Halloysite is actually a naturally occurring aluminosilicate nanotube with a specific gravity of 2.53 and have many applications especially in the field of pharmacy and health care (Kamble et al., 2012).

### 4.2 pH effects

The results in this study showed that the pH of the soil samples increased marginally with increasing nanomaterials content (Figure 2b). The increase in pH from 3.93 (samples without nanomaterials) to 4.16 can be considered as insignificant. In general, pH does affect the geotechnical properties of soil (Sunil et al., 2006). Thus, it is important to keep the soil at its original pH so that the geotechnical structure will perform according to what it was intended.

### 4.3 Compaction characteristics

The dry density vs water content plots are shown in Figure 3 for CNT and CNF. It can be observed that the soil without nanomaterial follows the traditional curve. For soil-nanomaterial samples, the dry side can be observed to be “elevated” showing increasing density with the addition of nanomaterials. This shows that at the dry side of the compaction curve, the nanomaterials are able to move into the pores to fill up the spaces between the particles and compact the mixture. This results in higher dry density of the soil-nanomaterial system at low water contents. Higher maximum dry density (1.89 g/cm$^3$ at 0.075 % nanomaterial) was obtained for soil samples with CNT possibly due to its finer dimensions compared to CNF. Again, such a small quantity of nanomaterials can result in measurable increase in dry density of the soil. The change in maximum dry density and optimum moisture content with the nanomaterial contents. It is observed that only the maximum dry density changes with the number of nanomaterials. The maximum dry density increased for all the amounts of nanomaterials tested and from the figures, the optimum amount of nanomaterial is 0.075 %. For optimum moisture content, a very slight decrease was observed for 0.075 % CNT but in general the optimum water content remains unchanged at all nanomaterial contents.

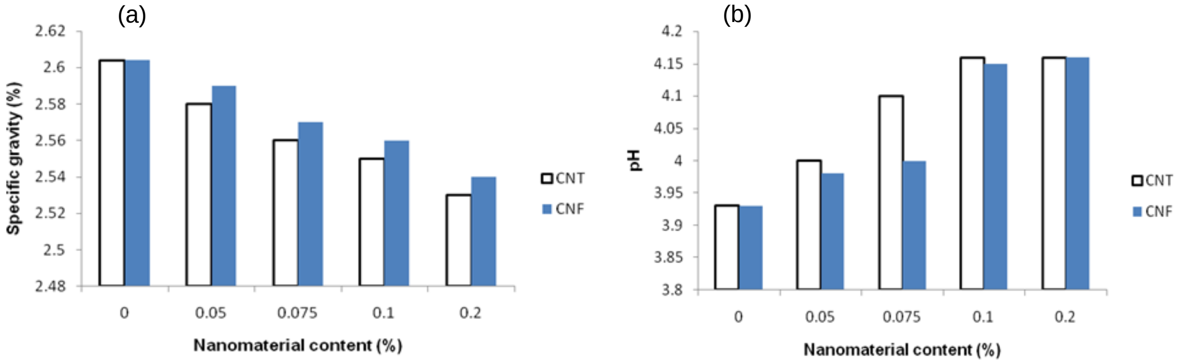



*Figure 2: (a) Effect of CNT and CNF on the specific gravity. (b) Effect of CNT and CNF on the pH*

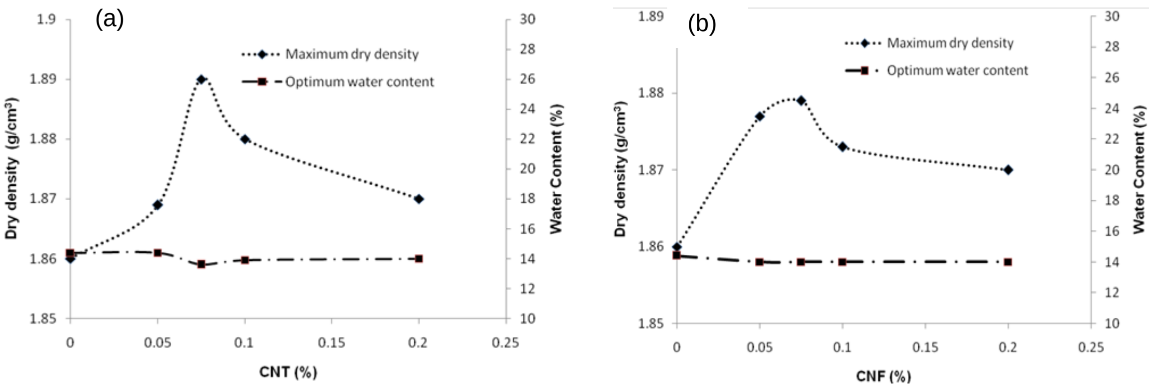



*Figure 3: (a) Effect of CNT on the OMC and MDD. (b) Effect of CNF on the OMC and MDD*

### 4.4 Atterberg’s Limits

Figures 4 and 5 presents the results and indicates that the LL increased slightly with increasing CNT. For CNF, the changes were not obvious. For PI, the change in its values is more apparent with the addition of CNT. Still all PI results with and without nanomaterials indicate soil in the low range of PI (Briaud, 2013). This is important since high PI represents soil with high shrink-swell index which is detrimental for soil liners and caps of waste containment systems.

### 4.5 Hydraulic Conductivity

The hydraulic conductivity test result drawn in Figure 6 clearly shows a decrease in the hydraulic conductivity value (k) of the tested soils corresponding with an increase in the CNT and CNF percentage. Nanomaterial contents less than the optimum content significantly affected the hydraulic conductivity values. Compared with the pure soil samples, the hydraulic conductivity values of soil-nanomaterials mixture decreased from

2.16 x $10^{-9}$ m/s to 9.46 x $10^{-10}$ m/s for soil samples reinforced by CNT and 2.16 x $10^{-9}$ m/s to 7.44 x $10^{-10}$ m/s for soil samples reinforced by CNF. This shows that with the small amounts of nanomaterials used in this study and with proper compaction on the wet side of optimum, the hydraulic conductivity can be reduced to the acceptable value of 1 x $10^{-9}$ m/s for soil liners. Using nanomaterials such as nano alumina and nano copper, Taha and Taha (2015) was able to maintain this level of hydraulic conductivity for other types of soils. This shows that nanomaterials can be used as an additive for compacted soils to achieve the desired hydraulic conductivity.

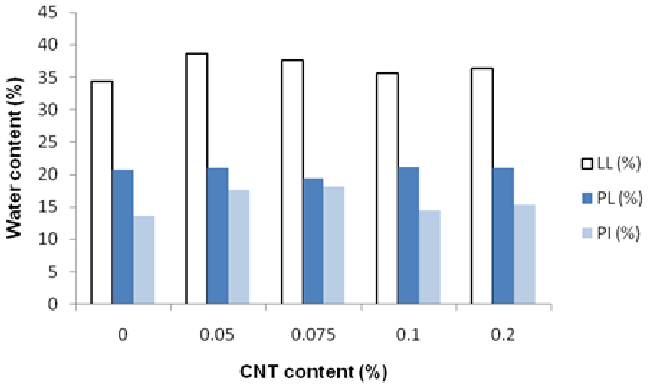



*Figure 4: Effect of CNT on LL, PL and PI*

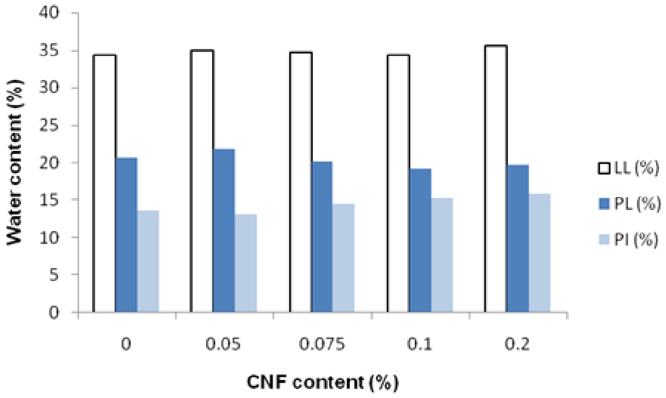



*Figure 5: Effect of CNF on LL, PL and PI*

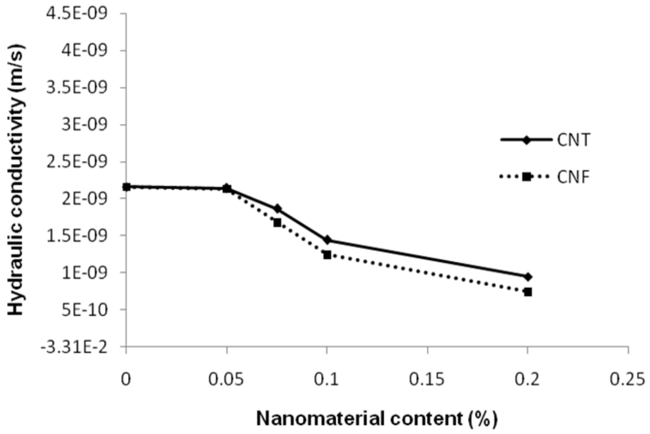



*Figure 6: Effect of CNT and CNF on hydraulic conductivity*

## 5. Conclusion

A study was conducted to evaluate the effects of adding a small amount (less than 0.2 %) of nanomaterials to a sandy clay soil. The nanomaterials used were from the nanocarbon family i.e. multiwall carbon nanotube (CNT) and carbon nanofiber (CNF). The specific gravity and pH of the mixtures both increase slightly with the addition of the nanomaterials. The increase in specific gravity, however, is more pronounced. The change in PI is more obvious for soil samples with CNT. It was found that the dry densities increase at the dry side of optimum for all soil-nanomaterial samples. This is probably due to the ability of the nanomaterials to move into the pores densifying the matrix. At the wet side of optimum, all compaction curves nearly merged with the curve for the pure soil. The hydraulic conductivity test showed that the nanomaterials have potential to reduce k value. A comparison between the results from the two different nanomaterials (CNT and CNF) showed that the soil samples reinforced with CNF had a higher reduction in hydraulic conductivity.

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