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# Effect of Adding Nanoclay on the Mechanical Behaviour of Fine-grained Soil Reinforced with Polypropylene Fibers

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**Abstract**

In this study the performance of clay nano-particles on the soil reinforced with Polypropylene fibers (PP-fiber) has been investigated. Also a series of investigations concerning the effect of random orientation of fibers on the engineering behaviour of soil were conducted. Soil mixtures were modified with varying percentages of nanoclay and Fibers. Unconfined compressive strength (UCS), Compaction, Atterberg limits, and microstructural (scanning electron microscopy) tests were conducted. In order to understand the micromechanical behaviour of nanoclay in fiber reinforced soil, the microstructure and morphology of fracture surfaces of samples were studied using Scanning Electron Microscopy (SEM). It was found that the addition of nanoclay significantly improves the performance of fiber reinforced soil in a unique way. This paper presents the understanding of nanoclay behaviour and its impact on the overall mechanical characteristic and laboratory performance of fiber reinforced soil.

**Keywords** : Nanoclay, iFbers , Soil Reinforcement

## 1. Introduction

Using auxiliary elements in strengthening and modification of the soil has attracted the human being attention from the earliest times so that with appearance of new materials and the requirement for structures like airport, highway, landfills and earth dams has paved the suitable ground for discovery of novel methods in geotechnical engineering science. Accordingly the improvement and modification methods of the soil engineering properties and following it, the reinforced soil theory and the related methods are important. Effectiveness and capability of the reinforced soil knowledge in presenting suitable practical solutions in different development projects has allocated it a valuable position among geotechnical engineering sciences. In general the soil reinforcement elements are employed in two ways of either regular form including gridded plates, stressed layers and straps placed in certain locations and directions or randomly including fibers and small chips mixture distributed into the soil. The idea of randomly distributed fiber reinforcement was firstly presented in early 70's and soon became the subject of several investigations. The main axis of these studies was based on the use of continuous and oriented elements aiming at strengthening and reinforcement the soil.

The idea of mixing the soil with fibers began early this decade. So that using Randomly Distributed Fiber Reinforcement became the research subject of many scholars. Results of all the studies showed that reinforcing the soil by adding fibers would causes increasing the strength and bearing capacity of the soil under static and dynamic loads [1-8].

On the other hand, since nanotechnology has entered virtually all the sciences, civil engineering is by no means an exception. In this study Nanoclay has been used to reach the desirable strength than. Results from unconfined compressive strength tests show that the strength of samples containing nanoclay has considerably increased [9-13].

Kananizadeh et al. [10] performed the Atterberg limits tests on the soil and nanoclay mixture. Results of their studies showed that the Nanoclay changes the Atterberg limits, so that plasticity index is increased. Arabania et al. [11] through conducting unconfined compressive strength tests, direct tensile strengths and CBR found that the

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sample´s modulus of elasticity obtained from the unconfined compressive strength test has increased up to 2% of nanoclay followed by a declining trend. Taha and Taha [14] conducted studies on stabilization of the soil using nanoclay and found that the increase in accumulated nanoparticles would cause decrease in the soil dry density and increase in amount of water in the existing pores. Moreover, excessive addition of nanoparticles would causes accumulation of particles which in turn would negatively affect the soil mechanical properties. Results of the study indicated that nanoclay would improve the engineering properties of the soil.

Additionally the fiber's volume variability by addition of nanoclay to the soil-fiber's mixture will be discussed. Previous literature has mainly investigated the nanoparticles or Polypropylene fibers effect on improvement of the soil, but no worthwhile study has been conducted on the simultaneous effect of clay nanoparticles and the Polypropylene fibers on the problematic soils. Azzam [15] studied the Polypropylene nanocomposite reinforced with nanoclay to reduce the swelling and shrinkage of soil. Also Eslami et al. [16] studied the thermal conditions' effects on the tensile properties of reinforced basalt fibers in a nanocomposite composed of Polypropylene fiber-nanoclay. Sadrmomtazi and Fasihi [17] investigated the effect of Polypropylene fibers on the performance of Nano-SiO2 containing mortar. But they made no comprehensive investigation on the effect of the nanocomposite made of Polypropylene fibers and nanoclay on the soil. The gap between the current technical literature and the studies restricted to investigations on the behaviour of the soil containing fiber reinforced Nanoparticles have made the present study a requirement.

## 2. Materials and methods

### 2.1. Materials

The soil used in the study was supplied from Incheh-Borun region, located north of Gorgan towards northeast of Iran. The physical specifications of the under study soil has been represented in (Table 1). The Nanoclay used in the study was of Cloisite 30B, a modified montmorillonite, which is supplied by the Southern Clay Products Co. as the reinforcer. The average diameter of particles and the interlayer spacing were 7nm and 1.85nm respectively, supplied by the above company, the properties of which have been presented in (Table 2).

The Polypropylene fibers were used with 6, 12 and 18 mm in length. Polypropylene fibers are hydrophobic, non-corrosive and resistant to alkaline materials, chemicals and chlorides. Properties of Polypropylene fibers used have been represented in (Table 3).

### 2.2. Mixing and proportions of the samples

Since making of samples is of high importance, the sample preparation procedure has been described in detail below:

(1) Drying of the soil: Primarily the selected soil is put into the oven for 24 hours at approximately 105°C prior to be used in the mixture.

In this empirical method, the nanoclay- Polypropylene fibers- soil mixtures has been investigated.

Table 1: Specifications of used soil

| Soil properties | Values |
|---|---|
| Specific gravity | 2.52 |
| Consistency limit | |
| Liquid limit | 21.4 |
| Plastic limit | 16.1 |
| Plasticity index | 5.3 |
| Classification | CL-ML |
| Compaction study | |
| Optimum moisture content | 13.8% |
| Maximum dry density | 1.82 g/cm3 |

Table 2: Specifications of Cloisite 30B Nanoclay

| Particle size | Density | Modifier Concentration | Color |
|---|---|---|---|
| 1-100 nm | )g/cc(1.98 | 90 meg/100g clay | Yellow |

Table 3: Specifications of Polypropylene fibers

| Behaviour parameters | Values |
|---|---|
| Diameter (micron) | 19 |
| Length | 6, 12 and 18 mm |
| Unit weight | 91 g/cm3 |
| Aspect Ratio | 315, 631 and 947 |
| Breaking tensile strength | 450 MPa |
| Elongation at break | 80-100 % |
| Burning point | 160-165 |

(2) Obtaining the optimum moisture content**:** Using the standard proctor test the moisture content and the maximum dry density of the samples have been obtained. Should be noted that to make a sample the soil density must be taken as constant so that the fibers and nanoclay effect could be identified.

(3) Mixing of the materials: The nanoclay quantities include 0.5, 1 and 2 percent of the soil dry weight and the Polypropylene fibers' quantities include 0.3, 0.6, 0.9 and 1.2 percent of the soil dry weight.

At first the soil and nanoclay are mixed in dry condition and then the fibers are detached manually from one another so that it could fulfill the required efficiency. Then the fibers are manually mixed with the soil, making sure that all the fiber threads are mixed to obtain a thoroughly homogeneous mix. Then the required water obtained from the stage (2) is added to the mixture, and meanwhile gradually adding the remaining water, the mixing operation is continued until a uniform mixture is achieved. All the mixings are made manually and the proper treatments for the preparation of homogeneous mixture in each mixing stage have been considered. The mixture is poured into a lidded container special for sample making and is left intact for 24 hours so that the mixture moisture is retained [18].

(4) Separating the mixture for making each sample: The wet soil weight required for making each sample is determined and is proportionately taken from the mixture supplied in the stage 3 and is divided into 3 parts (equal to the number of uniaxial sample layers). Next the required weight for each layer is determined with 0.01 precision, then the wet soil sample is poured into the lidded container and the lid is closed so that the moisture loss is prevented.

(5) Making the uniaxial sample: The first layer's mixture of soil, fibers and nanoclay (lowest layer) is poured into the mold and its surface is leveled using a spatula; then the compaction operation is carries out until reaching to the desired height using the especial sample-making hammer. Also before pouring each layer into the mold, in order to better connection and continuity of the layers with each other, short grooves are made into the soil surface in several points and various directions, about one-tenth of the layer thickness in depth using the especial spatula tip. In 3 equal layers in a mold of 3.8cm diameter and 7.8cm height, each layer was uniformly compacted using the hammer and then the samples undergone the uniaxial tests.

Fig. 1. The Procedure of preparing the samples

In order to make samples with identical compaction and possibility of comparing the findings resulting from different percentages of the under study additives, there is the requirement of determining the weight ratios of soil samples. The soil, nanoclay and fibers' ratio is determined as per their dry weight in proportion to the soil and nanoclay dry weight.

Considering the previous studies and the possibility of making the study samples as well as the performed proctor tests, the values 0.5, 1 and 2 has been considered for weight percentage of Polypropylene fibers; such values for Nanoclay weight percentage had been 0.3, 0.6, 0.9 and 1.2 percent. (Table 4) shows the mixture ratios.

**3. Tests Program**

As a prerequisite, the mechanical and chemical specifications of the soil (dry weight, Atterberg limits, classification, etc.) are determined in laboratory based on ASTM and (Table 4) represents the proportions of the materials mixed with the soil.

**3.1. Atterberg limits test**

The plastic limit and liquid limit tests have been performed on samples containing Nanoclay according to ASTM-D-4318-98 standard.

**3.2. Standard proctor test**

The standard proctor test was performed on the soil-nanoclay samples reinforced and unreinforced with fibers in accordance with ASTM 698 standard.

**3.3. Unconfined compressive strength tests**

Considering the ASTM 2166 standard, the unconfined compressive strength tests to determine the compressive strength of the soil compacted with nanoclay was performed. The unconfined compressive strength test is a fast and cost-effective way of obtaining approximate compressive strength of the cohesive soils. The results are indicative of the increase in the compressive strength values as a result of adding nanoclay and fibers.

**3.4. Scanning Electron Microscope (SEM) tests**

The additive's effect on the soil structure and the fibers surface was estimated through SEM observation and analysis.

Two 1cm × 1cm × 1cm soil samples (NF1 and NF25) were prepared after the unconfined compressive strength test. The samples were put into the liquid nitrate prior to the experiment. Finally the SEM images clearly show the surfaces of the soils containing the nanoclay reinforced with the fibers.

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Table 4: Fibers and nanoclay ratios in mixtures

| sample | Mix Proportion in mass (%) | | Fiber Length (mm) | Sample | Mix Proportion in mass (%) | | Fiber Length (mm) |
|---|---|---|---|---|---|---|---|
| | Nanoclay | Fiber | | | Nanoclay | Fiber | |
| S | 0 | 0 | 0 | NF11 | 0.5 | 1.2 | 12 |
| F1 | 0 | 0.3 | 6 | NF12 | 0.5 | 1.2 | 18 |
| F2 | 0 | 0.3 | 12 | NF13 | 1 | 0.3 | 6 |
| F3 | 0 | 0.3 | 18 | NF14 | 1 | 0.3 | 12 |
| F4 | 0 | 0.6 | 6 | NF15 | 1 | 0.3 | 18 |
| F5 | 0 | 0.6 | 12 | NF16 | 1 | 0.6 | 6 |
| F6 | 0 | 0.6 | 18 | NF17 | 1 | 0.6 | 12 |
| F7 | 0 | 0.9 | 6 | NF18 | 1 | 0.6 | 18 |
| F8 | 0 | 0.9 | 12 | NF19 | 1 | 0.9 | 6 |
| F9 | 0 | 0.9 | 18 | NF20 | 1 | 0.9 | 12 |
| F10 | 0 | 1.2 | 6 | NF21 | 1 | 0.9 | 18 |
| F11 | 0 | 1.2 | 12 | NF22 | 1 | 1.2 | 6 |
| F12 | 0 | 1.2 | 18 | NF23 | 1 | 1.2 | 12 |
| N1 | 0.5 | 0 | 0 | NF24 | 1 | 1.2 | 18 |
| N2 | 1 | 0 | 0 | NF25 | 2 | 0.3 | 6 |
| N3 | 2 | 0 | 0 | NF26 | 2 | 0.3 | 12 |
| NF1 | 0.5 | 0.3 | 6 | NF27 | 2 | 0.3 | 18 |
| NF2 | 0.5 | 0.3 | 12 | NF28 | 2 | 0.6 | 6 |
| NF3 | 0.5 | 0.3 | 18 | NF29 | 2 | 0.6 | 12 |
| NF4 | 0.5 | 0.6 | 6 | NF30 | 2 | 0.6 | 18 |
| NF5 | 0.5 | 0.6 | 12 | NF31 | 2 | 0.9 | 6 |
| NF6 | 0.5 | 0.6 | 18 | NF32 | 2 | 0.9 | 12 |
| NF7 | 0.5 | 0.9 | 6 | NF33 | 2 | 0.9 | 18 |
| NF8 | 0.5 | 0.9 | 12 | NF34 | 2 | 1.2 | 6 |
| NF9 | 0.5 | 0.9 | 18 | NF35 | 2 | 1.2 | 12 |
| NF10 | 0.5 | 1.2 | 6 | NF36 | 2 | 1.2 | 18 |



## 4. Results and Discussion

### 4.1. Atterberg limits test

Atterberg test results of S, N1, N2 and N3 samples have been represented in (Fig. 2). Adding nanoclay causes increase in the plastic and liquid limits so that the liquid limit increase is higher than the plastic limit and in the end these changes cause increase in the plasticity index of the soil (PI).

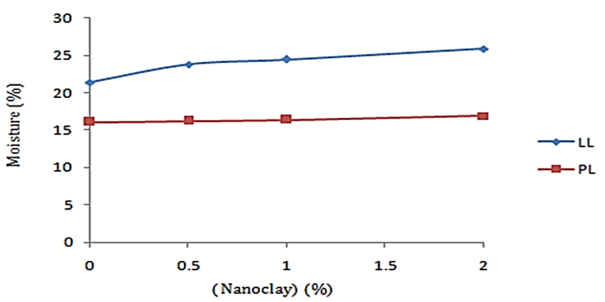



Fig. 2. Effect of adding Nanoclay on the Atterberg limits of the under study soil

The cause for the increase in the liquid and plastic limits is the presence of moisture in Nanoclay accumulations which plays no role in soil plasticity and is only removed in the oven.

### 4.2. Standard proctor test

Standard proctor tests were performed on the reinforced and non-reinforced soils using nanoclay and fibers. In order to make better comparison of the under study additives effects results and facilitating the preparation of the proctor test samples, fibers with 6, 12 and 18 mm (FL) in length were tested. The standard proctor test results have been represented in (Fig. 3). Considering the below figure, due to closeness of the standard proctor test results with different lengths, the 18mm length was selected for all of the proctor test samples. In order to find a suitable way of sample making and understanding the density changes procedure due to reinforcing mechanism, the standard proctor tests were performed on ordinary and reinforced samples with 0% to 2% of nanoclay and 0% to 1.2% of fibers were performed. Test results show that the soil's optimum moisture content is equal to 13.8% and its maximum dry density is 1.82 kg/cm3.

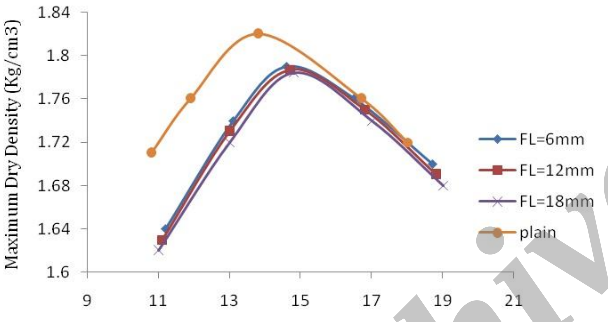
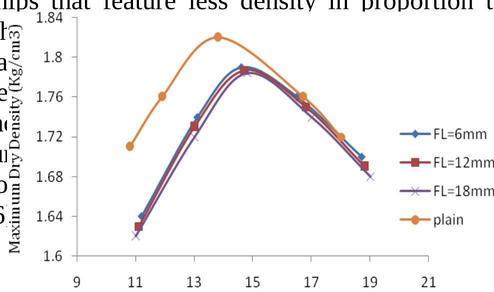



Fig. 3. The proctor curves of samples with 0.9 weight percentage with 6, 12 and 18 mm lengths

The results indicate that adding the fibers causes increase in the optimum moisture and decrease in the maximum dry density. The reason for the increase in the optimum moisture content value can be attributed to the higher water absorption properties of the fibers compared with the soil and the cause for the decrease in the maximum dry density lies in the soil grains replacement with the chips that feature less density in proportion to the soil. Th ... se in the na ... value has de ... ntent has in ... les; this in tu ... the water co ... ry density [6 ...



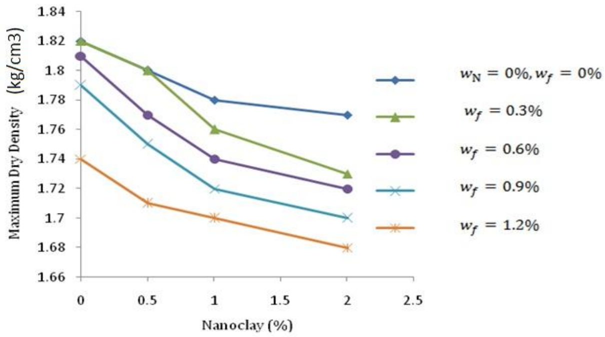




Fig. 4. The maximum dry density changes with the nanoclay content

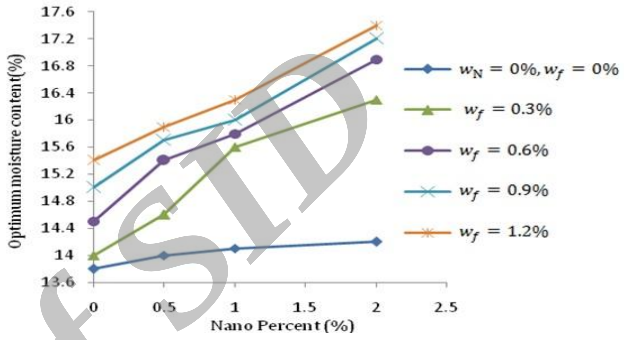



Fig. 5. The optimum moisture changes with the increase in the nanoclay content

### 4.3. Effect of the fibers on the uniaxial compressive strength of the under study soil

Fig. 6 shows the effect of adding fibers on the unconfined compressive strength of the under study soil. The effect of adding fibers on the stress-strain relationship of the soil mixture causes increase in the maximum compressive strength value. The stress-strain relationships for the soil-fibers mixture with the fibers 6, 12 and 18mm in length has been represented in the (Fig. 5).

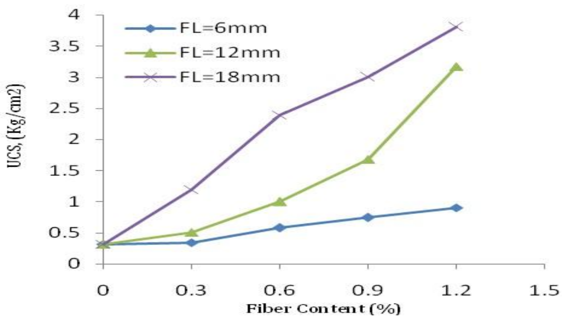



Fig. 6. The compressive strength changes with the fiber addition

For all of the samples reinforced with fibers, the maximum compressive strength is increased with the increase in the fiber's quantity. Also in some samples reinforced with the fibers (18mm in length) a considerable increase in the axial stress is observed. The compressive strength in such a condition has been defined in terms of allowed deformation value.

Usually the compressive strength has a strain value between 15 to 20%. So in the present analysis, the compressive strength is the maximum stress or the corresponding stress with 20% strain, each one which is achieved sooner. It is obviously unequivocal that the strength of all the soil-nanoclay samples is increased with the increase in the fibers content. Similar observations with the gravel reinforced with the fibers confirm the above results. Also in (Fig. 6) it clearly can be seen that in the soil-fibers mixture, with the increase in the fibers length, the fibers share in the compressive strength is decreased. Similar observations in relation with the composite fibers has been obtained [19].

Fig. 6 shows the effect of the fiber's amount in samples containing 0.3, 0.6, 0.9 and 1.2 percent of fibers. These samples underwent the unconfined compressive strength test; although, the primary part of the stress-strain curves of the reinforced and non-reinforced samples are almost similar to each other. Accordingly, it seems like that the load applied to the soil is tolerated at small strain levels so that the load imposed by the fibers is borne at more strain levels. It can be concluded from the greater strains corresponding to the maximum stresses represented by the samples reinforced by the fibers, that the fibers increase the flexibility of the reinforced samples. The flexibility behaviorr in the samples with higher amount of fibers is by far greater than other samples. For the samples with different fiber quantities, the corresponding strain of the maximum strength is increased with the increases in the fibers quantity. With the soils non-reinforced with the fibers, the maximum strength strain is by far lower compared with the samples reinforced with the fibers. These observations show that the fiber's movement occurs with the start of tension at higher strain levels. Figure 6 represents the effect of the fiber's length on the stress-strain behavior. As can be seen in the figure, the samples reinforced with the fibers longer than 18 mm show higher compressive strength. The maximum stress is increased linearly with the increase in the fiber's length. The strain corresponding to the maximum strength is increased with the increase in the fiber's length. Longer fibers need greater shear deformation reactions for complete strength reaction movement. As a result, the macroscopic axial strain in the maximum stress is expected to be greater for the samples reinforced with longer fibers.

**4.4. Effect of nanoclay on the uniaxial compressive strength of the under study soil**

Fig. 7 shows the stress-strain curve response of the soil-nanoclay mixture in the absence of fibers.

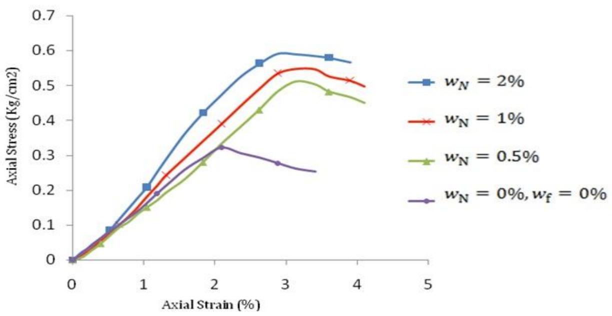



Fig. 7. The stress-strain curve of the soil-nanoclay mixture without the fibers

The axial compressive strength of the samples containing nanoclay is higher than the plain sample. The final axial strain corresponding to the axial stress is equal to 2.1, 2.9, 3 and 3.1 percent for the plain and soil containing 0.5%, 1% and 2% nanoclay respectively; the above results have already been confirmed by the previous literature [10, 20].

**4.5. The effect of nanoclay on the uniaxial compressive strength of the soil reinforced with Polypropylene fibers**

Comparing the UCS of the soil samples containing nanoclay reinforced with Polypropylene fibers shown in (Fig. 8), the USC value is increased with the increase in the nanoclay content from 0 to 2 percent.

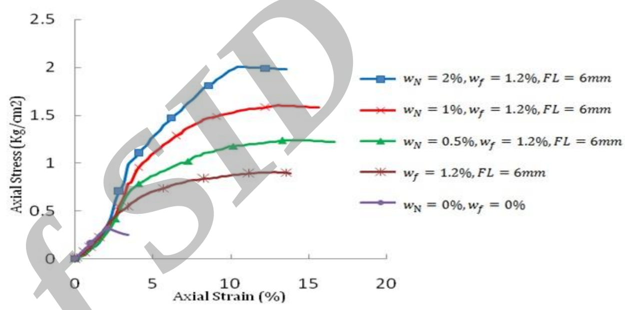



Fig. 8. Stress-strain curves of the soil mixture containing nanoclay, reinforced with fibers

The addition of nanoclay improves the compressive strength of the soil reinforced with fibers much more than the compressive strength of the soil reinforced only with the fibers without nanoclay. (Figs. 9 to 12) illustrate the stress-strain curves of the nanoclay containing soil reinforced with the fibers obtained from the unconfined compressive strength tests.

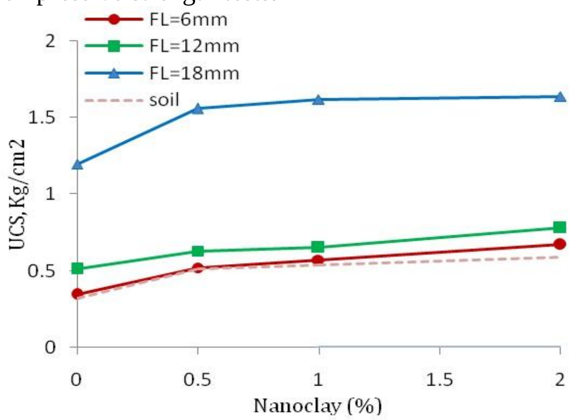



Fig. 9. Compressive strength of the soil-nanoclay with 0.3 weight percentage of fiber

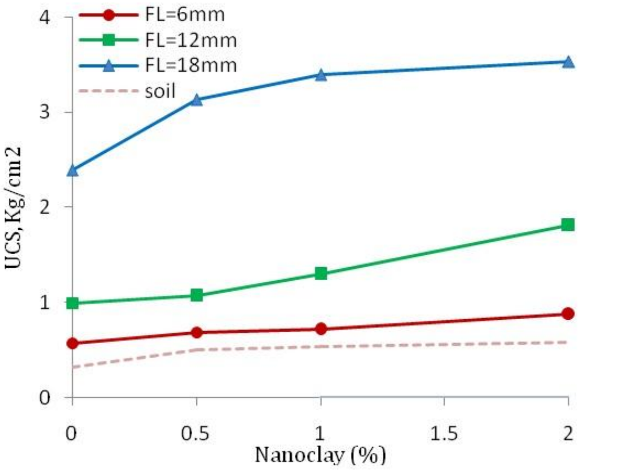



Fig. 10. Compressive strength of the soil-nanoclay with 0.6 weight percentage of fiber

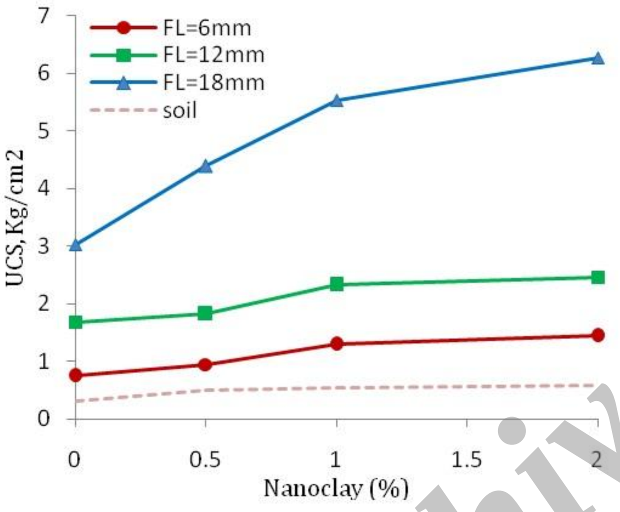



Fig. 11. Compressive strength of the soil-nanoclay with 0.9 weight percentage of fiber

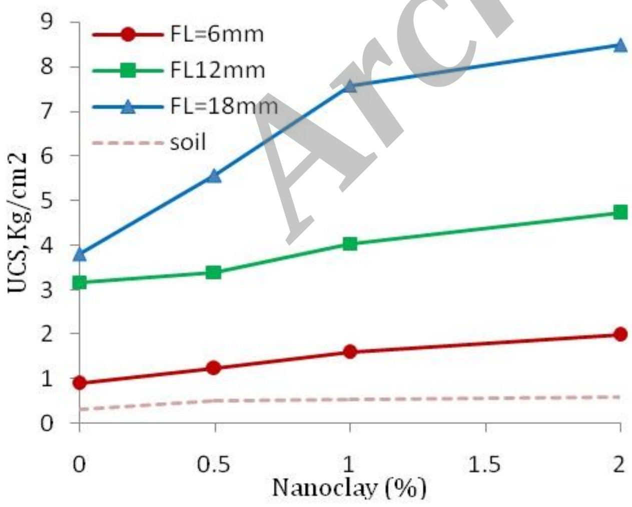



Fig. 12. Compressive strength of the soil-nanoclay with 1.2 weight percentage of fiber

Easily it can be seen that the behavior of the plain soil samples has been significantly influenced by the variables of the study. The maximum strength has changed as a consequence of separate effect of fibers or the effect of fibers and nanoclay. The unconfined compressive strength of the soil samples containing nanoclay reinforced with fibers is by far more than the samples containing nanoclay.

**4.6. The effect of reinforcing on the secant modulus of the under the study soil**

The Young's modulus of the samples is improved by the nanoclay content considering the dispersion of Nano-layers in the soil matrix. This improvement is due to the exfoliated structure of the nanoclay particles in the matrix which limits the polymer chain's movement under the load. Orientation of the soil plates and the Polymer chains can boost the reinforcing effect considering the loading direction. (Fig. 13) shows the Young's modulus quantities of different samples.

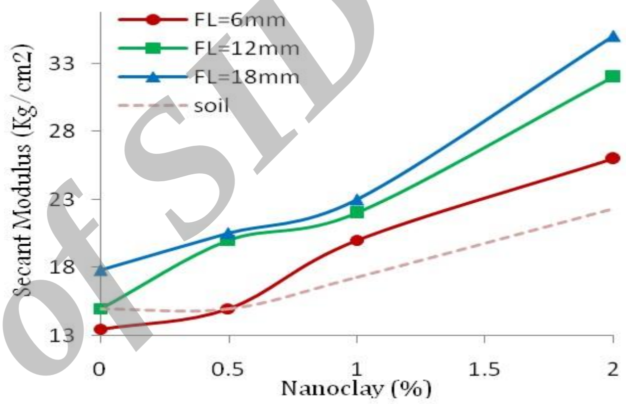



Fig. 13. Effect of nanoclay on secant modulus of reinforced soil with 0.3 weight percentage of fiber

Molecules are pressed together and there are many bonds between the molecules of the soil containing 2% of nanoclay and 1.2% fiber, so that they have positive contribution in the Young's modulus. The modulus of the soil therefore becomes much greater by adding 2% of nanoclay and 1.2% of fibers. Maximum Young's modulus belongs to the composite which is containing 2% of nanoclay. NF27, NF30, NF33 and NF36 samples contain nanoclay quantities of 35, 36.5, 37.7 and 39.7 respectively and the minimum Young's modulus belongs to the composite which is containing 0.5% of nanoclay. The samples NF7, NF10, NF1, and NF4 contain quantities of 26, 28, 30 and 30 respectively. When the nanoclay content reaches to 2%, the Young's modulus (of the soil containing 2% of nanoclay and 1.2% of fibers) is increased for 78% in comparison to the plain soil. Although the Young's modulus is improved but the nanoclay does not produce a considerable effect on the yield strength.

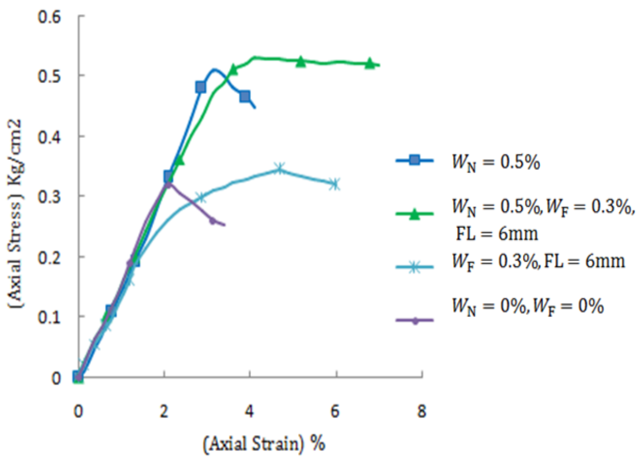



Fig. 14. Stress strain curves of reinforced samples

As can be seen from the (Fig. 14), adding a 0.5% of nanoclay to the soil containing 0.3% of fibers with 6mm length would increase the maximum axial stress so that it would be almost equal to the maximum axial stress of the sample containing 0.5% of nanoclay.

**4.7. Scanning Electron Microscope (SEM)**

Scanning Electron Microscope (SEM) has been used for better investigation of the nanoclay dispersion in the soil. The samples NF1 and NF25 have been photographed using the SEM equipment. (Figures 14 and 15) show the microstructure of failure surfaces with different scales. The SEM of the failure surface's microstructure shows that the surface bonds of the sample NF25 is superior to that of the sample NF1. It seems like that for the sample NF25 (Fig. 16), the Polypropylene fibers have been surrounded by the matrix and the clay nanoparticles.

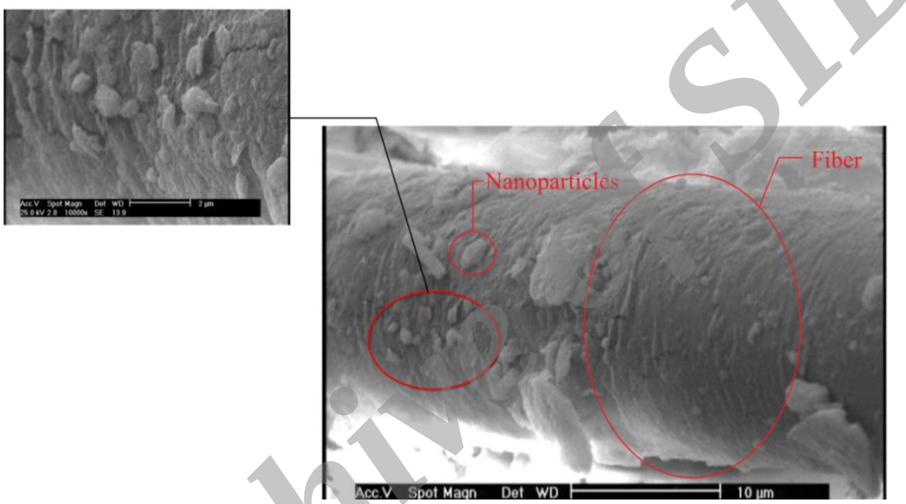



Fig. 15. The SEM image of the sample containing 0.5% of nanoclay and 0.3% of fibers

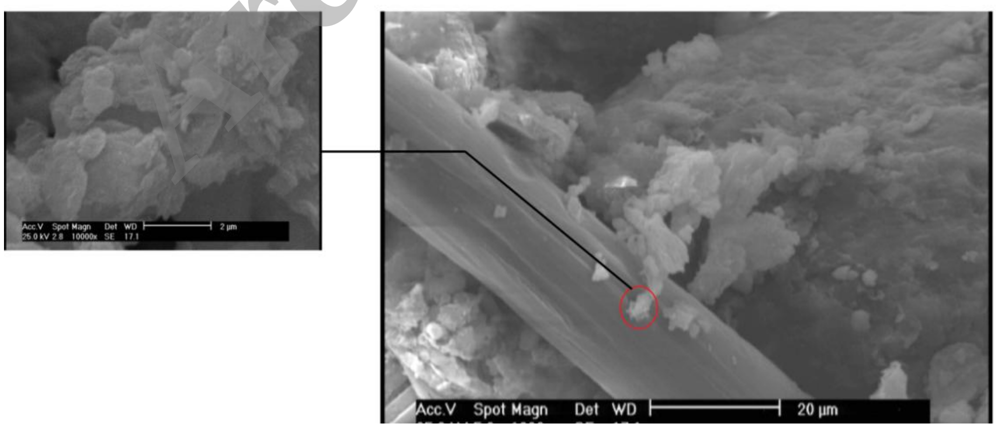



Fig. 16. The SEM image of the sample containing 2% of nanoclay and 0.3% of fibers

**5. Conclusions**

In this paper, the effects of adding nanoclay to the soil reinforced with the fibers on the mechanical behaviour of fine-grained soil reinforced with polypropylene fibers have been investigated. Results show that the increase in the nanoclay content will increase the plasticity index. By adding 2% of nanoclay, the soil type in nanocomposite sample has transformed from the silt soil with low plastic properties (CL-ML) into the clay (CL). Results of the standard proctor test showed that adding fibers could cause increase in the optimum moisture content and reduction of maximum dry density weight. Also the findings show that with the increase in the nanoclay amount, the maximum dry density weight reduces and the optimum moisture increases. Presence of fibers will increase the maximum compressive strength and flexibility of the soil. With the increase in the fiber's length, the fibers share from the maximum compressive strength decreases so that the increase in consequently the matrix cracks constitute the primary mechanism of fracture. On the other hand, for the sample containing 0.5% nanoparticles and 0.3% fibers (Fig. 15), the failure surfaces of the fibers are almost smooth so that surface bonds are indicative of the main fracture mechanism. Also it is worth mentioning that for the sample containing 2% nanoclay, the matrix-nanoclay remnants around the fibers are considerably more than the sample with 0.5% of nanoclay. From the SEM observations, it can be said that the sample with 2% of nanoclay has better surface connection compared with the sample containing 0.5% nanoclay. As a result, the increasing behaviour of Young's modulus and the yield strength in the nanocomposite can improve the surface resistance by nanoclay particles, a result that has been confirmed by the previous literature. The more volume and length of the fibers increase, the greater the secant modulus and the unconfined compressive strength of the soil would be, so that the 1.2% and 18mm fibers create the highest secant modulus and compressive strength. Also the presence of nanoclay produces significant effect on the engineering behaviour of the soil-fiber mixture. The more the nanoclay content increases, the secant modulus and unconfined compressive strength of the soil reinforced with the fibers will also increase, so that 2% nanoclay will result in the most secant modulus value and compressive strength. Finally, it should be noted that by adding nanoclay to the soil-fiber mixture a strength similar to that of the soil-fiber may be achieved, with the difference that the fiber's volume in the mixture containing nanoclay will considerably decrease.

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