The Potential Influence of Using Nanomaterials Additives on Unconfined Compressive Strength of Soft Soil

Mohammed A. Al-Neami¹, a*, Kawther Y. H. Al-Soudany ¹, b and Noor M. Tarsh ¹, c

¹Civil Engineering Department, University of Technology-Iraq, Baghdad, Iraq.
²40008@uotechnology.edu.iq, b40140@uotechnology.edu.iq,
³40454@student.uotechnology.edu.iq
*Corresponding author

Abstract. The building constructed on soft soils may fail due to their low strength, and an excessive settlement of the soil under a constant load could occur. Therefore, such soils must be improved before the construction eliminates or decreases the maintenance cost or collapse in buildings. Nowadays, nanoparticles are one of the modern materials that can be used in soil stabilization. The addition of soft particles such as nanomaterials may improve soil characteristics. This paper aims to clarify the influence of using conventional materials and nanomaterials on the unconfined compression strength of soft soil. Two types of nanomaterials (fly-ash and silica fume) are selected as improvement additives. Curing times (0, 1, 3, 7, 14, 28 days) are taken as one of the influencing factors to study the variation in unconfined compression strength with the addition of nanomaterials. Nanomaterials in a tiny amount (≤5%) by dry weight of the soil (0.5, 1, 3, and 5%) are mixed to prepare the samples for unconfined compression test according to ASTM D 2166. The laboratory results show that the unconfined compressive strength of treated soil increases until reaching the optimum content of (3%) nanomaterials, the nan after that, these additives exhibit a negative effect on UCS. The strength of the mixtures with nanomaterial was higher than the strength of mixtures with ordinary materials. Also, the curing time has a considerable effect on the unconfined compressive strength from increases their magnitudes.

Keywords: Soft soil; nanomaterial; ultrafine material; unconfined compression strength.

1. Introduction
Soft soils can typically be found in the field with high water content, namely approaching that of the liquid limit, which results in high settlement potential and low shear strength. Therefore, a stable condition should be reached to ensure that the settlement remains within the acceptance limit and higher strength is achieved to avoid the deformation and damages in the construction. In many civil works projects constructed on weak soils such as soft soils, many approaches can be employed to improve such soil. One of them is stabilization. Stabilization of soil is a conventional method used in soil improvement to meet the requirements of different types of projects [1-3]. In recent years, interest in the use of nanomaterials has been dramatically raised due to the wide range of applications of these materials and the pros of nanoparticles which consist of an eco-friendly approach, low cost, and rapid [4].

Nanomaterials are also considered one of the chemical methods used in most soils for soil improvement. Several soil improvement objectives include increasing bearing capacity, increasing
resistance characteristics, enhancing slope stability, and reducing subsidence [5]. Priyadharshini and Arumairaj [6] showed that using the optimum dosage of nano clay is 1%, nano MgO is 0.3%, and nano alumina is 0.75%, which led to the unconfined compressive strength increases up to 48%, 41%, and 43%, respectively. Abisha et al. [7] showed that 4% of nano clay mixed with weak clay modifies the shear strength. After this percent, the shear strength begins to decrease. This experimental study aims to determine the influence of using two types of nanomaterials (fly ash and silica fume) to enhance the unconfined compressive strength of soft soil.

2. Materials used

2.1 Soil
Soil samples are collected from one site in the Rustmia Region in the south of Baghdad City. All samples are disturbed soils taken from the excavated pit at a depth of 0.5 to 1.5 m underneath the natural ground level. Table 1 shows the values of the tests, which consist of the classification test and compaction characteristics of the untreated soil. Fig. 1 shows the particle size distribution of the soil. Fig. 2 shows the relationship between the moisture content and dry unit weight of soil.

| Index Property                  | Value | Standard specification |
|---------------------------------|-------|------------------------|
| Specific gravity, Gs            | 2.70  | ASTM D 854             |
| Sand (0.075 to 4.75 mm) (%)      | 3.00  | ASTM D 422             |
| Silt (0.005 to 0.075 mm) (%)     | 36.0  | ASTM D 422             |
| Clay (< 0.005 mm) (%)            | 61.0  | ASTM D 422             |
| Liquid limit, LL (%)            | 42    | ASTM D 4318            |
| Plastic limit, PL (%)           | 20    | ASTM D 4318            |
| Plasticity index, PI (%)        | 22    | ASTM D 4318            |
| Optimum moisture content, OMC (modified) (%) | 16    | ASTM D 1557          |
| Modified dry unit weight, MDD (kN/m³) | 18.8  | -                      |

Figure 1. Particle size distribution of soils used.
2.2 Improvement additives

In order to achieve the goal of the current study, the additives materials are mixed with the soil in two forms, ordinary form and nano form. These materials are (fly-ash, silica fume, nano fly-ash, nano-silica fume). A comparison between them will be made to concern which materials impact the compressive strength of soft soil. Fly ash-type C brought up from Al-Doura thermal power station is used, characterized by its cementitious and pozzolanic properties, and it contains more than 20% lime. The second additive is Silica fume (SF), which is considered a secondary product resulting from the reduction of high-purity quartz with the carbon in the electric furnaces during ferrosilicon alloys and silicon. It is composed of very fine glasses particles about 100 times less than the average particles of cement. Table 2 shows the chemical composition of silica fume and fly ash used in the tests.

| Composition | Fly-ash | Composition | Silica-fume |
|-------------|---------|-------------|-------------|
| SiO₂        | 40%     | SiO₂        | 98.87%      |
| Al₂O₃       | 17%     | Al₂O₃       | 0.01%       |
| Fe₂O₃       | 6%      | Fe₂O₃       | 0.01%       |
| CaO (Lime)  | 24%     | CaO         | 0.23%       |
| MgO         | 5%      | MgO         | 0.01%       |
| SO₃         | 3%      | K₂O         | 0.08%       |
|             |         | Na₂O        | 0.00%       |

3. Experimental work

3.1 Preparation of nanomaterials

A nanometer is defined in various prospects based on their application. Generally, 1 nm-100 nm sized particles are named ultrafine particles, 100 nm-250 nm particles as finer particles, and 250 nm-1000 nm as coarser particles in the nano range. Thus, from the particle size analysis result, the materials are in the finer particle range of nanometer [8]. In this study, nanomaterials are prepared in the laboratory by transforming the ordinary additives (fly ash and silica fume) to the nanoform, and they are used as improvement additives to the soft soil. The following procedure was followed to obtain nanomaterials: Firstly, stabilizing materials (fly ash and silica fume) should be oven-dried. Secondly, the sample is ground in a ball mill for 10,000 revolutions or it should be ground for 10-14 days. Grinding of the material sample continuously is a difficult process as the material particles stick to the wall of the cylinder. Thus, the cylinder should be cleaned every four hours for uniform grinding [9]. Thirdly, the
fine ground sample is analyzed in Particle Size Analyzer to determine the size of the particle Figure 3, which works on the principle of Dynamic Light Scattering (DLS). Particle size measurements can be made from 0.3 nm-8 µm. Fourthly, the sample must be dispersed in dispersing agents such as ethanol, sodium hexametaphosphate or sodium carbonate, or KNO₃. Thus, 1mg of the sample is dispersed in KNO₃ and taken in a test tube for half an hour such that the material particle disperses well. Then, the test tube is kept inside the instrument for analysis. The particle sizes obtained for nano fly-ash are between (10-10000) nm, while the nano-silica fume is between (100-1000) nm.

![Graph](image1)

(a) fly-ash

![Graph](image2)

(b) silica fume

**Figure 3.** Particle size analyzer works on the principle of dynamic light scattering (DLS).

### 3.2 Preparation of testing Samples

In order to prepare the USC samples, CBR mold was used to obtain the identical with dimensions of 38 mm in diameter and 76 mm in average height. Remolded soil samples are prepared based on a dry density equal to 15.2 kN/m³ and water content equal to 28%. The soil was compacted in a mold in three layers according to the moist–tamping technique using a manufactured steel tamping rod with has a weight of (300 gm), and dimensions of 37.5 mm bottom and 1.5 mm top in diameter and 8 mm in thickness. UCS samples are immediately obtained after 1,3,7 and 28 days of curing. The curing method was carried out using an airtight container with a wet sponge placed upon it. The specimen was wrapped in a plastic sheet and placed in an airtight container with a wet sponge for 1,3,7 and 28 days, see Figure 4.
Figure 4. Specimens during the curing period.

3.3 Unconfined compressive strength test

The test procedure was conducted according to the (ASTM D 2166). The vertical displacement rate was fixed at (0.3 mm/min) to make a slight difference between the results, and brittle soils need a slower rate of a strain than plastic soils to conform to this requirement [9]. In these tests, the unconfined compressive strength is acquired as the maximum load attained per unit area or the burden per unit area at 15% axial strain, whichever occurs first during the carrying out of a test.

4. Results and discussion

In this section, the unconfined compression characteristics of a soil sample (treated and untreated) with four percentages of additives materials are to be determined. A relationship between Stress-Strain for soil with the different percent of additives materials for curing time (1 to 28) days is shown in Figures 5 to 13. A relation between undrained shear strength and different percent of various materials (i.e., fly-ash, silica fume, nano fly-ash, nano-silica fume) are shown in Figure 14, and the relation between undrained shear strength and varying curing time (1, 3, 7, 14, and 28) days for various materials (i.e., fly-ash, silica fume, nano fly-ash, nano-silica fume) are shown in Figure 15, and the result of undrained shear strength show in Table 3.

From the figures, it can be noted that an increase in fly ash content leads to an increase in the unconfined compressive strength, and the increase in curing time has a positive effect on the UCS. The main reason for using fly ash in soil improvement applications is to improve the shearing and compressive strength of soils. The compressive strength of fly ash-treated soils is dependent on soil properties, curing period, moisture content at the time of compaction, and the ratio of fly ash addition. Also, it can be concluded that adding (0.5 to 5) % of silica fume leads to an increase in the UCS when and the enhancement increases with the curing period increase. This can be attributed to the internal friction of silica fume particles and the chemical reaction between silica fume and clay materials [10].

Furthermore, it can be seen that for nano additives (nano fly ash and nano-silica fume), the UCS increases due to increase the physical bonds between the additive’s materials and the surrounding soil, and the strength of the mixtures with nanomaterial is greater than the strength of the composing soil-ordinary materials. It worth noting that the increase of the nanomaterials exceeded the optimum limit may cause a conglomerate in nanomaterials particles in the soil matrix, and this is caused by an increase in the void ratio, which leads to a decrease in the unit weight of soil as nanomaterials increased up to 5%, so the soil cohesion will be decreased. Increasing curing time allows soil adhesion with addictive material to increase due to an increase in the area of contact between soil and additives products, so the increase in adhesion will improve the soil cohesion [11, 12]. Based on these findings, it can be concluded that the addition of 3% nanomaterial to the soils can be considered an optimum mix for design purposes to improve the soil since it provides a maximum cohesion value when added to the soil [13, 4].
Figure 5. Stress-strain relationship for soil at (0, 1, 3, 7, 14, and 28) days.

Figure 6. Stress-Strain curves for soil with fly ash % after 1 day curing.

Figure 7. Stress-strain curves for soil with Nano fly ash % after 1 day curing.
Figure 8. Stress-Strain curves for soil with silica fume % after (1 day) curing.

Figure 9. Stress-Strain curves for soil with Nano silica fume % after 1 day curing.

Figure 10. Stress-Strain curves for soil with fly ash % after 28 days of curing.
Figure 11. Stress-Strain curves for soil with Nano fly ash % after 28 days of curing.

Figure 12. Stress-Strain curves for soil with silica fume % after 28 days of curing.

Figure 13. Stress-strain curves for soil with Nano silica% fume after 28 days of curing.
Figure 14. Undrained shear strength for different percent of additive’s materials to the soil.

Figure 15. Effect of curing period on undrained shear strength with the different percent of materials.
Table 3. Results of unconfined compression tests.

| Additives          | Curing period | Additive ratio | $c_u$ (kPa) | IUCS (%) | Additives          | Curing period | Additive ratio | $c_u$ (kPa) | IUCS (%) |
|--------------------|---------------|----------------|-------------|----------|--------------------|---------------|----------------|-------------|----------|
| Untreated          | 14 day        | 0              | 7.16        | 0        | Untreated          | 28 day        | 0              | 9.89        | 0        |
| Fly ash            | immediately   | 0.5            | 9.58        | 34        | Fly ash            | 1 day         | 0.5            | 15.97       | 61       |
|                    |               | 1              | 16.44       | 130       |                    |               | 1              | 20.57       | 108      |
|                    |               | 3              | 26.04       | 264       |                    |               | 3              | 34.77       | 252      |
|                    |               | 5              | 43.65       | 329       |                    |               | 5              | 50.78       | 413      |
| Nano fly ash       | immediately   | 0.5            | 11.16       | 56        | Nano fly ash       | 1 day         | 0.5            | 15.76       | 59       |
|                    |               | 1              | 17.41       | 143       |                    |               | 1              | 22.29       | 125      |
|                    |               | 3              | 31.06       | 334       |                    |               | 3              | 39.17       | 296      |
|                    |               | 5              | 17.67       | 147       |                    |               | 5              | 22.42       | 127      |
| Silica fume        | 3 day         | 0.5            | 11.56       | 61        | Silica fume        | 7 day         | 0.5            | 16.67       | 69       |
|                    |               | 1              | 16           | 123       |                    |               | 1              | 22.39       | 126      |
|                    |               | 3              | 20.65       | 188       |                    |               | 3              | 26.87       | 172      |
|                    |               | 5              | 39.35       | 449       |                    |               | 5              | 46.69       | 372      |
| Nano silica fume   | 3 day         | 0.5            | 15.53       | 117       | Nano silica fume   | 7 day         | 0.5            | 17.29       | 75       |
|                    |               | 1              | 22.19       | 210       |                    |               | 1              | 22.85       | 131      |
|                    |               | 3              | 30.48       | 326       |                    |               | 3              | 40.06       | 305      |
|                    |               | 5              | 20.20       | 182       |                    |               | 5              | 24.74       | 150      |
| Untreated          | 28 day        | 0              | 12.09       | 0        | Untreated          | 28 day        | 0              | 20.33       | 0        |
| Fly ash            | 3 day         | 0.5            | 24.04       | 99        | Fly ash            | 7 day         | 0.5            | 29.55       | 45       |
|                    |               | 1              | 24.26       | 101       |                    |               | 1              | 34.44       | 69       |
|                    |               | 3              | 39.23       | 224       |                    |               | 3              | 50.73       | 150      |
|                    |               | 5              | 57.95       | 379       |                    |               | 5              | 76.61       | 276      |
| Nano fly ash       | 3 day         | 0.5            | 28.63       | 137       | Nano fly ash       | 7 day         | 0.5            | 32.69       | 61       |
|                    |               | 1              | 38.45       | 218       |                    |               | 1              | 38.75       | 97       |
|                    |               | 3              | 43.45       | 259       |                    |               | 3              | 65.38       | 222      |
|                    |               | 5              | 41.59       | 244       |                    |               | 5              | 50.96       | 151      |
| Silica fume        | 7 day         | 0.5            | 18.84       | 56        | Silica fume        | 14 day        | 0.5            | 28.12       | 38       |
|                    |               | 1              | 26.91       | 123       |                    |               | 1              | 30.32       | 49       |
|                    |               | 3              | 36.6        | 203       |                    |               | 3              | 47.05       | 131      |
|                    |               | 5              | 52.92       | 338       |                    |               | 5              | 56.63       | 179      |
| Nano silica fume   | 7 day         | 0.5            | 21.25       | 76        | Nano silica fume   | 28 day        | 0.5            | 32.39       | 59       |
|                    |               | 1              | 33.73       | 179       |                    |               | 1              | 36.65       | 80       |
|                    |               | 3              | 41.41       | 243       |                    |               | 3              | 47.65       | 134      |
|                    |               | 5              | 32.99       | 173       |                    |               | 5              | 37.89       | 86       |
| Untreated          | 14 day        | 0              | 20.39       | 0        | Untreated          | 28 day        | 0              | 23.5        | 0        |
| Fly ash            | 14 day        | 0.5            | 32.84       | 61        | Fly ash            | 28 day        | 0.5            | 36.3        | 54       |
|                    |               | 1              | 39.89       | 96        |                    |               | 1              | 49.82       | 112      |
|                    |               | 3              | 52.48       | 157       |                    |               | 3              | 75.33       | 220      |
|                    |               | 5              | 80.28       | 294       |                    |               | 5              | 85.12       | 262      |
| Nano fly ash       | 28 day        | 0.5            | 34.66       | 70        | Nano fly ash       | 28 day        | 0.5            | 42.35       | 80       |
|                    |               | 1              | 39.01       | 91        |                    |               | 1              | 42.47       | 81       |
|                    |               | 3              | 75.33       | 269       |                    |               | 3              | 81.12       | 245      |
|                    |               | 5              | 51.8         | 154       |                    |               | 5              | 58.84       | 150      |
| Silica fume        | 28 day        | 0.5            | 28.19       | 38        | Silica fume        | 28 day        | 0.5            | 45.56       | 94       |
|                    |               | 1              | 44.05       | 116       |                    |               | 1              | 45.83       | 95       |
|                    |               | 3              | 63.61       | 212       |                    |               | 3              | 64.06       | 173      |
|                    |               | 5              | 63.33       | 211       |                    |               | 5              | 65.69       | 180      |
| Nano silica fume   | 28 day        | 0.5            | 38.62       | 89        | Nano silica fume   | 28 day        | 0.5            | 38.73       | 65       |
|                    |               | 1              | 40.6         | 99        |                    |               | 1              | 57.95       | 147      |
|                    |               | 3              | 54.07       | 165       |                    |               | 3              | 79.63       | 239      |
|                    |               | 5              | 51.49       | 153       |                    |               | 5              | 68.68       | 192      |

$c_u$: unconfined compressive strength.  
IUCS: the enhanced factor.
5. Conclusion
This research was conducted to study the effect of four materials (conventional and Nano) on the unconfined compressive strength of the soft soil (fly-ash, silica fume, nano fly-ash, and nano-silica fume). Evaluation of testing results approved that the increase in the unconfined compressive strength occurred with the increase of the nanomaterial content until reaching the optimum contents (3%). In contrast, in the common additives, the unconfined compressive strength increases from (0.5 to 5) % and doesn't reach the optimum percent. Furthermore, when nanomaterials content becomes more than the optimal content (3%), the particles will be agglomerated, and the effect of these additives will become negative on properties of soft soil, and the enhancement in soil wasn't achieved. Untreated soil specimens exhibited brittle behavior, and vertical shear planes occurred, and the specimens failed at a minimal axial strain, more ductile conduct, and less post-peak strength loss than treated soil. In treated specimens, the failure pattern is eventually transformed to plastic bulging with networks of tiny cracks with no visible shear plane at failure with an increase in additive material content. Relatively, a larger axial strain is observed before failure, and for higher nanomaterials content, the reduction in post-peak strength loss is more pronounced. With an extended curing time, the unconfined compressive strength increases.

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