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Experimental Study on Geotechnical Properties of Clay Soil with Adding Expanded Polystyrene Material

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Abstract. Recently, traditional inert materials were replaced with waste materials, as a contribution to sustainability and waste reduction, as well as development, by providing low-cost and easily accessible materials for Geotechnical soils. Expanded Polystyrene EPS is a kind of lightweight material which has a low density, high compressibility, good chemical, water resistance and ease of use. Non-traditional lightweight materials have been widely used in Geotechnical engineering projects in recent years. Lightweight materials are used to lower vertical and lateral earth pressures. They can also be used as a compressible inclusion behind a retaining wall, as well as lightweight fill in slopes or embankments. An experimental investigation has been carried out in the laboratory. Clay soil with EPS contents of 0.0%, 0.25%, 0.5%, 0.75% and 1%. The tests performed include two of the most important tests in studying the geotechnical properties of reinforced soils. Standard Proctor test, the Unconfined Compression test. The results show that adding EPS chips reduce the weight of the soil as well as the unconfined compression strength UCS. EPS-chip specimens, on the other hand, tended to reach their peak strength at higher strains. Microstructure analyses reveal that with an increase in the content of EPS, the number of pores/vacuums increases, which leads to increases in the optimum moisture content and a decrease in the maximum dry density. Also, with an increase in the content of EPS, the characteristic of the dispersion is dominant in fabric, thus it is less resistant to external loading, and this clearly appears in the unconfined test results.

Keywords: expansive soil, compaction, unconfined compressive strength, effect expanded polystyrene.

1. Introduction

The ever-increasing need to expand urban areas to satisfy population growth and industrialization has required additional land, and in some cases, land with suboptimal soil properties. Like having weak or soft clayey soil. The stability of any structure depends on the properties of soil on which it is to be built. The soil, which contains the clay particles show considerable sign of distress accompanied by loss of strength of the soil during rainy seasons and shrinkage during summer [1]. Soil properties like compressibility, workability and volume changes are also some of the problems associated with clay soils. Common stabilization solutions to counteract the adversities associated with problematic soils include soil replacement and/or soil stabilization. In general, soil stabilization is preferred since the soil replacement is often impractical due to the costs associated with transporting new materials from other locations [2]. Soil reinforcement technique is a method for improving the engineering properties of soil to develop parameters such as shear strength, compressibility and absorption of tensile loads. By incorporating materials that resist tensile stress and shear stresses to improve soil strength [3]. Different methods have been developed soil stabilization. Some of these methods include chemical reinforcement with chemical bonding materials, for example, cement and lime. Soil stabilization with cement and lime is well documented, but despite this, there are a series of disadvantages, including low durability against local environmental conditions. Periodic wetting and drying causes a loss of partial stability in the soil as well as high costs of transportation and production of materials [4]. Also, Geotextile and fibers are used for mechanical reinforcement in soil stabilization. Although they are more environmentally friendly than chemical stabilization, there are some drawbacks, such as the high cost of producing Geotextile, the lack of availability of these materials in any location, the potential for biological degradation. Recently, researchers have introduced another way of soil stabilization by using waste materials. As a contribution to sustainability and waste reduction as well as developing by providing low-cost and easily accessible materials for Geotechnical soils, it has shown efficacy in improving the engineering properties of soil [5]. Expanded Polystyrene EPS is a kind of lightweight material which has a low density, high compressibility, good chemical, water resistance and ease of use [6]. Non-traditional lightweight materials have been widely used in Geotechnical engineering projects in recent years. Lightweight materials are used to lower vertical and lateral earth pressures. They can also be used as a lightweight fill in slopes or embankments, as well as a compressible inclusion behind a retaining wall. The use of soil mixtures with EPS as a lightweight material can reduce the weight of the soil [7]. The use of EPS beads provides an advantage in controlling the settlement and avoids the possibility of bearing capacity failure, also be an attractive solution for highway construction. As a result, more research on the effect of adding EPS to soil is required. The main idea of this research was to conduct experimental investigation to assess the feasibility of the potential use of Expanded Polystyrene (EPS) in Geotechnical applications.

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2. Materials and methods

2.1. Clay Soil

The soil used for this study was taken from eastern, Libya, city of Shahat. At the beginning, the soil natural moisture content was determined immediately. After that, the soil samples were spread out in the laboratory for two weeks for air-drying at room temperature to remove the natural water which may influence the analysis. The soil is of low plasticity (CL) classified according to Unified Soil Classification System (USCS). The grain size distribution and engineering properties of the used soil are presented in Fig 1 and Table 1, respectively.

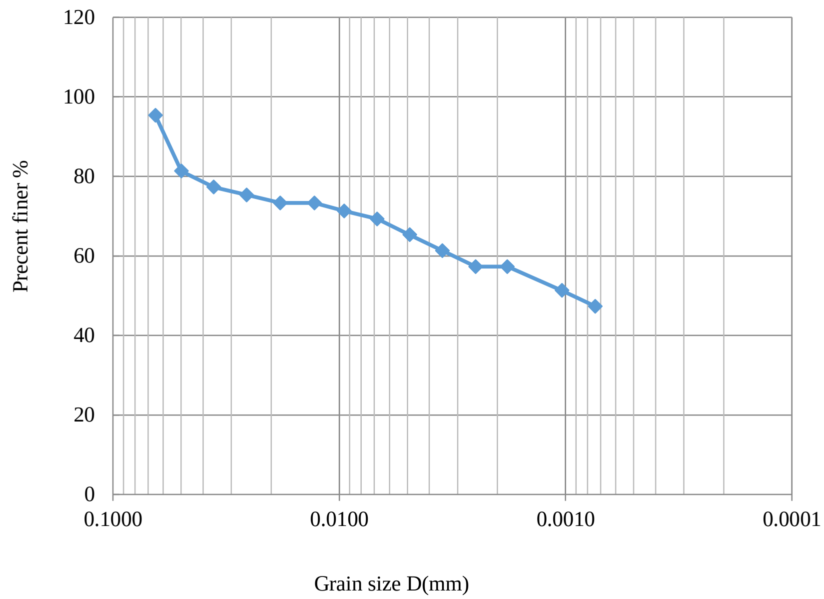

Fig.1. Percent of soil in suspension based on particle size.

Table 1.Clayey Soil physical properties.

Property	Value	
Specific Gravity (Gs)	2.87	ASTM D854[8]
Moisture Content (%)	34.75	ASTM D2216 [9]
Liquid Limit (LL %)	49.04	ASTM D4318[10]
Plastic Limit (PL %)	21.89	ASTM D4318[10]
Plasticity Index (PI %)	27.14	ASTM D4318[10]
Liquidity Index (LI %)	0.47	ASTM D4318[10]
Consistency Index (CI %)	0.53	ASTM D4318[10]
Activity (A)	0.5	ASTM D422[11]
Clay (<2/µm),%	57.3	ASTM D422[11]
Silt (2-75/µm), %	38	ASTM D422[11]
Max Dry Unit Weight(kN/m^3)	16.17	ASTM1998[12]
Optimum Moisture Content O.M.C (%)	20.04	ASTM1998[12]
Swelling Index (%)	60%	ASTM:D5890[13]

2.2.Polystyrene Expanded Materials

Expanded polystyrene (EPS) is a cellular polymeric material commonly used as a packaging medium for a variety of consumer appliances and electronic equipment. It is a lightweight material with a very low density. Expanded Polystyrene chips were prepared from waste that were collected from the home electrical machinery store. Shredded into chips of specific lengths and widths as shown in Fig.2. Length 12-14 mm and width 2-4mm. Properties of the EPS chips are presented in Table 2.

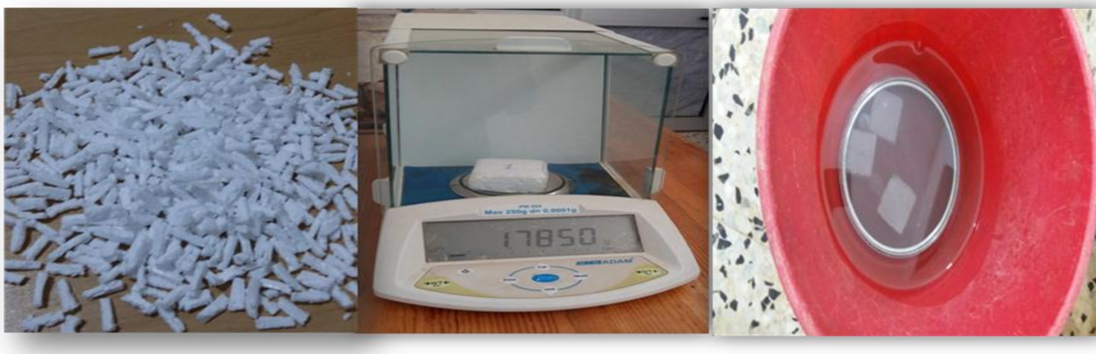

Fig.2.Polystyrene before crushing and after crushing

Table 2. The properties of EPS

Density (kg/m^3)	Water Absorption(%)	lengths (mm)	widths (mm)
15.3	4	12- 14	2- 4

The experiment involved heating asphalt to a specific temperature (180 ± 5 °C) until it reached a fully flowing state in a small container. Different percentages of SBS (3%, 4%, 5%, and 6% of the weight of the base asphalt) were gradually added to the melted asphalt using a high shear mixer operating at 4500 rpm for 2 hours. This process ensured that the blends became thoroughly mixed and homogeneous**.**

2.3. Specimen Preparation

To investigate the effect of EPS chips material on the geotechnical properties of the clay soil used, soil-EPS mixtures were prepared using different percentages of EPS chips material. A series of tests were first performed on nature soil. This was followed by additional tests, in which EPS chips were added to soil in different percentages (0.25%, 0.5%, 0.75%, and 1% referred to clay weight).

Standard (Proctor) compaction test, ASTM D698 -70. A minimum of five specimens were compacted for each mix with varying initial water content to obtain the maximum density dry and optimum water content for each mix.

The UC tests were procedure on according to ASTM D2166-06[14]. the optimum water content was added to each mixture, and the mixture was thoroughly mixed to ensure homogeneity. All samples were manually pressed into metal tubes measuring 50 mm in diameter and 100 mm in height. Following that, the samples were carefully removed and extruded from the metal molds, and then cured for different periods of 3, 7, and 28 days (dry and wet side of the optimum water content). These curing periods were adopted for samples to achieve its potential strength and durability.

SEM analysis for mix designs consisting of the natural soil, 0.5% EPS and 1%EPS. The desired samples, which were prepared in a similar fashion to that described for the unconfined test, were first air- dried for approximately 28days. The desiccated samples were carefully fractured into small cubic-shaped pieces measuring approximately 1 cm^3 in volume, as suggested in the literature [15,16] The samples were then scanned by means of the scanning electron microscope at various magnification ratios ranging from 200× to 5000 (Industrial Research Center - Tripoli).

3. Results and Discussions

3.1. Compaction Test

One of the ways the effect of adding polystyrene into the soil was investigated was the behavior of the reinforced soil during compaction. The maximum dry density and optimum moisture content were altered by the soil's addition of polystyrene (0.25%, 0.5%, 0.75%, and 1%) as shown in Fig.3. The values of maximum dry unit weight (γ_{dmax}) and optimum water content (OWC) as determined from standard Proctor compaction test are given in Table.3.

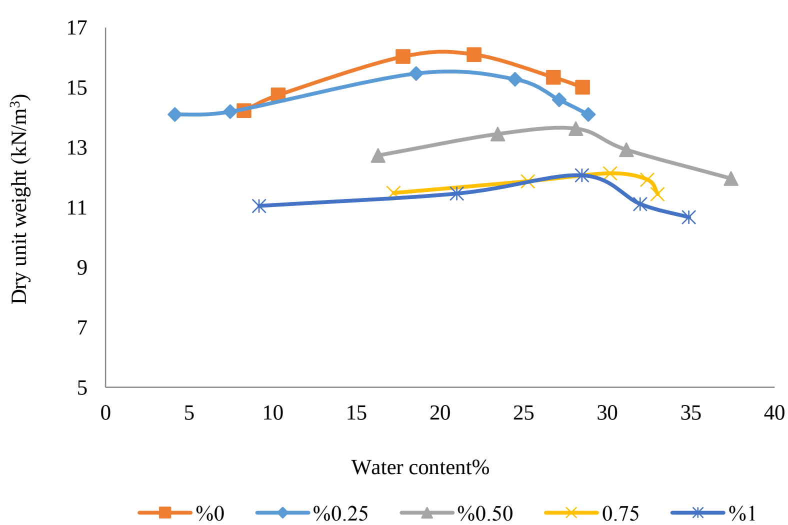

Fig. 3. Compaction curve of soil and EPS

Table 3. Compaction parameters values with polystyrene contents

Ratio EPS%	Ɣd(max) kN/m^3	OWC %
0	16.17	20.04
0.25	14.22	23.53
0.5	13.63	28.14
0.75	12.16	30.17
1	12.06	28.5

Effects of EPS on maximum dry unit weight

As seen in Fig.4, increasing the polystyrene chips content from 0.25% to1% leads to a reduction in the maximum dry unit weight the result is also in agreement with the test results of [17, 18]. The maximum dry unit weight of soil reinforced goes down from 1.65 g/cm^3 to 1.21 g/cm^3 (19.8%) with a change of to 1% EPS content. Due to the volume of soil replaced by the EPS chips, a little increase in EPS chips weight can result in a considerable decrease in the combined particle density, as illustrated in Table3.

A decrease in maximum dry unit weight is primarily attributed to their lower specific gravity (0.003) of polystyrene, also due to increased voids caused by polystyrene chips separation of the soil particles.

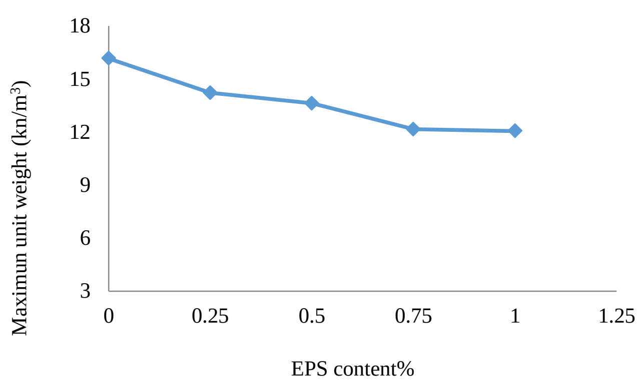

Fig.2. Variation in Maximum Dry Unit Weight for Different EPS content.

Effects of EPS on optimum water content

The inclusion of polystyrene chips in soil causes an increase in optimum water content is presented in Fig.5. Increase in EPS chips content increased the OWC. The maximum OWC is recorded as 30.17% for 0.75% EPS chips content, and as low as 23.53% for soil with 0.25% of EPS chips. Addition of 1%EPS chips caused a reduction of 28.5% in OWC. But in all cases, the OWC is greater than that of raw soil. This may be due to the presence of randomly oriented polystyrene chips in the clay resisting the compaction effort, forming an interlocked structure, with increasing polystyrene chips content from 0.25%to 1% make up many pores between EPS particles leading to a large amount of water being required to cohere with EPS and clay particle. As a result, the optimum water content of reinforced soil increases [19, 20].

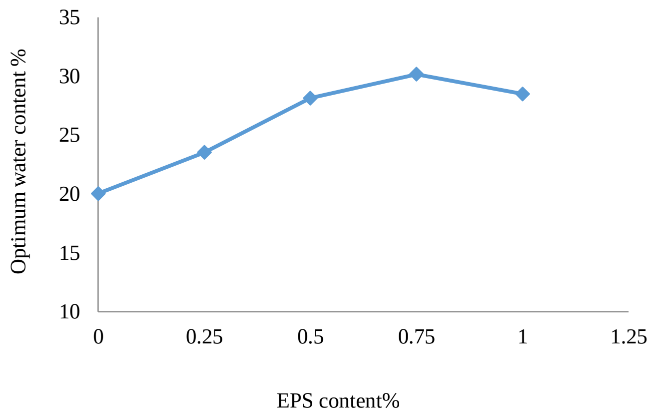

Fig.3. Variation in Optimum Water Content for Different EPS Content.

3.2. Unconfined Compression Test

The peak unconfined compression strength of unreinforced and reinforced soil specimens in various curing time (3, 7 and 28 days) in both wet and dry conditions are shown in Fig 6 and Fig 7. Observe that adding EPS to soil would result in significant change in UCS. During the cure periods in the dry condition, the UCS value decreased for all mixing ratios when compared to the unreinforced soil. A peak was observed in the reinforced samples at 0.25% mixing ratio. The UCS gradually decreased as the EPS content increased. This is because the presence of EPS in the soil sample reduces its compressive strength[19,20]. The reason for this could be that the maximum dry density of the samples decreased as the EPS content increased.

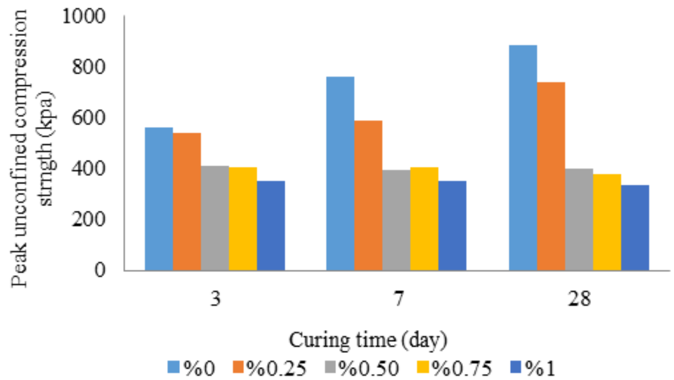

Fig. 6. peak unconfined compression strength of unreinforced and reinforced soil specimens at curing periods subject to drying

In the wet condition, note that after three days of curing. The compressive strength improved by 9-10% compared to the compressive strength of unreinforced soil. At higher water contents, the strength of the unreinforced soil decreases more rapidly than that of the reinforced soil. Fig 7 demonstrates that during curing time of 28 days, the highest UCS value is at 1% of the EPS content. The enhancement could be due to the presence of more EPS chips, which cause an increased probability of EPS chips crossing developing shearing planes. Better interlocking and intertwining of chips with clay soil particles. On the other hand, the size and the number of pores is much of the 1% EPS lead to the movement of particles more difficult. Once the shear stress reaches the shear strength of the sample.

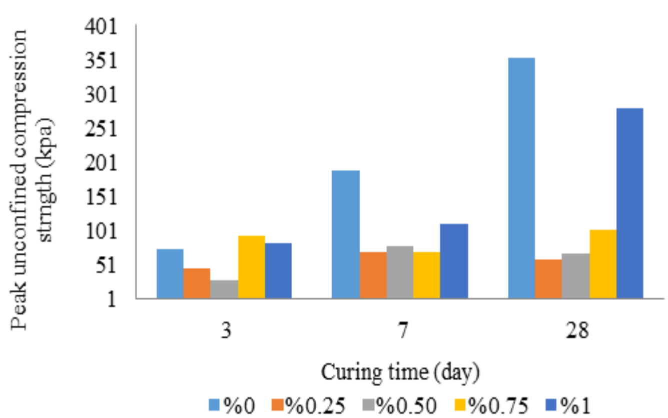

Fig. 7. Peak unconfined compression strength of unreinforced and reinforced soil specimens at curing periods preserved to moisture.

The strain relationship of development with curing time (dry and wet) for clays with EPS chips in Fig.8 and Fig.9 The inclusion of EPS chips, as well as the curing periods, have an effect on the strain relationship of soil clay by altering the soil behavior and deformation characteristics in terms of brittleness or ductility.

It is evident that for a given EPS chips content and different curing times, the ultimate unconfined strength decreases. While the development the ductility or strain experienced at failure, curve of a specimen with higher EPS content is found above that with lower ones. This indicated that the positive effect of EPS on ductility increase was expected to exist throughout all the curing periods (from 3 to 28 days).

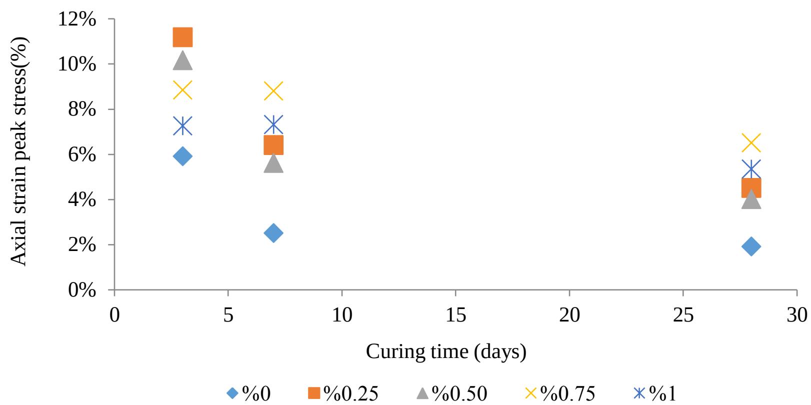

Fig. 8. Strain values at failure over curing time subject to drying.

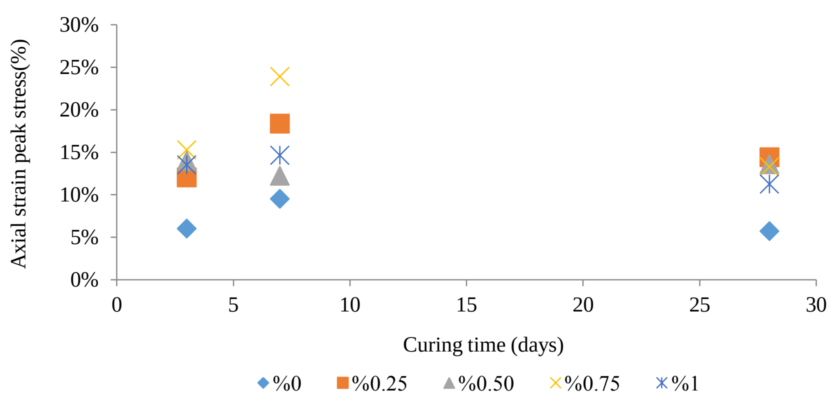

Fig. 9. Strain values at failure over curing time preserved to moisture.

By observing the specimens during the UCS tests, it is seen that unreinforced specimens show cracks when vertical strains are very small, and these cracks continue to grow until total failure, which was responsible for the lack of post-peak strength of the mix. The EPS chips reinforced specimens developed cracks much slower, as the bond stress between the EPS and soil mixture played a role in postponing the crack development. The shape of the failure of the unreinforced soil specimens was steep shear planes in Fig 10and Fig 11, whereas with the addition of EPS chips, dominated shear failure planes were not evident. In specimens with higher EPS chips content, EPS chips could confine the soil particles and increase the global stability of the soil mass. As a result, EPS chips influence the likelihood of soil particles sudden displacement behavior under axial loading instead of a more gradual deformation. Hence, the soil specimen bulged laterally and reshaped to a barrel form.

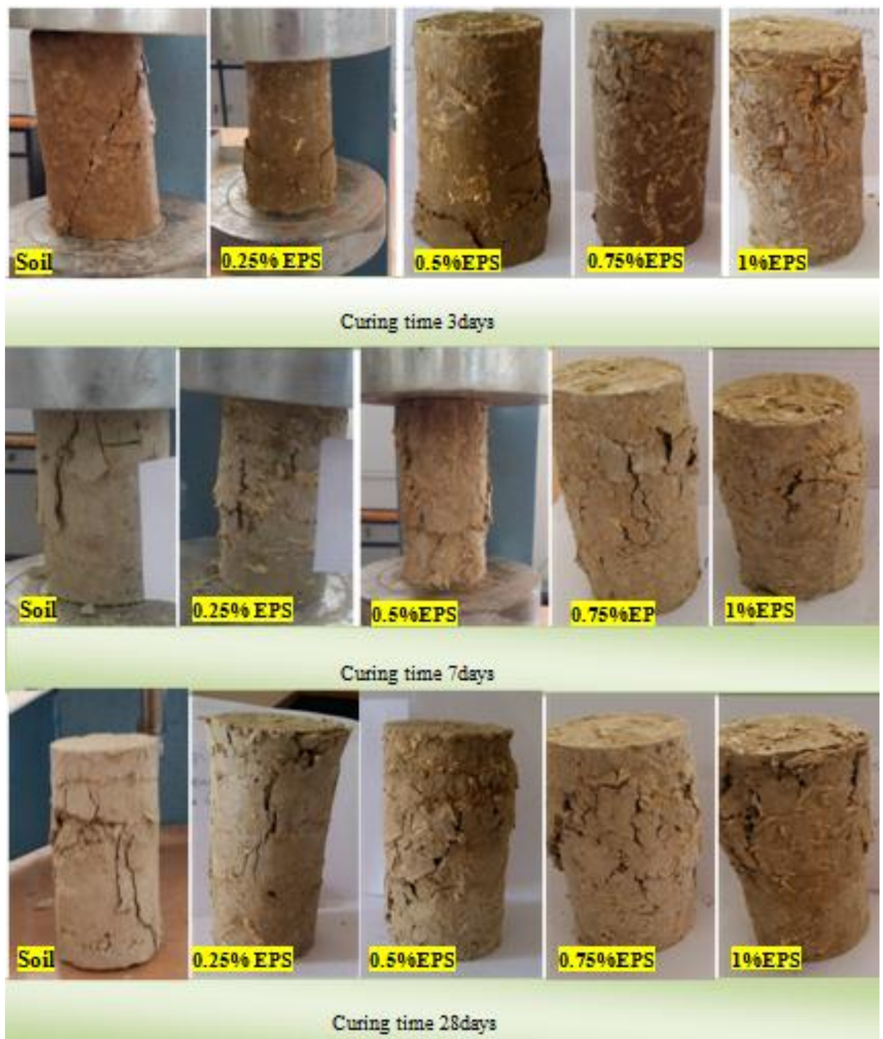

Fig. 10. Specimens at end of UCS tests at curing periods subject to drying

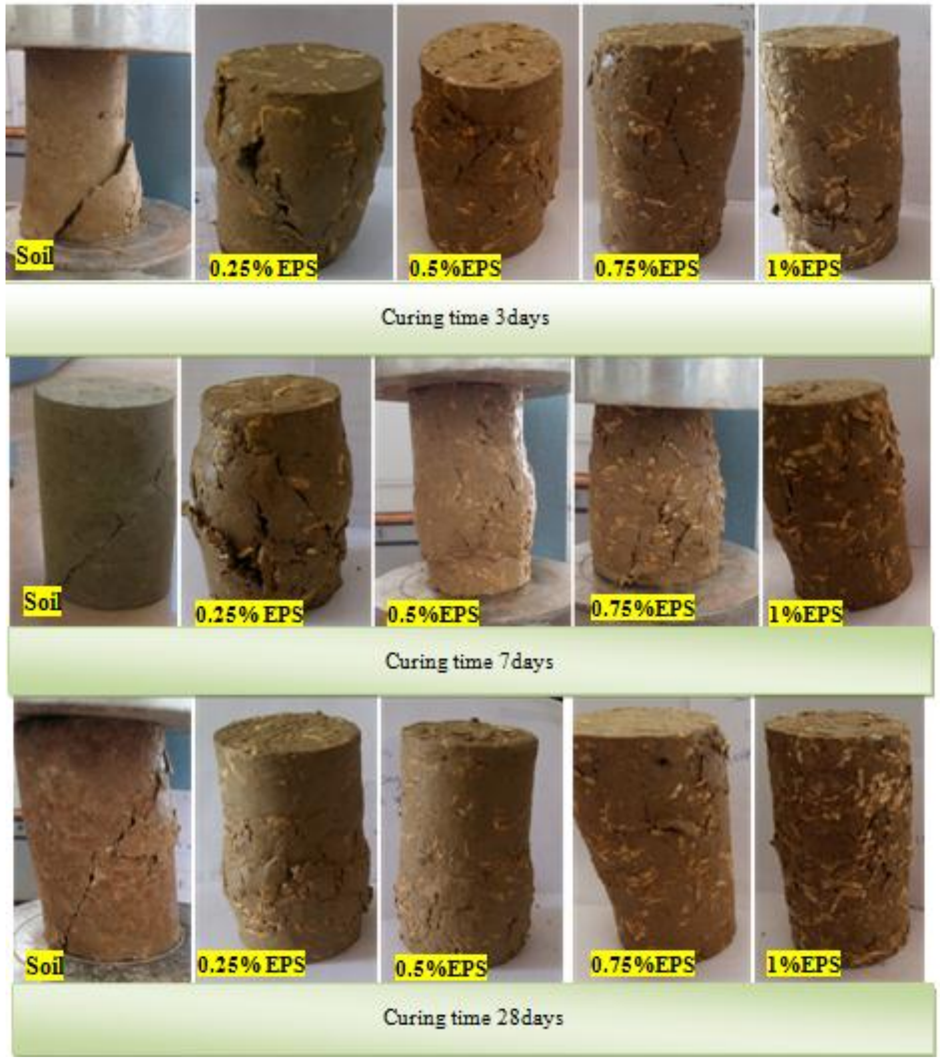

Fig. 11. Specimens at end of UCS tests at curing periods preserved to moisture.

3.3. SEM Analysis

Figs12-14 shows the comparison of SEM images of the unreinforced soil and the samples blended with 0.5% and 1% EPS respectively at 28 days of curing. The unreinforced soil sample exhibited a fully-dense, uniform matrix, which was accompanied by a limited number of rather small inter- and intra-assemblage voids/pore-spaces, (see Fig12). Clay soil reinforced with 0.5% EPS, SEM micrograph reveals a scaly-like surface morphology with a well-developed network of minor cracks. It demonstrates inter-grain porosity as a result of drying and microstructure changes distributed along the soil–EPS (see Fig13). In the case of 1% EPS inclusion, dispersed character clearly dominated the fabric. A dispersed fabric offers less resistance to external loading [19, 21]. As is evident with the presence of a fully-loose, non-uniform matrix accompanied by an increased number of relatively larger pore-spaces (see Fig14). As such, the degree of fabric dispersion is proportional to the EPS content, with The EPS contents influences the pore volume, leading to the loose state of the microstructure.

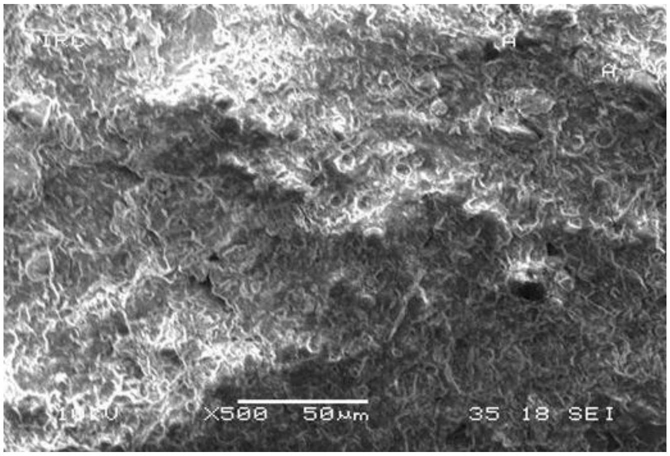

Fig. 12. SEM of unreinforced clay.

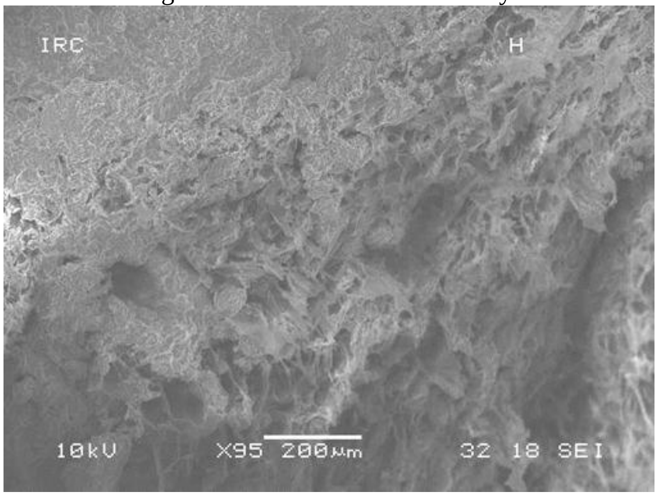

Fig. 13. SEM of reinforced clay with 0.5% EPS.

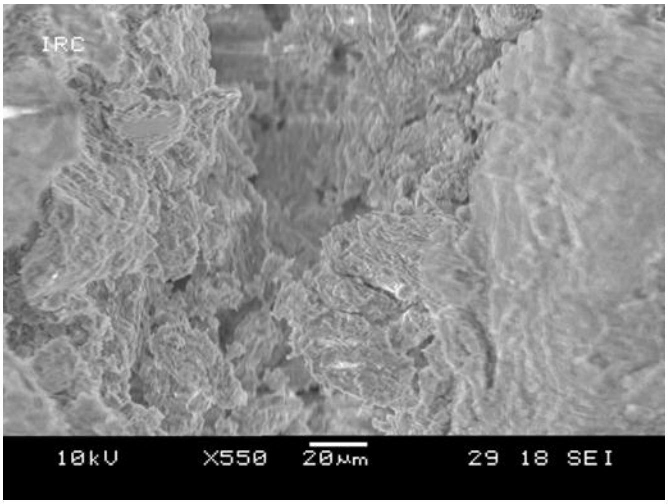

Fig. 14.4SEM of reinforced clay with 1% EPS.

This is in agreement with the results obtained from compaction and unconfined compress tests. Where the increase in the content of EPS, the number of pores/vacuums increases, which leads to increases at optimum moisture content and a decrease in the maximum dry density. Also, with an increase the content of EPS, the characteristic of the dispersion is dominant in fabric, thus it is less resistant to external loading, and this clearly appears in the unconfined test results.

4. Conclusion

This study experimentally assessed the behavior of reinforcing clay soils using EPS chips. The following conclusions are drawn based on the analysis and interpretation of the results obtained .

- A significant reduction was recorded in the maximum dry density results while optimum moisture content increased with increasing EPS content. This may be because the clay contains polystyrene chips that are randomly oriented and resist compacting, forming an interlocked structure. Additionally, as the EPS chips content increases, more pores form between the EPS particles, increasing the amount of water needed to cohere the EPS and clay particles.
- The addition of EPS to the soil would reduce in UCS. EPS-chip specimens, on the other hand, tended to reach their peak strength at higher strains. This means that incorporating EPS chips into clay soil will improve the ductility of the reinforced soil rather than increase its strength. In this study, higher ductility resulted in higher strain values.
- Microstructure results reveal that increase in the content of the EPS, increases the number of pores/vacuums, which leads to increases at optimum moisture content and a decrease in the maximum dry density. Also, with an increase the content of PES, the characteristic of the dispersion is dominant in fabric, thus it is less resistant to external loading, and this clearly appears in the unconfined test results.

5. Conflicts of Interest

The authors declare no conflict of interest.

6. List of Abbreviations

USCS Unified Soil classification system
A Activity
Cs swelling index
W Natural moist content
MDD maximum dry density
OWC optimum water content
EPS Expanded Polystyrene
G_s specific gravity of soil grains
L.L Liquid limit
P.L Plastic limit
PI Plastic index
LI Liquid index
CI Consistency index
UCS Unconfined Compression Strength

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