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The Effect of Adding of Polystyrene on the Engineering Properties of Clay Soil

Dr. Enas B. Altalhe
Assistant professor at civil and structural engineering department
omer Almukhtar University
enas.omer @omu.edu.ly

Eng. Ambaraka Saad Faraj
M.Sc. Student at civil and structural engineering department,
omer Almukhtar University
ambark.asaad@omu.edu.ly

Abstract— **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. Recently, traditional inert materials were replaced with material waste material. Useful materials can be produced from non-useful waste materials leads to use the plastic products like polystyrene. The main idea this research was to conduct experimental investigation for the understanding and evaluation of the interaction between clay soils and polystyrene. In purpose of examination of the effect the induced materials on behaviors of the clay; tests were carried out on different portions of polystyrene contents to test the unconfined compression. The results showed that increasing the EPS content decreased the maximum dry density while increasing the optimum moisture content. The addition of EPS to the soil would reduction of unconfined compression strength (UCS). Reinforced specimens, on the other hand, tended to reach their peak strength at higher strains. The addition of EPS chips reduces the weight of the soil while increasing its flexibility.**

Index Terms: **Clay, soil, polystyrene, compaction characteristics, un confined compression strength.**

I. INTRODUCTION

Due to urban expansion of design the heavy structures like bridges, embankments, buildings, and highways, etc., and lack of land, the sites used the ground of the low engineering properties. Engineers resort to soil reinforcement technology to deal with soil problems [1]. Therefore, the use of soil reinforced technology has become one of the most important geotechnical engineering works in civil engineering, which is more economical in terms of cost, effort and greater bearing capacity [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 reinforcement. Some of these methods include the chemical reinforcement includes chemical bonding materials, for example cement and lime. Soil reinforcement 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 loss of partial stability in the soil as well as high cost of transportation and production of materials [4]. In addition to Mechanical reinforcement is used by grouting stabilization by Geotextile and fibers , and although they are associated with an environment compared to chemical reinforcement, there are some disadvantages, including the high cost of producing Geotextile the lack of availability of these materials at any location, and the potential for biological degradation of natural fibers. It is evident that the mechanical and chemical methods need an economic cost and suffers in terms of sustainability.

Recently, traditional inert materials were replaced with materials waste material. The best way to handle such waste material is to utilize engineering applications. 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]. Polystyrene(EPS) is one of the leading waste materials and is generally used for packaging a variety of consumer appliances and electronic equipment, often having short life span and being discarded immediately after use. EPS is harmful in nature and is non-biodegradable to the soil. Therefore EPS has become popular in civil engineering applications due to its feature characteristics including very low density, high strength to density ratio, water resistance and ease of use [6]. EPS low mass density, ranging between 10 and 40 kg/m^3. This benefit can help reduce vertical and horizontal strains on subterranean structures, utilities, and compressible soils. The use of lightweight-fill decreases the amount of settlement produced by geotechnical construction, as well as the risk of harm to nearby structures and facilities. As a result, EPS is an appealing fill material due to its

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considerable difference in unit weight when compared to other materials [7].

Abdelrahman et al. [8] studied series of tests were performed on circular footing with different diameters rested on sand EPS mix replacement layer with different ratios of EPS beads(0, 0.3, 0.6, 0.9, 1.2). Increase beads content leads to decreased swelling pressure on the footing and decreases also the swelling settlement. EPS beads particles swelling energy absorption due to their compressive nature. The stress–strain behavior of EPS beads–sand mixtures can be influenced by the gradation of EPS beads. Edincliler and Ozer.[9] carried out a series of triaxial compression experiments under three different confining pressures to investigate the effect of the EPS beads particle size distribution on the mechanical properties of the mixture. A typical EPS beads–sand mixture's mobilized deviatoric stress was found to be a function of the EPS beads content, the EPS beads grain size distribution, and the all-around confining pressure. Figure 1 shows that, regardless of the type of EPS beads used, the peak deviatoric stresses of the EPS beads–sand specimens were lower than those of pure sand when subjected to the same confining pressures.

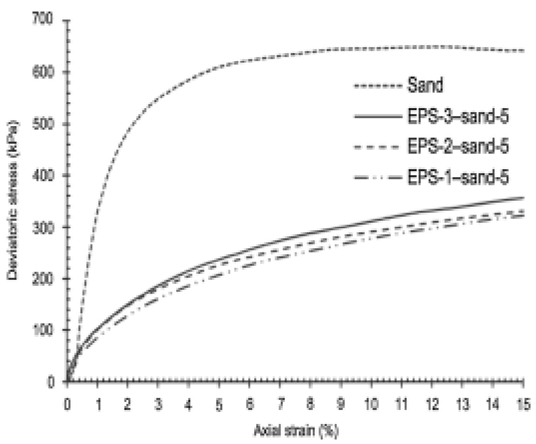


Figure 1 Stress–strain behavior of sand and EPS-sand mixtures (Edincliler and Ozer, 2014).

Silveira et al. [10] experimental investigation to evaluate the conduct of three sorts of soil (colluvial clayey soil, sandy soil, and bentonite) reinforced with the Polystyrene EPS beads, mixed with soil in different proportions (0.25, 0.50, 0.75, and 1%) of soil samples. Perform compaction tests, direct shear tests and drained triaxial tests on reinforced and unreinforced soil. The addition of EPS beads to colluvial clayey soil altered the resistance parameters of this soil, and the impact various depending on the amount of added material. The cohesion intercept value increased as the friction angle decreased for contents up to 0.75 percent. Both parameters were reduced when 1.0 percent was added the changes verified in the stress versus deformation behavior pattern and in the resistance parameters in performing triaxial tests are in agreement with the decrease of the material’s maximum specific. The addition of EPS beads to the clayey, sandy, and bentonite matrix did not result in a degradation of the material's behavior in any of the tested mixes, as one of the resistance parameters always rose. The mechanical behavior of soil reinforced with EPS beads demonstrates the material's potential for use as soil reinforcement in earthwork subjected to static loads, providing an environmental friendly alternative for this material.

Syahril et al. [11] studied the EPS effect as a lightweight fill material in stabilized soil with fly ash for embankment construction. The EPS contents are (0%, 0.2%, 0.4%, 0.6%, and 0.8%) and fly ash contents 25% measured from the weight of dry soil. The compaction test revealed that adding a little amount of EPS to the mixture can significantly reduce the maximum dry density of the mixture. The results of the triaxial UU and UCS tests indicate that if the amount of EPS in the mixture increases, the strength increases the strength of the mixture.; While, the presence of fly ash increases the strength of the mixture. As a result, using lightweight materials could be one of the soil improvement methods. Nawghare and Mandal [12] did series of tests to investigate the effect of fly ash mixed with polystyrene beads of different sizes are 1 mm, 2 mm, 3 mm, 4 mm, and 6 mm. The results indicate that the size of the polystyrene beads have benefits, according to the requirements of the engineering applications. The increase in the size of the polystyrene beads reduces the maximum dry density, but at the size of the smaller beads, an improvement is noticed in the shear resistance, the CBR value, and the permeability. The coefficient of consolidation increased until the beads a size of 4 mm, then reduced at the beads a size of 6 mm. Small size polystyrene beads can be useful in weak soil structures.[12] Chuanyang Liang et al. [13] carry out a series of tests compaction, coefficient of permeability, UCS, ductility, and compression. With a view of comparing effects of various sizes of the EPS particle on engineering properties of clays. The results showed that the maximum dry density of the mixture the ESP-clay decreases with the increase of the ESP particle size, while the OMC increases. Engineering properties, including the ductility, hydraulic conductivity, and compression index of EPS-clay blends, do not increase while the UCS does not decrease with the increase in the EPS particle size. Microstructure analysis to explain variation in the effect of particle size ESP as shown in pictures SEM of ESP-clay at the large particle size of large specific surface area and pores between particles result in more water being needed to cohere with EPS and clay particles, while the smaller EPS particles are close to the clay particles, the number of pores between the particles increases make EPS chips easily cohere with clay particles to form an elastic body

A. objectives

The main idea this research was to conduct experimental investigation for the understanding and evaluation of the interaction between clay soils and expanded polystyrene.

B. Scope

The following sections will be carried out to achieve the research's objectives.

- Compaction test: To determine the compaction characteristics of clay soil with and without reinforcement.

- Unconfined compression test: To determine the unconfined compression strength of research a samples.

II. METHODOLOGY AND MATERIALS

A. Research method

The flow chart for the present study is explained in (Figure. 2).

B. Sample collection

The soil used for the study is clay soil from eastern, Libya, city of Shahat. Soil samples a location is shown in (Figure.3) the locations of the sampling sites are given in table.1. The soil was extracted from a depth 0.5meter below the soil surface

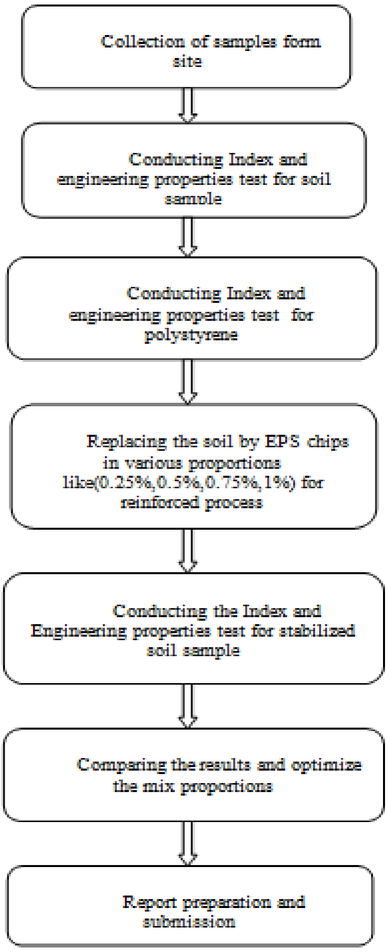


Figure 2. Flowchart of methodology of research work.

Figure 3. Soil sample collection site in shahat Libya

Table 1. location of the sampling

Latitude	Longitude
32.826061	21.86868

C. Expanded Polystyrene (EPS)

EPS (expanded polystyrene) is white polymeric (plastic) foam that is commonly used in packaging. EPS has a low thermal conductivity and air makes up nearly 98% percent of its volume. Because of its advantageous attributes, such as low density, strong insulating capabilities, chemical and water resistance, low cost, and ease of construction, EPS has a wide range of applications. [14] In this research using Polystyrene chips with dimensions (12mm* 1mm). The specific gravity of EPS is 0.03 and unit weight 0.016g/cm^3. As shown in (Figure.4).

Figure 4. Polystyrene before crushing and after crushing

D. Soil materials

All laboratory tests are in accordance to ASTM. The natural water content determines based on ASTM D2216-19. Laboratory tests conducted to obtain physical properties like specific gravity accordance with ASTM D854,Atterberg's limits based on ASTM D4318, compaction tests based on ASTM D 698 and unconfined compression test based on ASTM2166-06. The results are shown in Table.2.

Table 2. Physical properties of clay soil

Property	Value
Bulk Unit Weight (g/cm^3)	1.65
Specific Gravity(G_s)	2.87
Moisture Content(W_n)	34.75
Liquid Limit (LL %)	49.04
Plastic Limit (PL %)	21.89
Plasticity Index (PI %)	27.14
Liquidity Index (LI %)	0.47
Consistency Index(IC %)	0.53
Optimum Moisture Content O.M.C (%)	20.04
Max Dry Unit Weight γ_{dry}- max(g/cm^3)	1.65
Classification of Soil(USCS)	CL
Unconfined Compressive Strength UCS (KN/m^2)	26

III. TESTING PROCEDURE

A. Specimen preparation

EPS chips were mixed to the soil in proportions of 0.25%, 0.5%, 0.75%, 1%. It was observed that for EPS content greater than 1% con not produce a uniform mix. Thus, EPS chips content had to be limited to about 1% of the dry soil mass to avoid segregation and to have uniformity in the mix. As shown in the table.3, soil particles and EPS chips were combined in specific mass ratios.

When using soil as an engineering fill, it is almost always necessary to bring it to the highest density possible state in order to achieve the engineering qualities that are required and cannot be obtained with loosely placed material. Chemical stabilizers or other mechanical additives, such as fibers or tyre chips, which are added to soils to improve or alter their engineering properties, must also be compacted. To accomplish this, a compaction test is used. In the current research, the standard (Proctor) compaction test, ASTM D698 -70. 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%). All the tests were performed using manual compaction. 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. Figure .5 shows a compaction tests on soil samples in the laboratory.

Unconfined compression test was chosen as the preferred mode of evaluation of strength of the reinforced soil due to quickness and ease of use of the test.[4]

The UCS tests were procedure on according to ASTM D2166-06. Preparing specimens for the unconfined compression strength (UCS) tests OMC of the mixtures were used. Polystyrene (0.25%, 0.5%, 0.75%, 1%) was mixed from the dry soil's weight, then 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). As shown in the figure.6. These curing periods were adopted for samples to achieve its potential strength and durability.

Replicate tests were conducted on two specimens for each mixture ratio for reduce the error produced by the specimen preparation and testing procedure. For each mixture ratio, the average axial stress obtained from two replicate specimens and corresponding to the same axial strain was selected as the representative stress, and the average value of the peak stress was used as the representative unconfined compressive strength (UCS).

Figure 5. Compaction test in the laboratory.

Figure 6. Unconfined test in the laboratory.

Table 3. EPS ratio by soil weight

EPS content %	EPS ratio by soil weight %
0.25%	99.75 : 0.25
0.50%	99.5 : 0.5
0.75%	99.25 : 0.75
1%	99 : 1

IV. RESULTS AND DISCUSSTION

A. *compaction test*

The results obtained on tests are discussed in detailed manner below.

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%). The values of maximum dry unit weight (γ_{dmax}) and optimum water content (W_{opt}) as determined from standard Proctor compaction test are given in Table.4.

a. *Effects of EPS on maximum dry unit weight*

As seen in Figure. 7, 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 [12, 15]. 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 0.0% 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 Table 4.

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.

b. *Effects of EPS on optimum moisture content*

The inclusion of polystyrene chips in soil causes an increase in optimum water content is presented in Figure.8. Increase in EPS chips content increased the OMC. The maximum OMC 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 OMC. But in all cases, the OMC 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. [13, 16]

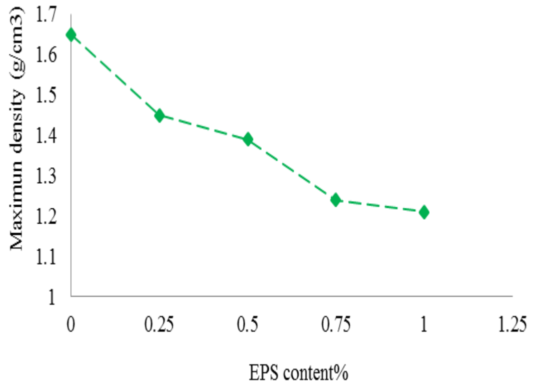


Figure 7.Variation in Maximum Dry Density for Different EPS content

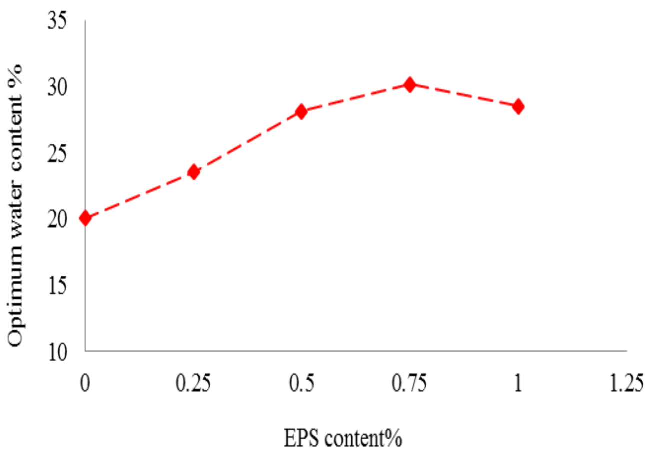


Figure 8. Variation in Optimum Moisture Content for Different EPS Content.

Table 4. Pressure parameters values with polystyrene contents

Ratio EPS%	ɣd(max)	OMC
0	1.65	20.04
0.25	1.45	23.53
0.5	1.39	28.14
0.75	1.24	30.17
1	1.23	28.5

B. *Unconfined compression test*

Prior to fiber inclusion, baseline data for the unconfined compressive strength of clay soil and the stress-strain relationship for different curing periods were obtained. Figure.9 shows typical clay soil results. The stress-strain relationships indicated, as expected, that the clay behavior was rigid and brittle at low water contents (dry condition) as shown in Figure.9a. The behavior changed to ductile at higher water contents (wet condition) as shown in Figure.9b. [17] Therefore, it is important to consider the water content of the clay when examining the effect of EPS chips inclusion.

a. Effects of EPS content on UCS

Table 5 shows peak UCS and corresponding vertical strain. There appears to be a difference in the peak strengths of the unreinforced and reinforced specimens in curing time (3, 7 and 28 days) in both wet and dry conditions, although specimens with EPS chips tended to reach their peak strength at higher strains. As shown in Table 5 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.[13, 18] The reason for this could be that the maximum dry density of the samples decreased as the EPS content increased.

In the wet condition, note that after three days of curing. The compressive strength improved by 9-10% of 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 the figure demonstrates that during curing time of 28 days, the highest UCS value is at 1% of the EPS content. The incurred enhancement could be due to the presence of more EPS chips that 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.

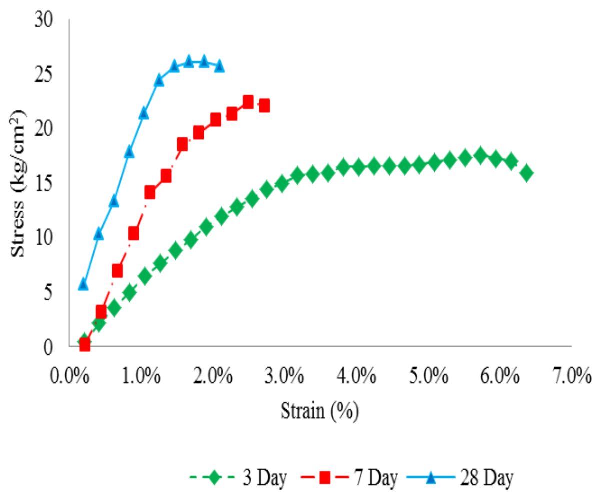


Figure 9a. Unconfined compression strength of clay for curing periods preserved to moisture .

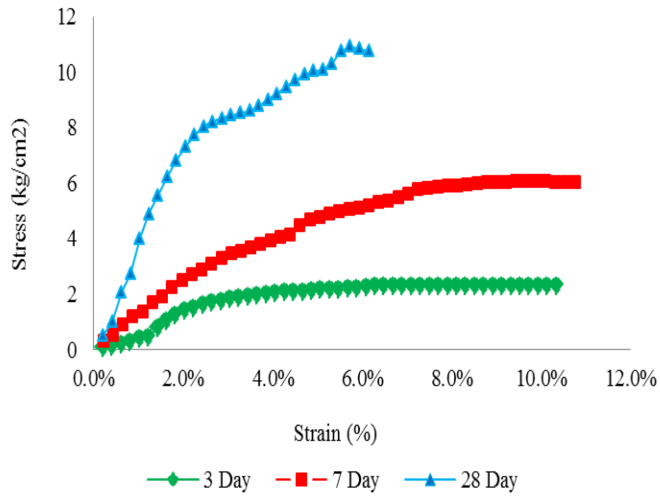


Figure 9b. Unconfined compression strength of clay for curing periods subject to drying.

b. Effects of EPS content on stress-strain curves

Figure. 10 contains the stress-strain plots of the UCS tests for EPS reinforced specimens with curing periods, subject to drying. Figures. 11 contains the stress-strain plots of the UCS tests for EPS reinforced specimens with curing periods, preserved to moisture. By analyzing the stress-strain curves shown in Figures. 10-11, the ductile behavior of stress-strain curves of reinforcement samples is demonstrated. Table 5 shows peak UCS and corresponding vertical strain. There appears to be a difference in the peak strengths of the unreinforced and reinforced specimens at given curing times, although specimens with EPS chips tended to reach their peak strength at higher strains. This means that the introduction of EPS chips into the clay soil may not help in strength gain, but will improve the ductility of the reinforced soil. Higher ductility in this study resulted in higher values of strain.

Table 5. Peak UCS and corresponding strain values

	PES content%	Curing Time (days)	Peak Strength kg/cm²	Strain at Peak Strength %
Preserved to moisture	0	3	17.52	5.72
	0.25	3	16.14	9.31
	0.5	3	12.61	6.01
	0.75	3	12.91	8.83
	1	3	10.93	7.69
	0	7	22.38	2.5
	0.25	7	18.56	7.5
	0.5	7	17.55	10.64
	0.75	7	12.91	8.83
	1	7	10.93	7.69
	0	28	26.08	1.88
	0.25	28	22.12	4.05
	0.5	28	12.07	4.09
	0.75	28	11.74	6.59
	1	28	10.77	7.05
Subject to drying	0	3	2.31	9.72
	0.25	3	1.6	15.83
	0.5	3	2.58	16.62
	0.75	3	3.26	16.08
	1	3	2.85	13.9
	0	7	6.07	9.67
	0.25	7	2.56	21.02
	0.5	7	2.55	17.47
	0.75	7	2.68	23.71
	1	7	3.78	15.7
	0	28	10.91	5.73
	0.25	28	2.08	15.81
	0.5	28	2.29	14.15
	0.75	28	3.59	20.98
	1	28	9.17	12.97

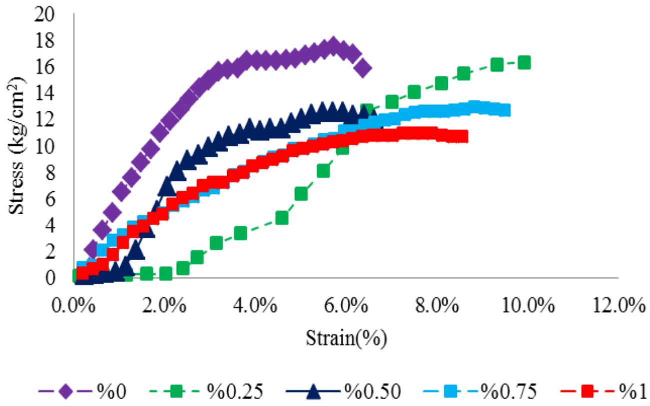
c. *Effects of EPS content on Failure Patterns*

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. 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. An example of this is shown in Fig. 12, where EPS chips reinforced specimen developed many small cracks and the stress level remained close to the peak stress. In the case of the unreinforced specimen shown, the stress level dropped significantly after reaching peak stress.

V. CONCLUSIONS

This paper assessed the method of stabilizing 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 a result of the clay contains polystyrene chips that are randomly oriented and resist compacting, forming an interlocked structure. In addition, 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.
- The study results contribute to a better understanding of the mechanical behavior of soil reinforced with EPS chips. The addition of EPS chips reduces the weight of the soil while increasing its flexibility, to Modify soil reinforced strength and hardness a binder such as cement can be added. This requires additional research.



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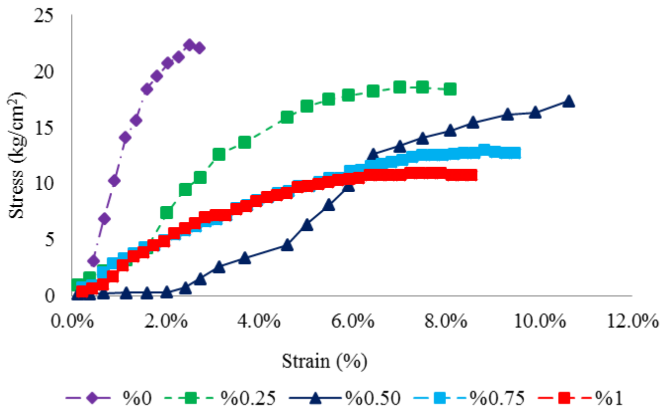

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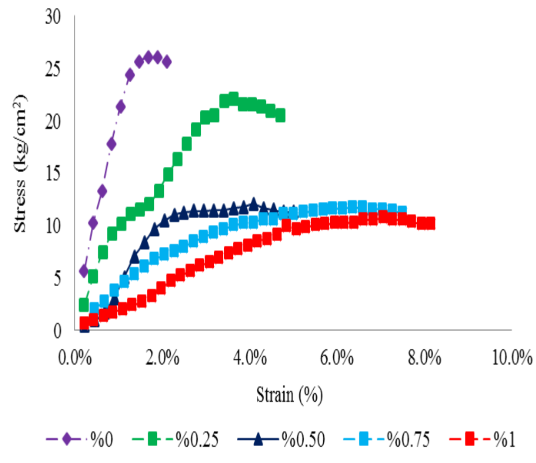
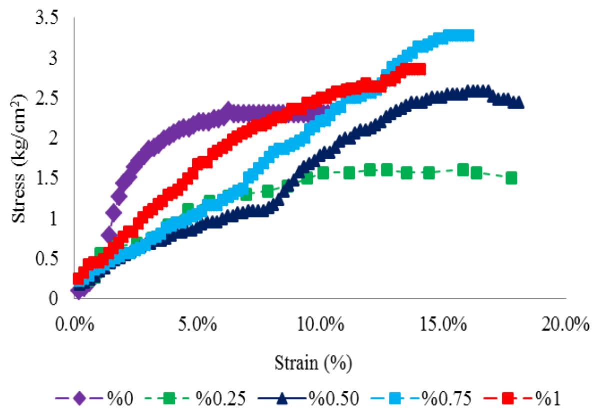


c)

Figure 10. Stress-Strain Plots for EPS content samples to curing periods, subject to drying: a) 3 Days; b) 7 Days; c) 28 Days



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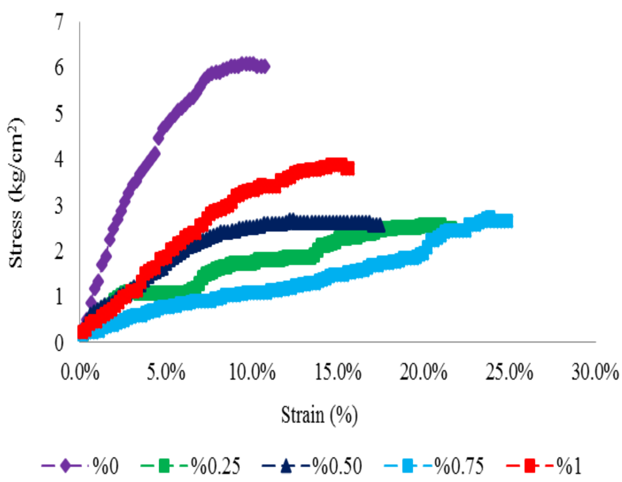

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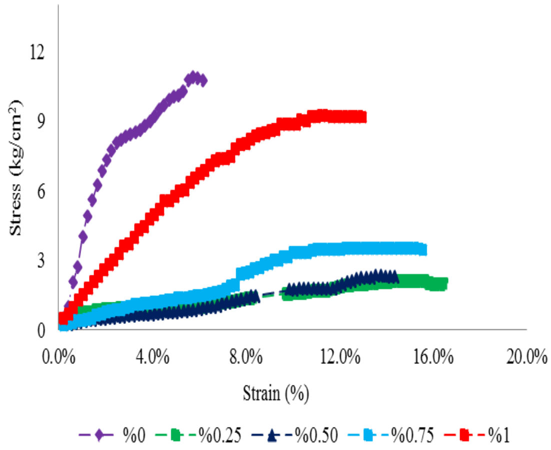

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Figure 11. Stress-Strain Plots for EPS content samples to curing periods, preserved to moisture: a) 3 Days; b) 7 Days; c) 28 Days

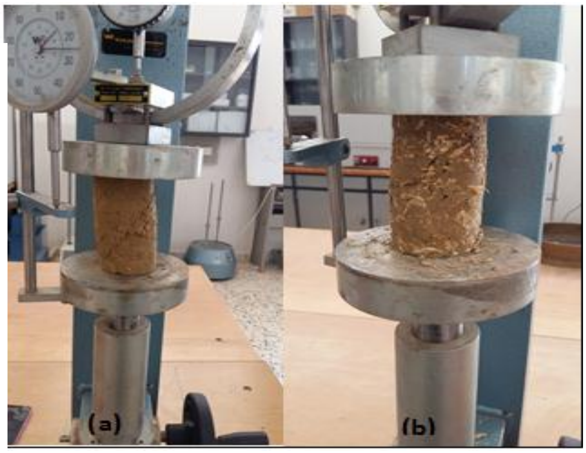

Figure 12. Specimens at End of UCS Tests (a) unreinforced soil, (b) 1% EPS

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