Experimental Investigation of Shear Strength Characteristics of Light-Weighted Backfill Soil

Sharafat Ali[1], Feng Yong[1], Sadaf Qasim[2], Mudassir Mehmood[3], Farhad Jamil[1]

[1] College of Civil Engineering and Architecture, Henan University of Technology, Lianhua Road, Zhengzhou 450001, Henan, China

[2] NED University of Engineering & Technology, Karachi, Karachi City, Sindh Pakistan

[3] Department of Civil Engineering and Architecture of Zhengzhou University, Lianhua Road, Zhengzhou 450001, Henan China

Corresponding author: Sharafat Ali

Abstract. Improving mechanical characteristics and minimizing the weight of the backfill material has remained an area of interest for geotechnical practitioners, and it has motivated the authors to investigate the mechanical behavior of light-weighted backfill (LWBS) soil. LWBS is an engineered mixture of cement, fly ash, silt, EPS beads, and water. The effect of cement, EPS beads, and fly ash contents on the shear behavior of LWBS were studied by using unconfined compression and direct shear tests. The test results show that increasing the fly ash and cement content does not affect the internal friction angle, but significantly increases the cohesion. On the other hand, increasing the content of fly ash and cement increases the UCS. However, the unconfined compressive strength, cohesion, and angle of internal friction decrease with increasing EPS bead size. It also improves ductility. The density of LWBS can be efficiently controlled by large-size EPS beads added to make the material.

The study finds that combining silty soil reinforced with EPS beads and 5% cement and 10% fly ash produces a high-strength, low-density material with twice the shear strength of normal silty soil. The results provide potential solutions for increasing the shear strength of simple silty soils by filling them with LWBS. The paper's findings are useful in the design and construction of infrastructure projects that require backfill material with specific mechanical properties

Keywords: light-weighted backfill soil, strength characteristics, fly ash, EPS bead

1 INTRODUCTION

Marginal soils such as soft clay, loose soil, and silt lack acceptable engineering properties and are considered not suitable for construction purposes. Much research is being undertaken to improve the strength characteristics to make it useful [1]. It has been proposed to use processing methods like Vibro-pressing, pre-consolidation, stone columns, etc. Generally, coarse-grained soils with a fineness of less than 15 are appropriate for subgrade or backfill soil. However, the absence of such soil compels field engineers to employ marginal soil, or poor soil, on many job sites. Despite their great compressibility, clay soils generally exhibit low shear resistance and pose new challenges both during and after construction. To make this soil acceptable for construction, several scholars have proposed stabilizing methods employing chemicals, sand, lime, cement, and so on [2-4]. Silty soil is produced by the lasting weathering of rocks, and because it primarily consists of powder and sand particles, it has weak cohesiveness, a loose texture, poor grading, low strength, and significant capillary action [5-7]. The shear characteristics of composite soils were examined by using triaxial testing and the influence of particle bonding on stiffness and strength was discovered using zero effective stress testing The test findings show that the initial expansion modulus is lower while the final expansion modulus of composite soil is higher than that of flat soil [8]. The effects of cement on the mechanical behavior of sandy soils and the shear strength and vertical deformation properties of cemented soils were investigated using direct shear tests. The test findings revealed that cement notably increased the cohesion and internal friction angle of sandy soil, thereby increasing the soil's resistance to deformation. The greatest development was obtained at a cement concentration of 10% [9]. Numerous stabilizing and strengthening chemicals are utilized nowadays to stabilize soils in a wide range of geoengineering applications [10-12]. Cement incorporated into sand aggregates closes pores, improves soil texture, and enhances the mechanical properties of cemented sand geomaterials [13, 14]. However, the use of cement as a soil stabilizer has several drawbacks, including its high cost, fragile reactivity, and the fact that it is not a long-term solution for soil remediation. These defects can be easily removed by adding chemicals to the mixture. This results in improved ductility and shear strength, while at the same time creating a lucrative and ecologically friendly design. [15-18]. Researchers investigated the geotechnical properties of a lightweight filler composed of sand, EPS beads, and cement as a binder [19]. thoroughly analyzed the geoengineering characteristics of EPS-soil mixes, including compressive strength, unit weight, creep capabilities, dynamic properties permeability, and water absorption properties [20]. To increase the strength and stiffness of granular materials, binding agents like cement and fly ash have long been utilized [21, 22]. Presented a newly developed building material composed of binder elements such as cement, EPS beads, and stone dust by performing a series of compression tests. [23].Found that UCS increased almost linearly with increasing cement concentration, but decreased when EPS beads were added to Create a lighter, more durable, and more compressible mixture [24-26]. It was discovered that the addition of EPS beads to the composite decreased the permeability, angle of internal friction, finite elastic modulus, and Young's modulus of the composite. However, K_o and volume compressibility showed inconsistent patterns. Last but not least, EPS bead-treated soil can be used for many geoengineering projects such as lightweight underlayment for beams and slabs, vibration dampers, etc. [27]. A study by Jamshidi Chenari presented that the addition of 0.1% EPS beads to treated sand improved ductility and lessen the density of the mixture by more than 10%. The UCS, California bearing rate, and shear strength properties of the soils under investigation were all developed by the addition of cement and fly ash [28]. A lightweight polymer was made by combining some waste materials such as rice husks and fly ash with expanded polystyrene beads. Expanded polystyrene beads reduce the unit weight and increase the ductility of the new material. [29-32].

However, no studies have yet been shown to support the combined use of EPS beads, cement, fly ash, and silt. Various mixing ratios are used in the laboratory to test the mechanical properties of this light weighted soil. The strength and deformation of this LWS have evaluated the effects of different additives on the friction angle and cohesion of the mixture.

2 MATERIALS AND METHODS

2.1 Silty soil

Alluvial silt soil was used as a base material taken from the Zhengzhou area of the Yellow River basin as shown in Figure 1(a). The fundament physical properties of the soil are listed in Table 1. All particles passed through US standard sieve No. 40 (425 m). A total of 89.62% of the particles passed through the No. 200 (0.075 mm sieve. The particle size gradation curve of the soil is shown in Fig 1(b). The soil density is 2.72, the liquid limit is 52.63, and the plasticity index is 22.31. According to the unified soil classification system (USCS), Silt soil is classified as highly plastic silts (MH), and the silt soil is quite poor quality with low shear strength.

2.2 Cement

Ordinary Portland cement (OPC) is composed of calcium aluminates and calcium silicate that hydrate to form cementitious products. And in this study, the OPC of 53 Grades of cement was used as binding material.

Table 1 Physical properties of silty sol

Properties	Values
Density kN/m^3	18.84
Specific Gravity G_s	2.72
Water contents ω	99.5
Liquid limit w_L	52.63
Plastic limit w_p	30.32
Plasticity index I_P	22.31
Liquidity index I_L	3.10
Volumetric weight r/KN/m^3	14.90
Pore ratio (e)	2.64

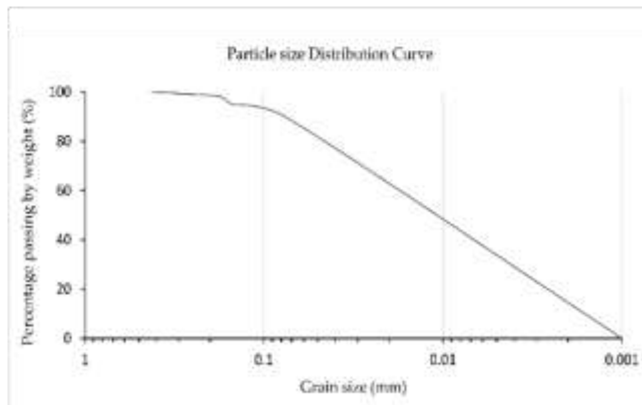
Table 2 Sieve Analysis

Percent of Particle (%)			
0.425-0.18mm	0.18-0.15mm	0.15-0.075mm	0.075-0.001mm
1.76	3.19	5.36	89.69

2.3 EPS beads

EPS beads are white spherical and range in size from 1 mm to 3 mm and their density is about 0.008g/cm^3. EPS beads are highly compressible. The density of the EPS beads decreases as the granule expands after pre-expanding, the final product will be expanded up to 40 times. The EPS beads are shown in Fig 2(a).

(a)



(b)

Fig. 1 a Yellow River beach b Gradation Curve of silty soil

2.4 Fly ash

Fly ash is left-over from thermal power plants. It is considered dangerous and contaminated. fly ash is produced in the amount of 200 million tons in the energy generation process. it can be used as a substitute construction material [33]. When combined with a cementing agent, fly ash can be employed in geotechnical applications. In this study, fly ash and Portland cement were used as binders to create bonding between silt particles and EPS beads. The fly ash proportions employed in these tests were 5% and 10%. The physical properties of fly ash used in this paper are shown in Table 3

Table 3 Fly ash properties

properties	Values
Maximum Dry Density KN/m^3 (MDD)	12.93
Optimum Moisture Content %(OMC)	34
Specific Gravity	1.75
Liquid limit %	3.8

(a) (b) (c)

Fig 2 (a) EPS beads (b) Direct shear apparatus (c) Unconfined compression test apparatus

2.5 Experimental procedure

In the experimental study, the process of preparing the specimen consisted of silt, fly ash, cement, EPS beads, and water. The test apparatus of UCS and DS tests are shown in Fig 2 (b) and (c) respectively. In this experiment, cement-modified silt soil with different sizes of EPS beads and fly ash is used. Dry silty soil is first mixed with 5% cement and fly ash (5% and 10%), potable water is added slowly according to the mixing formula, and then EPS beads are combined with composite soil. A shear box is used to prepare these specimens. The size of the shear box is 60 × 60× 20 mm plain and composite peripheral soil specimens are prepared to determine the shear properties such as cohesiveness and internal friction angle, the direct shear test is repeated with the same test piece while increasing the normal load such as 20 kPa, 40 kPa, and 60 kPa respectively

Compressive strength and deformation are determined by an unconfined compression test where the sample is not exposed to lateral pressure. Samples with a height of 80 mm and a diameter of 40 mm are prepared with the above-mentioned mixing ratio. These samples are compressed during the test using a computer-controlled axial load mechanism with a displacement control rate of 1.0 mm/min. At least three parallel samples are taken for each mixture ratio, and unique data is removed. The compressive strength of the sample is calculated when the stress-strain curve reached its maximum. If no peak value is detected or no peak value, the stress is calculated at 15% of the axial strain.

Table 4 Mixed Ratio Scheme

<table>
<tr><th>specimen</th><th>Cement contents %</th><th>Fly ash %</th><th>EPS bead sizes(mm)</th><th>Water content w%</th><th>Age t/d</th></tr>
<tr><td rowspan="17">Silty soil</td><td>5</td><td>5</td><td>1</td><td rowspan="16">50</td><td rowspan="17">28</td></tr>
<tr><td>5</td><td>10</td><td>1</td></tr>
<tr><td>5</td><td>5</td><td>2</td></tr>
<tr><td>5</td><td>10</td><td>2</td></tr>
<tr><td>5</td><td>5</td><td>3</td></tr>
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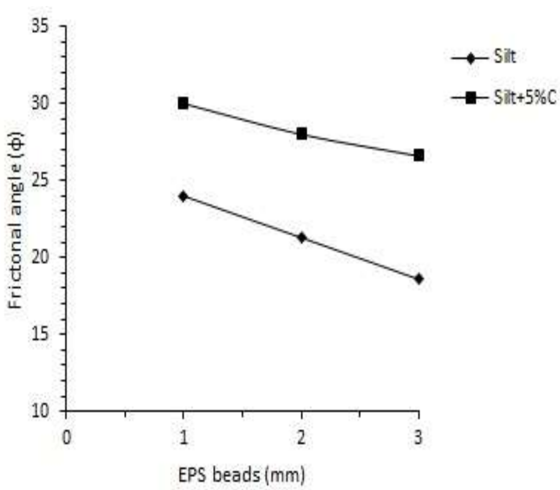
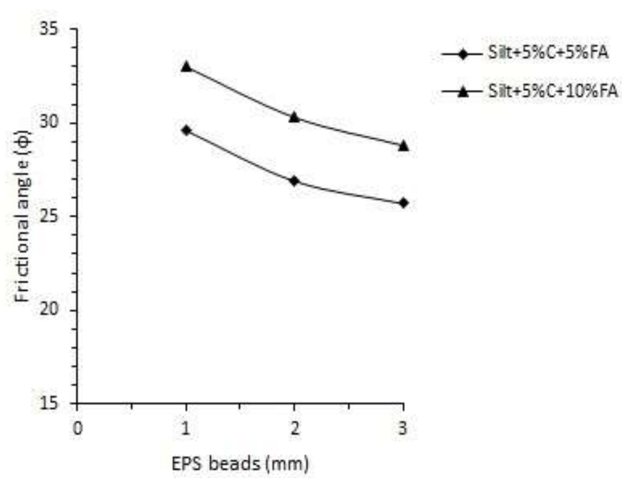
<tr><td>5</td><td>5</td><td></td></tr>
<tr><td>5</td><td>10</td><td></td></tr>
<tr><td></td><td></td><td></td><td>99.5</td></tr>
</table>

3 RESULTS AND DISCUSSION

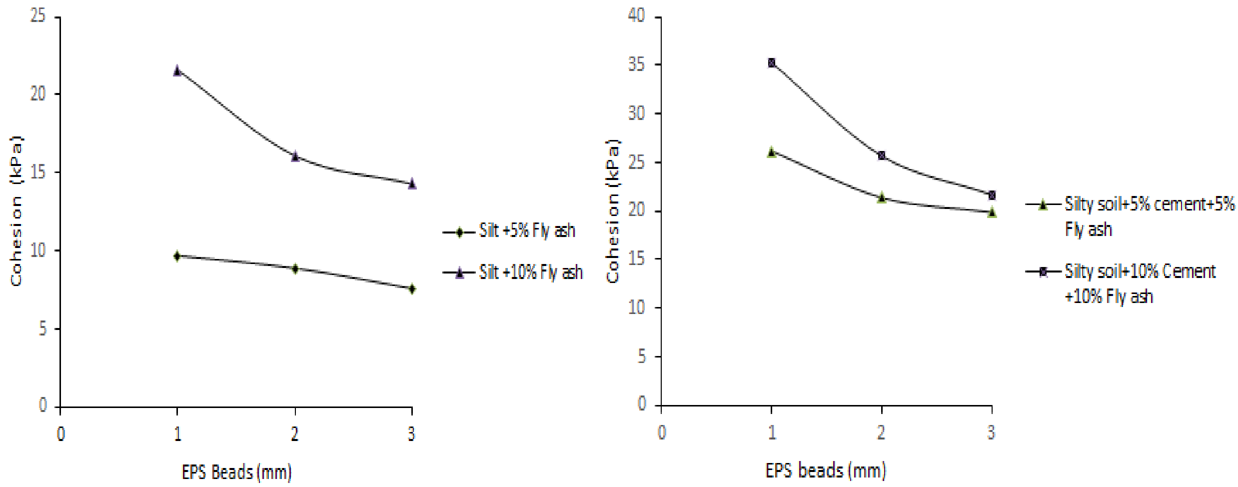
3.1 Direct shear test

The direct shear test was conducted to investigate the shear characteristics of light weighted soil. In this study, the sample was deforming at a controlled strain rate of 1mm/min on samples with dimensions of 60mm, 60mm, and 20mm.





(a) (b)



(c) (d)

Fig. 3 Effect of EPS beads sizes on Shear strength parameters (Angle of internal friction and cohesion)

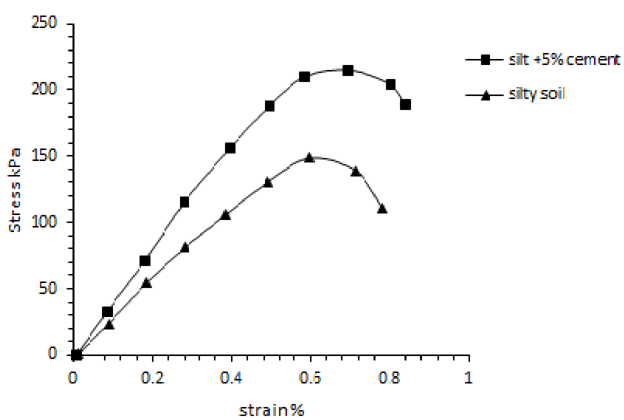
Shear resistance, displacement, and strength properties of the specimens were examined under different vertical loads of 20 kPa, 40 kPa, and 60 kPa. The maximum shear stress is determined by plotting a graph of shear stress (kPa) versus horizontal shear displacement (mm). To determine the shear strength properties (cohesion and angle of internal friction) of the compressed (LWS) samples, plots of maximum shear stress (ordinate) versus normal stress were created. A straight line was constructed between the plotted points and extended to connect the ordinate (best fit). The cohesion (c) of the sample is given by the shear stress intercept, whereas the slope of the line is given by the angle of internal friction (ϕ).

According to the findings illustrated in Fig 3, the EPS beads decrease the friction angle by interfering with the fly ash silt response mechanism and reducing the particle interaction. This is also true in terms of cohesion, as the EPS beads sizes increase, the cohesion decreases, and EPS beads prevent binders' silt particles from sticking together. By modifying shear characteristics like soil cohesiveness and internal friction angle using 5% cement, and 10% fly ash. A cement addition has made silty soils non-plastic. Silty soil shows plasticity. Furthermore, the cement and fly ash concentrations in the samples increase cohesion by forming cementation gels but do not affect significantly the friction angle. This is perhaps because cement and fly ash affect the stresses that bind particles together. As a result, it can be concluded that the binder material and the EPS beads controlled the cohesion and the friction angle, respectively. The results of these experiments indicate that cement and fly ash reinforcement increased soil cohesion and friction angle. The friction angle and cohesion of unreinforced silt were 26° and 10 kPa. For a cement content of 5%, fly ash content of 10%, and 1mm EPS beads in the reinforcing soil, the maximum friction angle and cohesiveness were 33° and 35.3 kPa, respectively. An improvement is seen when compared to the friction angle and cohesion for unreinforced soil.

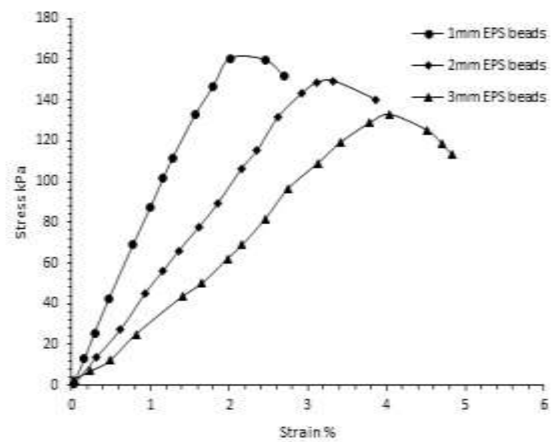
3.2 Unconfined Compression Test.

The unconfined compression test was performed on a cylindrical specimen having a diameter of 40 mm and a height of 80 mm. The specimen was placed in an unconfined compressive strength tester with a constant deformation rate of 1.25 mm/min. A dial gauge reading on the test ring was used to assess the axial load during the test, and another dial gauge reading was used to measure the axial shortening of the test component. These strengths allowed the stress-strain curves to achieve axial loads slightly beyond the breaking stage.

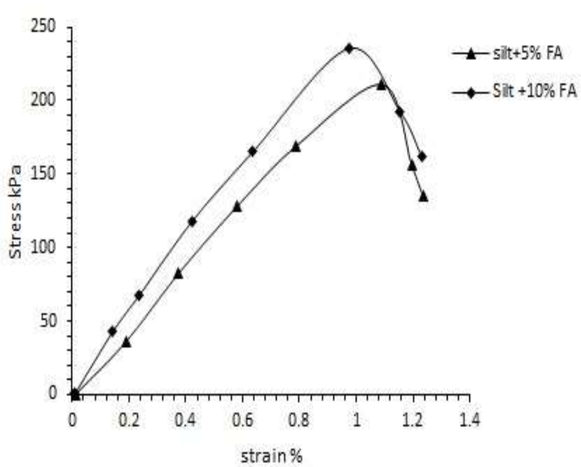
Figure 4 demonstrates the stress-strain curves for various particle samples. The data show that the stress-strain curves move rightward and downward, when the EPS particle size is 1 mm, 2 mm, and 3 mm respectively. This is because the 1 mm EPS sample is stronger and less ductile than the 2 mm and 3 mm EPS samples, the unconfined compressive strength increases linearly with increasing cement and fly ash concentrations. This shows that the smaller the EPS size content the faster the rate of strength growth



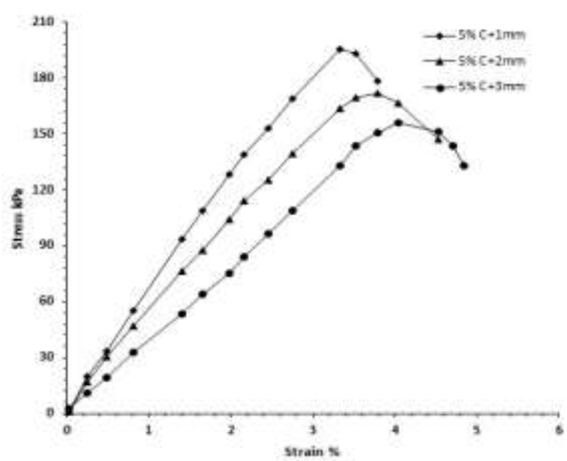
(a)



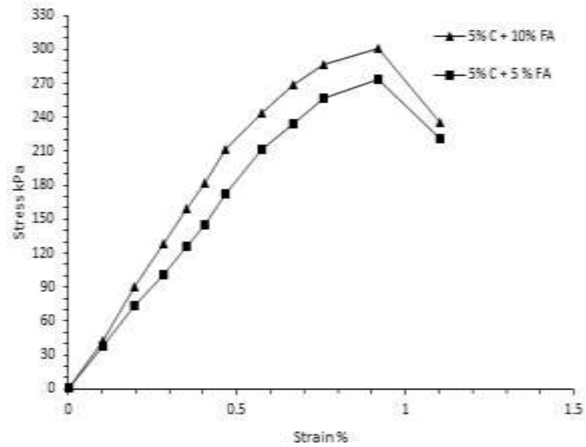
(b)



(c)



(d)



(e)

Fig.4 Stress-strain graph of samples a silty soil and 5% cement addition b silty soil mixed with EPS beads c silty soil mixed with 5% and 10% Fly ash d silty soil mixed with 5% cement and EPS beads e 5% cement mixed with 5% and 10% Fly ash.

The stress-strain curve has three stages. The initial load period is the first step. It rises in parallel with the strain and stress until the yield stress is achieved. The stress-strain relationship is nearly linear. The term "linear connection" refers to the ability to restore a sample to its original elastic state without causing any visible breaks. When the load increases in the second stage of the material plastic yield stage, new crack samples are generated and the previous cracks are improved. As the soil expands as it contracts, the strain growth rate is faster than the stress growth rate. The stress-strain relationship is curved, the slope of the curve becomes negative due to the fracture stage, and the stress sharply drops in the third stage. Strength and deformation are key parameters in design and construction because they are related to project safety. An unconfined compression test is used to assess compressive strength and deformation because the sample is not subjected to lateral pressure in this test.

The test findings show that the peak compressive stress, which measures compressive strength, decreased as the size of the EPS beads increased in all samples as shown in Fig 4.EPS beads have a compression ratio that is substantially larger than those of the other mixed components. In addition, EPS beads act as a barrier between the binder and the silt particles, preventing interaction between them, and they do not absorb water. However, increasing the size of the EPS beads causes the sample's fracture strain to increase, resulting in more ductile behavior as depicted in Figures 4(b) and (d).

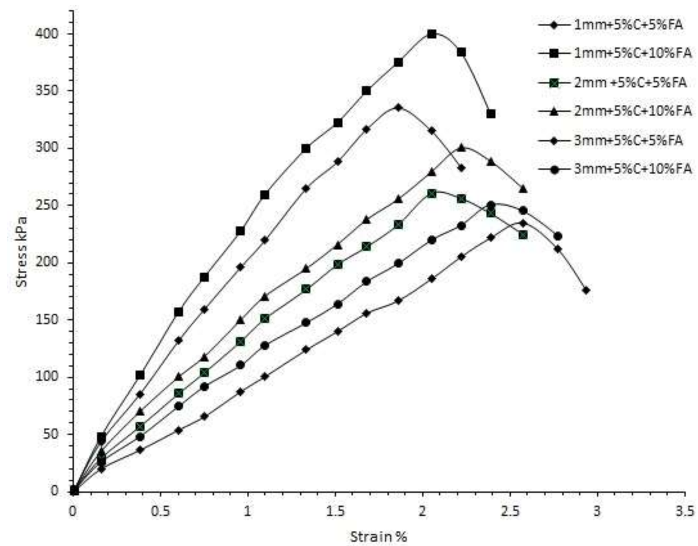
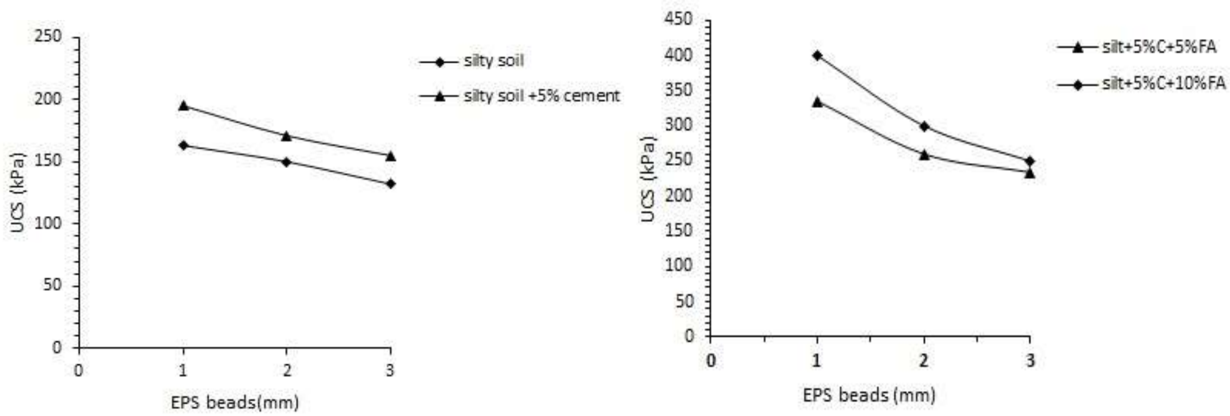


Fig. 5 Effect of various constituents on Stress-strain graph (Cement, Fly ash, and EPS beads**)**



(a) (b)

Fig. 6 Graph of Unconfined compression strength and various material and EPS beads

The influence of fly ash (FA), EPS beads, and cement on the UCS is shown in above figures. The unconfined compression strength increases with an increasing amount of fly ash. Fly ash is finer than the other ingredients in the mixture, promoting the interlock reaction and preventing particle movement. Silty soils can retain high compressive strength values after being treated with 5% cement. When 5% cement is injected into the surrounding soil, the plastic grains (silt) become non-plastic and the interlocking effect between the grains increases the strength value. The combination of silty soil and fly ash fills the interstices between the particles, greatly increasing the strength as shown in Figure 4 (c) and (e)

Table 4 Strength properties of light weighted geo material

Fig. 7 Samples of light weighted soil for UCS test.

A comparison of UCS and various EPS particle sizes are shown in Fig. 6(a) and b. The strength of LWS decreases with increasing EPS bead size. However, cement and fly ash, acting as a binder, increases the stress of the mixture with the passing days. Soil weight can be reduced by using EPS beads. The density of LWS can be efficiently controlled by the size of EPS beads added to make the material. Another advantage is that the lightweight fill material is as flexible as regular soil, so it can occupy more adaptable land. The amount of binder content (cement and fly ash) increases the strength and stiffness of the LWS and it can be used as a soil improvement solution for backfill material. The unconfined compression test demonstrates that, when EPS bead size increases, the strength of the LWS falls, Moreover ductility increases but on the other hand the inclusion of fly ash and cement enhances the strength of the LWS and makes it more brittle. It can be concluded that one of the soil amendment alternatives for backfilling retaining walls could be the usage of lightweight Soil.

4 CONCLUSION

The present paper investigates the shear strength parameter, unconfined compression strength, and deformation of light weighted soil (LWS) consisting of EPS beads, fly ash, cement, silty soil, and water. The study utilized the UCS and DS tests to obtain results. From the findings it can be concluded that the addition of EPS beads reduced compressive strength friction angle, and cohesion while increasing sample strain and ductility .However, in some cases, it also led to shortened crack propagation length resulting in minor damage.

Furthermore the addition of cement improved compressive strength and cohesion by forming cementation gels but did not affect the friction angle. However ,higher cement content resulted in a decrease in the fracture strain of the sample indicating brittle behavior .Adding fly ash resulted in more cementation compound ,improving compressive strength and cohesion without affecting the friction angle .Nevertheless, the increase in fly ash did not affect the fracture strain enough to be considered enough an advantage compared to cement

The paper suggest that cement and fly ash concentration of 5% and 10% respectively, significantly improve the strength quality of the sample and can be used in geotechnical engineering application to provide the required strength and performance at a reasonable cost .therefore, these findings can be useful for designing and construction infrastructure projects that require backfill material with specific mechanical properties.

AUTHOR CONTRIBUTION:

Conceptualization, Sharafat Ali. Methodology, Feng Yong.; validation, Investigation, Sharafat Ali and Farhad Jamil. Resources, Sharafat Ali and Mudassir Mehmood; writing—original draft preparation, Sharafat Ali writing—review and editing, Sharafat Ali and Sadaf Qasim. Supervision Feng Yong. All authors have read and agreed to the published version of the manuscript.

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Not applicable

CONFLICTS:

The authors declare that they have no conflicts of interest

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