Effect of expanded polystyrene beads and fly ash on the strength and deformation characteristics of soil

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Abstract

In the field of geotechnics, silty soil is not preferred as the best geotechnical material. However, the growing interest in utilizing waste, raw, and lightweight materials in civil engineering applications has opened the possibility of using modified soils as an alternative to unconventional materials for various geotechnical purposes. In this study, silt as a base material is mixed with fly ash as a pozzolanic material and expanded polystyrene beads (EPS) as a lightweight material to produce a lightweight soil (LWS) that can be used as a construction material. Various EPS bead sizes and fly ash were considered to evaluate their effects on maximum dry density (MDD), optimum water content (OWC), and unconfined compressive strength (UCS). The finding shows that as the size of the EPS beads increases at a given content, the ductility and deformation increase, and the strength and density decrease significantly. It was revealed that increasing fly ash concentration increases the stiffness and unconfined compressive strength (UCS) of lightweight soil from 165 kPa to 215 kPa but decreases, as the size of expanded polystyrene pellets increases. Studies have also shown that a mixture of tiny expanded polystyrene beads and fly ash is suitable for increasing strength. In contrast, heavily expanded polystyrene pellets weaken the fly ash bead combination. 15% and 20% fly ash, particularly in 1mm to 3mm sizes with an EPS bead content of 0.5%, are useful for construction materials. The advantages of each size of expanded polystyrene pellet depend on the requirements of the engineering application and the conditions in the field. The purpose of this study is to determine the effect of EPS beads and fly ash on the strength and deformation characteristics of soil and to ascertain an optimum content that can be adequate for improving the strength and deformation characteristics

Keywords: EPS beads, light weighted soil, Fly ash, unconfined compression test, strength and deformation, stress-strain

1 INTRODUCTION

Lime, cement, and other cementitious materials are commonly utilized in engineering practice to better treat the silty soils [1]. Mechanical stabilisation methods include fibres, geosynthetics, and compaction. Enzymes and polymeric resins are used as fertilizer in chemical processes [2-6]. It has been found that when the size of EPS Beads increase, the compressive strength of lightweight soil decreases [7, 8]. When expanded polystyrene pellets are mixed together with fly ash, the compressive strength decreases [9]. In order to create lightweight polymers, EPS beads were combined with other waste products including rice husks and fly ash. New materials' weight and adaptability have been improved by the introduction of EPS beads [10-13]. Fly ash is a byproduct of thermal power plants that serves an important purpose when used to civil engineering projects: minimizing negative effects on the surrounding environment. Fly ash cannot be used as a substitute for soil in civil engineering projects because it does not possess the required engineering properties. So many research examined the effects of modifying fly ash by using other materials (such fibres, lime, cement (EPS), expanded polystyrene beads, etc.). Lightweight reinforcements like sand, earth, and fly ash can all benefit from the use of EPS. In order to investigate the impact of EPS beads on various geotechnical parameters, several researchers have previously conducted tests with these materials in soil and sand. In terms of weight per cubic foot, fly ash, EPS beads in sand, and soil are all viable options. When combined with EPS beads, soil, sand, and fly ash all compress, resulting in a net loss of density [14–18]. Li et al. investigated the effects of traffic loads on lightweight soil by conducting a triaxle shear test. Different confinement pressures, cement mixing ratios, and soil conditions were analyzed, as were the impacts on axial cumulative strain, modulus of impact, and damping ratio. [19]. Dai Wenting analysed the characteristics of strength and the deformation law of mixed lightweight soil using ABAQUS finite element software and an indoor test. [20]. with the use of cutting-edge tools, we may better understand and quantify the microstructure strength mechanism of lightweight mixes. [21, 22]. A mechanical constitutive model of the lightweight mixture may be built, allowing for predictions of strength and deformation that can be used in engineering applications. [23-25]. When it comes to earthworks, lightweight materials like EPS particles are invaluable. This is true for airport runways, highway embankments, and railroad embankments, to name just a few examples. [26, 27]. The granule concentration had no effect on the shear modulus or the linear elastic stress-strain of wet mixtures of EPS granules, Portland cement, mud, or silty clay. Nonetheless, as material increases, the dynamic intensity will be diminished significantly. [28]. Have run a battery of tests including direct shear, unconfined compression, CBR, and a variant on the conventional proctor. This study looked at the geotechnical features of a typical EPSCS. The various components are made by combining binder ingredients like fly ash and cement with sand-EPS bead composites in varying concentrations. The results showed that an increase of just 0.1% in the proportion of EPS beads in the composite led to a 10% drop in density and a more malleable combination. The UCS and CBR values, together with the shear strength parameters, decrease with increasing percentages of EPS beads in the mixture, in contrast to the behaviour observed with increasing percentages of fly ash and cement. [29]. Regular triaxle and bending element tests may be used to examine the effect of EPS bead content on minor and major stresses, as well as the deformation and damping factor of sand and EPS bead mixes. Despite the absence of cement-based components, it has been discovered that the dynamic shear / normal deformation factor of EPS bead and sand mixes is lowered and attenuated with each application of EPS beads. The ratio clearly improves as a result. [30]. both a direct shear test and a triaxle test were performed to characterise the shear strength. The cohesive strengths and internal friction angles of both reinforced and unreinforced fly ash are reported. The economic value of EPS beads decreases but their volume increases when fly ash is used in the manufacturing process. The internal friction angle, secant modulus, compressive strength, and shear force were all best for reinforced 1 mm EPS beads. Cohesiveness and the angle of internal friction were evaluated with triaxle and direct shear testing. The internal friction angle of small EPS beads is high, whereas that of bigger ones is low [31].Many studies have been carried out, as is obvious from the aforementioned literature, to better understand the behaviour of lightweight-filled soil comprised of EPS beads, soil, and cement as binder materials. Weak attempts have been made to create lightweight soils by combining silt with EPS beads and fly ash. Focusing on the strength and deformation qualities of LWS while employing waste

EPS beads of varied sizes is the subject of this study. The environmental impact of trash may be considerably reduced by recycling. The theoretical utility of lightweight soil was confirmed by the study's findings.

Lightweight soil is a combination of soil, cementitious/pozzolanic agents, and other naturally occurring or synthetically produced materials with similar characteristics [32]. Lightweight soil is a mixture of dredged clay, cement, and lightning material [33]. Lightweight filler materials are an alternative for stabilisation when working with soft ground. Lightweight material has many advantages as fills, such as the ability to achieve the same volume or required run with significantly less weight than conventional materials, the ability to create stronger slopes and embankments over high compressibility soil, and the ability to use a smaller soil retaining structure. Abutments and piers of a bridge [34].

2 MATERIALS AND METHODS

2.1 Silt

Silty soil from the Yellow River basin in Zhengzhou, Henan Province, China was used as the primary resource for this paper. Figures 1(a) and 1(b) below illustrate this. According to Table 1, all of the particles in the sample are fine enough to pass through a No. 40 (425 m) sieve, and 89.69% are fine enough to pass through a No. 200 (0.075 mm) sieve. This demonstrates that the Yellow River's alluvial silt is very low-quality soil because it lacks sand and gravel. This material has low quality and is not used in engineering. The sample has a liquid limit of 52.63 percent and a plastic index of 22.31%, both of which are below the A-line on the plastic chart because they are lower than the PI of the A-line. The United States Geological Survey classifies silt as a "highly compressible" or "highly plastic" material (MH). In Table 2, we can see the most fundamental liquid and plastic limits, plasticity indices, and other physical and mechanical characteristics of silty soil. Microstructure of Yellow River alluvial silt is depicted in Figure 4a. If you compare this to the microstructure of typical residual silt, as shown in Figure 4b, you'll see a big difference.

(a) (b)

Figure 1: (a) Sample collection from Yellow River beach (b) silty soil

2.2 Fly Ash

Fly ash is a pozzolanic substance that produces cementitious compounds when mixed with water and calcium hydroxide. Soil can be strengthened using fly ash (FA). Byproduct from coal combustion in thermal power plants, fly ash provides environmental benefits when used [35]. That's for sure, it's polluted and maybe harmful. It can stand in for cement and other similar binding materials. This research used self-cemented Class C fly ash to restore 15-20% of the dry soil weight of the specimen. Fly ash from Class C that has been modified to be self-cemented may be utilized as a stabilizer in various construction projects without compromising on effectiveness or cost. Table 3 summarizes fly ash characteristics

(a)

(b)

Figure 2: (a) unconfined compression test apparatus (b) sample

2.3 EPS Beads

White polymer (plastic) foam known as expanded polystyrene (EPS) is widely used in the packaging sector. Almost all of the expanded polystyrene's (EPS) volume is filled with air, giving it a low thermal conductivity. For this purpose, you can use EPS either in the form of blocks (also called geo foams) or beads. As a result of its many advantageous properties, such as high insulation value, low density, resistance to chemicals, low price, resistance to water, and simplicity of construction, EPS finds extensive application. [36]. In this experiment, the EPS concentration was 0.5%, and the EPS beads' diameters were 1, 2, and 3 mm. Figure 3 depicts the various EPS bead sizes.

Figure 3: EPS beads with a particle size of 1mm, 2mm, or 3mm

Table: 1 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

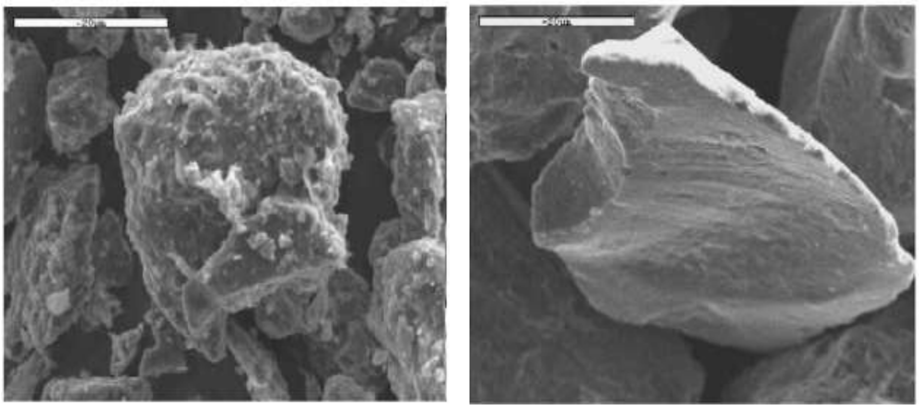
Table 2: Index Properties of Silty soil

Properties	Values
Water contents w	99.5
Liquid limit w_L	52.63
Plastic limit w_p	30.32

Plasticity index I_P	22.31
Density kN/m^3	18.44
Specific Gravity G_s	2.72
Liquidity index I_L	3.10
Volumetric weight r/kN/m^3	14.90
Pore ratio (e)	2.64

2.4 SEM analysis

The SEM analysis of the sample was carried out by
[37]



(a) Yellow river alluvial silt (b) residual silt

Figure 4. Scanning electron micrographs of a silty soil.

2.5 Sample preparation

When preparing samples, the silty soil serves as a foundation. This test mixture consisted of silty soil, EPS beads, fly ash, and regular tap water. On a massive tray, the silt fly ash mixture was continuously created. In order to achieve a consistent look, spray water from a spray bottle and stir with a spatula. After the sample was properly mixed and stirred, it was placed into a standard cylindrical steel mould to produce samples with dimensions of 80 mm in height and 40 mm in diameter. A thick plastic sheet was used to enclose the samples for 24 hours, during which time the water was allowed to permeate the EPS-silt mixture. The curing time for all of the specimens was 28 days. Table 4 displays the results from the UCS experiments conducted in this paper, including the mixing ratios used.

Table 3: properties of fly ash

Properties	Values
Specific Gravity G_s	1.78
Liquid limit w_L	44
Plasticity	Non-plastic

2.6 Test Plan

The testing protocol is laid out in Table 4. There are at least two samples of each mixed ratio. The shear strength was evaluated using a number of control variables during an unconfined compression test performed for engineering purposes. Different variables were tested to see how they affected the strength and deformation of silt lightweight soil. These variables included the amount of fly ash added, the mixing ratio, the stresses applied, the amount of EPS, and the size of the EPS beads. The following are the steps involved in conducting an unrestricted compression test:

Do the sample prep work. Prepare the specimen for compression by placing it in the machine in the correct orientation. Make sure you've checked out the instrument in its entirety. Turn the deformation dial to zero and the load dial gauge to zero. Involve the axial load piston and the sample. Start the machine and record the numbers displayed on the load and deformation gauges. Take the specimen out after shearing and double-check it against the specifications.

Table 4: Mixed Ratio Scheme

specimen	Serial number	Fly ash (%)	EPS contents (%)	EPS bead sizes(mm)	Water content (w %)	Age (t/d)
Light-weighted soil		15	0.5	1	50	28
	1	15	0.5	2	50	28
		15	0.5	3	50	28
Light-weighted soil		20	0.5	1	50	
	2	20	0.5	2	50	28
		20	0.5	3		28
silt	-	-	-	-	99.5	-

3 RESULTS AND DISCUSSION

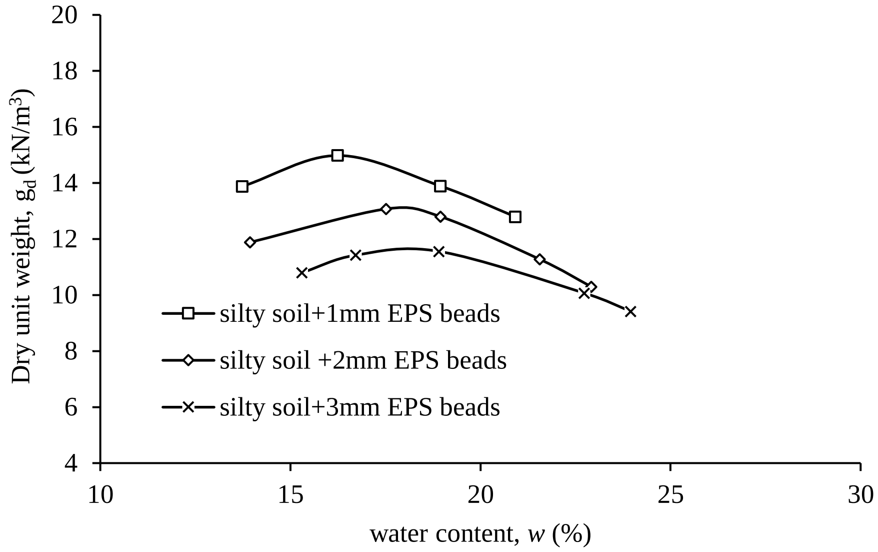
3.1 Influence of EPS Beads size and fly ash on Dry unit weight of light weighted soil

Proctor compaction tests were conducted on silty soil enriched with fly ash and EPS beads of varying sizes to determine the optimal water content and maximum dry unit weight of the resulting mixtures, as the degree of compaction has a significant impact on the strength and deformation characteristics of the soil. Fly ash and EPS beads of varied sizes were combined, and then water was added to form the samples. As can be seen in Figure 4, the ideal dry unit weight of the fly ash—EPS bead mixture dropped as the size of the EPS beads grew. The dry unit weight of the soil was decreased by the addition of EPS beads of varied sizes, which are lighter than both fly ash and silty soil (fly ash, EPS bead, water and silty soil). The bigger beads have reduced the unit weight of the lightweight soil. Because the resultant mixture may be utilized as backfill and has a low unit weight, it will put less pressure on the retaining wall.

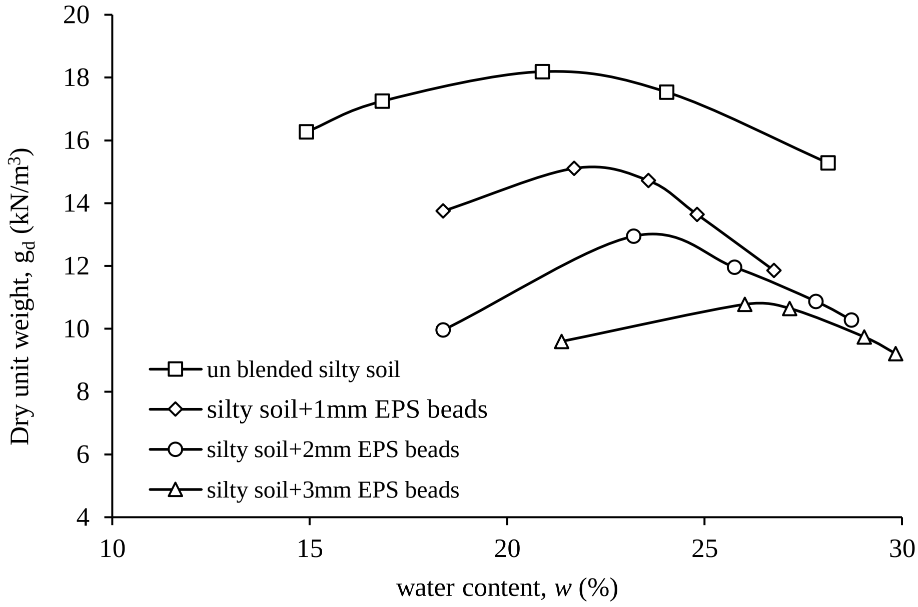
As can be shown in Table 5, the addition of EPS beads measuring 3 mm reduced the maximum dry unit weight of the fly ash from 18.84 to 10.78 kN/m3. The research demonstrated that OMC did not change noticeably between EPS bead sizes. The highest growth of EPS beads between 1 and 3 mm in size was 2%.

Table 5: Mixed Ratio Scheme

EPS Beads sizes	Water contents *w* (%)	Maximum Dry Density (kN/m^3)	EPS Bead sizes with 15 % FA	Water contents *w* (%)	Maximum Dry Density (kN/m^3)	EPS Bead sizes with 20 % FA	Water contents *w* (%)	Maximum Dry Density (kN/m^3)
0	20	18.84	0	20.89	18.19	0	22.12	18.51
1mm	16.25	14.98	1mm	21.70	15.11	1mm	23.57	15.90
2mm	17.52	13.07	2mm	23.20	12.96	2mm	25.21	13.18
3mm	18.91	11.55	3mm	26.02	10.78	3mm	26.02	11.57



(a)



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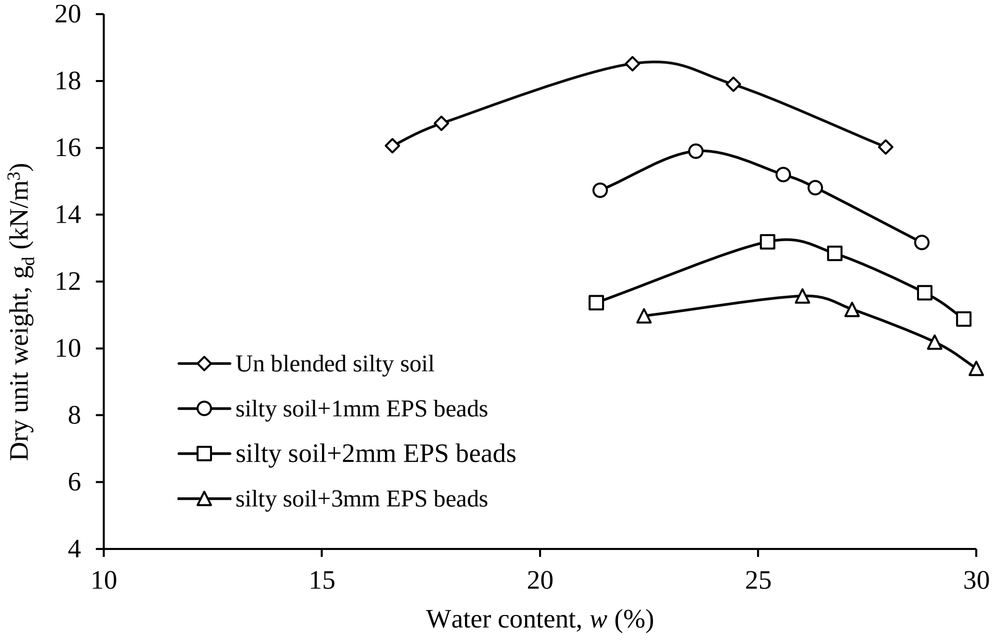

(c)

Figure 4: Density and Moisture Content Graph of EPS beads of Different sizes and silty soil (a) 0% FA (b) 15% FA (c) 20% FA.

3.2 Stress-Strain Behavior of LWS

Unconfined Compression tests can be used to measure the stiffness and stress-strain characteristics of lightweight soil. There is a strong correlation between the amount of fly ash and expanded polystyrene beads used to make lightweight soil and the soil's compressive strength and stress-strain behavior. Increasing the fly ash ratio and decreasing the EPS bead size enhances compressive strength and stiffness by shifting the stress-strain curve from ductile to brittle. If there are several sizable EPS beads in the system. This material has a shallow stress-strain relationship and poor compressive strength. When the size of the beads is increased, EPS loses some of its compressive strength, stiffness, and ductility in the stress-strain curve. Figure 5 shows the stress evolution as a function of strain for a relatively light soil. The structural transparency of the development of lightweight soil is displayed by the existence of a well-defined peak stress-strain curve across all curves for softening-type treatments.

Stress-strain curves typically feature three major inflection points. Initial loading is the first phase. Until the yield stress is reached, both strain and stress increase, but stress strain only increases in a linear fashion with strain. For the most part, a straight line may characterize the relationship between stress and strain. Restoring an elastic sample to its original condition without overtly cracking it is what we mean when we talk about a "linear connection." When the stress is increased further, the plastic yielding process enters its second stage, during which new crack samples are formed and existing cracks are reinforced. As the soil expands and contracts, strain grows more rapidly than stress. The stress-strain connection is shown as a curve that shows the correlation between the two parameters. In the third phase, when the curve's slope becomes negative, stress levels drop significantly.

3.3 Influence of fly ash and EPS bead sizes on stress and strain behavior of LWS

The stress-strain diagram in Figure 5 demonstrates that the concentration of EPS is equivalent to 0.5%. The figure shows that as the EPS bead size is increased from 1mm to 3mm, the plastic region widens, the strength decreases, and the strain value rises. Figures 6(a) and (b) display the stress-strain curve for lightweight soil at 15% and 20% fly ash ratios, respectively (b). Different proportions of fly ash in lightweight soil produce similar stress-strain relationship characteristics, albeit with slightly different curves. High dosage of fly ash results in a steep stress-strain curve and high stress, which leads to a small failure strain of around 4 to 7% and predominantly brittle failure; low dosage of fly ash results in a flatter stress-strain curve and lower stress intensity, leading to a larger failure strain of around 4 to 8% and predominantly ductile failure.

To guarantee the project's security, designers and builders must account for the strength and deformation of EPS lightweight backfill. A uniaxial compression test involves applying just vertical and horizontal pressures to a sample in order to determine its compressive strength and deformation. Incorporating the aforementioned dimensions, your finished sample should measure in at 40 mm in diameter and 80 mm in height. Compression was applied to these substances by an axial loading mechanism driven by a computer at a rate of 1 mm per minute. We took three independent samples for each possible combination of ingredients and eliminated any outliers. Compressive strength was measured as the stress-strain curve peaked. If no maximum value is found, a stress equal to 15% of the axial strain is calculated.

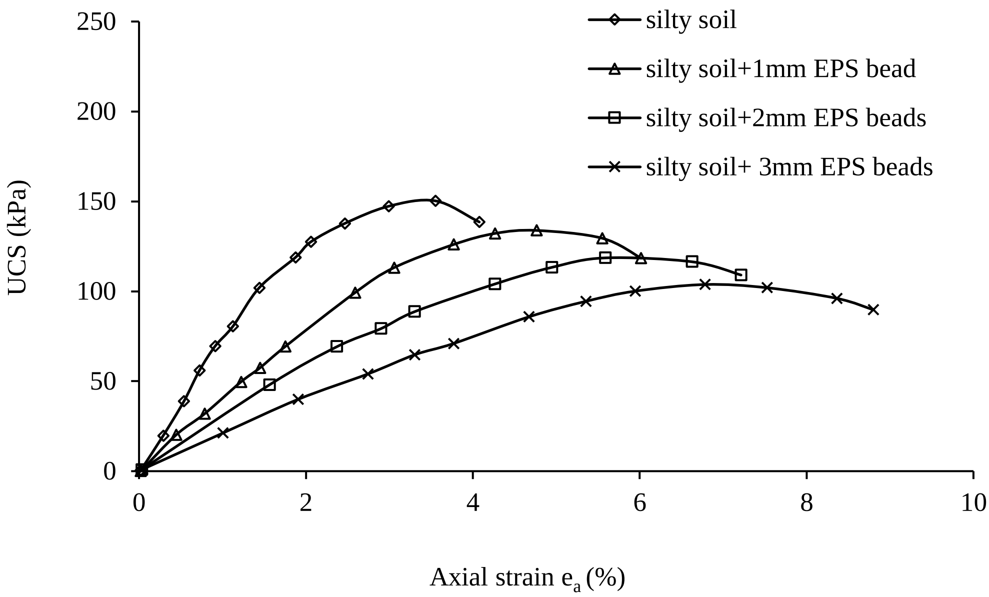

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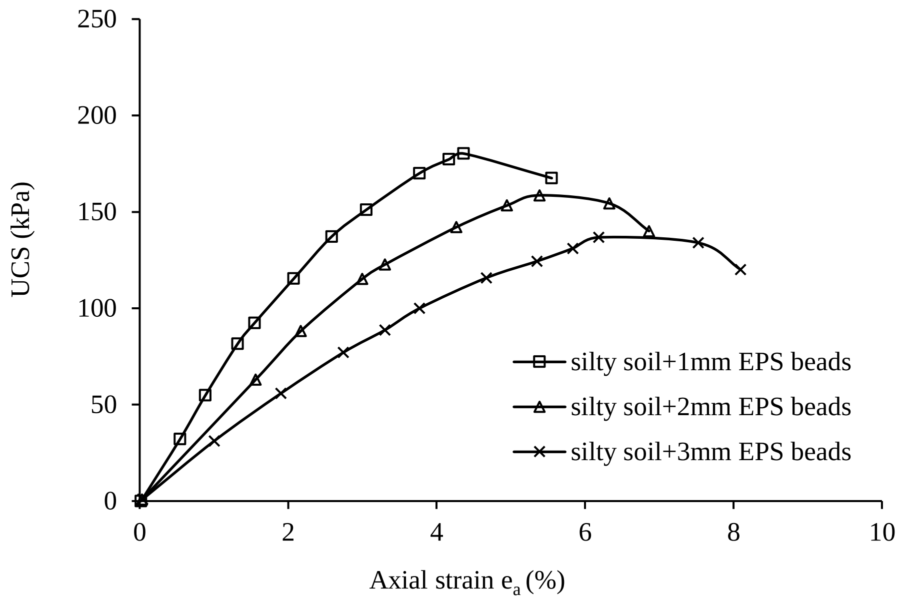
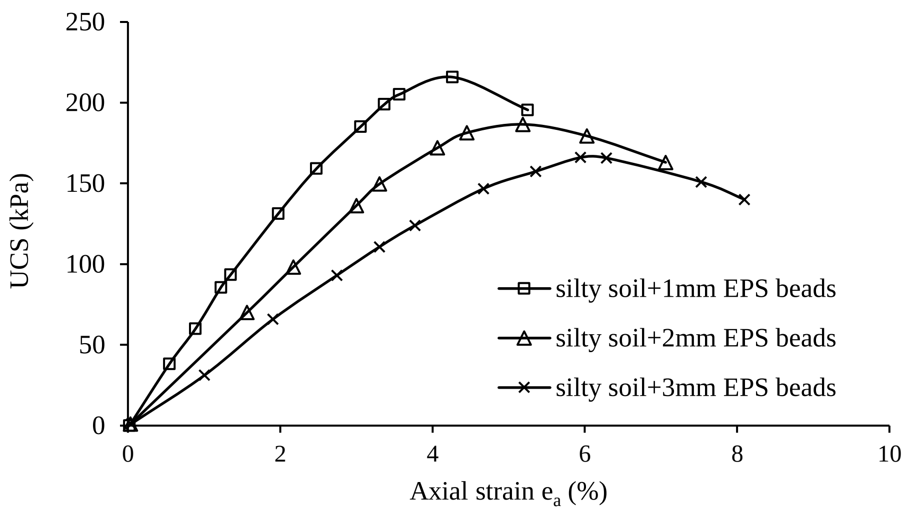
Figure 5: Stress-strain curve of 0.5% EPS contents and silty blends with various EPS beads size and 0% Fly ash



(a)

Figure 6: (a) Stress-strain curve of 0.5 % EPS contents and silty blends with various EPS bead sizes and 15% Fly ash



(b)

Figure 6: (b) Stress-strain curve of 0.5% EPS contents and silty blends with various EPS bead sizes and 20% Fly ash

The stress-strain responses of mixes of fly ash and expanded polystyrene beads of different sizes were quite diverse. The maximum stresses for 15% and 20% fly ash are 136 and 180 kPa, respectively, whereas those for 1 mm to 3 mm EPS beads range from 162 to 215 kPa. The stresses seen in Figure 8a are all the result of strains between 4% and 8%. The strain value increases as the size of the EPS beads increases. Changes in unconfined compressive strength due to an increase in fly ash content and a change in volume ratio are shown in Figures 6(a) and 6(b), respectively (b). Unconfined compressive strength is proportional to the percentage of fly ash. The use of fly ash improves the durability in both situations. Based on these results, it's clear that fly ash significantly impacts the material's compressive strength. Compressive strength of the lightweight composite diminishes with increasing EPS size. Adding more light particles increases the composition's porosity but weakens it overall.

When the percentage of fly ash is low, there is only a little variation in compressive strength for materials with various EPS particle sizes. Larger EPS particles (between 2 and 3 mm in size) and soil particles had less adhesion to one another. The 3 mm group is more challenging to combine because its low dry density is the result of its big particle size and high specific surface area. With a grain size of little more than 1 mm, EPS beads are able to form a strong bond with silt particles. Even though the EPS beads have pores, the sphere-shaped particles of fly ash are much smaller than the holes on the surface of the EPS beads. When combining EPS beads and fly ash, the presence of these particles may clog the pores of the beads and increase the resistance. Silty soil that hasn't been strengthened isn't very stable. The experimental findings revealed that the mixing ratio had a significant impact on the cohesiveness of EPS beaded mixed fly ash. In order to guarantee the accuracy of the results, the examination was repeated three, and in some cases, four times. Samples constructed with 1 mm EPS with 20% fly ash demonstrated greater strength and poorer ductility than those made with 2 mm and 3 mm EPS and the same quantity of additive. As the particles occlude and come into close contact with one another, the shear strength of the sample increases.

3.4 The Relationship between UCS and EPS beads in the stress-strain curve

Different EPS particle sizes are compared with UCSs in Figure 7a. It is clear that the UCS of 1 mm EPS beads is greater than that of 2 mm and 3 mm EPS beads. Due to an increase in particle size, the UCS of the light soil is decreasing. With an EPS concentration of 0.5%, the UCSs of 1-, 2-, and 3-mm samples are 133.84 kPa, 118.6 kPa, and 103.7 kPa, respectively. As a result, the microstructure of samples with 1 mm EPS beads is more refined and robust than that of the other groups. The UCS difference between EPS bead sizes in groups 1mm and 2mm is also larger than that between groups 2mm and 3mm. Soil with 1-, 2-, and 3-mm particles has a distinct compositional difference. Due to the EPS particle size being 3 times that of the soil particle, it is challenging to bind the two together. The maximum specific surface area and the smooth surface of EPS with a particle size of 3 mm weaken the occlusal interaction between soil particles, leading to the lowest intensity of all groups. Though the 1 mm group's pore count is higher, the pore size is much smaller. A considerable number of large pores, with diameters between 2 and 3 mm, can be found in the samples tested. When shear stress is applied, the sample's ductility increases by 2 mm and 3 mm in EPS particle size, respectively, because the pores between the particles help place the particles. However, in the 1 mm group, both the pore diameter and pore count are low, significant stress is applied, and brittle fracture is a distinct possibility. The unconfined compressive strengths of artificially created lightweight mixtures derived from the properties of various waste soils are all over the map.

4 CONCLUSIONS AND RECOMMENDATIONS

Through the use of proctor compaction and unconfined compressive strength tests, the performance of silty soil amended with fly ash and EPS beads was analysed. The following implications can be made about the testing results: The maximum dry density of lightweight soils is decreased by 18.84 to 10.78 kN/m3 upon addition of fly ash and various sized EPS beads, while the OMC is slightly increased. As EPS beads get bigger, the compressive stress drops and the lightweight material's stress-strain curve shifts to the ductile region of the graph. The combined strength of silt, fly ash, and small EPS beads was greater than that of samples containing large EPS beads. Lightweight soil shows low strength and high ductility, in contrast to traditionally moulded silt, as shown by the stress-strain curve of silty soil blended with EPS, which shows that the soil does not degrade and collapse abruptly as its axial strain values increase from 4% to 7%.The behavior of stress-strain is significantly influenced by all mixing ratios utilized in the creation of lightweight soil. Greater compressive strength and stiffness are shown at greater fly ash ratios and the stress-strain curve changes from ductility to brittleness.

There were 4-5% of strains in every specimen. This is because the employment of EPS beads in the space of the silt is improved and the silt skeleton of the mixture creates a supporting load. Additionally, when the stress-strain graphs were taken into account, samples with small EPS beads showed silt-like behavior and attained their maximum strength at the lower strains

AUTHOR CONTRIBUTION

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

DATA AVAILABILITY SYSTEM

Not applicable

CONFLICTS

The authors declare that they have no conflicts of interest

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