Lightweight fill using clay, EPS-beads and cement

Un Mélange Léger en Utilisant l'Argile, les Billes d'EPS et le Ciment

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ABSTRACT
An experimental study was carried out to investigate the mechanical characteristics of a lightweight fill composed of clay presented as Kaolin, Expanded Poly-Styrene (EPS) beads and a cementing agent as Portland cement. The effects of different compositions on the shear strength and compressibility characteristics of the lightweight mixture were studied using direct shear tests and unconfined compression test. It is observed that the density of the lightweight mixture can be effectively controlled by the amount and density of EPS-beads used. With the inclusion of 1 to 5 % of EPS-beads (of clay by weight), the dry density of the lightweight mixture formed can be inversely reduced. Also it causes decrease in unconfined compressive strength and shear strength parameters. Shear strength and stiffness of the lightweight mixture can be controlled by adjusting the amount of cement used (5 to 25% of clay by weight). The shearing resistance of the lightweight mixture increases with the increase of cement to soil ratio.

RÉSUMÉ
Une étude expérimentale a été menée pour étudier les caractéristiques mécaniques d'un mélange de sol de remblai allégé composé d'une argile d'origine Kaolin, de billes de polystyrène expansé "EPS" et d'un agent de cimentation de ciment Portland. Les effets de différentes compositions sur la résistance au cisaillement et les caractéristiques de compressibilité du mélange léger ont été étudiés en utilisant des essais de cisaillement direct et des essais de compression simple. Il est observé que la densité du mélange léger peut être efficacement contrôlée par la quantité et la densité de billes d'"EPS" utilisées. Avec l'inclusion de 1 à 5% de billes d'"EPS" (pourcentage en poids de l'argile), la densité sèche du mélange léger peut être inversement réduite. De plus, cette inclusion provoque une diminution des paramètres de résistance à la compression simple et au cisaillement. D'autre part, la Résistance au cisaillement et la rigidité du mélange léger peut être contrôlé en ajustant la quantité de ciment utilisé (5 à 25% en poids de l'argile). La résistance au cisaillement du mélange léger augmente avec l'augmentation de la proportion du ciment par rapport au sol.

Keywords: Polystyrene EPS-beads; Kaolin; stabilizing cement; lightweight mixture; shear strength.

1 INTRODUCTION

Construction technique using lightweight geomaterials has many practical advantages because of their light self weight which make it possible to reduce large deformations and differential settlement of a soft ground or a foundation with poor bearing capacity. It also may be used to improve slope stability adjacent to an embankment and to minimize the lateral earth pressure acting against or facing embankment wall. The use of Expanded Polystyrene (EPS) resources is quite advantageous both in the practical use of wasted resources and in reduction of earth pressures due to lightweight characteristics, (Kim et al., 2002). In recent years, lightweight materials, using, EPS, blocks geofoams, have been more widely used in the infrastructure rehabilitation and in the construction of new facilities such as roads and embankments. Liu et al., (2006) compared EPS-beads and EPS-blocks, the EPS-beads mixed lightweight fill may be controlled in terms of the density and also, shear strength. The most important advantage of EPS-beads mixture is that it can be made on the site into a slurry form and poured to anywhere before it harden. Thus it is particularly suitable to be used to fill cavities, underground openings of irregular shapes or for rehabilitation works. Another advantage of EPS- beads mixture over the EPS blocks is that it can be used in situations where compressive stresses higher than what the EPS blocks can provide. However, the EPS-beads mixed lightweight fill can be more expensive when cement is used and extra manpower or machines are required for mixing.

Recently, studies and applications of EPS beads mixed lightweight fill including the use of cement began in south Asia. Satoh, (2001) used EPS beads mixed lightweight fill under deep water. Qibao (2006), and (Minegishi, et al., 2002) investigated the characteristics of EPS-beads mixed lightweight geomaterial subjected to cyclic loading. Ruiming, (2006) studied the dynamic strength behavior of lightweight sand-EPS beads soil under different confining pressures and different mixing ratios. (Kim et al., 2002) studied the compressibility and expansibility using oedometer test with the permeability on EPS beads and weathered granite soils. Ma, (2003) used EPS beads mixed lightweight fill for embankment on a soft foundation. Liu et al., (2006) studied the effect of different ratio of EPS beads and cement on the clayey soil behavior using unconfined compression test.

In this research, laboratory study was carried out using compositions of different ratios between clayey soils as kaolin, three different densities of EPS-beads with different ratios, and different ratios of normal Portland cement mixtures. The effect of different compositions on the dry density, compression strength, stress strain behavior, and shear strength parameters have been studied. Test results showed that, adding EPS beads with different ratios, decreasing the dry density and shear strength parameters of the lightweight fill. Adding Portland cement with different ratios leads to increase of unconfined compressive strength and shear strength parameters of the mixture.

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2 EXPERIMENTAL PROGRAM

2.1 *Materials*

Three components, EPS beads, cement, and kaolin, were used to study the lightweight mixture. EPS beads is a super-light weight artificial material which belongs to a geofoam in geosynthetics, and an EPS beads has a soft and elastic nature, it is round in shape with diameters ranging between 1 and 5 mm as shown in table 1. The beads are highly compressible, having only about 1% of the density of a typical soil. Five EPS beads ratios were used, 1 to 5%, of the kaolin by weight. The EPS-beads densities used in this study were 0.10, 0.16, and 0.20 kN/m^3, which only about 1% of the clay density.

Table 1 EPS-beads property

EPS-beads (No)	Density γ_{beads} (kN/m^3)	Particle Size (mm)
400	0.10	1-2
500	0.16	2-3
600	0.20	3-5

The index properties of the kaolin are shown in table 2.

Table 2 Physical and Mechanical properties of Kaolin

Kaolin Properties	LL%	PL%	SL%	γ_d kN/m^3	G_s	>200 μ
	46	18.06	10.2	16.8	2.67	93.5%

An ordinary Portland cement was used as a stabilizing and cementing material. The cement ratios were used by dry weight percent to the Kaolin, 5, 10, 15, 20and 25 percent.

2.2 *Mix Ratios and Specimen Preparation*

The mixing ratio was defined as a ratio of kaolin weight. EPS-beads with different density and ratios were added with cement to kaolin. The effects of different mixing ratios on the dry density, unconfined compression strength and shear strength parameters (φ, and c) were studied.

Samples were prepared by adding desired ratios of beads, cement, kaolin and water in the electric mixture for ten minutes until the beads were evenly distributed within the slurry to get homogenous slurry. After a thorough mixing, slurry was cast into tests models for direct shear and unconfined compression tests. For the tests models, square steel moulds 60 mm and 30 mm in height for direct shear, and steel circular models75mm in height and 36mm in diameter were used for unconfined test. All specimens were placed into a curing chamber with temperature of 20C and relative humidity of 100% for curing for twenty eight days.

2.3 *Mixture Testing*

Effect of beads ratio, beads density, and cement ratio, on mixture dry density, shear strength parameters, unconfined stress strain behavior and unconfined compression strength were studied using direct shear and unconfined compression tests. After curing time of 28 day, the specimens were tested.

The unconfined compression test was conducted by conventional step loading method using a deformation rate of 0.5 mm/min. For direct shear test, the test was conducted by the conventional step loading method with different normal stress using a deformation rate of 0.59 mm/min.

3. RESULTS AND DISCUSSION OF UNCONFINED COMPRESSION TEST

3.1 *Mixture effect on dry density*

3.1.1 *Effect of EPS-beads ratio and density*

The dry densities measured for the specimens, using different beads ratios, by measuring specimen volume and weight after curing with 28 day and before testing. Figure 1(a) shows that by mixing 1 to 5% of EPS-beads (by kaolin weight), dry density of the specimens might be controlled from16.8 kN/m^3 for pure kaolin to 4 kN/m^3 at beads ratio 5%. This is significant improvement in terms of mixture dry density. The difference in the effect of the EPS-beads ratio to kaolin on dry density is attributed to the density difference between EPS-beads and kaolin. Within the range of 1% EPS-beads, results in 40% decrease in dry density. In case of ground water is existed, density should not be less than 9.8 kN/m^3, and beads ratio should not increase than 1% of soil weight. Beads ratios 3, 4, and 5 % of soil weight decrease the soil dry density nearly the same. Figure 1(b) indicates that the increase of EPS-beads density causes slight increases the dry density at the same beads ratio.

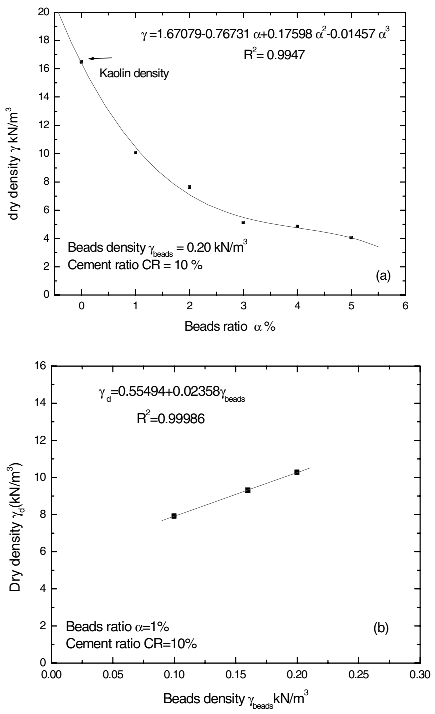


Figure 1. Effect of EPS beads ratios and density on mixture dry density.

3.1.2. *Effect of Cement Ratio*

To compensate the decrease in shear strength of lightweight mixture due to adding beads, Portland cement was used as a stabilizing and cementing material. When cement is used, the strength of the mixture will increase due to the cement hydration effect. Water has to be used in the mixing process to enhance the workability of mixing and to activate cement hydration. The effect of cement with EPS-beads and kaolin mixture on mixture dry density was investigated using 1% beads with 0.20 kN/m^3 EPS-beads density. Normally the cement content ranges from 4 to 16 % by dry weight of soil; however a feasible range of 5 to 10% is frequently dosed for all practical application. In this research five different percentages of cement ratios were 5, 10, 15, 20 and 25% were used to increase shear strength. As shown in figure 2, the increase of cement ratio from 5 to 25 % results in increase of dry density from 8.0 to 17 kN/m^3.

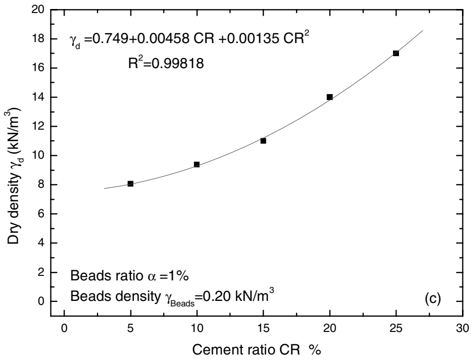


Figure 2. Effects of cement ratios on mixture dry density.

3.2 *Mixture behavior in unconfined compression test*

Unconfined compression test was used to evaluate the ultimate unconfined strength. Ultimate compressive strength obtained from tests with the EPS beads ratios varying from 1 to 5% are shown in figure 3(a). It is shown that with the increase of EPS-beads ratio, the ultimate unconfined strength decreases. While ultimate compressive strength increases with the increase of beads density as shown in figure 3(b).

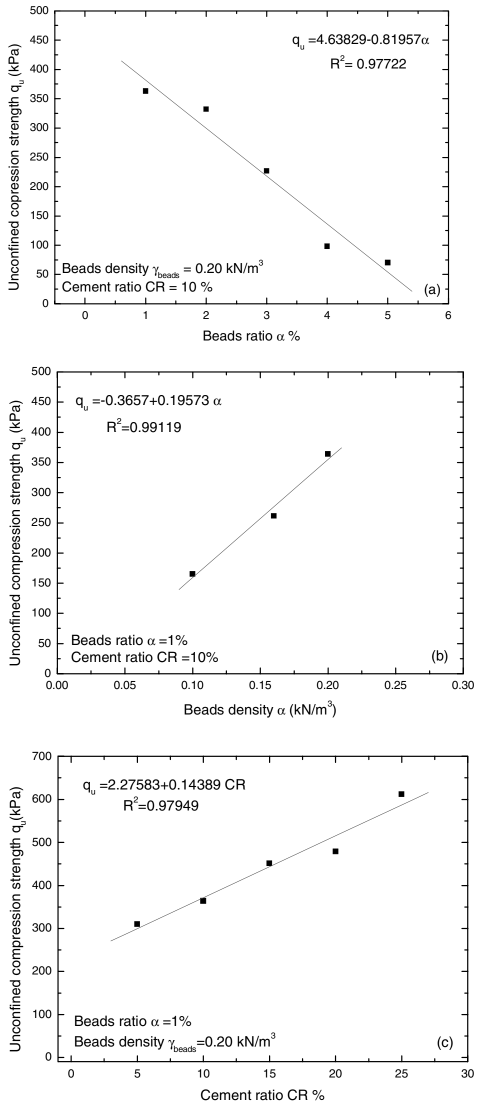


Figure 3. EPS-beads and cement effect on ultimate unconfined strength.

With the increase of cement ratio, with existence of 1% beads with density 0.20 kN/m^3 the ultimate unconfined compressive strength increases as shown in figure 3(c). Increasing cement ratio makes the mixture behavior becomes more brittle. The desired compressive strength and dry density of the mixture determines the most suitable cement ratio to be used.

3.3. *Mixture Stress–Strain Behavior*

The stress–strain behavior for different EPS-beads ratios with the presence of 10% cement is shown in figure 4. Unconfined strength and stiffness increase with the decrease of beads ratio as mentioned before. Adding beads more than 2% of clay weight causes high loss of mixture compressive strength. While proportional increases of unconfined strength is expected with higher beads density. Increasing cement ratio to 25% makes the mixture behavior becomes more brittle.

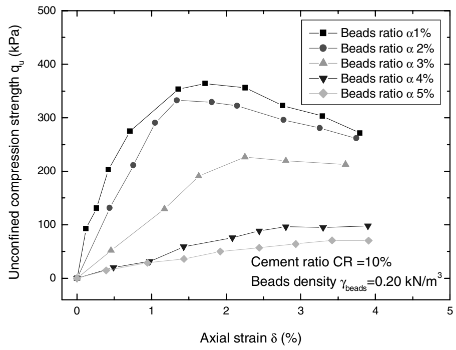


Figure 4. Stress–strain behavior of lightweight mixture.

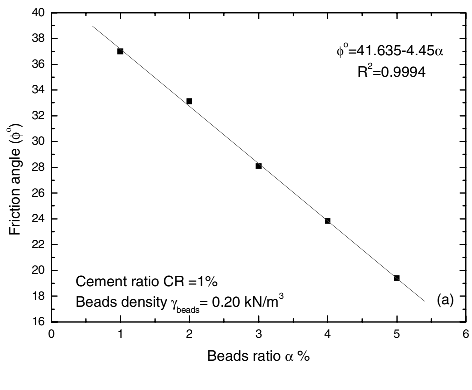
4. RESULTS AND DISCUSSION OF DIRECT SHEAR TEST

Direct shear tests were carried out on mixture specimens of varying beads ratios, beads density, and cement ratios to illustrate the additives effect on kaolin shear strength parameters. Angle of shearing resistance,φ^o, was gained due to the interface and friction between beads particles, and kaolin.

4.1 *Effect of Beads on Shear Strength Parameters*

The unconsolidated undrained shear strength was measured for mixture specimens consist of kaolin, and EPS-beads of different ratios and densities with different cement ratios. As shown in Figures 5(a), 1% EPS-beads ratio with 10% cement, leads to increase in friction angle, φ°, from zero at pure kaolin to 37°. According to the fitting line, increasing beads ratio decreases the angle of shear resistance, φ° from 37°at 1% beads to 19.38° at 5% beads ratio.

Kaolin cohesion was increased due to adding cement ratio 1% to be 65.8kPa, at zero beads ratio. Figure 5(b) shows the decrease of shear strength parameter c with the increase of beads ratio from 61 kPa at 1% beads ratio to 18 kPa at 5%, as a polynomial relationship.



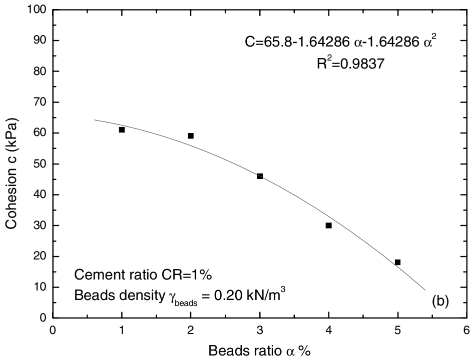


Figure 5. Effect of beads ratios on shear strength parameters.

Angle shearing resistance, φ°, measured for specimens of different beads density, is shown in Figure 6 (a). It can be seen that an increase in the beads density within a range from 0.1 to 0.2 kN/m^3 leads to a linear increase in the angle of shearing resistance, φ°. Cohesion, c, also increases with the increase of beads density as shown in figure 6(b).

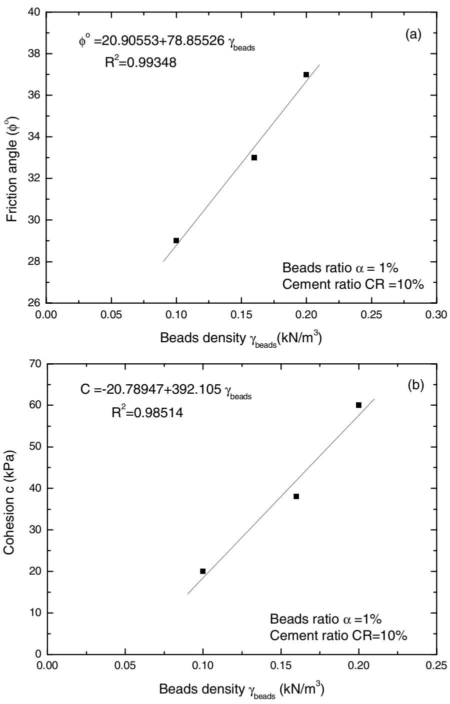
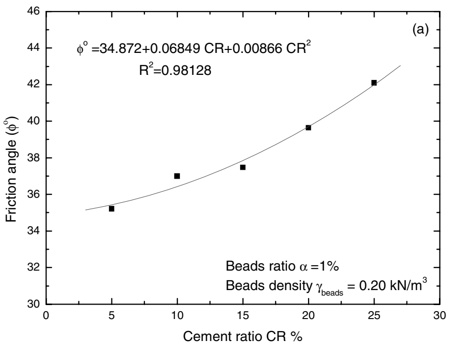


Figure 6. Effect of beads density on shear strength parameters**.**

4.2 *Effect of Cement on Shear Strength Parameters*

The increase in the cement ratio from 5 to 25% leads to slight increase in the angle of shearing resistance, φ°, as shown in Figure 7(a). According to the non linear relationship, the friction angle gains 7 degrees due to increase of cement ratio.



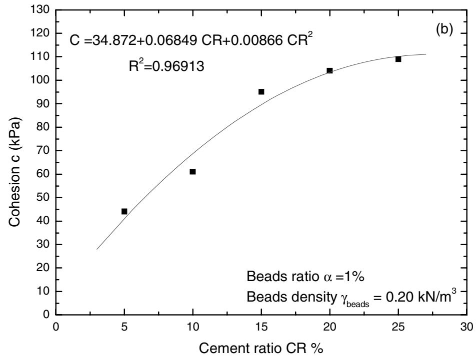


Figure 7. Effects of cement ratio on angle of shear strength parameters

The existence of cement increases the cohesion parameter c. With increasing cement ratio, the stiffness becomes higher as shown in figure 7(b).

5. CONCLUSIONS

The following conclusions can be drawn from this study:
Lightweight fill material can be produced by mixing EPS-beads with, clayey soil (as kaolin) and water. Its dry density is controlled mainly by the EPS beads ratio and density in the range from 4.12 to16.5 kN/m^3, by using EPS-beads ratio in the range from1–5%. This is much lighter than the density of conventional materials. One percent beads leads to 8 kN/m^3 decrease in the dry density of the lightweight mixture. The increase of EPS beads ratio, decreases dry density, angle of shearing resistance, and cohesion. It also increases the mixing water ratio. While the increase in EPS beads density, slightly increases the dry density and shearing resistance parameters.

Using stabilizing material as cement is an effective factor to improve the shear strength parameters, and shearing behavior of the lightweight fill. The increase in cement ratio increases the dry density, shearing resistance parameters, and stress strain behavior.

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