The Effect of expanded polystyrene and cement on properties of sand soils for foundation use

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ABSTRACT: The increase in Expanded Polystyrene (EPS) waste in Uganda is prone to cause serious environmental pollution owing to the related poor disposal methods. The common practices include open disposal and/or burning which are both environmentally degrading. Other approaches of recycling EPS are unpopular and quite expensive. This research aimed to investigate the effect of EPS and cement on sand soil for a foundation material. The soil was a poorly graded sand. Preliminary tests were carried out to determine the grading, Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of the sand. Initial cement consumption test was done to determine a constant weight of cement required for just the binding effect on the materials. The unconfined compressive strength, shear box, permeability and consolidation tests were performed on the treated soil specimens at various percentages of EPS. The sand-EPS-cement composite showed an increase in unconfined compressive strength and shear strength with the maximum at 0.5% EPS. The permeability of the composite decreased while there was a minimal increase in settlement with increasing EPS content.

1 INTRODUCTION

Expanded Polystyrene is a lightweight material that has been previously used as a geo-form to improve the bearing capacity of clay soil and also to construct embankments. It has been noted to improve the bearing capacity of the stabilized soil, decrease permeability and lower the unit weight of the stabilized soil thus producing a lightweight composite material with better engineering properties (Stark et al. 2012). On that background, this research investigated the appropriateness of sand-EPS-cement composite for a foundation material. This provides an alternative use for waste EPS as opposed to current disposal methods used in Uganda. It also reduces the accumulation of the waste EPS when disposed of in landfills since it occupies a lot of space due to its bulky nature. Previous research has shown good results when EPS was used as a geo-form (Bartlett et al. 2000), but further investigations have been recommended on EPS beads since they provide a better workability to suit specific site conditions (Abdelrahman 2010). This research therefore sought to investigate how the different properties of the sandy soil are affected by various compositions of the EPS and recommendations are given in regard to its suitability for a foundation material.

2 MATERIALS AND METHODS

2.1 *Expanded Polystyrene*

Expanded polystyrene is a rigid cellular thermoplastic material made out of expanded polystyrene beads. It is manufactured from a monomer called styrene and it basically contains hydrogen and carbon with chemical composition C_8H_8 (Aaboe 2000). EPS is a versatile lightweight material that was initially used in insulation and floating devices for boats (rafts, docks and billets) and life preservers. Currently it is used for purposes ranging from packaging of fragile goods, insulation and many other uses in the construction industry such as pipe insulation, lightweight fill material and concrete moulds (Illuri 2007). Table 1 indicates the properties of EPS.

EPS beads are suitably advantageous since they do not absorb water hence curbing problems related to water absorption. They are also naturally inert and resistant to chemical attack by the common inorganic acids and alkalis, including the de-icing salts (Illuri 2007). Additionally, they are resistant against biological attack by pests (Sivagnaname et al. 2005).

Table 1. Properties of EPS (Thompsett et al. 1995)

Grade	SD	HD	EHD	UHD
Density	15	20	25	30
Tensile Strength (kPa)	200	280	350	425
Bending strength (kPa)	190	270	350	450
Linear Expansion coefficient (10-5 m/mK)	7	7	7	7
Lowest service temperature (°C)	-110	-110	-110	-110
Highest service temperature (°C)	+70	+70	+70	+70

2.2 *Cement*

Hima Multi-Purpose cement, a Pozzolana cement, with fair strength characteristics was obtained. It was categorized as a CEM II type cement, of class 32.5 N, which contains a natural pozzolana manufactured from Portland clinker (DUS 310-1 2016).

Cement can be used to improve the properties of many soils especially those with an organic content less than 2 % or pH above 5.3 (ACI 230.1R-90 1990). It chemically reacts and binds the particles of the natural soil to improve its properties. Because of its binding effect, it was used in this research to provide a bond between the EPS beads and the sand soil particles.

2.3 *Sand*

Lake sand, originally mined from Lake Victoria, was utilised. The sand was collected from Luzira on the shores of Lake Victoria and transported to the laboratory in sacks. It was air-dried for 24 hours before carrying out any test on it. The sand was classified as a poorly graded sand (SP) with more than 93 % of the particles passing 2 mm and retained on 0.075 mm sieve. The fine particles (clay and silt) were 4 %. The uniformity coefficient, C_u was determined to be 2.48 and the coefficient of conformity as 1.0.

2.4 *Sample Preparation*

Waste EPS boxes were collected from electronics shops in Mukono town as a waste from packaging delicate electronics. They were then crushed to produce beads of average 0.5 mm diameter. As a precaution, similar boxes of waste EPS were crushed to produce beads of similar characteristics.

Sand was the main constituent of the composite. EPS and cement were added to sand by percentage weight of the composite soil sample. Cement was added in a constant measure of 5% of the sample. This dosage was derived from the initial cement consumption test of sand. EPS was added in increasing mass ratios of 0 %, 0.1 %, 0.3 %, 0.5 % and 0.7 %. These mixing ratios were proposed by Minegishi et al. (2002). They were appropriate for use in this research since volume mass ratio for EPS is high and therefore the composite soil characteristics are highly affected by the size and gradation of the EPS beads (Illuri 2007).

Calculated amounts of water, equalling to the OMC of the sand-Cement-EPS composite, were prepared. Sand, cement and EPS were then thoroughly mixed on a metallic tray until a uniform mixture was achieved. Then the prepared water was added using a measuring cylinder and mixed again until a uniform paste was formed. This was done for all the different samples. In order to maintain consistency between the sample preparations, the mixing water was controlled. In this study, samples were prepared at their corresponding OMC.

2.5 *Tests*

The following tests were carried out on the un-treated and treated specimens. The treated specimen was sand stabilised with cement and EPS beads. The un-treated specimen was sand alone.

- Particle size distribution (wet sieve analysis) in accordance to BS 1377: Part2: 1990
- Initial cement consumption in accordance to BS 1924: Part 2: 1990
- Compaction test in accordance to BS1377: Part 4:1990
- Unconfined compressive strength in accordance to ASTM D-2166
- Permeability test in accordance to BS 1377: Part7: 1990
- Shear box test in accordance to BS 1377: Part7: 1990
- Consolidation test in accordance to ASTM D2435

3 RESULTS AND DISCUSSION

3.1 *Compaction*

It can be seen from Figure 1 that the MDD decreased as the percentage of EPS added to sand increased. The neat sand had MDD of 1618 kg/m^3 which reduced by 1.73 % to 1590 kg/m^3 on addition of 0.1 % of EPS. At 0.3 % the MDD reduced by 0.63 % to 1580 kg/m^3, at 0.5 % it decreased by 1.33 % to 1559 kg/m^3 and by 0.7 %, the MDD had decreased by 4.94 % to 1482 kg/m^3. On average, the MDD of the stabilized soil decreased from that of the neat sand by 8.41 %. The same decrease was reported by Illuri (2007) and Hirasawa (2000).

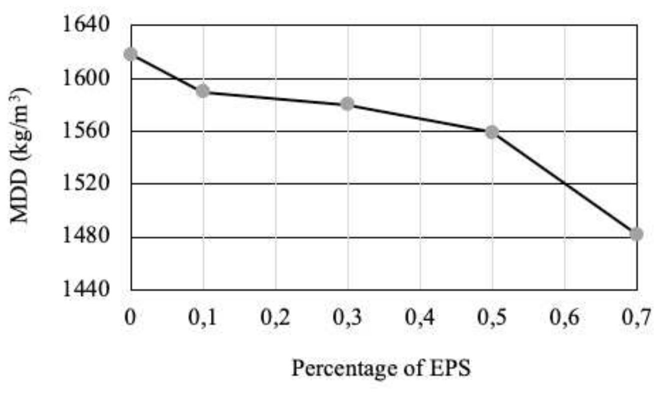

Figure 1. Variation of MDD with EPS content

The reduction is attributed to the EPS particles, of lower density, occupying the space that would have been occupied by the sand particles. Owing to the low volume mass ratio of EPS, the stabilised sample reduces in the MDD (Illuri 2007). However, the addition of 5 % cement alone without EPS slightly increased the MDD of the soil by 0.2 %. This is because the fine cement particles have a specific gravity of 3.15 compared to sands of 2.67 thus increasing the composite density. Generally, there was no effect on OMC as the percentage of EPS added to sand increased.

3.2 *Unconfined Compressive Strength (UCS)*

The unconfined compressive strength of the sand-cement-EPS composite increased with the percentage of EPS up to 0.5 %, Figure 2. Then it started to reduce. It initially increased by 23.08 %, then by 18.75 % and by 21.05 % on addition of 0.1 % EPS, 0.3 % EPS and 0.5 % EPS respectively. This can be explained by the increase in density of the composite, due to compaction, which was well bonded creating a denser and well packed sample. The strength of the EPS is dependent on its density (Illuri 2007). However, beyond 0.5 % EPS, the strength started to decrease. Since EPS has a high volume to mass ratio, there are many beads added at higher percentages which can't be adequately bound by the same initial cement consumption content (Abdelrahman 2009, Illuri 2007). The unconfined compressive strength of the neat sand soil, without a binder, was not determined because sand is cohesionless and can't form a specimen that can stand on its own to be tested.

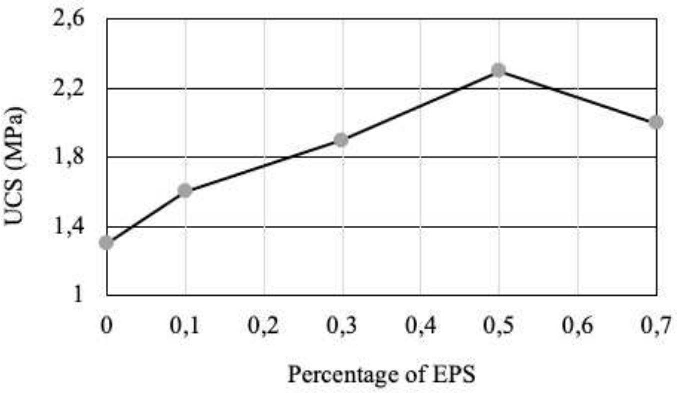

Figure 2. Variation of UCS with EPS content

3.3 *Shear Strength Parameters*

The shear strength parameters of the composite were assessed at different compositions of EPS. The composite specimens were subjected to a normal effective stress and tested for cohesion and angle of internal friction. It was observed that the cohesion increased by 24.6 %, 16.3 %, and 22.5 % for 0.1 %, 0.3 % and 0.5 % percentages of EPS respectively. The internal angle of friction increased by 0.9 %, then by 2.7 % and then by 1.7 % on addition of 0.1 %, 0.3 % and 0.5 % percentages of EPS respectively. However, there was also a decrease of 1.3 % on addition of 0.7 % EPS composition. The increase in shear strength parameters was as a result of the increase in the density of the EPS in the sample (Padade & Mandal 2004), and the decrease at 0.7 % EPS was as a result of the higher ratio of EPS to binder content at percentages greater than 0.5 %. This reduces the binding effect hence the particles easily disintegrate under the action of the applied load.

3.4 *Permeability*

The permeability of the soil composite decreased with the addition of EPS beads and cement. The permeability value (hydraulic gradient, K) reduced by about 30 %, 31 % and 66.8 % at EPS percentage compositions of 0.1 %, 0.3 % and 0.5 % respectively. However, the permeability started to increase again at 0.7 % EPS. The decrease in permeability of the composite samples with increasing EPS composition and cement was due to the binding effect of the cement that bonds particles together hence reducing the pore spaces upon compaction (Abdelrahman 2009). Since the EPS beads are water tight, this effect increased with increasing EPS composition. However, beyond 0.5 % EPS, the effective boding effect of the cement is reducing thus creating pores between the sample particles thus increasing the permeability again.

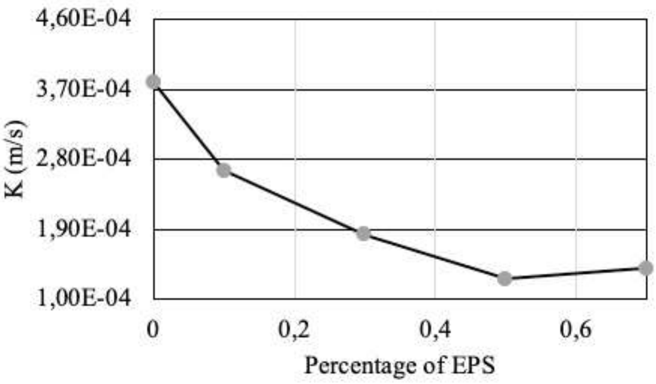

Figure 3. Variation of hydraulic gradient with EPS content

3.5 *Consolidation*

The results for compression during loading and unloading of the prepared composite soil samples at varying EPS percentages indicated a similar trend of settlement shown by a similar shape of displacement curves. Initially, there was increase in settlement upon loading and this was followed by a decrease in settlement during unloading. The maximum settlement for the neat sample was 1.88mm which initially gradually increased by 3.7% at 0.1 % EPS, then increased sharply by 20 % and 17 % and 32.4 % at 0.3 %, 0.5 % and 0.7 % EPS. The increased settlement upon loading and expansion on unloading is caused by the EPS beads which are very compressible since they contain up to about 98 % air thus can be deformed under loading and restored upon unloading. The sand - EPS composites could be regarded as having a low compressibility and thus a negligible expansive effect (Skempton & McDonald 1956).

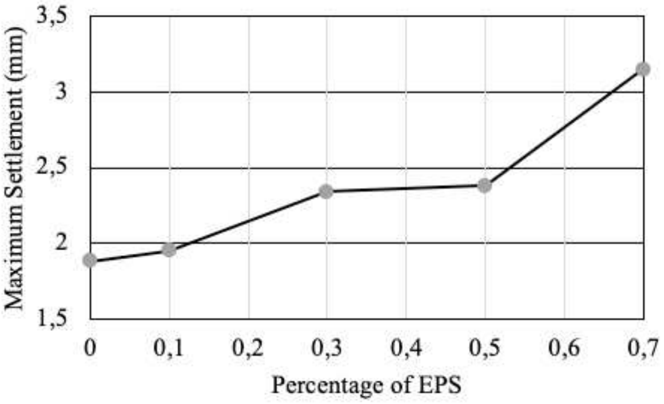

Figure 4. Variation of settlement with EPS content

4 CONCLUSION

A sand - EPS composite with a cement binder can make a good lightweight foundation material with a low settlement that is within the limits, 0 - 7 mm, as discussed by Skempton & McDonald (1956). The most appropriate percentage mix is with about 0.5 % EPS of the total weight of the composite and water at OMC plus a cement binder equivalent to the initial cement consumption of the sand soil.

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