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Strength and Compressibility of Kaolinite Clay Stabilized With Lime Sludge And Fly Ash

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Abstract. Present study investigates the strength and consolidation behavior of kaolinite clay stabilized with industrial byproducts. The use of industrial by products in soil stabilization is gaining more importance lately, in promoting sustainable environment. The byproducts used in this study are lime sludge (LS) from a water treatment plant, and fly ash (FA) from a coal fired thermal power plant. First, the kaolinite clay was stabilized using LS alone in varying percentages (i.e. 0, 2, 4, 6 and 8), and then LS & FA together were used in varying percentages (i.e. 0, 5, 10, 15 and 20) with dry weight of the soil. Standard Proctor tests were carried out on the kaolinite mixes, to find out the density and optimum moisture content (OMC). The unconfined compressive strength (UCS) samples were prepared, based on the standard Proctor density and its corresponding OMC. The UCS samples were tested after a curing period of 0, 7, and 14 days at room temperature. The strength increase in the kaolinite mixes with LS, LS and FA were evaluated based on UCS. The reason for strength increase was due to the chemical reaction between kaolinite, LS, and FA. Consolidation tests were conducted for all the similar mixes, which were used for the UCS test, compacted at its Proctor's density and corresponding OMC. The samples were loaded and unloaded in a specified sequence, and the compression index (C_c) was calculated for all mixes. For kaolinite clay mixed with LS, the C_c values had a decreasing trend except for 2%, as it might not be an optimum mix. Further, kaolinite clay mixed with LS and FA also had a decrease in C_c values, except for 10% and 15%, which had a minor increase. Also, the kaolinite mixes which had the higher UCS strength values, exhibited a lower C_c value.

Keywords: Lime sludge (LS), Fly ash (FA), Consolidation, Compaction, Unconfined compressive strength (UCS).

1 Introduction

With growing demand in energy, most of the industrial processes end up with generating by-products. Most of these by-products are transferred to a landfill, which increases the cost of transportation as well as any environmental regulations depending on the type of by-product generated from the industry. Using these by-products in construction, to stabilize the soil and to improve its geotechnical aspects, has been gaining more interest with regards to promoting sustainable environment. Unlike high-rise structures, the ability to use these by-products in pavement construction, will consume most of the material and prove economical with respect to construction costs. Following are few studies that used by-products from industries to treat expansive or problematic soils to reduce the settlement or volume change potential.

Savas (2016) studied dispersive soil stabilized with lime and natural zeolite, his findings demonstrated an improvement in the effect of dispersivity, swell properties and compressibility. Pozzolanic reaction between the soil, lime and natural zeolite reduced the compressibility of the dispersive soil. Fattah et al. (2014) have found that soft soil stabilized with lime and silica fume improved the Atterberg limits and reduced the compressibility index. The effect was more pronounced when lime and silica fume were used together, than using them individually. Amiralian et al. (2012) have found that the minimum percentage of lime usage, to have a significant effect on the compressibility index should be more than 2%. Reduction in compressibility index with increase in lime content is due to the Pozzolanic reactions between lime and soil. The compression index, coefficient of compressibility, and the coefficient of volume change decreased with increase in fly ash and dolochar content for expansive soil (Mohanty et al., 2016). Eberemu (2011) have found that with the increase in rice husk ash content, the plasticity index decreased. The coefficient of consolidation increases at higher consolidation pressure. Pre-consolidation pressure increased, and compression index decreased with increase in rice husk ash percentage up to 16%. However, at higher molding water content, the pre-consolidation pressure and compression index reduced. Phanikumar & Singla (2016) found that heave swelling potential and vertical swelling pressure decreased, with increase in fiber content for a given fiber length. However, this was valid up to a fiber length of 0.25%. At 0.30% fiber content, the swell potential and vertical swelling pressure increased. Lekan & Ojo (2013) found that lateritic soils stabilized with tire ash can be appropriate for recovering low-lying marginal land for foundations. Compression index and swell index were reduced, and pre consolidation pressure was increased with increase in tire ash content up to 8%. The magnitude of primary consolidation in the normally consolidated state increases, while in the over consolidated state it decreases (Salehi & Sivakugan, 2009). Geo polymer cements (GPC) are manufactured under alkali activated conditions and the properties of these cements are better than ordinary Portland cement. Soils stabilized with GPC's can manage consolidation settlement, resist high temperatures, and resist salts, sulphate, corrosion and acid attacks (Onyelowe & Van, 2018). Rice husk ash has been proved more effective in reducing the consolidation settlement of the soil in comparison with stone dust and fly ash (Jain & Puri, 2013). The oil contaminated soil demonstrated a decrease in unconfined compressive strength and void ratio and an increase in coefficient of consolidation and volume compressibility (Ijimdiya, 2013). The compression index, expansive index, coefficient of consolidation and recompression index decreased for the expansive soil treated with increase in lime and bagasse ash content (Manikandan & Moganraj, 2014). For structures built on clay modified by fly ash, the amount of settlement decreases and the rate of settlement increases, reducing the time required for reaching the final settlement (Phanikumar & Sharma, 2007). The improvement in consolidation characteristics of lateritic soil modified with cement addition, is due to the formation of a solid microstructure. The optimum content of cement was found to be 6%, to have a better mechanical performance (Mengue et al., 2017). Pre-consolidation pressure increased with lime and fly ash additions, leading the soil to form an over consolidated soil. Also, compression index reduced with lime and fly ash modified soils (Sureban, 2011).

Based on the literature review, most of the researchers used the by-products available in their vicinity to stabilize soil and reduce settlement. An attempt has been made in this study to stabilize commercially available EPK clay to reduce the compression index by adding industrial by-product. The by-products used are sourced from the vicinity, like fly ash from a coal fired thermal power plant and lime sludge from a water treatment plant. The findings can be applied to pavement construction, in stabilizing a weak subgrade.

2 Materials

2.1 EPK clay

The EPK clay used in this study, also called as kaolinite, is a commercially available material supplied by Edgar minerals, FL, USA. It is classified as silt with high plasticity (MH), according to Unified Soil Classification System (USCS). The specific gravity was determined using gas pycnometer and the value came out to be 2.61.

2.2 Lime sludge

Lime Sludge (LS) used in the present study is a by-product from treating water. It is collected from a water treatment plant in Southern Illinois (Saline Valley Conservancy District water Treatment plant, Saline County, IL). The water is treated using various chemical processes, and suspends a softening residual matter high in concentrations of calcium oxide (CaO). The sample is like a slurry, it has been air dried, crushed, mixed homogeneously and sieved through 2 mm sieve prior to use in experiments. The percentage of fine sand, silt and clay size fraction are determined using a laser particle analyzer, and the values came out to be 12.5%, 76.5%, and 11.0%. respectively. The specific gravity was determined using gas pycnometer, and the value came out to be 2.47.

2.3 Fly ash

The Fly Ash (FA) used in the present study is from a coal fired thermal power plant located at Southern Illinois University Carbondale (SIUC). The fly ash is classified as Class C fly ash as per ASTM C618. The specific gravity determined using gas pycnometer was found to be 2.76.

3 Methods

All the testing procedures is this study are according to the respective American Society of Testing and Materials (ASTM) standards.

3.1 Physical properties test

3.1.1 Specific gravity test

The specific gravity for all the EPK clay mixes with fly ash and lime sludge were conducted using an equipment called Gas pycnometer, manufactured by Quantachrome Corporation, FL, USA. Depending on the type of material to be tested, the test set up has three different types of sleeve sizes (small, medium, and large). Prior to testing, the respective sleeve size has to be calibrated, and the representative sample of known weight has to be taken in the sleeve. The sleeve is loaded in the equipment, and the instructions are followed according to the equipment manual to determine the specific gravity. The specific gravity is calculated, taking an average of 5 runs, making the readings accurate and reliable.

3.2 Engineering properties test

3.2.1 Standard proctor test

The standard Proctor test was conducted on the proposed mixes i.e. EPK clay, EPK clay with lime sludge and EPK clay with lime sludge and fly ash. Lime sludge was used in varying percentages of 2%, 4%, 6% and 8% by dry weight of the clay; and lime sludge plus fly ash were used in varying percentages 5%, 10%, 15% and 20% by dry weight of the clay.

The standard Proctor tests for the proposed mixes were carried out using a Harvard miniature compaction device, having a mold size of 33 mm in diameter and 71 mm in height. The compaction hammer used, had a diameter of 12.7 mm and weight (compaction effort) of 20 lb (9.07 kg). The samples were compacted in 5 equal layers and 5 blows per layer.

3.2.2 Unconfined compressive strength (UCS) test

The unconfined strength samples were prepared in a standard UCS mold, having a height to diameter ratio of 2:1. The samples were compacted in 3 layers and 25 blows per layer, corresponding to its optimum moisture content and dry density determined from the standard Proctor tests. The samples were extruded then, wrapped in plastic film and placed in a plastic bag for curing period of 7 and 14 days in a water bath having temperature maintained at 25^0C. The samples for 0 days curing, were tested right after the extrusion from the mold. The compacted samples were loaded in an UCS test machine with a strain rate of 1.27 in/min (32.26 mm/min) until the load reading drops or the strain value exceeds 15%. The stress strain graphs were plotted based on the load and deformation readings and the peak value of the graph is taken as the unconfined compressive strength.

3.2.3 Consolidation test

The consolidation tests for the proposed mixes were carried out in an automated consolidation device, manufactured by GeoComp Corporation, Boston, USA. The samples were compacted in the consolidation ring based on the standard Proctor moisture-density relationship. The top and bottom of the sample is covered with a filter paper followed by porous stones. The consolidation cell is loaded in the test set up and the load is zeroed. Then, the cell is inundated with water and the load is zeroed again before starting the test. The test runs automatically once it is initiated, with a specified sequence of loading and unloading. The data is then downloaded and necessary calculations are done.

4 Results and Discussion

4.1 Physical properties test

4.1.1 Specific gravity test

The specific gravity test results for EPK clay mixed with different percentages of lime sludge, different percentages of lime sludge and fly ash are presented in Table 1. From Table 1, it can be observed that the specific gravity values increased with increase in percentage of lime sludge from 2%-8%, lime sludge and fly ash from 5%-20%.

Table 1. Specific gravity values for EPK clay, EPK clay with different percentages of lime sludge (LS), EPK clay with different percentages of lime sludge (LS) and fly ash (FA).

Mix Details	Specific Gravity
EPK	2.5699
EPK + 2% LS	2.5595
EPK + 4% LS	2.5612
EPK + 6% LS	2.5655
EPK + 8% LS	2.5674
EPK + 5% LS + 5%FA	2.5842
EPK + 10% LS + 10%FA	2.5969
EPK + 15% LS + 15%FA	2.6014
EPK + 20% LS + 20%FA	2.6020

4.2 Engineering properties test

4.2.1 Standard proctor test

The test results for standard Proctor test for EPK clay mixed with lime sludge is presented in Figure 1. For the virgin EPK clay, the optimum moisture content and the dry unit weight from the Figure 1 is 32.17% and 12.98 kN/m^3, respectively. However, with increase in percentage of lime sludge from 2% to 6%, there was an increase in dry unit weight from 12.75 kN/m^3 to 13.15 kN/m^3. Further, at 8% lime sludge the dry unit weight had a slight decrease to 13.03 kN/m$^{3.}$ The moisture content on the whole decreased from 36% to 31% with increase in lime sludge percentage from 2% to 8%.

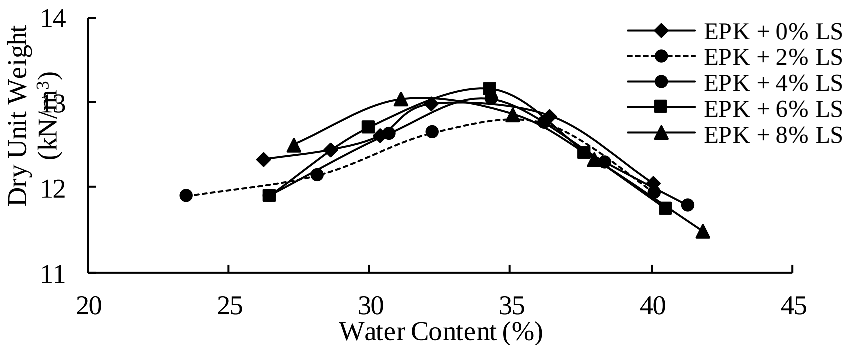

Fig. 1. Compaction curve for EPK clay with different percentages of LS.

The test results of standard Proctor test for EPK clay mixed with lime sludge and fly ash are presented in Figure 2. From Figure 2, it can be observed that, with increase in fly ash and lime sludge percentage from 5% to 20%, the dry unit weight increased from 12.92 kN/m^3 to 13.16 kN/m$^{3.}$ Also, with the increase in lime sludge and fly ash content from 5%-10%, the optimum moisture content (OMC) increased from 32.77% to 34.03%. Then, at 15% the OMC decreased to 33.72% and increased to 34.69% at 20% lime sludge and fly ash content.

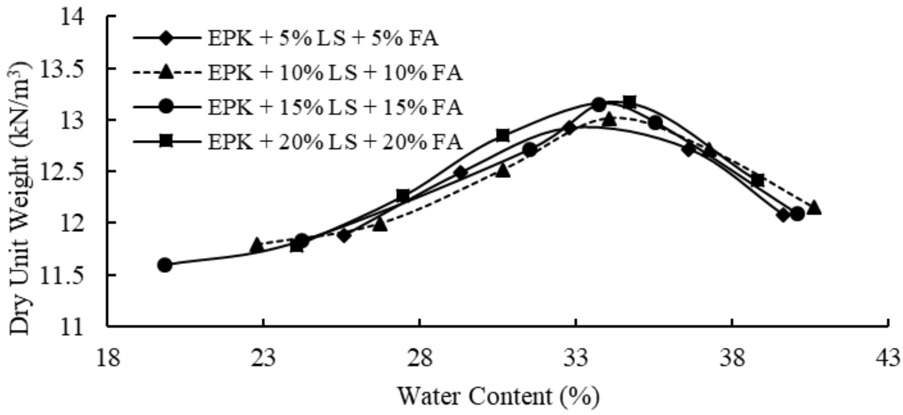

Fig. 2. Compaction curve for EPK clay with different percentages of LS and FA.

4.2.2 Unconfined compressive strength (UCS) test

The test results of the unconfined compressive strength (UCS) mixed with different percentages of lime sludge are presented in Figure 3. From Figure 3, it can be seen that the UCS value increases with increase of lime sludge content from 2% to 8% for a curing period of 7 days. However, the UCS value increased with the increase in lime sludge content from 2% to 6% and had a slight decrease at 8% for a curing period of 0 and 14 days.

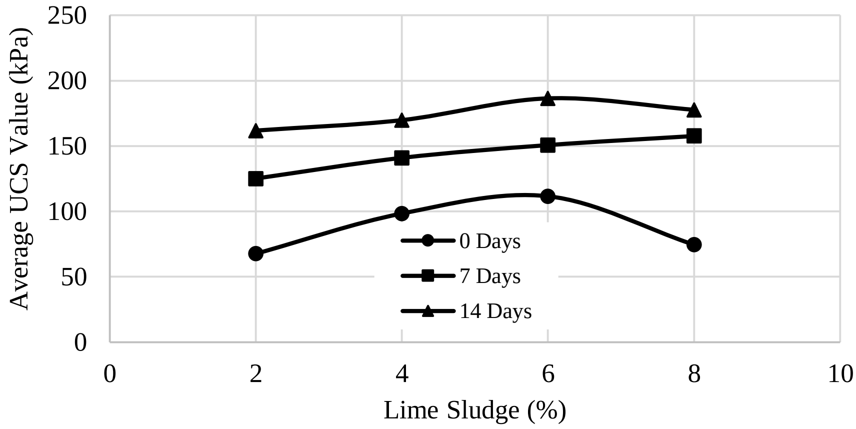

Fig. 3. UCS values of EPK with different percentage of LS at 0, 7, and 14 days curing.

The test results of the UCS mixed with different percentages of lime sludge and fly ash are presented in Figure 4. From Figure 4, it can be observed that, for a curing period of 0 days, the UCS value increased with the increase in lime sludge and fly ash content from 5%-15% and decreased for 20%. However, for a curing period of 7 and

14 days, the UCS value increased with the increase in lime sludge and fly ash percentage from 5% to 20%.

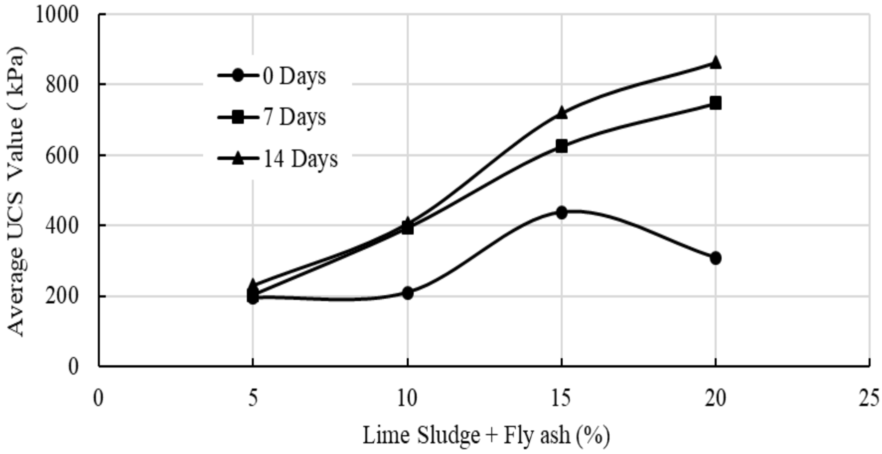

Fig. 4. UCS values of EPK with different percentage of LS and FA at 0, 7 and 14 days curing.

4.2.3 Consolidation test

The consolidation test results for EPK clay stabilized with lime sludge are presented in Figure 5 and Table 2. From Table 2, it can be observed that, the compression index value increased at 2% lime sludge content. As the percentage of lime sludge increased, the compression index values decreased gradually in comparison with the EPK clay.

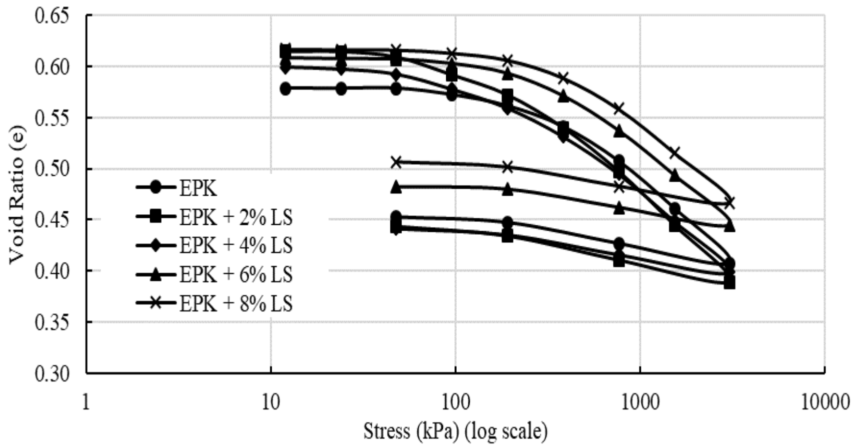

Fig. 5. Consolidation test for EPK clay with different percentages of Lime sludge

Table 2. Compression Index (C_C) of EPK clay with different percentages of Lime sludge.

Mix Details	C_C
EPK + 0% LS	0.1526
EPK + 2% LS	0.1690
EPK + 4% LS	0.1525
EPK + 6% LS	0.1445
EPK + 8% LS	0.1424

The consolidation test results of EPK clay stabilized with lime sludge and fly ash are presented in Figure 6 and Table 3. From Table 3, it can be observed that with the increase in lime sludge and fly ash content, the compression index value decreased at 5% addition, then had a slight increase for 10% and 15% and decreased for 20% addition in comparison to the original EPK clay.

Table 3. Compression Index (C_C) of EPK clay with different percentages of Lime sludge and Fly ash.

Mix Details	Cc
EPK + 0% LS + 0% FA	0.1526
EPK + 5% LS + 5% FA	0.1510
EPK + 10% LS + 10% FA	0.1527
EPK + 15% LS + 15% FA	0.1546
EPK + 20% LS + 20% FA	0.1370

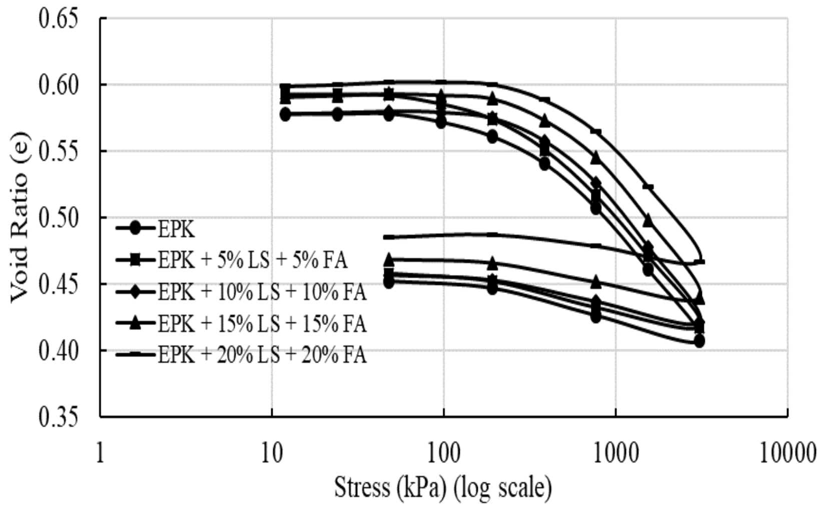

Fig. 6. Consolidation test for EPK clay with different percentages of Lime sludge and Fly ash

5 Conclusions

The aim of the study was to stabilize the EPK clay with lime sludge, and combination of lime sludge and fly ash to observe the compressibility behavior. The following conclusions were drawn based on the results.

1. The specific gravity values of EPK clay mixed with lime sludge, lime sludge and fly ash mixture demonstrated an increase in value with increase in percentage of lime sludge, lime sludge and fly ash addition.
2. The dry unit weight for EPK clay mixed with different percentages of lime sludge had an increase from 2% to 6% and had a slight decrease for 8%. Overall, the OMC decreased from 36% to 31% with increase in lime sludge content from 2% to 8%.
3. The dry unit weight for EPK clay mixed with different percentages of lime sludge and fly ash mixture had an increase from 5% to 20%. Overall, the OMC increased from 5% to 10%, decreased at 15% and then increased for 20%.
4. The UCS strength of EPK clay mixed with lime sludge, demonstrated an increase in value for a curing period of 7 days with the increase in lime sludge content from 2% to 8%. For a curing period of 0 and 14 days, the UCS value increased with increase in lime sludge content from 2% to 6% and had a slight decrease for 8%.
5. The UCS strength of EPK clay mixed with different percentages of lime sludge and fly ash had an increase in value for a curing period of 7 and 14 days from 5% to 20% addition. However, for a curing period of 0 days, the UCS value increased from 5% to 15% and decreased for 20% addition of lime sludge and fly ash. Curing played an effective role in strength gain and the UCS strength of EPK clay with lime sludge and fly ash was 4 times more in comparison with EPK clay with lime sludge.
6. The compression index (C_c) values of EPK clay mixed with different percentages of lime sludge had a slight increase at 2% addition and decreased thereafter in comparison with EPK clay.
7. The compression index values of EPK clay mixed with different percentages of lime sludge and fly ash did not follow a decreasing trend, but had slight increase for 10% and 15% addition and decreased for 20% addition. At the higher percentage of both lime sludge, lime sludge and fly ash, the compression index value reduced in comparison with EPK clay.

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