EFFECT OF FLY ASH STABILIZATION ON STRENGTH PROPERTIES OF CONTAMINATED CLAY-SAND SOILS

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***ABSTRACT* — Calcium –based stabilization/solidification (S/S) is an effective and economic remediation technique to immobilize heavy metals in contaminated soils and sludges. In the present study, flay ash was used as binder to stabilize lead and chromium present in clayey sand soils as artificial pollutants. The strength properties of the compacted specimens, as determined during testing, formed the basis for evaluating both the degree of immobilization of the heavy metal contaminants and the reuse potential of the treated waste form. Thus, in this study, the reusability of the stabilized waste forms in construction application was investigated by performing the unconfined compressive strength for stabilized contaminated sand-clay soils. Nevertheless, the presence of these metals may lead to a more complicated strength development for stabilized soils as a result to interfere the contaminates with the process of stabilization. The investigated admixtures were fly ash with lime; the amount of lime was fixed at 5 percent with the amount of fly ash 5, 10 and 15 percent. The results from the experimental investigation show that by increasing the amount of fly ash the strength properties of lime-fly ash stabilized contaminated soils were improved in different length of curing time. The control samples (stabilized soils without heavy metals) are also prepared for comparison purpose. X-ray diffraction (XRD) and scanning electron microscope (SEM) analyses were also implemented to elucidate the mechanisms responsible for immobilization of the heavy metals under study.**

Keywords: Stabilization, Fly ash, Lime, Contamination, Heavy Metals

I. INTRODUCTION

Protective the environment from hazardous contaminants connected with waste generation and disposal is a major concern of today's heavily industrialized world. Thus far, various technologies have been developed for this purpose. Stabilization / solidification (S/S) is one of the most important technologies for treating and disposing of hazardous wastes by reducing or preventing them from the mobility and leaching into the ground water[5], [16][17] and [6]. This technique can alter the contaminants chemical form into environmentally compatible form for safe disposal or construction so that leachability is eliminated or substantially reduced [18-20]. Moreover, the stabilized wastes may improve the geotechnical properties to enable their utilization in construction applications, such as engineering fill, road or pavement subgrade, backfill, and base material.

Some of clayey sand contaminated soils, treated with only lime may attain poor geotechnical and environmental properties and may not meet the requirements for reuse in construction applications. That is mainly attributed to the limited pozzolanic surface area that is available for cementing reactions. Thus, fly ash can be added to such wastes in order to increase the available pozzolanic surface area, and hence improve one or all of the strength properties of the stabilized waste soils

According to [15], he reported that the improvement of the strength properties of residual clay using fly ash as sole additive. However, he further observed that the additional of a small amount of lime in fly ash-soil mixtures further improved the strength of the stabilized soil. Subsequently, many authors have indicated the use of fly ash as an additive in lime soil mixtures to achieve better strength of the mixture. Nevertheless, there exist about little literature describing the use of fly ash and lime to immobilize and to treat the contaminated waste soils.

Fly ash is regularly used as a partial replacement for cement in treatment of waste soils because of its pozzolanic properties. It is also the form of ash, which has the greatest potential for use in ground modification [1]. Increased use as a partial cement or lime replacement would also represent a savings in energy (fly ash has been called a high-energy waste material).

Overall, the main study objectives are: to investigate the potential for reuse of the treatment final product as readily available construction material, strength test was the main tool used towards a preliminary evaluation of reuse potential. Unconfined compressive strength of stabilized soil with different curing time is tested as indicator for the evaluation effect of the heavy metals on clayey sand soils stabilized using fly ash.

II. MATERIAL AND EXPERMINTAL PROGRAM

Clay–sand mixes, artificially contaminated using heavy metal, were dry mixed with fixed percentage of lime. For the artificial soil mixes, kaolinite clay was used with fine quartz. The physical properties and chemical composition of investigated soil is shown in Table (1).

Fly ash, a nonlayered iron aluminosilicate was added into the contaminated soils to improve their physico-chemical behaviour. The mechanical and physico-chemical behaviour of the compacted specimens, as determined during testing, formed the basis for evaluating both the degree of immobilization of the heavy metal contaminants and the reuse potential of the treated waste form.

Hydrated lime $Ca(OH)_2$ was one of the chemical stabilizer in this research. It was obtained in the powder form. To ensure the proportionate of chemical composition, the lime used in this research was kept in a high temperature oven to inhibit the gradual agglomeration of particles. The chemical composition of the hydrated lime is shown in Table 2.

TABLE 1. THE PHYSICAL PROPERTIES AND CHEMICAL COMPOSITION FOR SELECTED SOIL

ENGINEERING &Physical Properties(Kaolin)	VALUES	Chemical Composition Oxides	VALUES
CEC (meq/100 g)	12.87	SiO2	48.18
pH (L/S = 2.5)	4.34	Al2O3	31.10
Specific Gravity	2.65	Fe2O3	1.03
Liquid Limit, LL (%)	37	K2O	4.01
Plastic Limit, PL (%)	20	SO3	2.07
Plasticity Index, PI	17	CO2	1.34
(%)BS Classification	CI	Soluble aluminum (Al)	5.80ppm
ICL (%)	3	Solluble silica (SiO2)	4.00ppm
Maximum dry density (Mg/m3)	1.48	Soluble calcium (Ca)	0.4ppm
Optimum moisture content (%)	24.3		
Unconfined compressive strength (kPa)	150		

Due to lack of aluminates and silicates in the granular material, pozzolanic reactions may did not occur in these soils and thus lime will often achieve poor geotechnical and environmental properties and may not meet the requirements for reuse in construction applications. On the other hand, the presence of contaminates may lead to inhibit the geotechnical properties of soils. Thus for that, another additive stabilizer has been used in this study like Fly ash to increase the available pozzolanic surface area, and hence improve the strength, workability, and heavy metal leachability. As reported by [12], [9], and [4], fly ash possesses artificial pozzolans, which upon reaction with lime result in significant development of strength through cementation. Moreover, it should be noted that fly ash is by itself considered a waste. Thus, adding fly ash to treat contaminated areas would be a cost-effective method of disposing of it. It would provide economic benefits by reducing disposal costs and mitigating possible negative environmental effects, originating in either the fly ash or the solid waste, through proper engineering control [6].

Fly ash is defined as ‘‘the finely divided residue resulting from the combustion of ground or powdered coal which is transported from the firebox through the boiler by flue gases; known in UK as pulverized fuel ash (pfa)’’ (ACI Committee 226, 1987). In this research, combustion of subbituminous coal produces a fly ash (fly ash class C) has been used. This type is rich in calcium, with self-cementing characteristics, which has been successfully used in a wide range of construction applications [8]. The chemical composition of a fly ash presents in Table 3 below.

The reagents that were added to emulate inorganic metal contamination, chromium nitrate ($Cr(NO_3)_3$) and PbO ,were used as the pollutant sources for Cr^{3+} and Pb^{2+}, respectively.

TABLE 2. CHEMICAL ANALYSIS OF HYDRATED LIME

Chemical Composition	Values (%)
CaO	74.1
Al_2O_3	0.11
SiO_2	0.4
MgO	0.74
Fe_2O3	0.17
$CaSO_4$	0.12

TABLE 3. CHEMICAL ANALYSIS OF FLY ASH

Chemical Composition	Values (%)
SiO_2	10.7
Al_2O_3	5
Fe_2O_3	16
CaO	40.2
MgO	24.7
SiO_3	3.4
Total	100

III. PREPARATION OF SPECIMENS

This study was conducted using artificial soil specimens composed of clay and fine sand were prepared and used for the stabilization/solidification experiments. The heavy metals contents in the artificial soils were (5000 mg/kg and 650 mg/kg) of each of $Cr(NO_3)_3$ and PbO respectively.

Due to the limitation of the selected appropriate contents of the stabilizers to improve contaminated soil, it had been depended on the previous studies conducted regarding the stabilizer content which are required for modification and pozzolanic reaction as reported by [7], [13], [10], [17]. Thus, depending on the suitable percentages of stabilizers for pozzalanic reaction and for reducing the cost, it was selected 5% as the appropriate content for lime as a fixed content.

It should be noted that the amount and proportions of the lime and fly ash admixtures for stabilize contaminated soils are governed by the desired strength amount, and also depend on the types of lime and fly ash, the economy, and the minerology of the soils[14].

Fly ash was used in percentages of 5, 10 and 15 while the lime contents were used in percentage of 5 only. The required quantities of samples were prepared from air-dried soil, broken into smaller sizes, and sieved through a 2 mm sieve. Sieving was done to ensure that the soil was of uniformed grade. Index property tests of the selected soils without any treatment and contaminants were carried out to characterize the soils. Index tests include atterberg limit test, specific gravity, and grain size analysis.

The time-dependent effects of the lime-fly ash stabilized soils were determined. When heavy metals were added to the mixtures, the optimum water contents of the respective uncontaminated sample were used, thus allowing for direct comparison of the effects of contaminant. The BS 1377: Part 4: 1990 (clause 3.3.4.1)[2] was used to determine the compaction characteristics, which was achieved by compacting the soil in three equal layers into a 1 L Proctor mould by applying 27 blows of 2.5 kg rammer dropping from the controlled height of 300 mm. The moisture-density relationship curve was plotted for the soil with the two stabilizers of various content to investigate the effect of stabilizer on the compaction parameters for clay soil. Finally, after compacting the soil into standard mold (38 mm diameter × 76 mm length) under constant compactive effort as specified in BS1924: Part2 1990 (clause 4.1.5)[3], the sample was removed by using hydraulic jack. Then, they were wrapped with thin plastic film and placed in a plastic container with a tight lid to prevent any lost of moisture during the curing time. It should be noted that all labware and sampling apparatus were pre-soaked in 5% nitric acid solution followed by distilled water for a day prior to sampling to remove trace concentrations of metals. The samples were then stored in a room at a controlled temperature (27±2°C) until the requisite time for testing at each of the five curing periods, i.e., 7 days, 14 days, 28 days, 100 days, and 200 days. The curing condition is also thought to effectually in the case of contaminated samples to evaluate the effect of these contaminants on the soil characteristics for the short and long term.

IV. RESULTS AND DISCUSSION

Due to the slow reaction of lime absorption, the development of compressive strength of a soil, lime and fly ash mixture is slow. Therefore, the rate of development of compressive strength of lime-fly ash reaction is directly related to the rate of lime absorption by the fly ash as reported by [11]. The rate of lime absorption is limited by the rate of diffusion of the calcium through the reaction product. Al ansary, 2006[1] found that the coarser the material to the stabilized with lime and fly ash, the higher the volume of fly ash that is required.

A. *Strength Properties*

Figures 1 and 2 show the compressive development for the contaminated clay –sand soils. It can see as shown in Figure 1, the compressive strength of contaminated soils with 0% lime and different percentages of fly ash (5%C, 10%C, and 15%C) possesses a development in the strength. It can observe that this strength enhancement increase with increasing the fly ash content and with the time progressing. Thus, the time factor can be considered an effective parameter for strength improvement in the contaminated soils [16]. However, as shown in Figure 2 when treated with 5% lime and as a comparison with no lime Figure 1, it can indicate increasing the enhancement in the strength values upon lime addition to be 3250 kPa at 200 day. This indication is related to the fact that fly ash class C in the presence of lime is a superior strength enhancement agent especially for weak soils [6]. Over all, the lime-fly ash treatment resulted increasing in the strength values aboutt more than 1000 times higher than values those measured for the untreated soil.

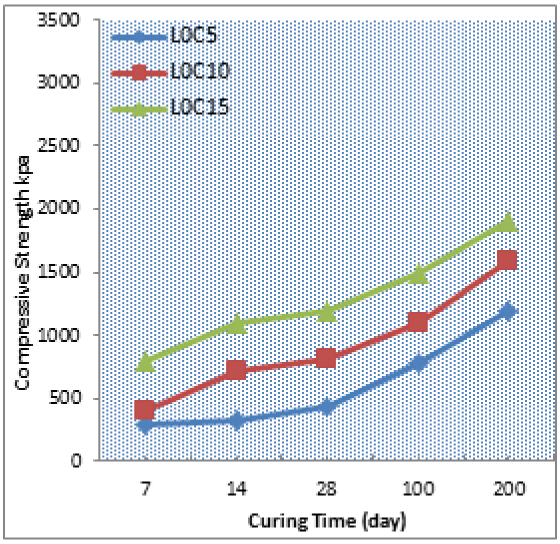

FIGURE 1. UNCONFINED COMPRESSIVE STRENGTH OF 0% LIME-FLY ASH C TREATED CONTAMINATED SOILS

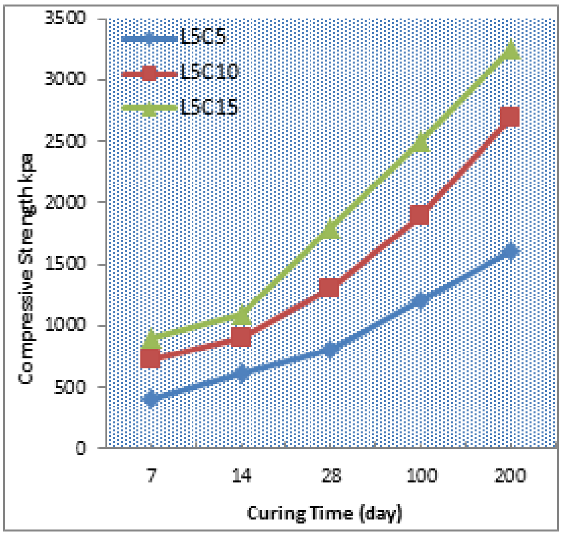

FIGURE 2. UNCONFINED COMPRESSIVE STRENGTH OF 5% LIME-FLY ASH C TREATED CONTAMINATED SOILS

B. Microstructural Properties

The Figure 3 shows the X-ray diffraction analyses of (L5C15) samples for 7, 100, 200 days. The test was carried to indicate the mineralogy and pozzolanic reactions. At 100 and 200 days, the formation of Gismondine (CASH) was observed, as the result of reactions between portlandite and the soil mixture. These findings agreed with [10] and [16]. This compound was responsible on cementious the matrix of heavy metal-soils. As time progressed, the alkaline environment responsible for pozzolanic reactions ensured an increased dissolution of silica and alumina. Thus, the pozzolanic reaction continued to produce CASH, which then increased the strength of lime with fly ash. Furthermore, the presence of portlandite at 7day was responsible on strength development in this period.

To observe effects from lime and fly ash on the microstructure and morphology of these samples, it was employed Scanning Electron Microscope (SEM) to visually examine hydration products and micro-structural changes in the matrix of lime-fly ash-heavy metals matrix.

Figure 4a shows the micrographs of sample (L0C15) at 7 days. Figures 4b, c, d show the morphology textures for fly ash stabilized contaminated soils with presence of lime at 7,100, and 200 days curing time. As comparison with Figure 4a (no lime), L5C15 samples at 7day show insignificant modification in the texture of the matrix. Little flocculation was detected with small signs of $Ca(OH)_2$ as dedicated by X-ray diffraction. However, by 100 and 200 days, crystalline formations and the fabric's texture of the lime-fly ash stabilized matrix had developed, recognized by the formation of white lumps. These changes were attributed to the progression of lime's production of calcium alumina silicate hydrates

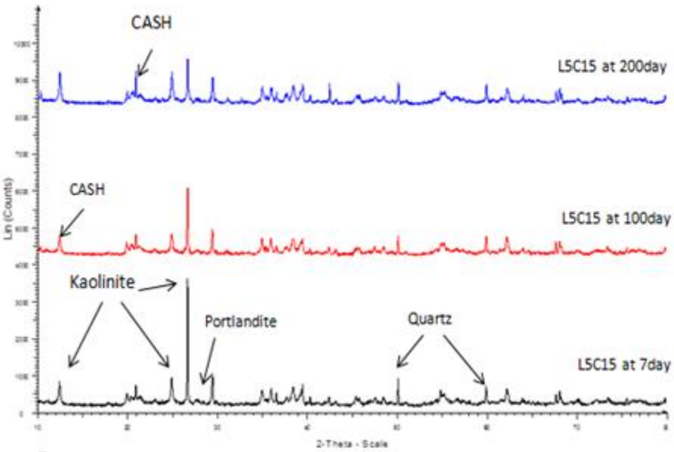

FIGURE 3. X-RAY DIFFRACTION OF 5% LIME-15% FLY ASH C TREATED CONTAMINATED CLAY-SAND SOILS AT 7, 100, AND 200DAYS

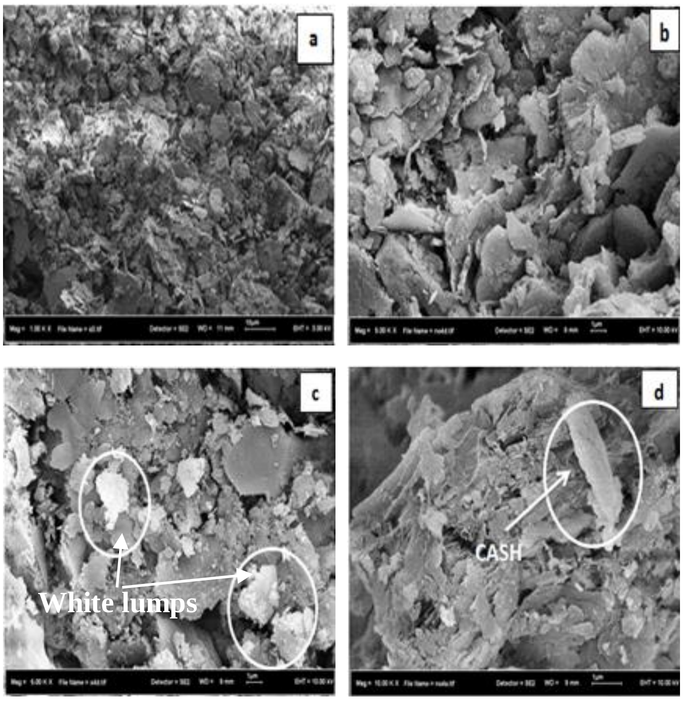

FIGURE 4. SEM MICROGRAPHS OF A (L0C15-7DAYS), B(L5C15-7DAYS), C(L5C15-100DAYS) AND D(L5C15-200DAYS)

V. CONCLUSIONS AND RECOMINDATIONS

In recent years and due to the progressing in industrial constrictions, these lead to increase the percentage of weak soils contaminated by industrial wastes and heavy metals. Therefore, there is a need to increase the use of fly ash and other industrial by-products in order to avoid increasing disposal costs. Due to their pozzolanic nature, fly ash and other waste products, can be effectively used in a variety of construction applications. In this research, it was indicated that the addition of fly ash with the presence of lime S/S treatment of heavy metal contaminated soils is mainly responsible for their effective immobilization.

Fly ash addition also results in significant improvement of the strength properties of the treated solids, therefore enabling their reuse in construction applications. Furthermore, it was observed that the enhancement in the strength with presence lime-fly ash increasing with the progressing in curing time. This was attributed to the formation pozzolanic cementious CASH (Gismondine) with the long term of time. This compound was responsible on the cementious the lime-fly ash-heavy metals-soil matrix and then lead to enhancement in the strength of this matrix.

As recommendation, additional research should be carried to evaluate the efficiency of lime-fly ash to prevent the leaching of heavy metals. However, one more study has been planned to assess the immobilization of both lead and chromium.

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