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Reclamation of Heavy metal Contaminated kaolinitic soil by OPC-FA Immobilization

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Abstract—The reclamation of contaminated soils from domestic or industrial waste have been found to be cost demanding and involves further treatment requirements. The migration of potential contaminants from generated leachate is reduced by stabilization approaches involving the incorporation of cement-based hardeners. Samples of natural kaolinitic soil contaminated by heavy metals from landfill domestic waste and stabilized by the addition of commercially available cement blended Fly ash (FA) in comparison to plain Ordinary Portland cement (OPC) in varying proportions were tested. The influence of immobilization of the kaolinitic soil on the density, unconfined compressive strength (UCS) and the leachability of heavy metals were investigated. There was clear indication that the use of blended OPC-FA as hardeners reduced the density and UCS of the samples and was more efficient in the reduction of the leachability of heavy metals contaminated kaolinitic soils than plain OPC.

Index Terms— Leachability, Stabilization, kaolinitic, Fly ash, Heavy metals, Unconfined compressive strength.

1 Introduction

The insistent and rapid industrialization of developing countries calls for the need to effectively dispose and manage generated wastes. Most domestic and industrial wastes are hazardous and capable of having consequential impacts on surrounding soil and ground water resources if not properly disposed off. These wastes generated at landfills contribute to the increased amounts of migrating contaminants into the environment. Improperly disposed wastes are known to pose severe health, environmental and aesthetic challenges [1]. These waste materials as recorded by [2] are often disposed together with non-hazardous waste in landfills not designed to handle hazardous wastes. Soil and ground water contamination by domestic and industrial waste is reported to be one of the major challenges of environmental pollution. Industrial activities have left vast land contaminated by chemicals unusable for future use. Due to need for uncontaminated fields or 'green areas', various reclamation methods of contaminated sites to facilitate sustainable industrial development are been harnessed. Methods such as; stabilization, soil washing, hardening or immobilization etc., are acceptable techniques for curtailing soil and ground water contamination by migrating contaminants from waste deposition. Amidst the numerous soil remediation methods in use, [3] stated that the stabilization hardening method appears the most effective due to its binding ability (i.e., stabilization) or entrapping of waste within a solid cementitious matrix. Stabilization is defined as those methods reducing contamination potentials of waste by transforming the contaminants into their least soluble, mobile or toxic form [4]. However, the physical nature and handling characteristics of the waste are not necessarily affected by stabilization. Solidification refers to techniques that encapsulate the waste in a monolithic solid of high structural integrity. Solidification thus alters the physical properties of a contaminated substance. Expected changes could include: increased strength, decreased permeability and retention of migrating hazardous contaminant species [4]. Encapsulation may be of fine waste particles (micro-encapsulation) or of a bolder block or container of waste (macro-encapsulation). Solidification does not necessarily involve a chemical interaction between the waste and the solidifying reagents but may mechanically bind the waste monolithically. Contaminant migration (i.e., leaching) is restricted by decreasing the surface area exposed to leaching and/or by isolating the waste within an impervious stratum. Flowing or runoffs cannot displace the chemicals as it moves through hardened treated soil. As such in this study, the influence of immobilization of kaolinitic soil on the density, unconfined compressive strength (UCS) and the leachability of heavy metals were investigated. Samples of natural kaolinitic soil contaminated by heavy metals from landfill domestic waste and stabilized by the addition of available cement blended Fly ash (FA) in comparison to plain Ordinary Portland cement (OPC) in varying proportions were tested.

2 Experimental Procedure

Samples of kaolinitic soil were collected around a landfill in Johannesburg city, South Africa and were mechanically and chemically tested. The soil sampling area is shown in figure 1. Leachate contaminants generated from the decomposition of solid wastes, waste with high moisture content, entrapment of surface or runoffs in landfill buried waste bodies were collected from the leachate basins designed to hold such contaminants as seen in figure 2.

Fig. 1. Pictorial view of sampling vicinity

Soil layers compacted to 225mm thickness in a laboratory test model setup was used in the leachability sessions. The modeled device, a Modular-leaching column with 160mm diameter is attached is made of anodized material resistant to aggressive chemical attacks and scratches. A view of the model device is shown in figure 3. The model consists of two parts: (i) the bottom part called the leachaing bucket; which contained the plain and stabilized soil compacted in layers as shown in figure 4., and (ii) the upper portion above the leaching bucket whiched functioned as the leachate/contaminant reservoir as seen in figure 5. The leachate reservoir was marked to hold a constant head of 250mm through-out the tests duration.

Fig. 2. Contaminants collected from an engineered basin

Soil layers were prepared inside the bottom chamber. Wetted geotextile on a porous stone served as filter to prevent clogging the outlet of the device. After the components were assembled, O-rings, gasket corks and silicon sealants were used to ensure proper fastening between the top and bottom parts of the device. The leachate was added and the setup was monitored over the respective durations.

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Fig. 3. Modular-leaching column device

The hydraulic conductivity, k_z value, was calculated and used to determine the flow rate, Q. Consequently, the effluent and samples collected from six sectioned cores of the leaching layer were tested and measured for concentration of targeted source ions in pore water using pulverized pore fluid extraction method. The analyses were conducted using the 902 Double Beam Atomic Absorption Spectrophotometry in line with [5].

(a) (b)

Fig. 4. (a) Wetted geotextile on porous stone to prevent clogging (b) Layers of treated soil compacted in the leaching bucket

The grain size distribution curve for the kaolinitic soil used in the investigation is shown in figure 6 while water content-dry unit weight relationship was determined by compaction test in accordance with [6].

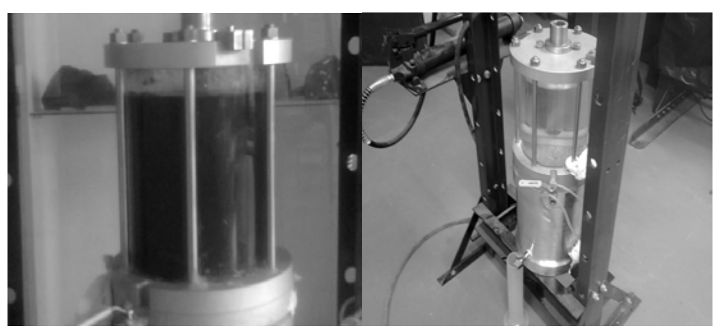

Fig. 5. (a) Leachate reservoir with de-ionized water and actual leachate contaminant

The test yielded optimum water content and maximum dry unit weight of about 15.7% and 17.4kN/m^3 respectively. The compaction curve is shown in figure 7. The standard proctor compaction test was done using a light rammer with selfweight of about 0.0244kN and striking effort of about 595kN-m/m³

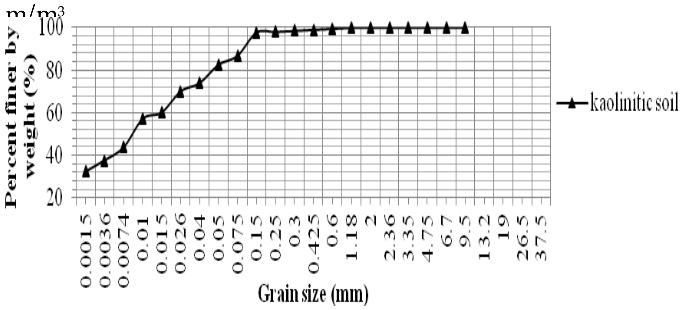

Fig. 6. Grain size distribution curve for the soil

Values for permeability coefficient were measured by falling head test in accordance with [7] as seen figure 8 was obtained at MDD and OMC.

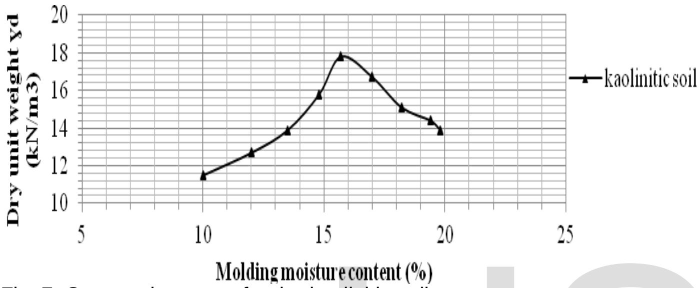

Fig. 7. Compaction curve for the kaolinitic soil

The contaminant ions were measured by full spectral analysis method on the influent and effluent and compared to standard drinking water. The parameters analyzed from heavy metal contamination included the following: Fe and Pb. This was conducted in conformance to [8], [9].

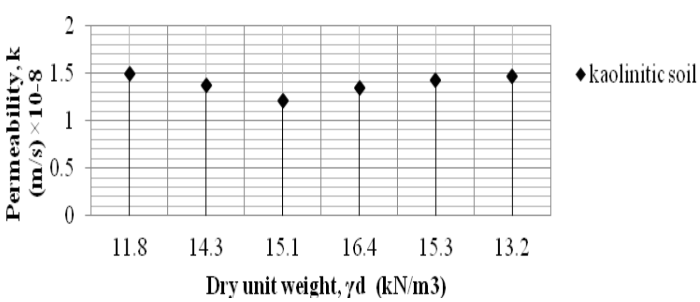

Fig. 8. Permeability variation of the kaolinitic soil sample

Table 1 shows the initial concentrations (mg/l) of the targeted chemical parameters/ions from chemical analyses for the leachate while Table 2 shows the chemical composition of the locally available FA collected from a power plant in South Africa.

TABLE 1
ANALYSIS OF LEACHING TEST PERMEATE

Parameter	ASTM Test No.	Concentration of sample (mg/l)	Standard for Drinking Water (mg/l)*
Fe	D 1068	6.0	15
Pb	D 3551	1.2	0.05

Type I OPC blended with an adequate percentage of FA served as the binder for the hardening stabilization treatment.

TABLE 2
CONSTITUENT OF FA

	SiO_2	AL_2O_3	Fe_2O_3	MnO	MgO	CaO
FA	83.0	8.00	2.65	0.55	0.22	0.18
	Na_2O	K_2O	TiO_2	P_2O_5	Cr_2O_3	NiO
FA	0.04	0.00	0.2600	0.400	0.0050	0.0000

3 Result and Discussion

3.1 Effect of OPC-FA contaminant flow-time relationship

The test herein was for the sample collected around the landfill site. The leachate contaminant passage rate was measured and the concentration of the migrated heavy metals through the layer of compacted soil was determined to investigate the effect of soil stabilization treatment on the prevention of contaminant migration. The contaminant flow rate-time relationship is shown in figure 9.

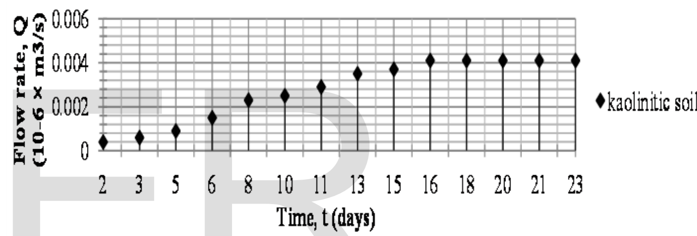

Fig. 9. Contaminant flow against time for kaolinitic soil

The flow rate was observed to reach a steady state 20days into the leaching test. The contaminant passge rate was monitored over a 30day period and the changes were recorded. It was discovered that in the samples treated with OPC-FA, the flow through the system was slower and such a lesser contaminant passage was revealed. Thus, the stabilized hardened specimens behaved better than the plain samples.

3.2 Effect of moisture on strength properties (UCS)

The UCS test results obtained for the kaolinitic soil-binder mixtures are presented in figure 10. This was for the purpose of selecting an optimal FA-moisture content proportion.

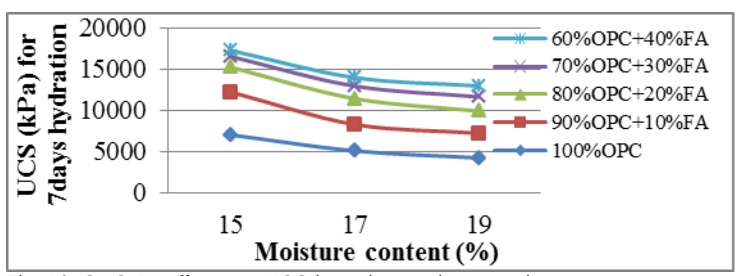

Fig. 10. OPC-FA effects on UCS based on optimum moisture content

It can bee seen that the plain OPC (control) specimens had the lowest UCS values across the different moisture variations.

The 60%OPC-40%FA was found to have the best outcome across the moisture variations. However, UCS values for the entire samples regardless of percentage binder variations were noticed to decrease as the moisture content increased. This can be best explained such that the higher moisture contents lead to a loss in the minding materials across the samples. The development of strength with increased FA replacements can be associated with the pozzolanic tendencies of the FA. It can also be observed that the optimum moisture content required to achieve the highest UCS value across the entire replacements falls to 15%.

3.3 Effect of stabilization on density

The results of the tested stabilizer variations and its effect on the 28days density of the Fe contaminated and uncontaminanted samples are shown in figure 11. It can be seen that the density of the respective samples for all stabilizer ratios increased with increasing stabiler contents.

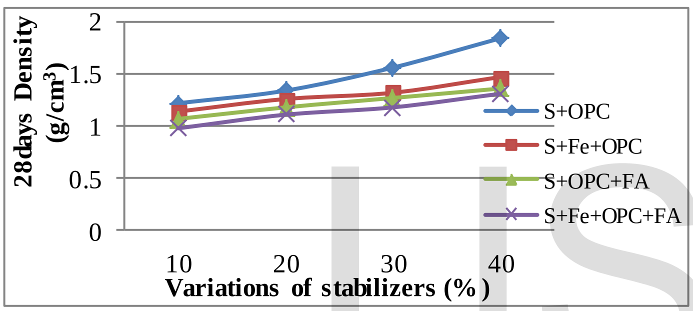

Fig. 11. Stabilizing effects on density based on Fe contamination

The control specimen (S+OPC) was found to have the highest sample density. The Fe ion contaminated soil from the leaching test having OPC-FA binders showed the least density. The reduced densities can be associated with the low specific weights of FA and the consequent Fe contamination effects on the samples.

3.4 Effect of stabilization on strength properties (UCS)

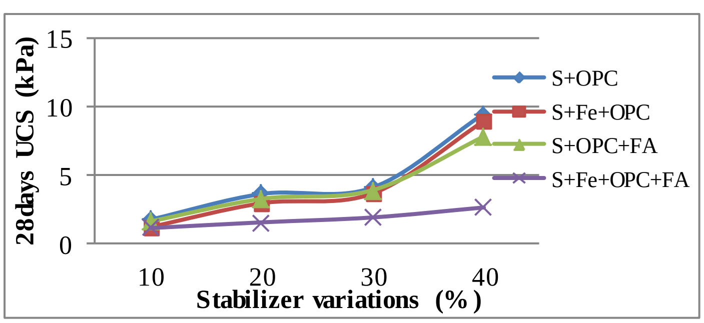

Fig. 12. Stabilizing effects on density based on Fe contamination

From figure 12 the control sample had the highest UCS property across the entire binder variations as expected. The lowest strength however, was gotten for samples contaminated by heavy metal from the municipal landfill leachate. It was noticed that at the 28day curing period, an increase in stabilizer resulted in an increase in the UCS of the different samples.

4 Conclusion

Immobilization of kaolinitic soil on the density, unconfined compressive strength (UCS) and the leachability of heavy metals were investigated. Samples of natural kaolinitic soil contaminated by heavy metals from landfill domestic waste and stabilized by the addition of available cement blended Fly ash (FA) in comparison to plain Ordinary Portland cement (OPC) in varying proportions were tested. The following conclusions were then arrived at;

The OPC alone as binder performed better than the blended OPC-FA. However, permeability of the treated mixtures experienced slight changes when variations of blended OPC-FA were used.

Blends of OPC-FA used as binder performed better than plain OPC as with regard to Fe contaminant reduction.

Optimum moisture contents of 15% and 60%OPC-40%FA ratios were found as the best matrix for immobilizing contaminated kaolinitic soils.

The stabilization hardening treatment approach was found to reasonably meet the UCS, density and leachability requirements for reclaiming soil contaminated by heavy metals from landfill leachates in conformance with EPA Standards [10].

Acknowledgment

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