Solidification/Stabilization (S/S) of Lead Contaminated Soil

Athira Sindhu Manikantan[1], Rani V[2]

[1]*Mtech: Geotechnical Engineering, Dept of Civil Engineering, Marian Engineering College, Kerala, India*
[2]*Associate Professor, Dept of Civil Engineering, Marian Engineering College, Trivandrum, India*

Abstract - *An Heavy metal contamination in soils is widespread in India as well as other parts of the world .These heavy metals generate leachate during leaching process causing the soil and ground water contamination during its interaction with the both. This is not only harmful for the subsurface water aquifers but also for structures existing on it. Unlike organic compounds that can be destroyed, heavy metals can only be covered, isolated, removed and recycled, moved to a safer location, or transformed into a less toxic form.*

Solidification/stabilization (S/S) is an effective technique for reducing the leachability of these contaminants in soils. In this technique the migration of potential contaminants from generated leachate is reduced by the incorporation of various amendments which isolates the waste within a solid cementitious matrix. In the present study high plastic clay was artificially contaminated using Lead Acetate at different concentration and an attempt is made to remediate it using a mixture of Class F fly ash and OPC. The impact of the treatment was evaluated by means of compressibility, plasticity tests and toxicity characteristic leaching procedure (TCLP).

***Key Words*: Stabilization/solidification, TCLP, Heavy metal remediation, Lead contamination**

1. INTRODUCTION

The engineering and index properties of soil are affected by past land use, current activities on the site and nearness to pollution sources. The insistent and rapid industrialization of developing countries calls for the need to effectively dispose and manage generated wastes. Every year the solid wastes dumped into the soil are increasing at an alarming rate all over the world. The problem of soil pollution is compounded by the use of agrochemicals like pesticides, fungicides, bactericides, insecticides, fertilizers etc. The soil pollution differs from air and water pollution in the sense that the pollutants in soil remain in direct contact with the soil for relatively longer periods and different pollutants in their tendency to end up in water held in the soil or in the underlying groundwater, volatilize into the air or bind tightly to the soil. Among these contaminants heavy metals in the industrial waste constitute a major group of inorganic chemical hazards. These contaminants affects the soil mineralogy and clay content and also causes alterations in soil properties like pH, swell shrink behaviour, permeability, shear strength and compressibility.

With greater public awareness of the implications of heavy metal contaminated soils on human and animal health and due to need for uncontaminated fields or 'green areas' there has been increasing interest amongst the scientific community in the development of technologies to remediate contaminated sites and facilitate sustainable industrial development. Amidst the numerous soil remediation methods in use, stated that soil immobilization or stabilization /solidification (S/S) appears the most effective due to its binding ability or entrapping of waste within a solid cementitious matrix and cost effectiveness. In the present study high plastic clay is artificially contaminated using Lead Acetate and then an attempt is made to immobilize the soil using a mixture of Flyash and OPC. The variation in geotechnical properties due to contaminant addition and amendment addition to the contaminated soil is studied.

2. MATERIALS AND METHODS

2.1 High Plastic Clay

Calcium bentonite used in this study was procured from a quarry near Coimbatore in Tamilnadu. The properties of the samples are presented in Table I. The soil sample was artificially contaminated by mixing it with different molarity of lead acetate solution. The SEM image of Ca Bentonite Clay is shown in Fig 1.

Table -1: Properties of Calcium Bentonite Clay

Soil Properties	Values Obtained
Specific Gravity	2.26
Liquid limit (%)	110
Plastic limit (%)	46
Plasticity index (%)	64
IS classification	CH
OMC (%)	19.38
Dry density(g/cc)	1.46
% clay	77.5
% silt	16.2
% sand	6.3
UCC strength (kN/m^2)	92.33
Free swell index	6.27

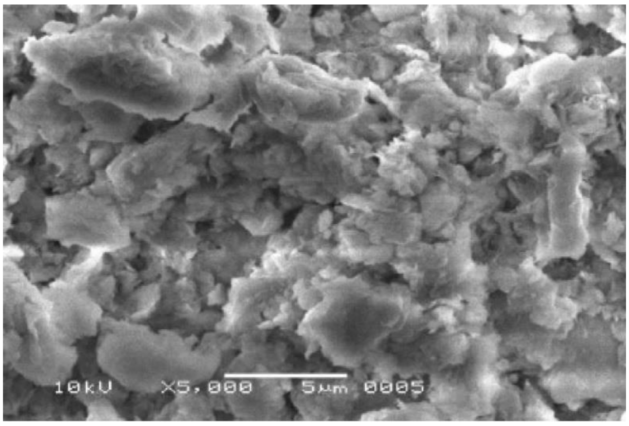

Fig -1: SEM Analysis of Ca Bentonite Clay

2.2 Flyash

Flyash also known pulverized fuel ash is one of the coal combustion products composed of finer particles driven out of the boiler with the flue gases. Fly ash used in this study is class F fly ash which was purchased from thermal power plant in Thoothukudi. The chemical and physical properties of fly ash are presented in Table 2 and 3. In order to immobilize the artificially contaminated soil, optimum dosage of flyash was found out carrying out compaction and compressibility tests. The SEM image of flyash is shown in Fig 2. The optimum flyash – OPC mixture is added only to the artificially lead contaminate soil and the variations in properties are studied.

Table -2: Chemical Properties of Flyash

Composition	Percentages
SiO_2	57.5
Al_2O_3	33
Fe_2O_3	4.8
TiO_2	1.4
CaO	0.5
MgO	0.2
Na_2O	0.2
K_2O	0.4
Loss on Ignition (% Max)	1.5

Table -3: Physical Properties of Flyash

Soil Properties	Flyash
Specific Gravity	2.18
Liquid limit(%)	28.3
Plastic limit(%)	Non Plastic
Plasticity index(%)	Non Plastic
% clay	16.25
% silt	29.75
% sand	46
Uniformity coefficient(Cu)	6.31
Coefficient of curvature(Cc)	1.383
IS classification	SM
OMC(%)	31.3
Dry density(g/cc)	1.16
pH	10.9
Coefficient of Permeability (cm/sec)	$2.79 * 10^{-5}$
UCC strength (kN/m²)	92.33
Angle of internal friction (º)	34
Class of Flyash (ASTM C618)	F

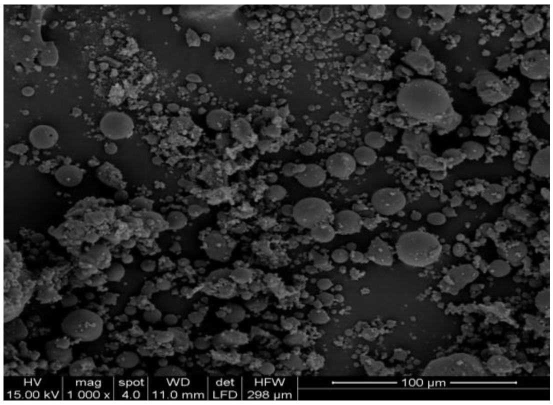

Fig -2: SEM Analysis of Flyash

2.3 Cement

Since the fly ash is class F it has pozzolanic properties, but little or no cementitious properties. Therefore small percentage of OPC 43 grade cement is added for soil modification and to provide the fly ash cementitious property. Hence the percentage of OPC is fixed as 3%.

2.4 Heavy metal Solution

In this investigation, [$(CH_3COO)_2Pb.3H_2O$] Lead acetate salt of analytical reagent grade was used for preparing different concentrations (molarity) of lead solutions for artificially contaminating the soil. Lead ranks fifth behind Fe, Cu, Al and Zn in industrial production of metals. It is highly toxic for human and animals. EPA defines a soil lead regulatory limit as 500 ppm in the residential and 1200 ppm in industrial areas.

2.5 Immobilization of contaminated soil

Soil stabilization/solidification (S/S) appears the most effective due to its binding ability. The waste material is converted into solid forms via entrapping within a monolithic matrix by adding appropriate reagents. This technique involves a combined application of the solidification and stabilization process and thus ensures the mixing of the contaminated waste materials with the treatment agents, and consequently, both the physical and chemical immobilization of the hazardous components occurs. This technique is a non- destructive approach to eradicate or inhibit the mobility of contaminants in the waste materials (US EPA 1999). It has been evaluated that the average operational time for the S/S projects was shorter (~1.1 months) than many other approaches (e.g. soil vapour extraction, land treatment and composting) and cost effective with an average cost per cubic yard between USD 194 to 264 (US EPA 2000),i.e. approximately 13000 to 17500 rupees. In the present study mixture of Fly ash - OPC are being used to immobilize the contaminated soil. For

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056
Volume: 04 Issue: 05 | May -2017 www.irjet.net p-ISSN: 2395-0072

ensuring the effectiveness of this method USEPA have provided various criteria's to be fulfilled as listed in table 4..

Table -4: Typical Solidification/Stabilization Criteria for Soils (USEPA)

Parameter	Units	Average Value
Unconfined Compressive Strength	Pounds per Square Inch	>50
Hydraulic Conductivity	cm/s	$< 10^{-8}$
Hydraulic Conductivity (stabilized waste destined for land burial)	cm/s	$<10^{-5}$
Atterberg Limits (Morgan et al., 1984) Plastic Limit	%	20 – 50
TCLP (US EPA, 1986)	mg/L	<= Regulatory Limit

3. MATERIALS AND METHODS

3.1 Optimum Percentage Of Amendment On High Plastic Clay

In the present study a mixture of Fly ash - OPC is used to immobilize the heavy metal contaminated soil. Since the fly ash is class F it has pozzolanic properties and to provide it more effective cementitious property OPC is added and the percentage of OPC is fixed as 3%. Compaction and UCC test is carried out on soil mixed with varying percentages of flyash (10%, 20%, 30%, 40%, 50%) and the optimum percentage of fly ash is found out from the test results. Variation in Dry Density, OMC is shown in Table 5. The graphical representation of variation in UCC strength with the addition of varying percentage of flyash is shown in Chart 1.

Table -5: Variation in Dry Density and OMC with the Addition of Varying Percentage of Fly Ash

Flyash (%)	0	10	20	30	40	50
γ_d (g/cc)	1.46	1.42	1.38	1.3	1.25	1.25
OMC	19.38	21	22.1	24	25.3	26.1

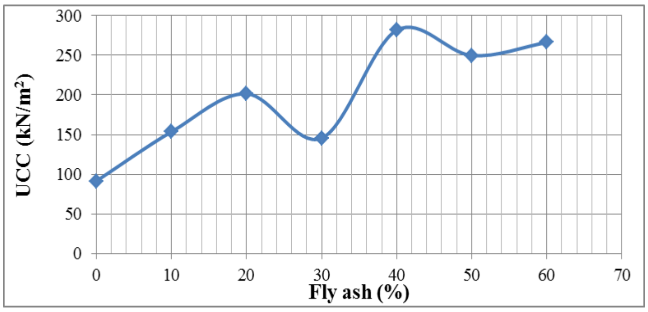

Chart-1: Variation in UCC With the Addition of Varying Percentage of Fly Ash

The decrease in dry density may be because of the lower dry density of fly ash compared to the kaolinite clay and the higher OMC maybe due to the poor grain size distribution and the presence of large and hollow cenospheres in fly ash (Fig 2) which increases its water holding capacity and the increase in UCC may be attributed to the better bonding of clay particles by fly ash. A slight reduction in strength with the addition of 30% flyash is observed this may be because the free lime available in fly ash may be taken by bentonite for its cationic reactions and hence is not available for pozzolanic reactions for fly ash. From the compaction and UCC result the optimum percentage of flyash for CH is 40%. The addition of cement above 5% does not contribute to strength (Ahmet et al., 2005), as the mixture does not contain all the elements for cementation. Therefore 3% OPC is added to the fly ash to provide it cementitious property. The compaction curve of the CH mixed with 40% fly ash- 3% cement is shown in Chart 2.

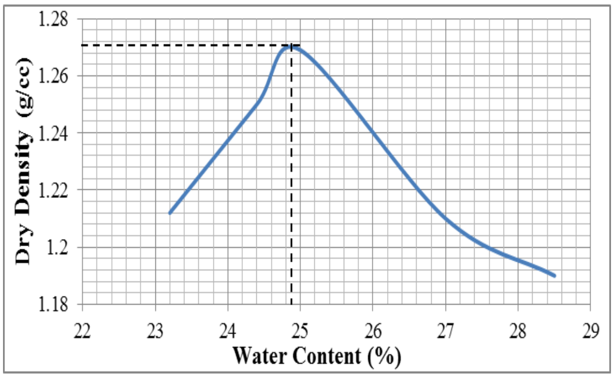

Chart-2: Compaction Curve of Bentonite + Optimum Mix

3.2 Effect of Amendment on Contaminated Clay

3.2.1 Effect of amendment on Plastic Limit

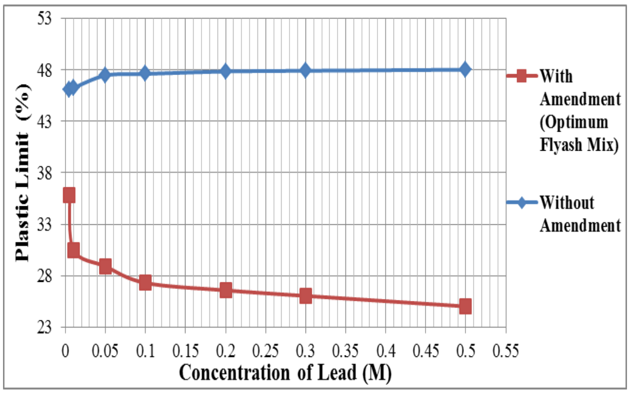

Chart-3: Variation of Plastic Limit on Contaminated CH Clay Due to Addition of Amendment

From Chart 3, it can be seen that the Plastic limit increases slightly with increasing lead concentration for CH clay and after the addition of amendments the value decreases which is a positive trend. This may be because of the effect of pH, in the presence of metal ion the soil has a slightly acidic pH which caused an increase in plasticity index but by the addition of fly ash and cement of alkaline nature the pH was almost neutral which made the soil structure stable. Also the

Si^{4+} and Al^{3+} in the fly ash might have replaced the metal ions in double layer hence reducing the double layer thickness and thus reducing the plastic limit and plasticity index. The plastic limit of most of the samples satisfies the typical Solidification/Stabilization Criteria for soils (USEPA, 1989) (Table 4) and hence remediation is effective.

3.2.2 Effect of amendment on Unconfined Compressive Strength

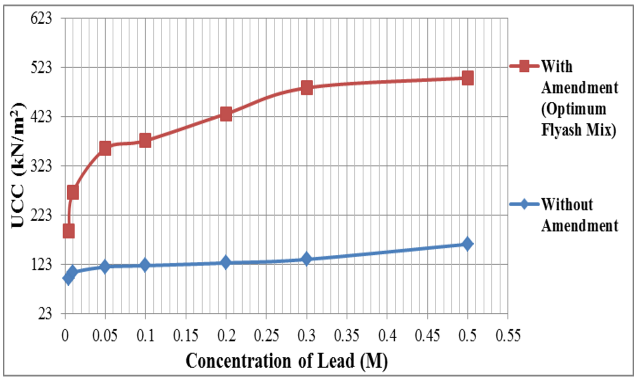

Chart-4: Variation of UCC on Contaminated CH Clay Due to Addition of Amendment

From Chart 4, it can be seen that the unconfined compressive strength value increases with increasing lead concentration for CH clay, since the amount of lead adsorbed in clayey soils increases with increase in lead concentration to certain extent and this adsorption of lead in clayey soils tends to reduce the thickness of diffused double layer and thus causes flocculation and thereby increased the unconfined compressive strength. The value further increased with the addition of fly ash to the contaminated soil. This increase is strength is mainly due to the pozzolanic nature of flyash and cementitious nature of OPC which caused a better bonding between the clay particles. The unconfined compressive strength of most of the samples satisfies the typical Solidification/Stabilization Criteria for soils (USEPA, 1989) (Table 4) and hence remediation is effective.

3.2.3 TCLP Test Results

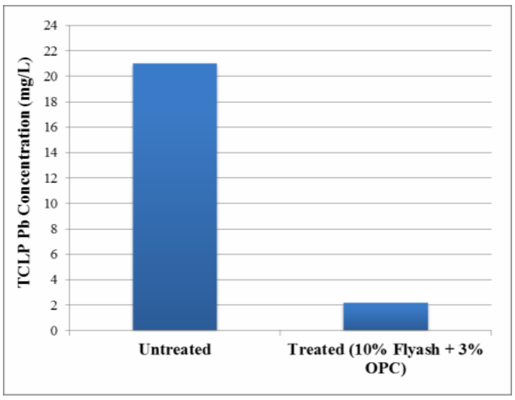

Chart-5: TCLP Pb Concentration of Untreated (Control) and Treated Samples

Treated soils were tested for their regulatory levels of heavy metal leaching by means of conducting TCLP tests. Pb concentrations in the solution were measured using an ICP atomic emission spectrometer. The leaching solution was deionized water (pH 6.80). After 28 days of specimen curing, for 0.1M Lead acetate contaminated untreated cases, the amount of Pb release was 21mg/L. Whereas, following 40% of flyash and 3% OPC treatment, these values were sharply reduced to 2.2mg/L respectively, which indicated that levels of TCLP Pb release were below the regulatory benchmark of 5ppm when amendments were added to the contaminated soil as shown in Chart 5. An efficiency of ~90% was obtained by this immobilization technique.

4. CONCLUSIONS

In this study, an optimum mixture of Flyash and OPC was used to remediate/decontaminated artificially Pb contaminated high plastic clay. The effectiveness of the immobilization process was evaluated using Unconfined Compressive strength test, plasticity test and TCLP. With the increase in salt concentration an increase in plastic limit and UCC strength was observed. However with the addition of amendments the plastic limit decreased and UCC strength increased. The combined treatment of 10% Flyash and 3% OPC caused a drastic reduction in Pb (~90%) leachability based on TCLP test. The Plastic limit and unconfined compressive strength of most of the samples and the TCLP test results satisfies the typical Solidification/Stabilization Criteria for soils (USEPA) (Table 4) and hence remediation is effective.

REFERENCES

[1] Aneke Ikechukwu Frank., Agbenyeku Emem-Obong Emmanuel, "Reclamation of Heavy metal Contaminated Kaolinitic soil by OPC-FA" International Journal of Scientific & Engineering Research, 2014, Volume 5, Issue 1, 1475-1479.

[2] A. Sridharan, N. S. Pandian, S. Srinivas, "Compaction behaviour of Indian coal ashes." Proceedings of the Institution of Civil Engineers Ground Improvement, 2001, Volume 5, Issue 1, 13-22.I.S.

[3] Sally Gutierrez, "Technology Performance Review: Selecting and Using Solidification/Stabilization Treatment for Site Remediation." National Risk Management Research Laboratory, 2009, U.S. Environmental Protection Agency

[4] S. H. Chew, A. H. M. Kamruzzaman, H. LeeF, "Physico chemical and Engineering Behavior of Cement Treated Clays." Journal of Geotechnical and Geoenvironmental Engineering , 2004, Volume 130, Issue 7, 696-706, ASCE.

[5] A. Sridharan, B. A. Mir, “Physical and Compaction Behaviour of Clay Soil–FlyAsh Mixtures.” Geotech Geol Eng, 2013, Volume 31, Issue 4, 1059–1072.D.

[6] Yan-Jun, Ning-Jun Jiang, Song-Yu Liu, Fei Jin, Devendra Narain Singh, J. Anand, “Engineering Properties And Microstructural Characteristics Of Cement-Stabilized Zinc-Contaminated Kaolin.” Canadian Geotechnical Journal, 2014, Volume 51, Issue 3, 289-302.

[7] A. Sridharan, N. S. Pandian, S. Srinivas, “Compaction behaviour of Indian coal ashes.” Proceedings of the Institution of Civil Engineers Ground Improvement, 2001, Volume 5, Issue 1, 13-22.

[8] Q. Y. Chen, M. Tyrer, C. D. Hills, X. M. Yang, P. Carey, “Immobilisation of heavy metal in cement-based solidification/ stabilisation: A review.” Waste Management, ELSEVIER, 2009, Volume 29, Issue 1, 390–403.

[9] E. Eisa, A. Essam, R. Maha, Mohmoud K.Mahmoud, A. Badria, “Inertization of Lead by using blended cement pastes.” Housing and Building National Research Center Journal, 2012, Volume 8, Issue 3, 153-158, ELSEVIER.