STABILIZATION/SOLIDIFICATION (S/S) OF COPPER CONTAMINATED SOIL

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Abstract: The industrial slag and e-waste which contains a high concentration of lead, nickel, zinc, copper etc. Such type of waste is disposed to open environment cause health issue like liver damage, kidney disease, and several others health problem. When this contaminant comes in contact with the soil, the geotechnical properties of soil is altered and water-soluble contaminant is transported in the direction of the groundwater flow. The present study describes the geotechnical behavior of artificially copper contaminated soil stabilization of the copper contaminated soil. The stabilization/solidification (S/S) is a remedial technique which is used to stabilize the contaminated soil. The binder which used for the stabilization purposes that create a layer on the contaminant and encapsulate in the solid matrix. Use of fly-ash as binding material help to stabilize two waste material into the stable solid matrix. For the study purpose, three different soil-binder ratios are selected for treatment, in which micro fine cement differ up to 5%, 10%, 15% and fly ash is varied up to 10%, 20%, and 30% by weight. For the economical reason micro fine cement is not used more than 15% and fly ash is waste material so using that waste also helps to economize the mix. The effectiveness of the treatment was assessed by the physical testing of the solidified soil-cement-fly ash mixture using Unconfined Compressive Strength (UCS), Energy-dispersive X-ray spectroscopy (EDS) and Scanning Electron Microscopy (SEM). Additionally, column leaching tests were performed to identify the property of the leachate. Durability study of the stabilization was verified using wetting and drying cycles of 12 days with alternating the wetting and drying sessions. The results showed the contaminant changes the geotechnical properties of soil. The contaminant causing a decrease in the liquid limit, maximum dry density ($\gamma_{d\ max}$) and angle of internal friction(ϕ).Also, increase in the specific gravity (G) of soil and optimum water content. The contaminant decreases the compressive strength of soil by 26% compared to natural soil.

Index Terms **- heavy metals, contaminant, stabilization/solidification (S/S), unconfined compressive strength (UCS), durability, energy dispersive x-ray spectroscopy, scanning electron microscopy (SEM), column leaching test.**

I. INTRODUCTION

The mining industry extracting the mineral from the mines. The copper is third most used metal in the world even one of the toxic heavy metals too. The copper element can be found in the fly ash or near any Printed Circuit Board factory which releases sludge that contains high concentrations of copper, lead, and zinc etc. The industrial slag and e-waste which contains a high concentration of heavy metal are disposed to open environment. The problem started when this waste is disposed of without providing any proper engineering treatment. In rainy season water contact with open pit dumped waste and water dissolve some waste element which is soluble in the water. This liquid which contains a highly toxic compound with it commonly known as leachate. When this leachate reaches to the groundwater table causing further damage to the ecosystem on the whole. The municipal solid waste comes from residential areas. The municipal solid waste generated by near about 50% of total waste, various studies reveal that about 90% of MSW is disposed of unscientifically in open dumps and landfills, creating problems to public health and the environment(Sharholy, Ahmad, Mahmood, & Trivedi, 2008).

The fuel oil contaminated soil samples show severe changes in the geotechnical parameters which are collected from Vadodara, Gujarat. Oil contamination decrease the maximum dry density (-4%), cohesion (-66%), angle of internal friction (-23%) and unconfined compressive strength (-35%) and increase in liquid limit (+11%). Contaminated soil is stabilized using various additives like lime, fly ash and cement independently as well as an admixture of different combinations. It is observed that stabilization agents improved the geotechnical properties of the soil by way of cation exchange, agglomeration, and pozzolanic actions(Shah, Shroff, Patel, Tiwari, & Ramakrishnan, 2003). To study contamination effect with varying percentage of 0% to 100% of waste revels that increase in the percentage of waste increases the liquid limit from 59.40% to 64.60% and also plastic limit from 25.9% to 29.20%. The contaminant changes the swelling behavior of the CH soil. The swelling pressure increased and value is 1.9 times to the original value and Free Swell Index value doubled after the contamination. Such type of drastic change in the soil is responsible for the cation exchange. Increase in the dielectric constant reduces interparticle shear resistance and increases double layer thickness which also shows an increase in the liquid limit(Shah, D.L. Shroff, 1998). The S/S method to stabilized lead-contaminated soil with cement and sulfur as binding material, In that way two waste is stabilized in a common single matrix with help of cement which is a binding agent, such type of solidified wastes could be used as construction fills, such as a sub-base course in road pavement construction(Lin et al., 1996).To achieve economic solution different binders are used with the cement with different proportion to stabilize lead-contaminated soil. Mixtures of different additives (lime, activated carbon, clay, zeolite, sand, and cement) with artificially lead-contaminated soil samples(Alpaslan & Yukselen, 2002).

II. THE MATERIAL USED FOR INVESTIGATION

1. Soil

The natural soil sample collected from the Nandesari Industrial Area, Vadodara, Gujarat at a near about 0.5-meter depth. This soil contains a small amount (5 to 7%) of silt and clay mixture which imparts little cohesion to the soil. The soil has a pH value of 6.18 which show the acidic nature of the soil.

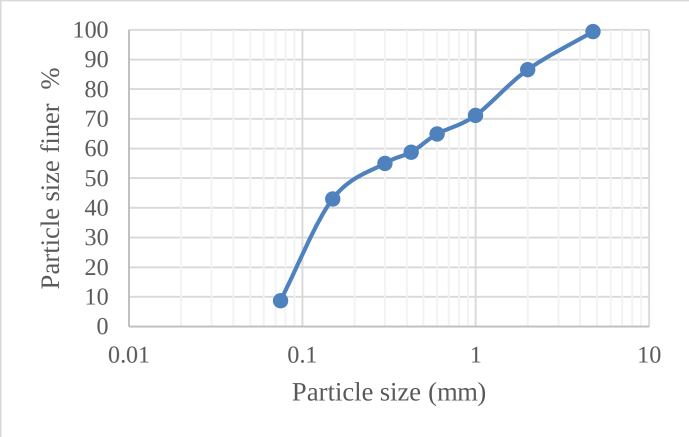

Figure 1 Grain size analysis

Table 1 Engineering properties of soil

Sr.No	Properties of soil	Value
1	D_{10} (mm)	0.0765
2	D_{30} (mm)	0.12
3	D_{60} (mm)	0.46
4	Co-efficient of Uniformity (C_u)	6.01
5	Co-efficient of Curvature (C_c)	0.409
6	IS Soil Classification	SP-SM
7	Specific Gravity	2.62
8	Maximum Dry Density ($\gamma_{d\ max}$) (g/cc)	1.82
9	Angle of Internal Friction (ø)	36º
10	Liquid limit	32.00%
11	Permeability (cm/s)	10^{-5}
12	UCS value (kPa)	363

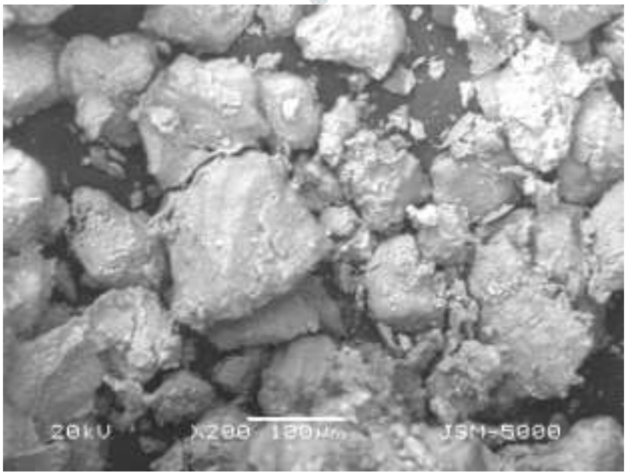

Figure 2 Natural soil particle under scanning electron microscope

2. Micro-fine cement

The micro-fine cement is used for stabilization of copper contaminated soil. The Blaine fineness value of micro-fine cement is greater than 8000 cm^2/gm and particle size $d_{95} < 12$ µm. This micro-fine cement helps to encapsulate more soil particle because of the larger surface area of cement. Chemical element analysis was carried out by energy dispersive x-ray analysis (EDS).

Table 2 Chemical element analysis of micro-fine cement

Element	Comp%	Formula
Mg K	2.71	MgO
Al K	9.23	Al2O3
Si K	24.64	SiO2
S K	4.02	SO3
Ca K	56.77	CaO
Fe K	2.62	FeO
O		
Totals		

3. Fly ash

The fly ash is used for stabilization of copper contaminated soil. The physical property of the fly ash is given in Table3 and chemical element analysis of fly ash is investigated using an EDS test which shown in Table4. The EDS analysis of the fly ash shows the higher amount of the silica and alumina content and ferrous mixture contains 95% amount which indicates the wanakbori thermal power plant fly ash is Class F.

Table 3Physical properties of fly ash

Property of fly ash	Value
Gravel % 4.75mm and above	Nil
Sand % 0.075mm to 4.75mm	52%
Silt size % 0.002mm to 0.075mm	48%
Liquid limit	36.8%
Plastic limit	Non-plastic
MDD	1.21 gm/cc
OMC	22.5%
Specific gravity	2.59
The angle of internal friction	30^o

Table 4 Chemical properties of fly ash

Chemical Properties of fly ash	Value
Silicon dioxide + Aluminium oxide + Ferrous oxide	95%
Silicon dioxide % by mass	62%
Total Sulphur as Sulphur Trioxide (SO_3)	0.3%
Magnesium Oxide	0.5%
Available Alkali as Sodium Oxide (Na_2O)	0.9%
Loss of Ignition % by mass	1.2%
Total Chloride content	35%

III. EXPERIMENTAL METHODOLOGY

1. Preparation of the artificially copper contaminated soil

The test was carried out by using artificially prepared copper contaminated soil sample (spiked sample). For the contamination of the soil clean water is used and copper is added in the water in such way that 500 ppm concentration can be achieved. The 5 gram of copper nitrate is dissolved into the 10 liters of water vessel to make 500 mg/liter concentrated liquid sample. For the Contaminate clean soil samples, a dry soil sample was transferred to a 5 L plastic vessel. The clean soil is mixed thoroughly using the mechanical mixture in the copper nitrate solution after proper mixing the spiked soil is kept 96 hours without disturbing to room temperature. Excess of moisture which is present in the soil removed through air drying soil and spiked soil sample is placed in the sunlight

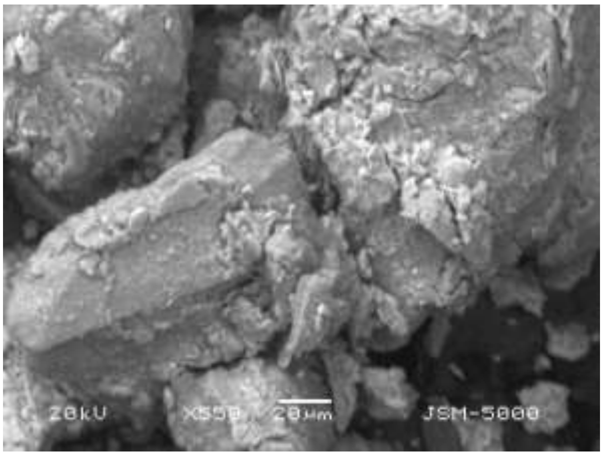

Figure 3 Copper particle which is attached to the soil surface

2. Soil-binder proportion used for the stabilization

The soil-binder proportion is needed to fix a limit for an economic solution. The excessive use of cement in proportion make costly solution rather use cheaper material which leads to an economic solution and also stabilized the contaminated soil. Three mix proportions are used for stabilization of copper contaminated soil which is shown in table 5. The Micro-fine cement is varied from 5%, 10% and 15% by weight of dry soil. fly ash is varied upto10%, 20%, and 30% by weight of dry soil. Micro-fine cement is used in proportion compared to the fly ash is very less because of its cost.

Table 5Mix proportion used for the Stabilization of copper contaminated soil

Mix Proportion	Soil	Micro-fine cement	Fly ash
M-1	Contaminated soil	+ 5% MF +	10% FA
M-2	Contaminated soil	+ 10% MF +	20% FA
M-3	Contaminated soil	+ 15% MF +	30% FA

3. Setup for the column Leaching test

To study the leaching behavior of stabilized copper contaminated soil, the column is prepared as shown in Figure 4. Three columns are filled with the mix proportion which is given in Table 5 and compacted at optimum moisture content which given in table 6. The water is applied to the column with help of pumping system or pressure system at the top of the column and it is collected from the base of the column. The collected water is used for further chemical analysis which gives the leached value of copper from the solidified matrix.

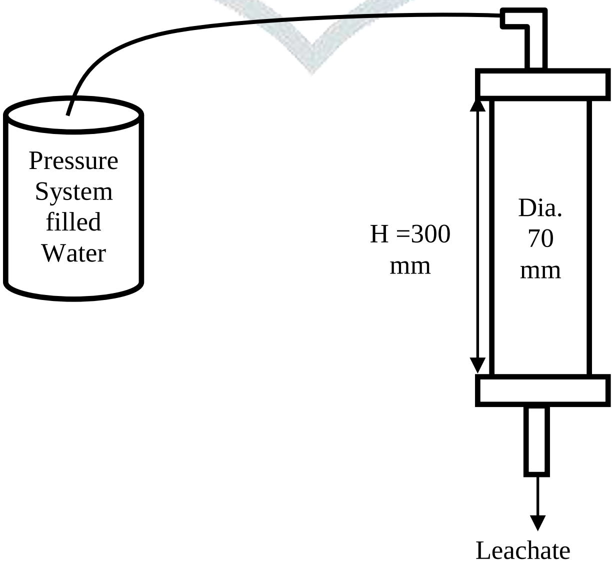

Figure 4 Setup for column leaching test

Table 6 MDD and OMC Values for the different mix proportions

Mix proportion	Optimum Moisture Content (%)	Maximum Dry Density (gm/cc)
M-1	15.61	1.766
M-2	17.41	1.759
M-3	15.31	1.704

4. Effect of wetting and drying cycle

Durability test is performed to observe the effect of actual weather condition of wetting and drying cycle on the stabilized soil sample. The specimen is prepared by compacting stabilized soil into proctor mold and compacted at OMC. The weight of the sample is measured and sample submerged into the potable water period for the 5 Hour and removed. Specimens shall be weighed and their dimensions measured. After that sample is placed in an oven at 70˚C for 42 hours and removed. One cycle (48 h) of wetting and drying is necessary. The specimens shall again be submerged in water and the procedure continued for 12 cycles. The durability test samples are prepared and the test was performed according to IS: 4332 (Part-4) – 1968. The test results after the 12 cycles of wetting and drying are given in Table 7.

Table 7 Soil-binder loss after wetting and drying of cycle

Mix proportion	Soil-Cement loss after 12 cycles of wetting and drying (%)
M-1	12.41
M-2	7.87
M-3	6.41

IV. RESULTS AND DISCUSSION

4.1 The result of the engineering properties of soil

1. Liquid Limit

The liquid limit for the natural soil, copper contaminated soil, and soil with the different mixture is shown in Figure 5. Liquid limit value decrease for copper contaminated soil and use of the additive in the mixture increases the liquid limit. Presence of cement and fly ash increases the liquid limit of a different mix. The higher liquid limit is noted for Mix-3. The copper contaminant changes the soil liquid limit.

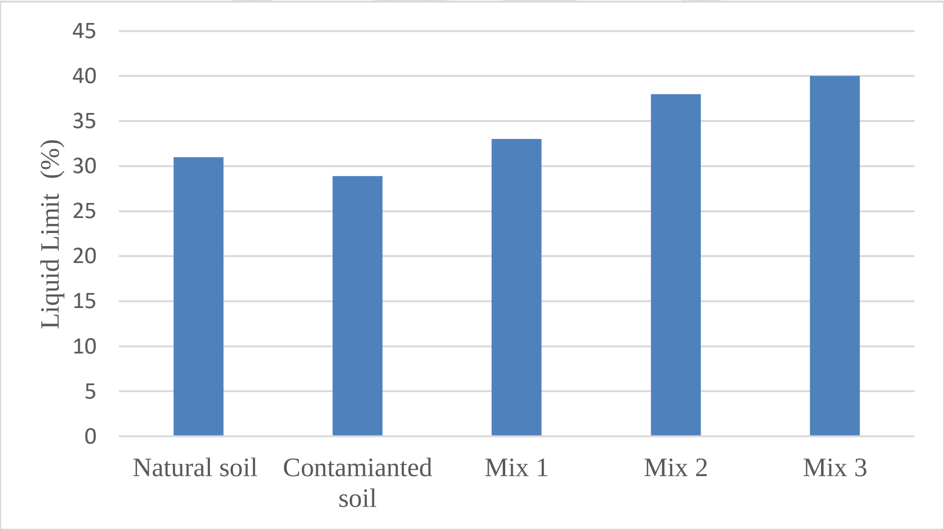

Figure 5 Liquid limits for the Soil and with different additive

2. Soil moisture-density relationship

The natural soil, copper contaminated soil, and three different mixes MDD and OMC were tested using standard Proctor test. The results of soil moisture – density is shown in Figure 6. The increase of additive material leads to an increase in Optimum moisture content and decrease in Maximum dry density. However, the optimum moisture content of Mix - 3 decreases.

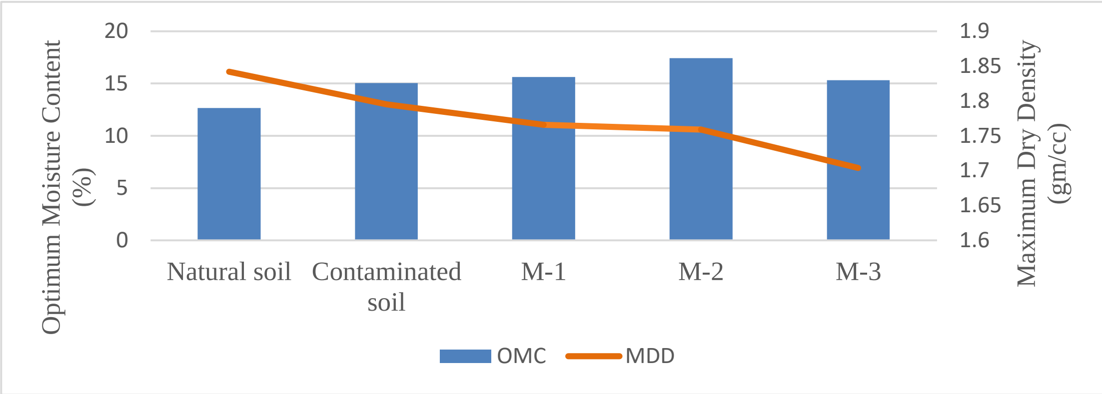

Figure 6 Maximum dry density and Optimum Moisture Content of soil and with different additive

3. Column leaching test

The leaching of the copper contaminant from the stabilized soil is studied by column test. The pump is used to circulate the water from the top of the column and results are shown in Figure7. The results show as days of curing increases, leaching of the copper contaminant from the stabilized soil decreases.

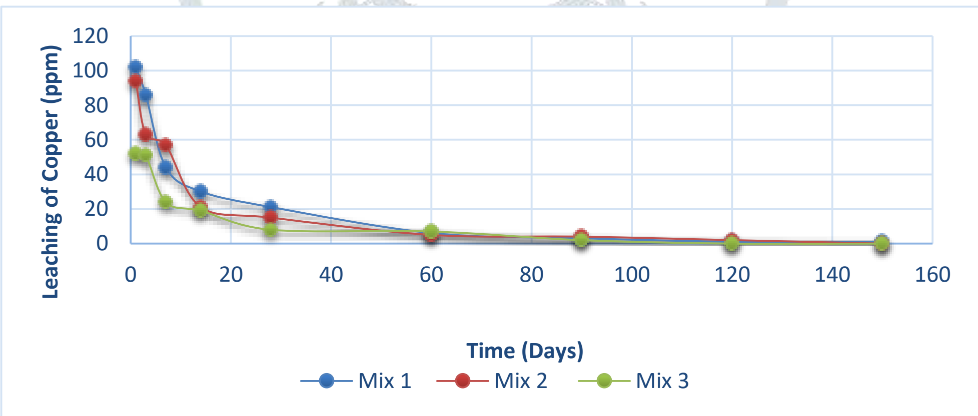

Figure 7 Leaching of the copper contaminant from the stabilized column

4. Unconfined compressive strength

The natural soil, copper contaminated soil, and stabilized soil sample compressive strength is measured using the UCS test. The natural strength of soil is observed 368 kPa. The contamination of copper decreases UCS value to 272 kPa. The UCS value of the stabilized sample shown in Figure 8. The ultimate strength of Mix-1, Mix-2, and Mix-3 observed1309 kPa, 2109 kPa, and 2850 kPa.

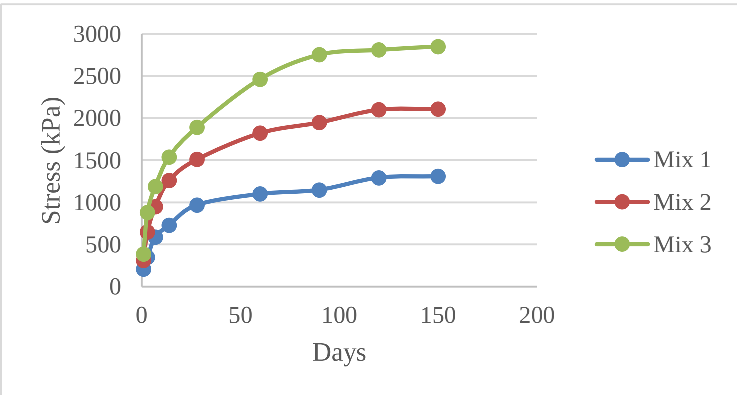

Figure 8 Change in the UCS value of the sample with time

V Conclusion

1. The copper contaminant changes engineering properties of soil because of change in the thickness of the double diffuse layer which affects the all major properties of the soil. Clay portion in the natural soil is not available in large quantity so the properties do not change to the drastic level.
2. The reduction in the maximum dry density changes the soil structure arrangement. The copper contaminant causes the slightly loose arrangement of soil. The frictional angle also decreases because of the loose packing.
3. The specific gravity of natural soil and copper contaminated soil is 2.62 and 2.75 respectively. The increase in the specific gravity is due to the presence of copper.
4. EDS and SEM result shows the change in the chemical properties and structure of the copper contaminated soil. The copper particle can be seen on the surface of the contaminated soil.
5. The micro-fine cement encapsulated the copper contaminant and leaching of copper is excessive up to 28days. The hydration of microfine cement under copper contaminated environment can slow down the process of mineral formation which can be the reason of leaching of copper contaminant for early days.
6. The Permeability of natural and copper contaminated soil is 10^{-5} cm/sec for both soil. Hence there is no change in the permeability

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