Full Paper

THE EFFECTS OF FERROUS SULPHATE HEPTAHYDRATE AND LEAD NITRATE ON THE ATTERBERG LIMITS AND CONSOLIDATION INDICES OF LATERITE

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ABSTRACT

Open dumping of wastes is a common practice in developing world. Leachates of varying chemical compositions including heavy metal are introduced into the soil from the dumped wastes. The adsorption of heavy metal ions and displacement of hydrogen ions in the soil may lead to changes in the geotechnical properties of the soil and affect the performance of the soil as foundation material. In this paper, the change in the Atterberg limits and consolidation indices of an artificially contaminated soil sample with iron and lead is presented. A selected soil sample was analysed in its uncontaminated state and the index and other geotechnical properties determined. The soil sample was contaminated with different concentrations of iron and lead and the soil samples were cured in separate sealed containers for 0, 28 and 72 days. The Atterberg limits and consolidation properties of the contaminated soil samples were determined using standard methods and compared to that of the uncontaminated soil. The results showed that the tested heavy metals have significant effect on the selected geotechnical properties of soil apart from posing only environmental threats with $F=20.85$; $F_{crit}=3.48$; $p<0.05$, (for iron contamination) and $F=62.52$, $F_{crit}=3.48$; $p<0.05$ (for lead contamination).

Keywords: *Atterberg Limits, Consolidation Indices, Contaminated soil, Heavy Metals*

1. INTRODUCTION

The geotechnical properties of soil are quite important as they determine the suitability of soil for various construction purposes such as road, dam, and landfill liners and foundations. Some of the important geotechnical properties are: shear strength, consolidation indices, permeability and Atterberg limits. The geotechnical properties of soil depend on multiple classes of factors such as physical, chemical and environmental conditions. Chemical conditions include the soil mineralogy, chemical constitution of the soil and the presence of chemical contaminants. The presence of man-made chemicals in soil as a result of the alteration in the natural soil environment is referred to as soil contamination. Soil contamination results from the indiscriminate disposal of industrial and municipal wastes. In developing countries, places where wastes are indiscriminately dumped are referred to as dumpsites. Due to paucity of land and increased urbanisation, there might be need to reclaim dumpsites for construction purposes in the nearest future. However one of the characteristics of dumpsites is the discharge of leachates composed of all kind of elements including heavy metals which contaminates the subsoil and the contained ground water. Fang (1997) showed that geotechnical properties of soil change due to changes in environmental conditions. There are also evidences that some contaminants such as caustic soda, acetic acid, sodium salts, hydrocarbon and even heavy metals affect the geotechnical properties of soil (Singh and Prasad, 2007; Arasan and Yetimoglu, 2008; Sunil et al., 2008; Sunil et al., 2009; Ayininuola et al., 2009; Arasan, 2010; Sitaram et al., 2010; Asadi et al., 2011; Naeini and Jahanfar, 2011 and Resmi et al., 2011). The effects of heavy metal contaminants in soils have been researched in the past years with emphasis on the adverse effects on the Agricultural, Environmental, and Geo-

Environmental sectors such as contamination of surface and ground waters due to leaching, damage to plants and crops through uptake from roots in contaminated soils and subsequent harm to humans and animals who feed or rely on such plants. Few works have been carried out on the effects these contaminants may have on the geotechnical properties of soil. The displacement of hydrogen ions (H^+) by the adsorption of heavy metal ions in clayey soils can result in flocculation, decrease in strength and increase in the coefficient of permeability of the soil (Resmi et al., 2011). Among the various heavy metals found in leachates from dumpsites, lead (Pb) and iron (Fe) are the most common and of high concentration (Abdus-Salam et al., 2011, Ojoawo et al., 2012). It is therefore important to study in a quantifiable manner the effects of these heavy metals on the geotechnical properties of soil. This study is important when the soil is to be used for foundation and landfill purposes. The compression index and the coefficient of consolidation are used to obtain the knowledge of the rate at which the compression of a soil layer takes place which is essential from design considerations. Founding of any structure on a compressible soil layer might leads to its settlement; and the amount of settlement is related to the compression index, Cc (Sridharan and Nagaraj, 2012). Plasticity and compressibility are typical properties of clayey soils. The Atterberg limits which is the range of water contents at which soil change from one state to another reflect the clay content and clay type of a soil Nath and DeDalal, 2004). This study examines the effect of selected salts of heavy metals on the Atterberg limits and consolidation indices of a lateritic soil.

2. EXPERIMENTAL PROCEDURE

2.1. Experimental Design

The effects of Ferrous Sulphate Heptahydrate ($FeSO4.7H_2O$) and Lead Nitrate ($PbNO_3$) on the geotechnical properties of soil were determined in the laboratory by monitoring changes in the properties of artificially contaminated soil samples. The baseline properties of the uncontaminated soil samples were compared with that of the contaminated soil samples. The two salts were chosen because of their solubility. The geotechnical properties determined are the Atterberg Limits (Liquid Limit, LL and Plastic Limit, PL), Compression Index (C_c) and Coefficient of Consolidation (C_v). These properties were determined using ASTM standard methods.

The soil samples were contaminated with concentrations corresponding to 70, 300, 700 and 1500 ppm of Iron, and 200, 500, 1000 and 2000 ppm of Lead. The contaminated soil samples were each cured in a sealed polythene bags for 0, 28, and 72 days respectively. At each curing age the aforementioned geotechnical properties of the contaminated soil were determined appropriately.

One-way Analysis of Variance tests were carried out on the results obtained in order to determine statistical significance. Using the Analysis Toolpak of Microsoft Excel 2013, the variation between groups (concentration level of pollutant) and those within groups (curing age per sample) were compared, allowing the determination of F scores, which were then compared with the critical F values (F_{crit}) from standard F Tables with "alpha" = 0.05.

2.2. Materials and Equipment

A disturbed soil sample was obtained from Obafemi Awolowo University International School (OAUIS) in Ile-Ife, Osun State, Nigeria with a GPS location of 7.519819 N and 4.534708 E where excavation works for the construction of a football field is ongoing. The natural moisture content of the soil was determined and the soil sample was air-dried in the Laboratory. $FeSO_4.7H_2O$ and $Pb(NO_3)_2$ were obtained in powder form.

The equipment and apparatus used for the various tests include the oedometer, Atterberg Limit apparatus, set of sieves, mould and rammer, electric weighing balance, Oven, Specific Gravity bottle, dial gauge (0.0001 inch = 1.0 on dial), Sample trimming device, glass plate, stop watch, clock, moisture can, filter papers, etc.

2.3. Determination of the Index and Consolidation Properties of Uncontaminated Soil Sample

The collected soil was air-dried under atmospheric conditions to bring the moisture content in the soil to a minimum and then pulverised to loosen up lumps of particles. The natural moisture content was however determined before air drying. Index properties such as Liquid Limit (LL), Plastic Limit (PL), specific gravity (G), and particle size distribution of the air dried soil sample were determined in the laboratory using standard methods. The compaction properties (maximum Dry Density, MDD and Optimum Moisture Content, OMC) were determined using standard proctor method. The soil sample was then compacted at the OMC and Cc and Cv determined using One dimensional Oedometer test.

Consolidation was carried out to determine the magnitude and rate of volume decrease that the laterally confined soil specimen would undergo when subjected to varying amounts of vertical pressures.

2.4. Preparation of contaminated soil samples

Different molar solutions of the salts were prepared by dissolving known masses of each salt in volumes corresponding to the OMC. The resulting solutions were mixed with known weight of the soil sample such that the required ppm is obtained. Each of the contaminated soil was then sealed in a polythene bag to avoid loss of water till the appropriate curing age when it was tested. There were 12 separately sealed contaminated samples for each of the salts. Curing was done to allow for the retention of the introduced heavy metal contaminants by giving time for contaminant-soil reaction over a period of time.

2.5. Comparison of the geotechnical properties of both uncontaminated and contaminated soil samples

At each of the curing ages, the contaminated soil sample was removed from the sealed bag and part of it used for the Atterberg limit tests while the other part was compacted in a standard proctor mould. The compacted soil sample was then used for the Oedometer test. The results obtained for the contaminated soil samples at the different concentrations and curing ages were compared to that of the uncontaminated soil sample.

3. RESULTS AND DISCUSSIONS

3.1. Index and Consolidation Properties of the Uncontaminated Soil Sample

The liquid limit, plastic limit and plasticity index of the uncontaminated soil sample were found to be 46.35%, 33% and 13.35% respectively as shown in Table 1, these values imply that the soil sample is low plasticity silt (ML) according to the Unified Soil Classification System (USCS). The particle size distribution of the soil sample shows that 28% passes sieve No. 200 (75 μm), 45.45% passes No. 40 sieve (425 μm) as shown in Table 1. The XRD and XRF analysis of the soil sample are also shown in Figure 1 and Table 2 respectively. The peaks in Figure 1 show that the active minerals in the soil are Hematite (Fe_2O_3, H), Magnetite (Fe_3O_4, M), Quarts (SiO_2, Q) and Aluminium Oxide (Al_2O_3, A). These minerals are typical of lateritic soil.

Table 1: Uncontaminated Soil Properties

Property	Value
Natural Moisture Content (%)	12.91
Specific Gravity	2.63
Percent Passing sieve No. 200 (P200)	27.99
Percent Passing Sieve No. 40 (P40)	45.45
Organic Matter Content	0.312
pH	4.25
USCS Classification	ML
Compaction Properties	
optimum moisture content OMC (%)	17.2
maximum dry density (MDD, Mg/m3)	1.78
Atterberg Limits	
Liquid Limit (LL, %)	46.35
Plastic Limit (PL, %)	33.00
Plastic Index (PI, %)	13.35
Consolidation properties	
Compression Index (Cc)	0.29
Coefficient of Consolidation (Cv, x 10^{-6} m^2/s)	2.27

Table 2: Mineralogical and Chemical Composition of Uncontaminated Soil

Elements	*Conc. Value (ppm)	*Conc. Error	Mineralogical Constituent
Ca	1073	± 82	Aluminium Oxide (Al_2O_3)
Ti	10227	± 177	Aluminium Silicate (Al_2SiO_5)
Cr	5	± 0	Silicon Oxide (SiO_2)
Mn	1449	± 34	
Fe	167108	± 468	
Cu	12443	± 100	
Zr	8477	± 100	

**Conc. = concentration*

The compaction parameters of the uncontaminated soil sample are shown in Table 1, while the compaction curve is shown in Figure 2. The result shows that the soil sample will attain a maximum dry density at a moisture content of 17.2%. The compression index (C_c) of the soil as obtained from a plot of the void ratio versus the logarithm of effective pressure (Figure 3) is 0.29. This result shows that the soil is normally consolidated with C_c range of 0.20 and 0.50 (Das, 2006). The coefficient of consolidation (Cv) of the soil was obtained to be approximately 2.27 x 10^{-6} m^2/s. Cv signifies the rate at which a saturated soil undergoes 1-dimensional consolidation when subjected to an increase in pressure.

3.2. Effect of Concentrations on Atterberg limits

The summary of the results of Atterberg limits for different concentrations of both heavy metals and at the different curing ages are given in Table 3 and Table 4. Figures 4 and 5 show that contamination with both lead and iron increases the liquid limit of the tested soil sample significantly. Increase in the concentration of iron contamination first increased the LL for 0 and 28 days curing age, but the LL reduced as the concentration increases. The LL consistently reduced with increase in concentration at 72 curing age as shown in Figure 4. The LL first reduced as lead concentration was increased, but it later increased with concentration as shown in Table 4 and Figure 5. According to Arasan (2010), the polarity of water molecules makes metals cations to always attract a hydration shell of water molecules by electrostatic attraction to the positive charge of the cations. This explains why the Liquid limit increases by the addition of the metallic cations. Increase in concentration did not however cause much change in the LL especially for iron contaminated soil samples but the LL increased with increase in concentration for lead contaminated soil.

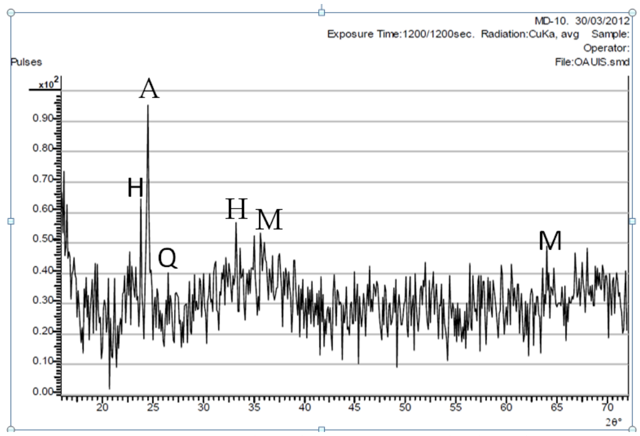

Figure 1: XRD analysis of the uncontaminated soil sample

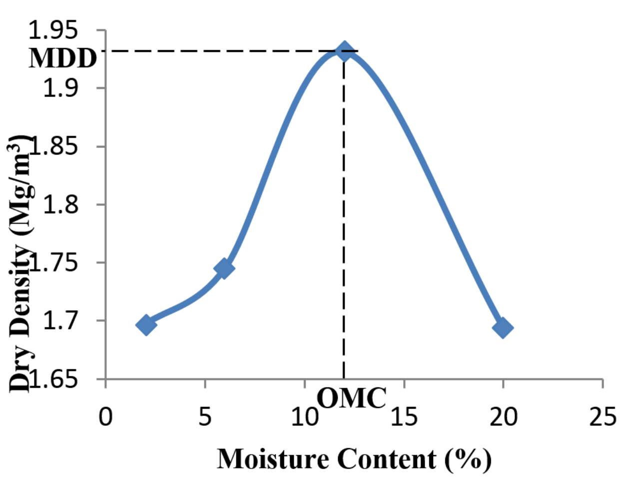

Figure 2: Compaction curve for uncontaminated soil

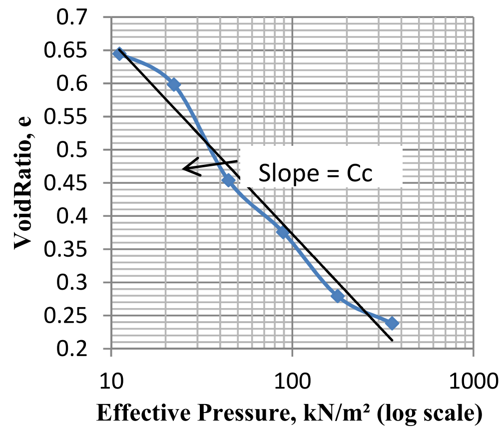

Figure 3: Plot of e-log σ for the consolidation for uncontaminated soil

Table 3: Atterberg Limits of Iron Contaminated Soil at Different Concentration and Curing Ages

Atterberg limits (%)	Conc. (ppm)	Curing ages (days)		
		0	28	72
Liquid Limit (LL)	0	46.4	46.4	46.4
	70	53.4	57.2	60.8
	300	58.7	59	60.3
	700	57.2	56.8	59.8
	1500	56.5	59.4	56.6
Plastic Limit (PL)	0	33	33	33
	70	29.24	27.41	32.64
	300	29.94	26.85	26.63
	700	25.09	24.69	24.35
	1500	26.63	24.52	19.24
Plasticity Index (PI)	0	13.4	13.4	13.4
	70	24.16	29.79	28.16
	300	28.76	32.15	33.67
	700	32.11	32.11	35.45
	1500	29.87	34.88	37.36

Table 4: Atterberg Limits of Lead Contaminated soil at Different Concentration and Curing Ages

Atterberg limits (%)	*Conc. (ppm)	Curing ages (days)		
		0	28	72
Liquid Limit (LL)	0	46.4	46.4	46.4
	200	61.6	63.1	62.4
	500	61.2	56.6	61
	1000	58.4	58.5	60.6
	2000	62.6	64.6	61.8
Plastic Limit (PL)	0	33	33	33
	200	34.23	30.84	32.92
	500	34.09	27.30	28.75
	1000	36.20	30.49	27.16
	2000	35.97	28.68	28.85
Plasticity Index (PI)	0	13.4	13.4	13.4
	200	27.37	32.26	29.48
	500	27.11	27.30	32.25
	1000	22.20	28.01	33.44
	2000	26.63	35.92	32.95

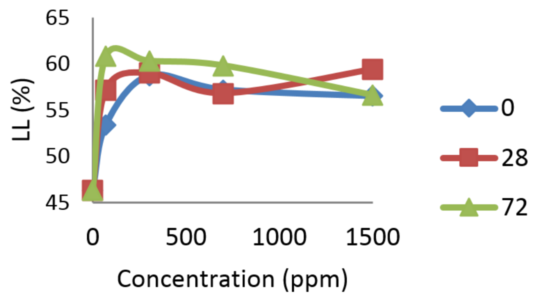

Figure 4: Effect of Iron at different concentrations on the Liquid Limit of soil

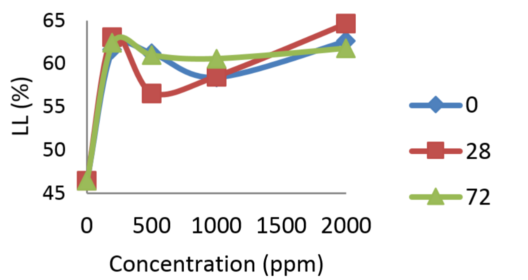

Figure 5: Effect of Lead at different concentrations on the Liquid Limit of soil

The addition of Iron and Lead contamination reduced the Plastic limit of the soil sample. The plastic limits of the contaminated soil generally reduced significantly as the concentration of iron increased at all ages of curing as shown in Figure 6. The reduction is more pronounced for contaminated soil cured at 72 days as the Pl reduced from 32.64% at concentration of 70 ppm to 19.24 at a concentration of 1500 ppm. The PL of lead contaminated soil increased from 33% (i.e at 0 concentration) to 34% (at 200 ppm) for 0 day curing age but the value reduced to about 31% (at 200 ppm) at 28 days curing age with no significant increase for the 72 day curing age. The general trend, however is that as the concentration increases, there is a reduction in the PL as shown in Figure 7. While the effect of iron concentration was significant ($F=8.85$; $F_{crit}=3.48$; $p<0.05$), that of lead did not prove to be so ($F=0.40$; $F_{crit}=3.48$; $p<0.05$)

The plastic index of soil is the range of moisture content at which soil is plastic and it is the difference between liquid limit and plastic limit (i.e. LL-PL). There was also a significant increase in the PI of iron contaminated soil from 13.4% (at 0 ppm) for all the curing ages ($F=32.93$; $F_{crit}=3.48$; $p<0.05$). The general trend however is that as the concentration of iron increases there is an increase in the PI of the soil for all the curing ages as shown in Table 3 and Figure 8. This result indicates an increase in the plasticity of the soil. The PI increased from 29.87% to 34.88% between 0 day and 28 days and to 37.36% at 72 days respectively for the highest concentration of 1500 ppm. As the concentration of iron contamination increases, the PI was tending to same value. The PI of lead contaminated soil increased significantly ($F=11.90$; $F_{crit}=3.48$; $p<0.05$) from 13.4% (at 0 ppm) concentrations) as shown in Table 4 and Figure 9. The general trend as concentration of lead increases is a reduction in the PI with the exception of that for 72 day curing age where an increase in the PI was observed. The results agree with that observed by Arasan and Yetimoglu (2008), with LL increasing and PL reducing at lower concentrations, also LL was reducing and PL increasing at higher concentrations of contamination.

The increase in the liquid limit of the soil with the addition of contaminants implies that the lowest moisture content at which the soil behaves as liquid was increased which is as a result of change in the affinity of the soil for water. The plastic limit of soil is defined as the lowest water content at which soil behaves like a plastic material. Due to the change in the soil's affinity for water, it will require a lesser amount of water to get to the plastic limit than the uncontaminated soil sample. These results also show that the range of plasticity of the soil increases with contamination and increasing concentration. This implies the contaminated soil is now of high plasticity which also implies that the compressibility of the soil has increased and the permeability reduced (Das, 2006).

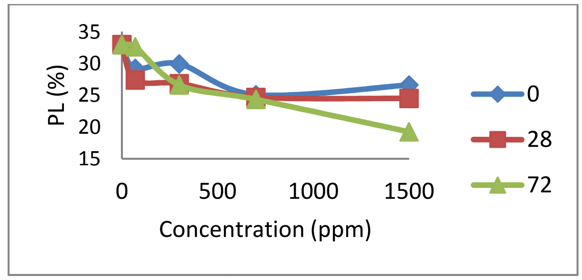

Figure 6: Effect of Iron at different concentrations on the Plastic Limit of soil

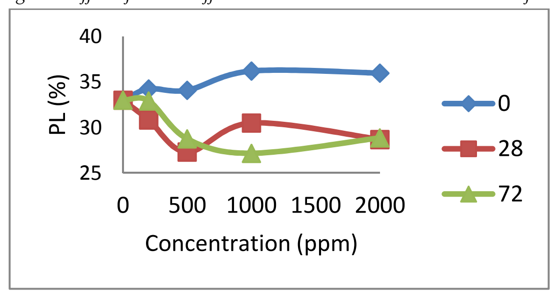

Figure 7: Effect of Lead at different concentrations on the Plastic Limit of soil

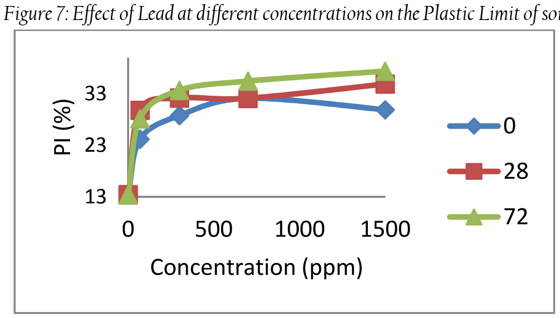

Figure 8: Effect of Iron at different concentrations on the Plasticity Index of soil

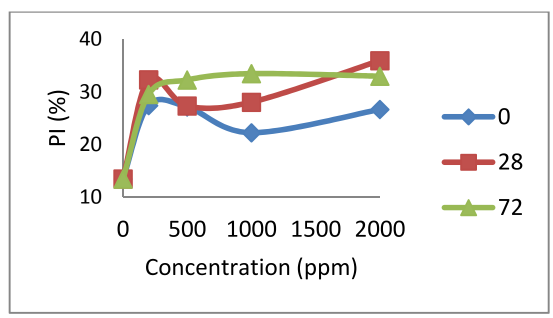

Figure 9: Effect of Lead at different concentrations on the Plasticity Index of soil

3.3. Effect of Concentrations on Consolidation Parameters

Consolidation tests were carried out to obtain the compression index (C_c) of the soil while the coefficient of consolidation (C_v) was obtained at the 88.8kN (40 kg) loading on both the iron and lead contaminated soil samples. C_c is related to the amount of settlement of a compressible layer Sridharan and Nagaraj (2012). The results of the consolidation parameter for both iron and lead contaminated soil samples are shown in Tables 5 and 6.

Both lead and iron contamination reduced the Cc of the of the soil sample, although, the impact did not appear to be statistically significant at an alpha of 0.05 (for iron, $F=2.83$; $F_{crit}=3.48$, while for lead, $F=1.14$; $F_{crit}=3.48$). The C_c generally decreased at lower concentrations of the iron contaminant and increases slightly to 0.264 and 0.205 for 0 day and 72 days respectively at higher concentrations with exception of the 28 days of curing where the Cc falls steadily to 0.209 as shown in Figure 10. The Cc of lead contaminated soil also reduced as concentration increases, however a slight increase of the Cc was seen at 28 days of curing, and the value got to a peak for 500 ppm concentration and reduced afterward as the concentration increases as shown in Figure 11. This reduction in Cc is similar to that observed in the PL as concentration increases. Nath and DeDala (2004) in correlating Atterberg limits with compression index found that the PI is best correlated with the compression index. The correlation shows that the C_c is directly proportional to PL which is not consistent with the results of this study. It can be inferred thus that the addition of contaminants altered the studied properties and as such the correlation equation for uncontaminated soil does not apply to contaminated soil.

Table 5: Consolidation Parameter of Iron Contaminated Soil

Consolidation parameters	*Conc. (ppm)	Curing ages (days) 0	28	72
Compression Index (Cc)	0	0.29	0.29	0.29
	70	0.24	0.26	0.26
	300	0.27	0.22	0.19
	700	0.23	0.27	0.20
	1500	0.26	0.21	0.20
Coefficient of consolidation x 10^{-6} (Cv)	0	2.27	2.27	2.27
	70	5.30	4.09	5.30
	300	5.94	3.93	4.52
	700	6.71	3.93	5.94
	1500	5.94	5.30	4.76

**Conc = concentration*

Table 6: Consolidation Parameters of Lead contaminated soil

Consolidation parameters	*Conc. (ppm)	Curing ages (days) 0	28	72
Compression index (Cc)	0	0.29	0.29	0.29
	200	0.24	0.29	0.23
	500	0.26	0.32	0.20
	1000	0.22	0.27	0.21
	2000	0.22	0.26	0.25
Coefficient of consolidation x 10^{-6} m^2/s (Cv)	0	2.27	2.27	2.27
	200	2.75	3.55	5.30
	500	1.85	1.68	4.76
	1000	5.94	5.30	5.94
	2000	6.71	5.42	6.31

**Conc = concentration*

The coefficient of consolidation (Cv) signifies the rate at which a saturated clay undergoes 1-dimensional consolidation when subjected to an increase in pressure (Robinson and Allam, 1998). The Cv was determined using square-root of time method given by Taylor (1948). The Cv generally increased with the addition of iron and lead contaminant. Cv and was observed to increase with increase in concentration of iron contamination up to 700 ppm and decreases with further increase in concentrations of the iron contaminant for 0 day and 72 days duration, at the 28 days of curing, however, Cv increased steadily at an even higher concentration levels (Figure 12). Figure 13 shows that lead contamination generally increased the Cv of soil as the concentration increased. Although there was an initial fall in the Cv at a concentration of 500 ppm for all the curing ages. The observed behaviour were all statistically significant: for the effect of iron concentration, F=6.57, F_{crit}=3.48, p<0.05, while for lead, F=8.54, F_{crit}=3.48, p<0.05.

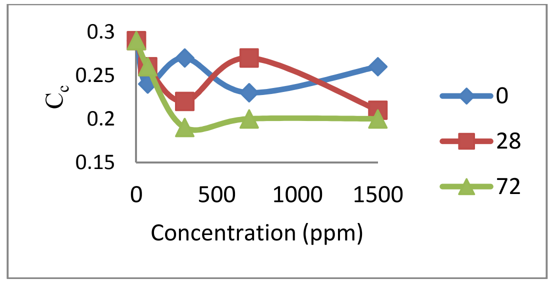

Figure 10: Effect of Iron at different concentrations on the compression index of soil

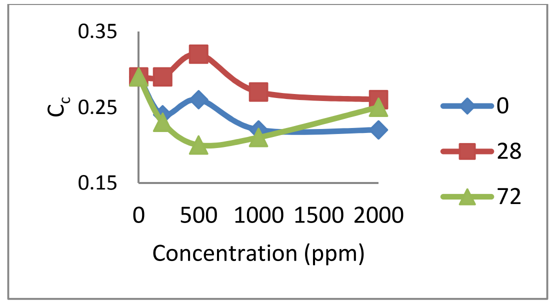

Figure 11: Effect of Lead at different concentrations on the compression index of soil

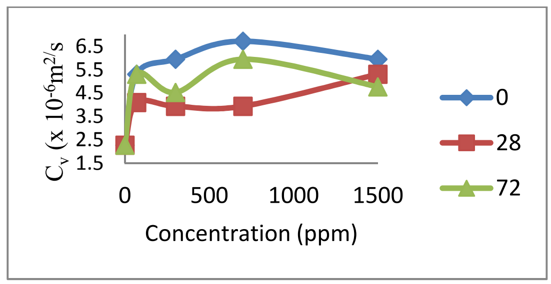

Figure 12: Effect of Iron at different concentrations on the coefficient of consolidation of soil

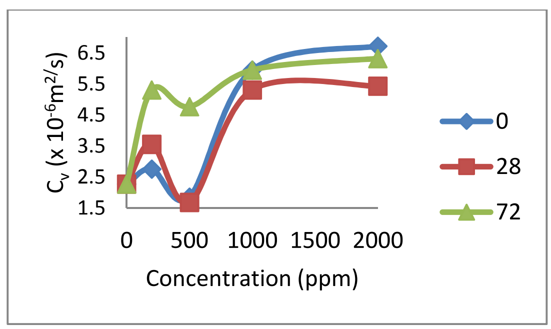

Figure 13: Effect of Lead at different concentrations on the coefficient of consolidation of soil

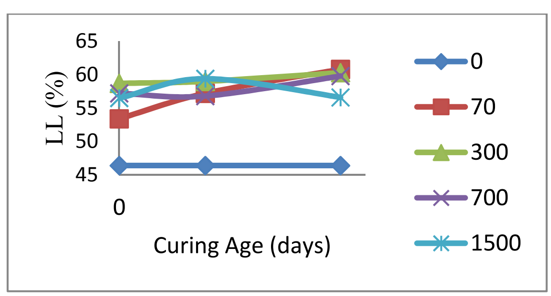

Figure 14: Effect of Iron at different curing ages on the liquid limit of soil

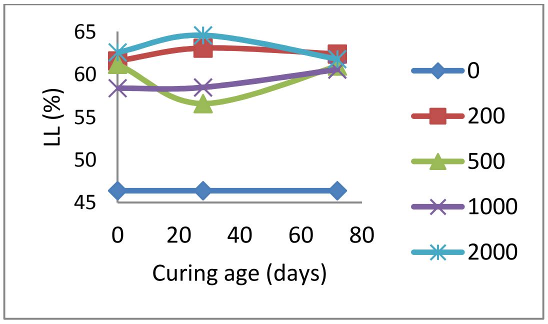

Figure 15: Effect of Lead at different curing ages on the liquid limit of soil

3.4. Effects of Curing Age on Atterberg limits

The effect of curing age on the LL of iron contaminated soil is shown in Figure 14. The general trend is an increase in the LL as the curing age increased except for the soil sample contaminated with 1500 ppm. The effect of lead on the LL with increasing curing age does not follow a general trend. LL reduced for both concentrations of 200 and 2000 ppm, while it increased for concentrations of 500 and 1000ppm as shown in Figure 15.

The PL of both iron and lead contaminated soil samples reduced as the curing age increased as shown in Figures 16 and 17 except for concentration of 70 ppm for iron and 200 ppm for lead.

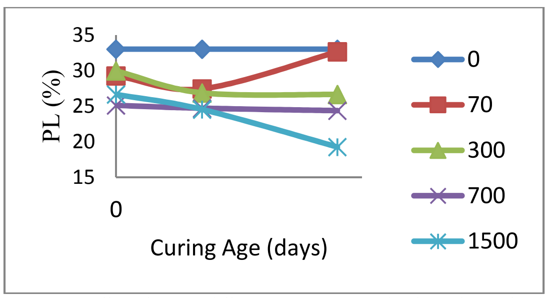

Figure 16: Effect of Iron at different curing ages on the plastic limit of soil

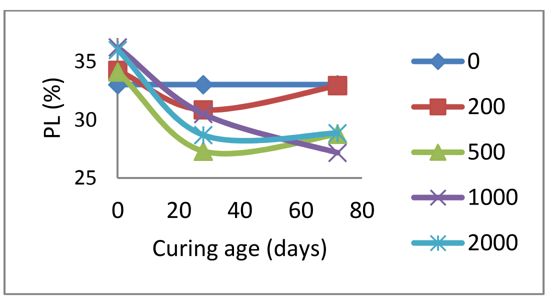

Figure 17: Effect of Lead at different curing ages on the plastic limit of soil

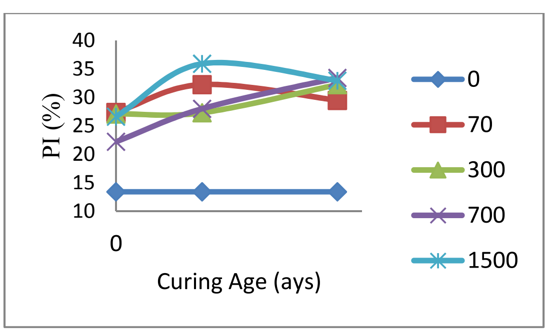

Figure 18: Effect of Iron at different curing ages on the plasticity index of soil

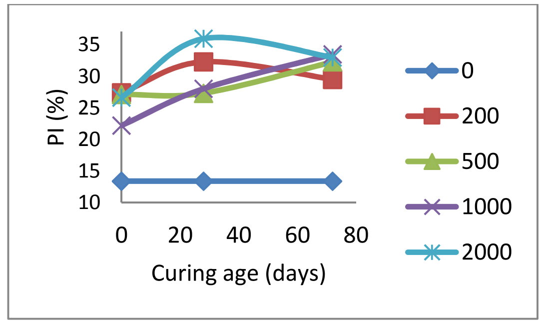

Figure 19: Effect of Lead at different curing ages on the plasticity index of soil

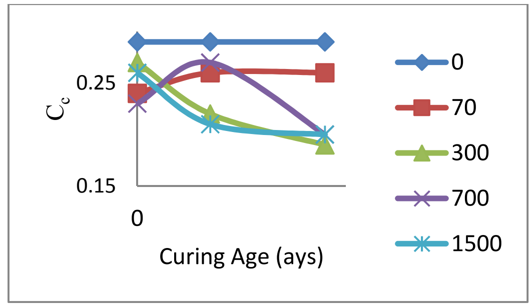

Figure 20: Effect of Iron at different curing ages on the compression index of soil

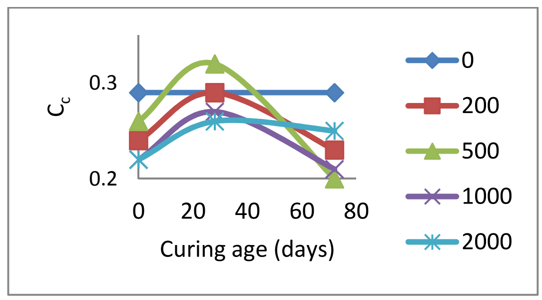

Figure 21: Effect of Lead at different curing ages on the compression index of soil

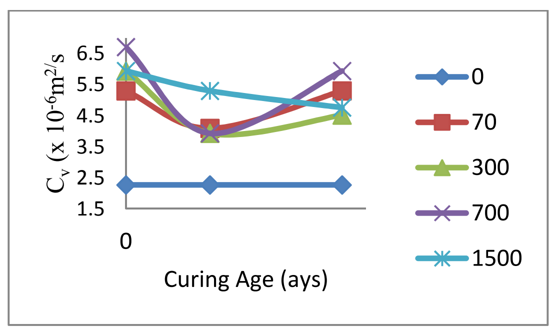

Figure 22: Effect of Iron at different curing ages on the coefficient of consolidation of soil

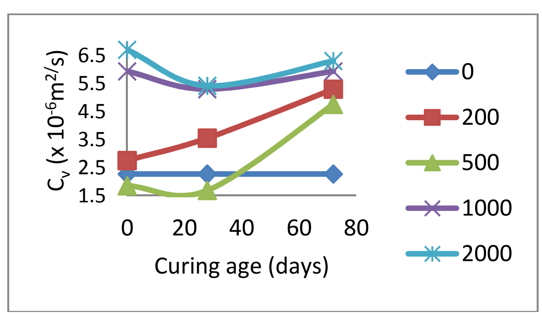

Figure 23: Effect of Lead at different curing ages on the coefficient of consolidation of soil

The change in the PI of both iron and lead contaminated soils follow the same trend as shown in Figures 18 and 19 respectively. The PI generally increases as the curing age increased. PI increased steadily with increasing concentrations of both contaminants for all curing ages indicating increase in soil plasticity

3.5. Effects of Curing Age on Consolidation Parameters

There was a significant reduction in the Cc of Iron contaminated soil with increasing curing age at all concentrations except for 70 ppm concentration as shown in Figure 20. The Cc of lead contaminated soil sample also decrease generally with increasing curing age as shown in Figure 21. These results implied that if the curing age is increased, the contaminants will be more adsorbed unto the soil particle which is typical of real insitu condition and the effect of the contaminant will be more on the tested properties.

The Cv of iron contaminated soil increased as the curing age increases, although there was an initial reduction as shown in Figure 22. C_v generally followed the same trend at all curing ages for concentrations lower than 1500 ppm as it decreased at 28 days where the value of Cv was approximately 4.76 x 10-6 m2/s and increases at 72 days of curing; at 1500 ppm concentration of iron, the Cv generally reduced with increasing number of curing ages. The C_v of lead contaminated soil also increased as the curing age increased.

4. CONCLUSIONS

The effect of iron and lead contamination on the Atterberg limits and the consolidation parameters of a lateritic soil sample was studied by carrying out a series of standard geotechnical engineering tests in the laboratory. Tests were carried out on soil samples contaminated with different concentrations of iron and lead. Tests were also carried out on contaminated soil samples cured at three different curing ages. From the results obtained, it may be concluded that the tested properties are affected by the adsorption of both iron and lead. The conclusions drawn from the current study are summarized thus:

i. Iron contamination caused an increase in the liquid limit. Lead contamination also caused an increase in the liquid limit. The liquid limit also increased with increase in lead concentration
ii. Iron contamination reduced the plastic limit of the soil with increasing concentration. Lead contamination also caused a reduction in the plastic limit of the soil.
iii. The plasticity index of the soil sample increased with iron and lead contamination.
iv. The compression index and the coefficient of consolidation reduced with increasing concentration of iron and lead. This implies that increased in sorbed concentration of contaminants resulted in the increase in Cv.

This study has shown that apart from environmental concern of heavy metal contamination, it is detrimental to the geotechnical properties of soil by increasing the water retention capacity of the soil which can result in larger settlement and failure when such soil is used as foundation material.

ACKNOWLEDGEMENTS

The authors wish to thank Messers Akinkumi, Ogune and Olukoya for helping in conducting the laboratory experiments.

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