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THE EFFECTS OF POTASSIUM PERMANGANATE ON THE GEOTECHNICAL PROPERTIES OF SOILS

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Abstract. In Nigeria, potassium permanganate ($KMnO_4$) is used as a chemical oxidant in the removal of hydrocarbons from polluted soils and groundwater, but there is no information on the effects of $KMnO_4$ on the geotechnical properties of the soil. In this study, $KMnO_4$ was added separately to lateritic soil and kaolin at concentrations of 0 %, 2 %, 5 % and 10 % by weight of dry soil. Each of the mixes was then subjected to grain size analysis, Atterberg limits, specific gravity, compaction, and California bearing ratio (CBR) tests. The results showed that an increase in $KMnO_4$ from 0 % to 10 % generally decreased the values of maximum dry density (MDD), optimum moisture content (OMC) and both unsoaked and soaked CBR for both soils. In conclusion, the study shows that although $KMnO_4$ is excellent for the remediation of contaminated sites, it reduces the geotechnical properties of soil and therefore should not be used alone (without the use of other additives) for soil stabilisation.

Keywords: Atterberg limits, California bearing ratio, kaolinitic soil, lateritic soil, potassium permanganate.

1. Introduction

According to Schoonover and Crim [1], soil serves an important purpose in various aspects, agricultural, ecological, but especially in civil engineering. The construction of structural works in civil engineering depends on soil characteristics. Because virtually all structures rest on soils. The load, generally the weight of the materials, is transferred to the soil. If the strength of the soil is known, the choice of foundation type can be easily determined [2]. When various materials (including different types of soil) are added to the soil and the soil is compacted to improve its properties, it becomes stabilised. The aim of soil stabilisation is to alter its physical properties, increase its strength and durability, and thus provide a satisfactory foundation and walling material. Soil stabilisation is most commonly used in the construction of road pavements, airports, dams. Other commonly used soil improvement methods are foundation improvement techniques of various types, sand drain, and chemical injections [3–5].

Potassium permanganate is extensively used in the purification of groundwater, site remediation, and bioremediation, particularly hydrocarbon contamination by oxidising the carbon components from groundwater [6–11]. Some of the studies involving the use of potassium permanganate on soil include the following;

Bajagain et al. [12] investigated the degradation of petroleum hydrocarbons in unsaturated soil and its effects on a subsequent biodegradation by potassium permanganate. The findings reveal that the potassium permanganate can degrade total petroleum hydrocarbon in soil and significantly promote the biodegradation rate in unsaturated diesel-contaminated soil when combined with bioaugmentation foam.

Boulange et al. [13] studied the Fenton-like and potassium permanganate oxidation of PAH-contaminated soils and the effect of oxidation on the behaviour of PAH and polar PAC (Polycyclic aromatic compound). The results show that the permanganate treatment was more efficient than the Fenton-like in decreasing the PAH content, the latter being limited by the availability of the contaminant.

However, the permanganate treatment resulted in an incomplete PAH degradation, leading to the formation of O-PACs, which was limited with an application of a higher dose. It underlines the importance of the dose and the type of oxidant in the selection of oxidation parameters for remediation purposes, as an improper use of oxidant can lead to the accumulation of oxidation by-products that can be as toxic as the parent compounds.

Also, the results obtained in this study emphasize the importance of the choice of the dose and the oxidant for contaminated soil remediation. The soil properties that can impact the treatment efficiency (e.g. contamination availability, EOM content) should be taken into account (calculation of the SOD_{EOM}) and the compounds monitored throughout the treatment should include potential by-products, i.e. O-PACs, as they are known to be severely toxic and can potentially accumulate in soil. Another aspect to explore – and which we are currently investigating – is the risk of aqueous mobilisation of polar-PACs associated with these treatments, as they are more water soluble due to the presence of polar functional groups.

Liao et al. [14] investigated the effects of various chemical oxidation reagents on the soil indigenous microbial diversity in the remediation of soil contaminated by PAHs. The results showed that the total organic carbon (TOC) content in the soil was significantly increased by adding a modified Fenton reagent (1.4–2.3 %) and decreased by adding potassium permanganate (0.2–1 %), owing to the nonspecific and different oxidative properties of the chemical oxidant. The results also demonstrated that the removal efficiency of total PAHs was in the following order: permanganate (90.0–92.4 %) > activated persulfate (81.5–86.54 %) > modified Fenton (81.5–85.4 %) > Fenton (54.1–60.0 %). Furthermore, the PAHs removal efficiency was slightly increased on the 7th day in the case of the Fenton and modified Fenton treatments, by about 14.6 %, and 14.4 %, respectively, and the PAHs removal efficiency only increased by 4.1 % and 1.3 %, respectively, from 1st to 15th day in the case of the potassium permanganate and activated persulfate treatments. The oxidants greatly affect the growth of soil indigenous microbes, which further influence the degradation of PAHs by bioremediation.

Dangi et al. [15] investigated a comparison of the soil natural oxidant demand exerted by permanganate hydrogen peroxide, sodium persulfate, and sodium percarbonate. The goal of this study was to assess the soil NOD demand of four different oxidants that included potassium permanganate, hydrogen peroxide, hydrogen persulfate, and percarbonate. The soil natural oxidant demand was determined by measuring the permanganate chemical oxygen demand (PCOD) of the soil before and after the chemical oxidation with the various oxidants. The difference in permanganate chemical oxygen demand values is representative of the amount of natural oxidants removed from the soil by each oxidant. Equivalent concentrations of each oxidant used (low, medium, and high) were established based on their standard reduction potentials at 25 °C. Each oxidant exhibited a different degree of PCOD removal during the oxidation. Although each of the oxidants was shown to interact with the soil, the natural oxidant demand associated with potassium permanganate was the highest.

Li et al. [16], studied the quantification of oxidant demand and consumption for in situ chemical oxidation design for potassium permanganate. The estimation model of soil oxidant demand (SOD) and simulation equations of potassium permanganate ($KMnO_4$) dynamic consumption based on the reaction equation of $KMnO_4$ with reductive minerals, and the estimation model of SOD was established. Model validation, model application, and simulation assessment were carried out. The results indicated that the simulations are in good agreement with the measured data. The confidence level of the SOD estimation model of $KMnO_4$ was over 80 %, with sensitivity in decreasing order as follows: organic matter content > initial $KMnO_4$ concentration > reductive minerals (RMs). Particularly, the organic matter played a dominant role in the SOD model estimation. The coefficient of determination (R^2) of the SOD dynamic consumption simulation equation was above 0.9. Among the various types of soils, the overall trend of the SOD value and reaction period decreased as follows: clay > loam > sand. However, the consumption rate of $KMnO_4$ decreased in the order of clay > sand > loam. In addition, the SOD value, reaction period, and reaction rate all increased as the initial concentration of $KMnO_4$ went up. This work can provide a methodology and reference for selecting and estimating the optimal oxidant doses and reaction period during a field application.

In Nigeria, studies have been carried out on the use of potassium permanganate as a chemical oxidant in the removal of hydrocarbons from polluted soils and groundwater. Nowadays, it is a general practice to inject large quantities of potassium permanganate into the soil and groundwater for remediation of contaminated soils and groundwater by In Situ Chemical Oxidation (ISCO), but there is no information on what effects potassium permanganate has on the geotechnical properties of the soil. Research done by [17–22] has reported the effects of other materials in soil stabilisation and the effects potassium permanganate may have on soils when used as a stabilising material. Most of the reactions with potassium permanganate are redox reactions. A redox reaction is a chemical reaction in which one substance is oxidised and another is reduced. The reaction of permanganate is complex. Due to its multiple valence states and mineral forms, manganese can participate in numerous reactions. Potential oxidation – induced effects include colloid genesis leading to a reduced permeability, mobilisation of redox – sensitive and exchangeable sorbed metals; possible formation of toxic by-products, heat and gas evolution, and biological disturbance [23].

The aim of this research is to investigate the geotechnical effects of injecting potassium permanganate at varying concentrations of 0 %, 2 %, 5 % and 10 % (by weight of the soils) into two different soils – kaolin and lateritic soil.

2. Materials and methods

2.1. Materials

The lateritic soil sample was obtained from Iworoko, Ekiti, Nigeria. It is located at longitude 07 ° 37 ' 16 " and latitude 05 ° 13 ' 17 ". The soil sample was collected at a depth of 1.2 m below the ground level using the disturbed sampling technique and put in a cellophane bag to prevent the loss of moisture from the sample during the process of transportation and storage. It was brought to a soil laboratory and marked indicating the soil description, sampling depth, and the date of sampling. The soil sample was air-dried for two weeks to allow for partial elimination of natural water

Tests		Potassium permanganate [%] 0	2	5	10
Natural moisture content	[%]	26.30	–	–	–
Percentage passing No. 200 B.S. sieve	[%]	48.6	49.4	51.3	54.8
Liquid limit	[%]	35.6	46.3	49.6	55.8
Plastic limit	[%]	28.7	24.9	18.3	13.8
Plasticity index	[%]	6.9	21.5	31.3	42.0
Shrinkage limit	[%]	15.0	15.7	26.0	37.1
Specific gravity	[–]	2.65	2.40	2.22	1.87
Maximum dry density (Standard Proctor)	[$kg\,m^{-3}$]	1910	1850	1550	1350
Optimum moisture content (Standard Proctor)	[%]	12.8	9.2	8.7	6.4
Unsoaked CBR	[%]	81.8	78.8	72.7	65.2
Soaked CBR (4 days)	[%]	51.5	47.0	42.4	34.9

Table 1. Summary results of the effects of potassium permanganate on the geotechnical properties of the lateritic soil at (0, 2, 5, 10) %.

content, which may affect the analysis, then sieved with a sieve No. 4 (4.75 mm opening) to obtain the final soil sample for the tests. After the drying period of two weeks, lumps in the sample were pulverised under minimal pressure.

Kaolin (a natural clay mineral) was purchased from Akure, Nigeria. The potassium permanganate used is a technical grade and it was manufactured in India by Libox Chem India private limited.

2.2. Methods

All laboratory tests were performed according to the general specification as given in the British specification BS 1377-2 [24]; and American (ASTM) standard [25]. The moisture content of the soil samples was measured immediately after they arrived at the laboratory. The samples were then air dried for two weeks to allow for partial water elimination, which may affect the analysis, thereafter, the sample was sieved using a sieve No. 4 (4.75 mm opening) to obtain the final soil sample for the test. The soils without the addition of $KMnO_4$ were then subjected to a grain size analysis, Atterberg limits, specific gravity, compaction, and CBR tests. The compaction and CBR tests were carried out at Standard Proctor compactive effort. $KMnO_4$ in ratios of 2 %, 5 %, 10 % by weight of the dry soil was thoroughly mixed with the dry soil samples. The following geotechnical properties for each soil type at both natural and treated states (with $KMnO_4$), were determined by subjecting the samples to the following tests: compaction, Atterberg limits, (using the Casangrande apparatus), specific gravity, California Bearing Ratio (CBR) (Soaked and Unsoaked).

3. Results and discussion

The geotechnical properties of the soils determined in this research included the natural moisture content, grain size analysis, liquid limit, plastic limit, plasticity index, shrinkage limit, specific gravity, maximum dry density, optimum moisture content, and CBR (soaked and unsoaked). Table 1 shows the geotechnical properties of the natural lateritic soil sample (that is, at 0 % potassium permanganate). The value of natural moisture content is 26.30 % and the percentage passing the sieve No. 200 is 48.6 %. The liquid limit, plastic limit, plasticity index and shrinkage limit values are 35.6 %, 28.7 %, 6.9 % and 15.0 %, respectively. The specific gravity of the lateritic soil sample is 2.65. The values of maximum dry density and optimum moisture content are 1910 $kg\,m^{-3}$ and 12.8 %. While the values of unsoaked and soaked CBR are 81.8 % and 51.5 %, respectively.

Table 2 shows the geotechnical properties of the natural kaolin soil sample (that is, at 0 % potassium permanganate). The value of natural moisture content is 15.69 %, the percentage passing the sieve No. 200 is 57.3 %. The liquid limit, plastic limit, plasticity index and shrinkage limit values are 62.2 %, 40.6 %, 21.6 % and 13.3 %, respectively. The specific gravity of the lateritic soil sample is 2.63. The values of maximum dry density and optimum moisture content are 1750 $kg\,m^{-3}$ and 14.5 %, respectively, and the values of unsoaked and soaked CBR are 34.9 % and 16.7 %, respectively.

3.1. Grain size analysis

Figure 1 shows the result of sieve analysis for the lateritic soil. The percentage that passed through the sieve No. 200 (0.074 mm) was 48.6 % (as shown in Table 1). According to AASHTO [26], the soil belongs to one of the following groups A-4, A-5, A-6 and A-7; this is because the percentage passing through the sieve No. 200 (0.075 mm) is more than 36 % (this is the minimum required). The liquid limit is 35.6 %; which puts the soil in either group A-4 or A-6 (with 40 % being the maximum liquid limit), and with the plasticity index of 6.9 %, the soil belongs in the A-4 group and is a silty soil.

Figure 2 shows the result of the sieve analysis for the kaolinitic soil. The percentage that passed through the sieve No. 200 (0.074 mm) was 57.3 % (as shown in

Tests		Potassium permanganate [%] 0	2	5	10
Natural moisture content	[%]	15.69	–	–	–
Percentage passing No. 200 B.S. sieve	[%]	57.3	59.4	64.2	67.3
Liquid limit	[%]	62.2	76.2	81.7	87.7
Plastic limit	[%]	40.6	37.4	31.2	20.4
Plasticity index	[%]	21.6	38.9	50.5	67.3
Shrinkage limit	[%]	13.3	19.8	27.9	39.3
Specific gravity	[–]	2.63	2.34	2.15	1.94
Maximum dry density (Standard Proctor)	[$kg\,m^{-3}$]	1750	1500	1405	1208
Optimum moisture content (Standard Proctor)	[%]	14.5	12.8	11.5	9.8
Unsoaked CBR	[%]	34.9	30.3	26.5	20.5
Soaked CBR (4 days)	[%]	16.7	13.6	10.6	8.3

Table 2. Summary results of the effects of potassium permanganate on the geotechnical properties of the kaolinitic soil at (0, 2, 5, 10) %.

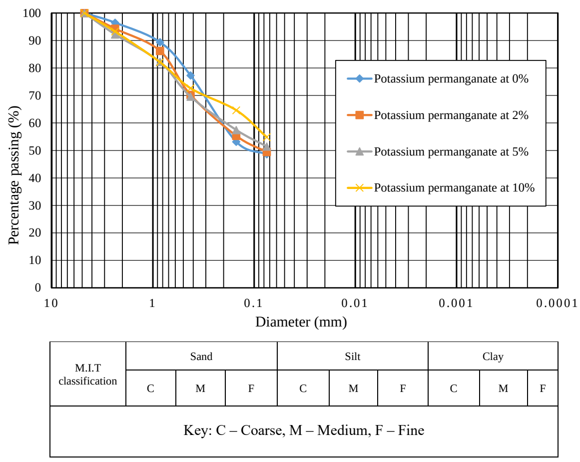

Figure 1. Sieve analysis for the lateritic soil when $KMnO_4$ was added at (0, 2, 5, 10) %.

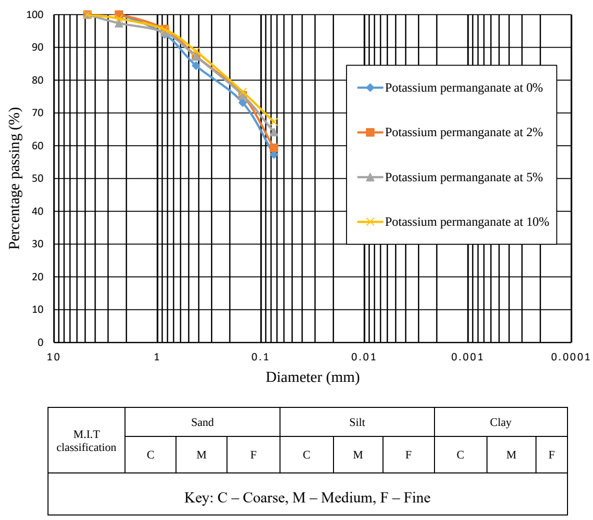

Figure 2. Sieve analysis for kaolinitic soil when $KMnO_4$ was added at (0, 2, 5, 10) %.

Table 2). According to AASHTO [14], the soil belongs to one of the following groups A-4, A-5, A-6 and A-7 this is because the percentage passing through the sieve No. 200 (0.074 mm) is more than 36 %; (this is the minimum required). The liquid limit is 62.2 %; which puts the soil in either group A-5 or A-7 (with 41 % being the minimum liquid limit), and with the plasticity index of 21.6 %, the soil belongs in the A-7 group. According to AASHTO [26], the soil is further classified to be in the A-7-5 group and it is a clayey soil.

The effects of potassium permanganate on the sieve analysis for the lateritic and the kaolinitic soils are shown in Figures 1 and 2, respectively. As the percentage of potassium permanganate increases, the percentage of soil particles passing the sieve No. 200 (0.074 mm) increases. For lateritic soil, the percentage of fines passing the sieve No. 200 (0.074 mm) increases consistently from 48.6 % for 0 % of $KMnO_4$ to 49.4 %, 51.3 % and 54.8 % for 2 %, 5 % and 10 % of potassium permanganate, respectively. For kaolinitic soil, the percentage of fines passing the sieve No. 200 (0.074 mm) increases consistently from 57.3 % for 0 % of $KMnO_4$ to 59.4 %, 64.2 % and 67.3 % for 2 %, 5 % and 10 % of potassium permanganate, respectively. This may be the due to the redox reactions that had taken place resulting in more friable particles [27].

3.2. Atterberg limits

The effects of $KMnO_4$ on Atterberg limits for the lateritic soil is shown in Figure 3 (and also shown in Table 1). The liquid limit of the soil increases consistently from 35.6 % for 0 % of $KMnO_4$ to 55.8 % for 10 % of $KMnO_4$. The plastic limit of the soil decreases consistently from 28.7 % for 0 % of $KMnO_4$ to 13.8 % for 10 % of $KMnO_4$. The shrinkage limit of the soil increases consistently from 15.0 % for 0 % of $KMnO_4$ to 37.1 % for 10 % of $KMnO_4$. The plasticity index of the soil increases consistently from 6.9 % for 0 % of $KMnO_4$ to 42.0 % for 10 % of $KMnO_4$. For the kaolinitic soil, the effects of $KMnO_4$ on Atterberg limit are shown in Figure 4. The liquid limit of the soil

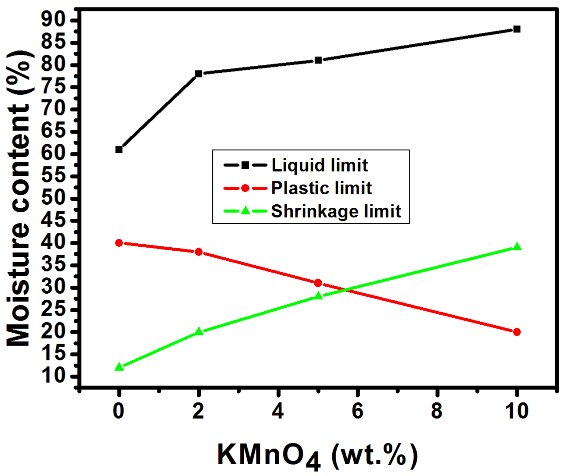

FIGURE 3. Effects on Atterberg limits for the lateritic soil when $KMnO_4$ was added at (0, 2, 5, 10) %.

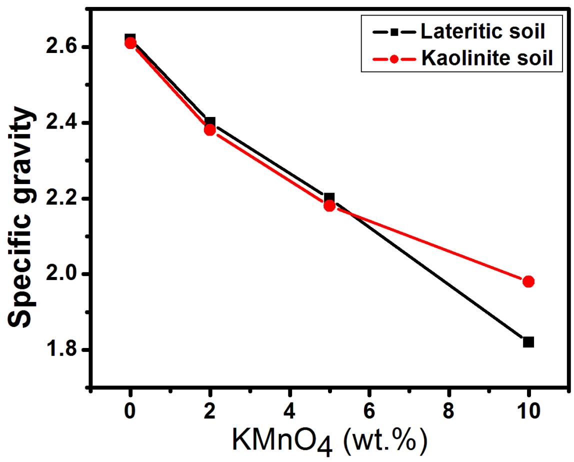

FIGURE 5. Effects on specific gravity when $KMnO_4$ was added at (0, 2, 5, 10) % for the lateritic soil and the kaolinitic soil.

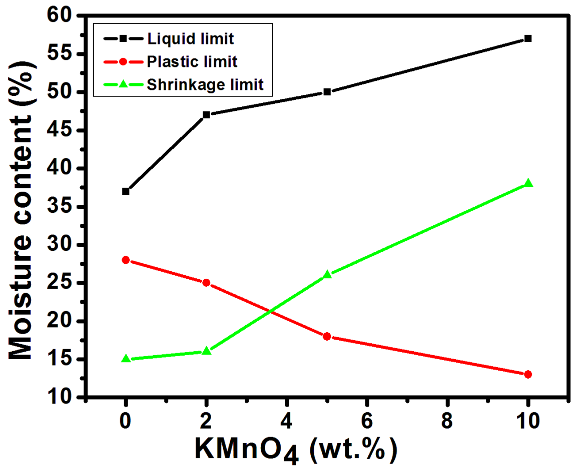

FIGURE 4. Effects on Atterberg limits for the kaolinitic soil when $KMnO_4$ was added at (0, 2, 5, 10) %.

increases consistently from 62.2 % for 0 % of $KMnO_4$ to 87.7 % for 10 % of $KMnO_4$. The plastic limit of the soil decreases consistently from 40.6 % for 0 % of $KMnO_4$ to 20.4 % for 10 % of $KMnO_4$. The shrinkage limit of the soil increases consistently from 13.3 % for 0 % of $KMnO_4$ to 39.3 % for 10 % of $KMnO_4$. The plasticity index of the soil increases consistently from 21.6 % for 0 % of $KMnO_4$ to 67.3 % for 10 % of $KMnO_4$.

As the percentage of potassium permanganate increases, the liquid limit for the soils increases significantly. Ola [28] observed that the liquid limit increases as a result of increased surface area because of the increase in the fines of a colloidal nature. This is consistent with the research by Arsyad and Soenoko [29]; which showed that as the percentage of potassium permanganate increases there is a corresponding increase of the surface area.

The plastic limits of both soils (lateritic and kaolinitic) are reduced by approximately 50 % when the potassium permanganate content is increased from 0 % to 10 %. As shown in Figures 3 and 4; as the percentage of potassium permanganate increased, the liquid limit and plasticity index for the lateritic soil and the kaolinitic soil also increased while the plastic limit decreased. In general, the effect of potassium permanganate on the Atterberg limits is due to the increase in surface area which is due to the increase in the fines of the soils. The shrinkage limit of the soils increases as the percentage of potassium permanganate increases. This is probably due to the increase in fines with a larger surface area present in the soils, or may be attributed to the primary redox reaction for permanganate in both, which is a complex reaction involving chemical, heat, and gas evolution, in which acidic media produce water and manganese ions [27].

3.3. SPECIFIC GRAVITY

The effects of $KMnO_4$ on specific gravity for the lateritic soil and kaolinitic soil are shown in Figure 5. The specific gravity of the lateritic soil decreases from 2.65 for 0 % of $KMnO_4$ to 1.87 for 10 % of $KMnO_4$. The specific gravity of the kaolinitic soil decreases from 2.63 for 0 % of $KMnO_4$ to 1.94 for 10 % of $KMnO_4$.

The specific gravities of the lateritic and the kaolinitic soils decreased as the percentage of potassium permanganate increased. Potassium permanganate has a specific gravity of 2.60. A study by Mandal et al. [21], reported a reduction in bulk density (which is related to specific gravity) in the analysis of potassium permanganate reactive soils. Therefore, the lower specific gravity of potassium permanganate can be attributed to the redox reaction between the lateritic soil and potassium permanganate on the one hand and the kaolin and potassium permanganate on the other hand [27].

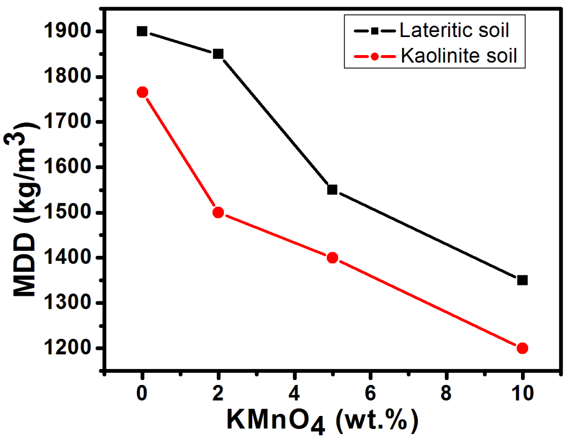

Figure 6. Effects on maximum dry density when $KMnO_4$ was added at (0, 2, 5, 10) % for the lateritic soil and the kaolinitic soil.

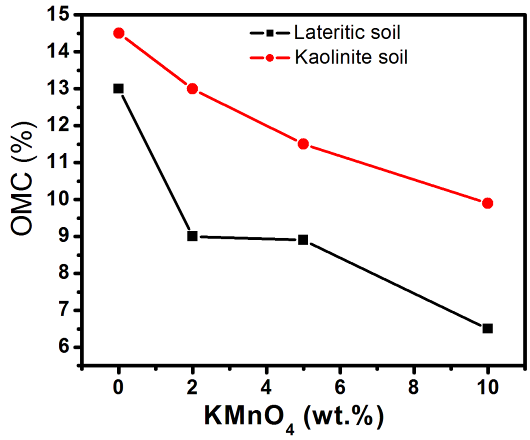

Figure 7. Effects on optimum moisture content when $KMnO_4$ was added at (0, 2, 5, 10) % for the lateritic soil and the kaolinitic soil.

3.4. Compaction characteristics

The compaction characteristics, described by maximum dry density and optimum moisture content, for the lateritic soil and the kaolinitic soils were determined from standard Proctor compaction tests on the soil samples.

3.5. Maximum dry density (MDD)

The effect of $KMnO_4$ on maximum dry density (MDD) for the lateritic soil and kaolinitic soils is shown in Figure 6 (and also shown in Tables 1 and 2). The maximum dry density of the soil decreases from 1910 $kg\,m^{-3}$ for 0 % of $KMnO_4$ to 1350 $kg\,m^{-3}$ for 10 % of $KMnO_4$. For the kaolinitic soil, the maximum dry density of the soil decreases from 1750 $kg\,m^{-3}$ for 0 % of $KMnO_4$ to 1208 $kg\,m^{-3}$ for 10 % of $KMnO_4$.

The maximum dry density generally decreased for the lateritic soil and kaolinitic soils as the percentage of potassium permanganate increased up to 10 %. This can be attributed to the reduction in specific gravities and adhesion of the lateritic and the kaolinitic soil particles upon the addition of potassium permanganate, which has a comparatively lower specific gravity of 2.60. Also, the addition of $KMnO_4$ reduces the particle size and increases the surface area. Based on this physical reaction, the MDD should decrease and the OMC should increase. However, we also have redox reactions, which are complex and involve chemical reaction, exchange of ions, heat and gas evolution, taking place in the soil at the same time, which reduced the OMC, with the addition of more $KMnO_4$. The results of maximum dry density obtained for the lateritic soil and the kaolinitic soils are in conformity with the research by Khatri et al. [20, 30, 31].

3.6. Optimum moisture content (OMC)

The effect of $KMnO_4$ on the optimum moisture content (OMC) for the lateritic and kaolinitic soils is shown in Figure 7 (also shown in Tables 1 and 2). The optimum moisture content of the lateritic soil decreases from 12.8 % for 0 % of $KMnO_4$ to 6.4 % for 10 % of $KMnO_4$. For the kaolinitic soil, the optimum moisture content of the soil decreases from 14.5 % for 0 % of $KMnO_4$ to 9.8 % for 10 % of $KMnO_4$.

These results are in agreement with the investigation by Harith et al. [17]; they reported that potassium permanganate caused a slight decrease in the optimum moisture content on the compaction characteristics of the soil and cement mixtures.

3.7. California bearing ratio

The effect of $KMnO_4$ on unsoaked and soaked (4 days) CBRs for the lateritic soil is shown in Figure 8. The unsoaked CBR of the soil decreases from 81.8 % for 0 % of $KMnO_4$ to 65.2 % for 10 % of $KMnO_4$. After 4 days of soaking, the soaked CBR decreased from 51.5 % for 0 % of $KMnO_4$ to 34.9 % for 10 % of $KMnO_4$. For the kaolinitic soil, the effects of $KMnO_4$ are shown in Figure 9. The unsoaked CBR of the soil decreased from 34.8 % for 0 % of $KMnO_4$ to 20.5 % for 10 % of $KMnO_4$. After 4 days of soaking, the soaked CBR decreases from 16.7 % for 0 % of $KMnO_4$ to 8.3 % for 10 % of $KMnO_4$.

Soaked and unsoaked CBR values of the soils are measures of their mechanical strength. The soaked and unsoaked CBRs decreased in a linear relationship with increasing percentage of potassium permanganate for the lateritic and the kaolinitic soils. The decrease in CBR values can be attributed to the redox reaction in the separate acidic media of the lateritic soil and kaolinitic soil [27, 32].

4. Conclusion

From the geotechnical tests carried out, we can conclude the following:

(1.) According to AASHTO, the lateritic soil is an A-4 silty soil and the kaolinitic soil is an A-7-5 clayey soil.

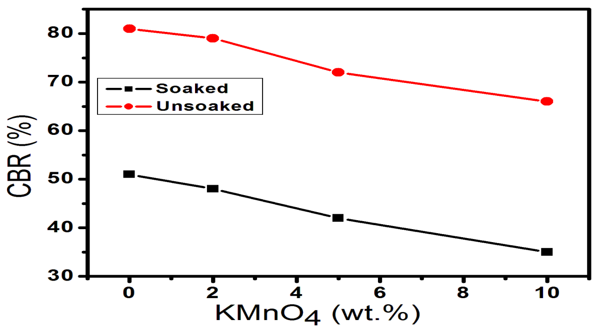

Figure 8. Effects on unsoaked and soaked CBRs when $KMnO_4$ was added at (0, 2, 5, 10) % for the lateritic soil.

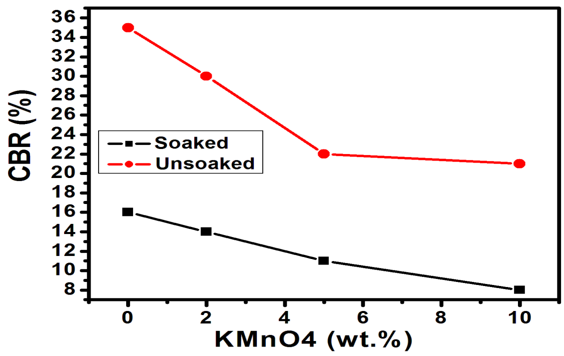

Figure 9. Effects on unsoaked and soaked CBRs when $KMnO_4$ was added at (0, 2, 5, 10) % for the kaolinitic soil.

(2.) The percentage of fines passing No. 200 B.S. sieve for the lateritic and the kaolinitic soils increases as the percentage of potassium permanganate increases.

(3.) Increasing the percentage of potassium permanganate from 0 % to 10 % increases the liquid limit of the lateritic soil from 35.6 % to 55.8 % and that of the kaolinitic soil from 62.2 % to 87.7 %.

(4.) Increasing the percentage of potassium permanganate from 0 % to 10 % decreases the plastic limit of the lateritic soil from 28.7 % to 13.8 % and that of the kaolinitic soil from 40.6 % to 20.4 %. The reduction in plastic limit for both soils was approximately a 50 % reduction when 10 % of potassium permanganate was added.

(5.) As the percentage of potassium permanganate increases from 0 % to 10 %, the plasticity index of the lateritic soil increases from 6.9 % to 42.0 % and that of the the kaolinitic soil from 21.6 % to 67.3 %.

(6.) The shrinkage limit increases for the lateritic soil from 15.0 % to 37.1 % and for the kaolinitic soil from 13.3 % to 39.3 % as the percentage of potassium permanganate increases from 0 % to 10 %.

(7.) Potassium permanganate decreases the specific gravity of the soils.

(8.) The maximum dry density decreases from 1910 kg m^{-3} to 1350 kg m^{-3} for the lateritic soil and from 1750 kg m^{-3} to 1208 kg m^{-3} for the kaolinitic soil as the percentage of potassium permanganate increases from 0 % to 10 %.

(9.) The optimum moisture content decreases from 12.8 % to 6.4 % for the lateritic soil and from 14.5 % to 9.8 % for the kaolinitic soil as the percentage of potassium permanganate increases from 0 % to 10 %.

(10.) The unsoaked CBR value decreases from 81.8 % to 65.2 % for the lateritic soil and from 34.9 % to 20.5 % for the kaolinitic soil as the percentage of potassium permanganate increases from 0 % to 10 %.

(11.) The soaked CBR value decreases from 51.5 % to 34.9 % for the lateritic soil and from 16.7 % to 8.3 % for the kaolinitic soil as the percentage of potassium permanganate increases from 0 % to 10 %.

(12.) The study conclusively shows that all the major geotechnical properties of the two soils used (including soil strength) were significantly reduced by the addition of $KMnO_4$ and will therefore have a negative impact on the bearing capacity of soils and foundations, potassium permanganate should be used primarily for site remediation but not for soil stabilisation.

(13.) It is recommended that more tests are carried out to determine the redox reaction of Potassium permanganate on other soils.

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