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Effect of oil palm empty fruit bunch ash (OPEFBA) on the compaction and some Index Properties of Sand-Bentonite Mixtures

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Abstract
The effort to improve the shear strength and leakage-proof of sand-bentonite mixtures used in waste containment liners prompted the investigation of the effect of oil palm empty fruit bunch ash (OPEFBA), a pozzolanic material on the mixture. Index property tests were carried out on sand, bentonite and sand-bentonite mixtures. The sand belongs to the American Association of State Highway and Transportation Officials (AASHTO) group A-1. Bentonite was added to the sand in increments of 0, 10, 20, 30, 40, 50% by weight. Index property test results show that specific gravity decreased with increase in bentonite content while liquid limit, plastic limit, plasticity index and linear shrinkage increased with increase in bentonite content. Compaction test results show that Maximum Dry Unit Weight (MDUW) decreased with increase in bentonite content while Optimum Moisture Content (OMC) increased with increase in bentonite content. OPEFBA was incorporated in the mix at 2, 4, 6, 8 and 10% by weight. Graphical and statistical results obtained show that OPEFBA at the percentages used does not have significant effect on sand-bentonite mixtures. Since the initial trial was not successful, it is recommended that experimental design should be carried out for the other possible combinations and investigated further.

Keywords: Atterberg limits, Bentonite, Compaction, OPEFBA, Sand, Sand-Bentonite

1. Introduction

Waste management using waste containment barriers have been a topic of much research in recent times (Ghazi, 2015, Proia et al, 2016, Meier and Shackelford, 2017, Thakur and Yadav, 2018). The reason for this is due to increasing challenges faced by man in waste management and its contribution to climate change. The world population is on the increase, commercial and industrial activities that generate many wastes are on the increase, thus, there is need to establish the best ways to manage these wastes because of their hazardous threat to the biotic environment. Soils mixtures consisting of sand and bentonite have largely been used by Geo-environmental Engineers as liners and covers in waste containment bins (Sivapullaiah, Sridharan, and Stalin, 2000; Ghazi, 2015). The reason for this is due to the low hydraulic conductivity of this mix under various conditions of initial moulding water content and dry density (Haug and Wong, 1992; Stoicescu, Haug, and Fredlund, 1998) and relative high shear strength (Vanapalli, Lu, Infante Sedano, and Oh, 2012). In landfills, the typical cross-section of the liner should consist of: a sand-bentonite layer, two filter layers, and a protective layer.

Hydraulic conductivity which is the most important test for the suitability of sand-bentonite mix as liner is expected not to exceed 1×10^{-9} m/s which is the satisfactory limit recommended by various waste regulatory bodies for landfill liners. In addition to low hydraulic conductivity, semi-permeable membrane behavior, or the ability to restrict the migration of aqueous miscible chemical species (solutes), which has been demonstrated extensively for many bentonite-based barriers have also been shown to be a viable waste containment function for sand-bentonite mixtures (Meier and Shackelford, 2017). The increase in the shear strength and reduction of hydraulic conductivity of sand-bentonite mixtures can be achieved by adequate compaction of the mix.

Sand-bentonite mixtures fall into the class of expansive soils that witness excessive swelling characteristics due to increase in water content (Agus and Schanz 2004, Vanappali et al, 2012). This behaviour would likely cause damages to the liners during operation and thereby cause leakages. The leakages associated with waste containment bins made with sand-bentonite mixtures is a challenge that partly defeated its purpose. When there is leakage, groundwater pollution takes place. Generally, the permeability of waste containment bins should not exceed 1×10^{-9} m/s but the reverse is most often the case as manifested in leakages. The preparation of waste containment liners involves the compaction of sand-bentonite mixtures. As much as this compaction is necessary, its effectiveness can be examined by hydraulic conductivity tests. This is in line with the work of (Khalid, Mukri, Kamarudin, and Abdul Ghani, 2020) who showed that high compaction effort is required for sand-low bentonite content mixtures and low compaction effort for sand-high bentonite content mixtures. Generally, as the compaction energy increases, the hydraulic conductivity reduces. In addition, hydraulic conductivity reduces with increase in bentonite content at different compaction energies. Efforts are being made to ensure that there are none or very minimal leakages in waste containment bins. It is known that hydraulic conductivity is affected by compaction conditions and index properties of soils (Benson and Trast, 1995). The aim of this paper is to show the effect of OPEFBA on the index properties and compaction behaviour of sand-bentonite mixtures which it is expected to help improve the compacted strength of the liner materials, reduce its hydraulic conductivity and its susceptibility to leakages.

2.0 Material and methods

2.1 Materials

The materials used for the work were sand, sodium bentonite and oil palm empty fruit bunch ash (OPEFBA). The sand was collected from Onitsha in Onitsha South Local Government area of Anambra state of Nigeria. Onitsha is well known city in Nigeria and West Africa for harbouring the largest main market in the region. It is located on Latitude 6^{o} 08^{1} 03^{11} N and Longitude 6^{o} 47^{1} 31^{11}E. The city lies at the shore of River Niger and the river sand popularly called Onitsha river sand is a product of routine dredging activities on the river. Figure 1 shows the map of Nigeria with the location of Onitsha indicated.

Figure 1: Onitsha city on the map of Nigeria

The sodium bentonite was bought from borehole materials suppliers at Onitsha main market. Empty palm bunches were collected from palm oil fruit farmers and palm oil producers at Egbeagu and Orebe village in Amansea, Awka North local government area of Anambra state.

2.2 Sample preparation

The river sand when collected was transported to the Geotechnics laboratory of Nnamdi Azikiwe University, Awka and air-dried in an open shade for a space of two weeks before being stacked in sacks in preparation for tests. Soduim bentonite was bought from a market. Due to the presence of adulterated sodium bentonite products in the market, the sodium bentonite upon purchase was tested by appropriate means to ensure that it is original product.

The OPEFBA was gotten from oil palm empty fruit bunch (OPEFB) collected from different oil palm milling sites. The OPEFB upon collection were sun-dried within three to four weeks to expel all entrapped water. Thereafter, they were burnt in an electronic kiln furnace at the temperature of $700^{0}C$ at Scientific Equipment Development Institute (SEDI), Enugu. After burning, the ash was sieved to remove large particles.

2.3 Methods

All the laboratory tests were carried out in accordance with BS 1377: 1990. The laboratory tests performed on modified and unmodified sand-bentonite mixtures include sieve analysis, specific gravity test, Atterberg limit tests and compaction tests. The choice of these tests lies on their relevance to the topic of study. Sodium bentonite was tested for free swell while OPEFBA was tested for its oxide composition (See Table 1) using x-ray fluorescence (XRF) apparatus.

Table 1: Oxide composition of OPEFBA based on XRF test

Oxide	Concentration (%)	Oxide	Concentration (%)
SiO_2	18	Br	0.03
Cl	6.35	Rb_2O_3	0.21
K_2O	20.4	SrO	0.08
CaO	4.18	Y_2O_3	0.01
TiO_2	0.98	ZrO_2	0.18
MnO	0.28	Al_2O_3	46.80
Fe_2O_3	2.52	Eu_2O_3	0.10
CuO	0.09	Re_2O_7	0.02
ZnO	0.22	HgO	0.02

3.0 Results and Discussions

The results and discussion shall consider the index properties of the sand and bentonite, the effect of increment of bentonite on the index properties and compaction characteristics of sand-bentonite mixtures and the effect of increment of OPEFBA on the index properties and compaction characteristics of sand-bentonite-OPEFBA mixtures.

3.1 Index properties of sand and bentonite

The index properties of sand investigated are the specific gravity and particle size analysis. The Atterberg limit tests was not done because the sand was not a plastic material. The specific gravity of the sand was 2.65 which is typical of the specific gravity of sand (ASTM D 854-14). The gradation curve is shown in Figure 2. The coefficient of uniformity, C_u is 3.6 while the coefficient of curvature, C_c is 1.6. This shows that the sand is between the interface of poorly-graded to well graded sand. Based on AASHTO soil classification, the soil belongs to group A-1. Based on USCS system, the soil belongs to group SM (silty-sands).

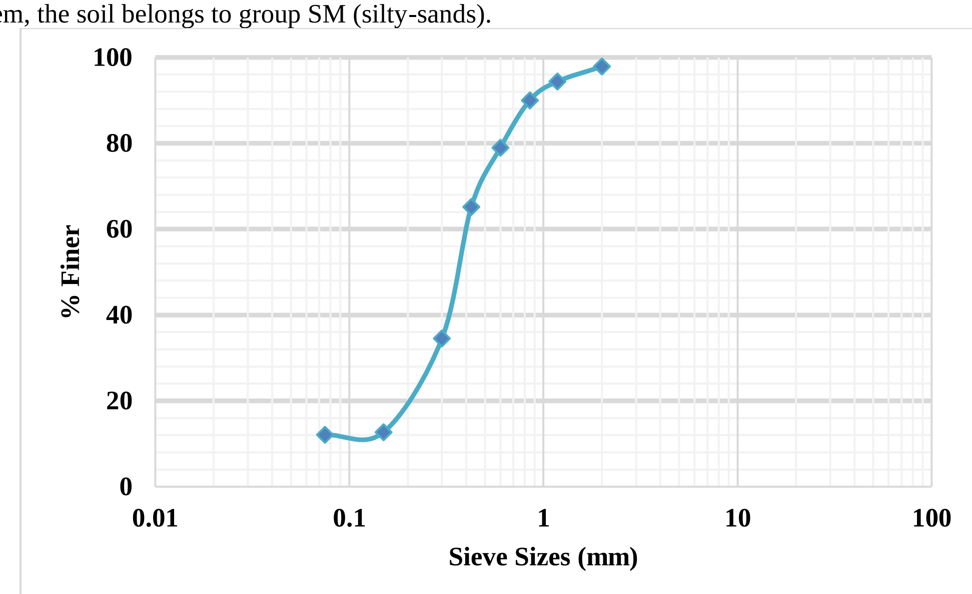

Figure 2: Gradation curve of the river sand

The bentonite has a specific gravity of 2.25 and a swelling index of 850%.

3.2 Properties of sand-bentonite mixtures

The bentonite was used to partially replace the soil in a 100% mix. While the bentonite content was increased from 0% to 50%, the sand was reduced from 100% to 50%.

3.2.1 Index properties of sand-bentonite mixtures

Figure 3 shows the effect of partial replacement of sand with bentonite incrementally. With the addition of bentonite, the specific gravity increased initially until 30% bentonite and began to decrease. The increase may be attributed to the filling of voids in the sand skeleton by the bentonite. When there are no more voids to fill, the specific gravity begins to reduce. Figure 4 shows the variation of some Atterberg limits (liquid limit, plastic limit, plasticity index) with the increment in bentonite content. With the increment in bentonite content, the liquid limit, the plastic limit, the plasticity index and the linear shrinkage of the mix continue to increase showing a transformation from a non-plastic state to a plastic state for the sand. A remarkable increase was observed for the liquid limit and plasticity index.

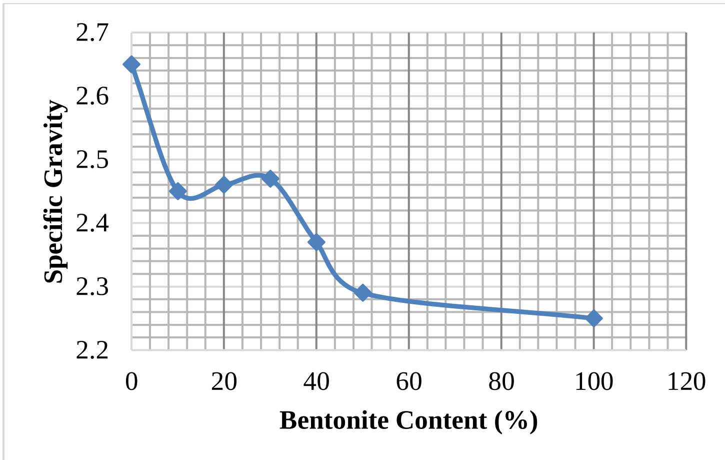

Figure 3: Variation of specific gravity with bentonite content

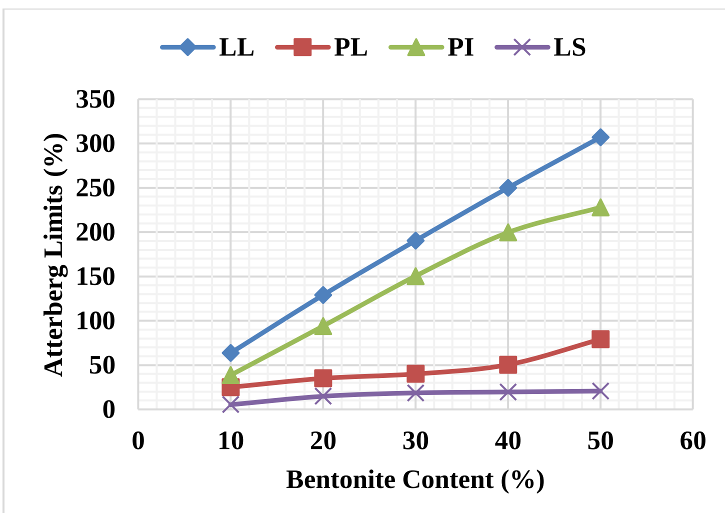

Figure 4: Variation of Atterberg limits with bentonite content

3.2.2 Compaction characteristics of sand-bentonite mixtures

Figure 5 (a & b) shows the variation of MDD/OMC with bentonite content for BSL and BSH. As the bentonite content increased, the MDD decreased while the OMC increased. The results are in agreement with the findings of Amadi and Eberemu (2012) and Ghazi (2015) who also reported decrease of MDD and increase of OMC with increase in bentonite content in soil. The variation may be due to high water retention capacity and reduction in the inter-locking capacity of the sand grains by the lubrication the plastic bentonite content.

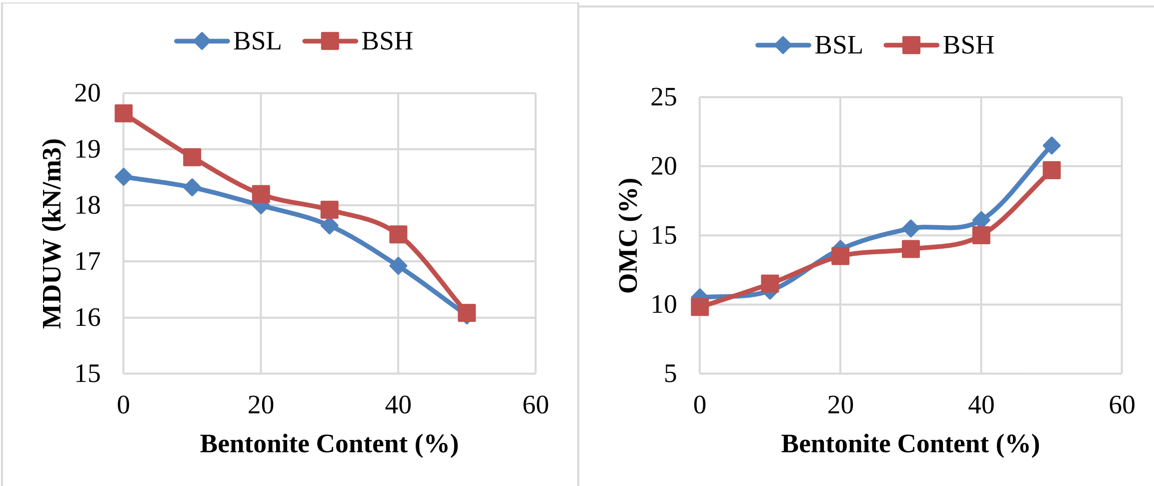

Figure 5: Variation of MDD (a) /OMC (b) with bentonite content

3.3 Properties of sand-bentonite-OPEFBA mixtures

OPEFBA was added to the sand-bentonite mixtures of 100S:0B; 90S:10B; 80S:20B; 70S:30B; 60S:40B and 50S:50B in the increments of 2% to 10%.

3.3.1 Index properties of sand-bentonite-OPEFBA mixtures

Figure 6 shows the effect of OPEFBA on the specific gravity of sand bentonite mixtures. The maximum value was observed at 100S + 0B + 8OPEFBA while the minimum value was observed at 70S + 30B + 8OPEFBA. Figure 7 shows the variation of Atterberg limits with OPEFBA content on a 50S + 50B mixture. For the plastic limit, there was mild reduction with increase in OPEFBA while mild increase in linear shrinkage was recorded with increase in OPEFBA content.

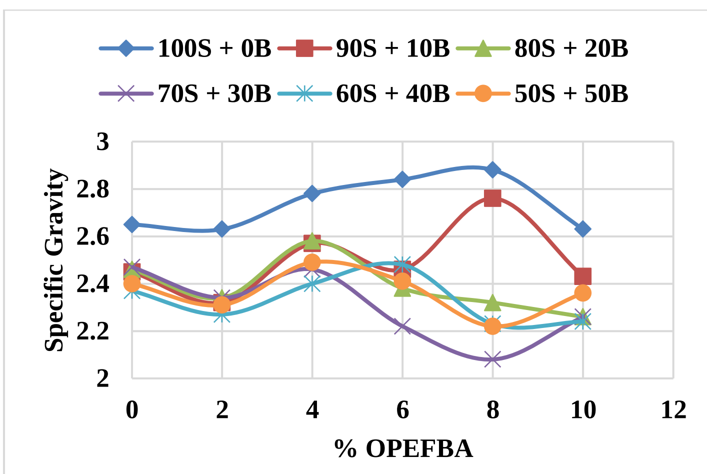

Figure 6: Effect of OPEFBA on specific gravity of sand-bentonite mixtures

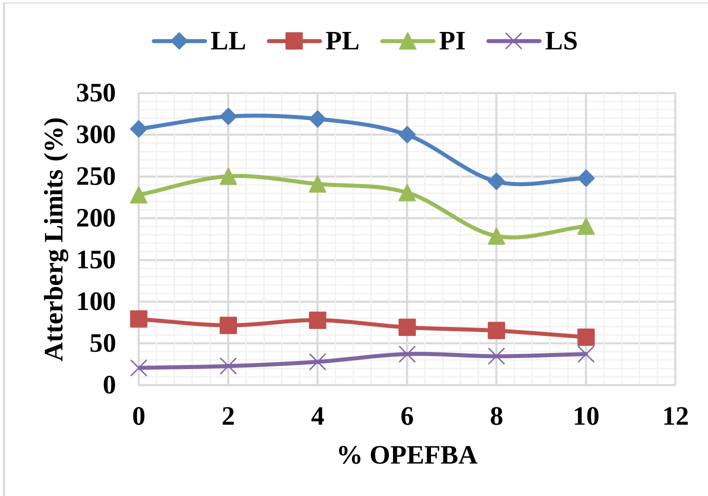

Figure 7: Variation of Atterberg limits with OPEFBA content on a 50S + 50B mixture

3.3.2 Compaction characteristics of sand-bentonite-OPEFBA mixture

Compaction is very important in the investigation of suitability of sand-bentonite mixtures for liners in waste containment bins. This is because compaction is necessary to investigate the compressive strength of the materials, which in addition to hydraulic conductivity and volumetric shrinkage are necessary for assessing the suitability of materials as liners in waste containment, bins. Figures 8 to 13 show the results of compaction tests on sand-bentonite-OPEFBA mixtures for BSL and BSH respectively. There is no defined pattern in which the OPEFBA content affects the sand-bentonite mixtures.

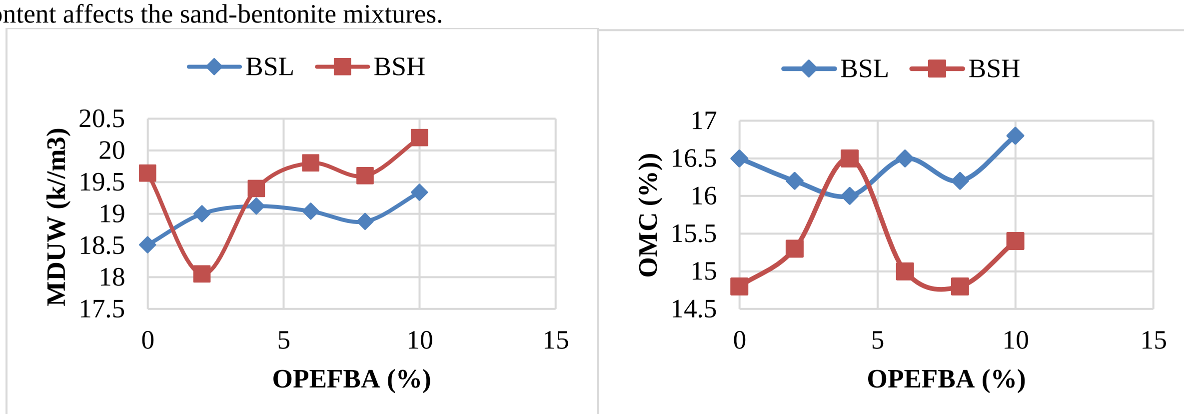

Figure 8: Variation of MDUW (a)/OMC (b) with OPEFBA content at 100S – 0B mixture

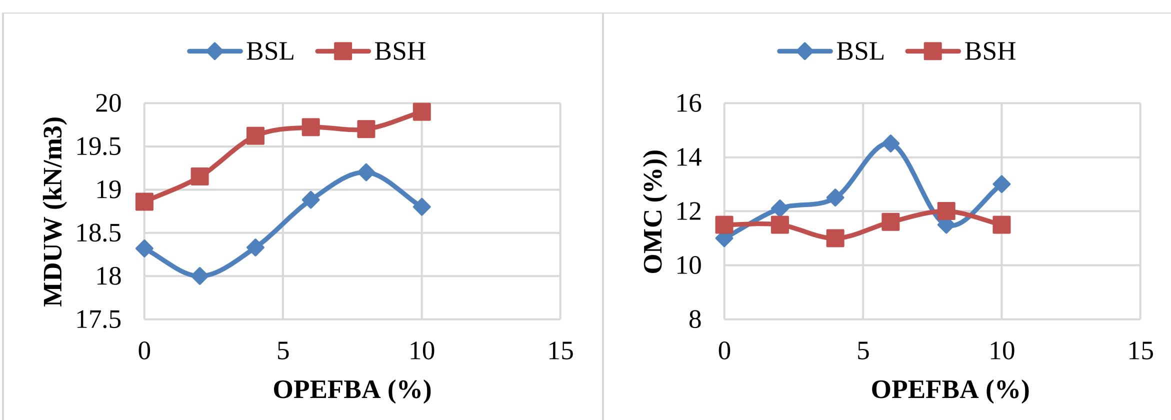

Figure 9: Variation of MDUW (a)/OMC (b) with OPEFBA content at 90S – 10B mixture

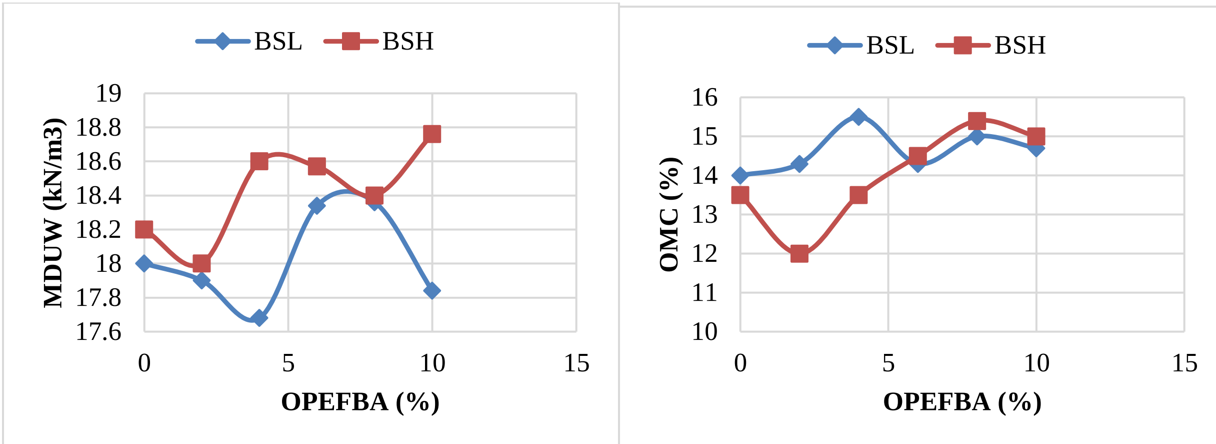

Figure 10: Variation of MDUW (a)/OMC (b) with OPEFBA content at 80S – 20B mixture

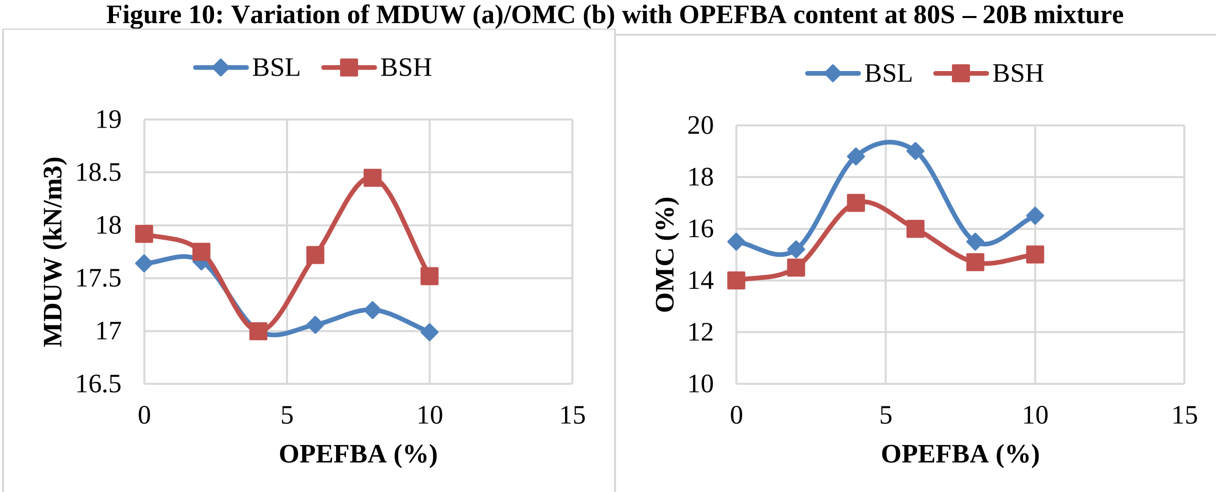

Figure 11: Variation of MDUW (a)/OMC (b) with OPEFBA content at 70S – 30B mixture

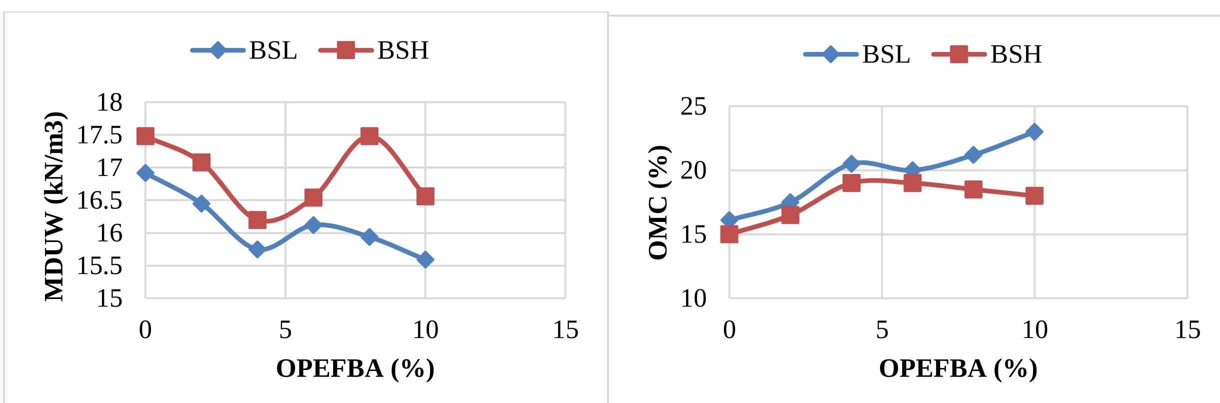

Figure 12: Variation of MDUW (a)/OMC (b) with OPEFBA content at 60S – 40B mixture

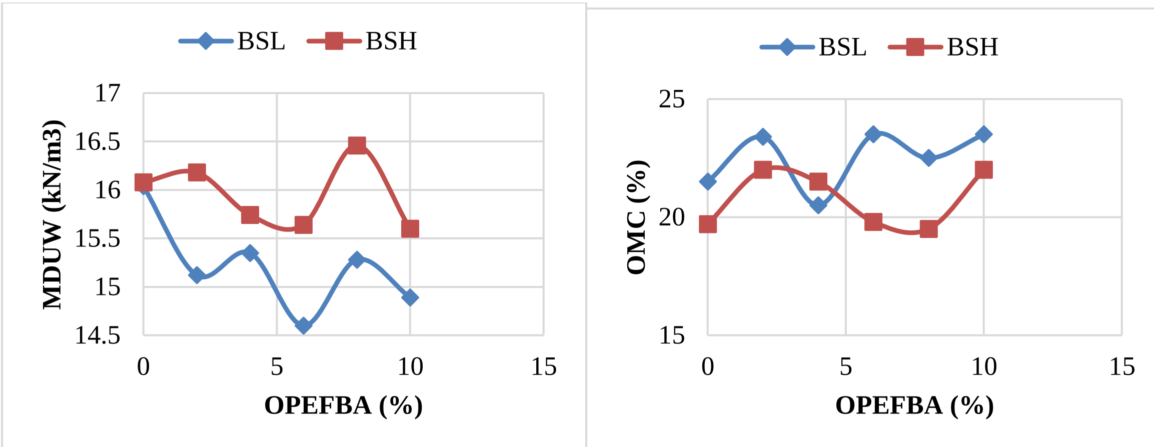

Figure 13: Variation of MDUW (a)/OMC (b) with OPEFBA content at 50S – 50B mixture

3.4 Statistical Analysis

Analysis of Variance (ANOVA) and regression were used in this section to examine whether there is effect of the independent variables (bentonite, OPEFBA and log of compaction energy (log E)) on the dependent variables (compaction results (MDD/OMC)) obtained from the test.

3.4.1 ANOVA

In the ANOVA, it was examined to know whether bentonite content and compactive effort (CE) are statistically significant. Table 2 and 3 shows the summary of result output for MDUW and OMC. In Table 2, F-values were greater than F-crit in each case. Therefore, p-values were less than 0.05 in all cases. This made both the bentonite and CE statistically significant. In Table 3 for OMC, similar trend was observed except for CE at 2% and 4% OPEFBA where F-value are less than F-crit. (p-value > 0.05).

Table 2: Summary of ANOVA for MDUW

Parameters	0% OPEFBA		2% OPEFBA		4% OPEFBA		6% OPEFBA		8% OPEFBA		10% OPEFBA	
	Bentonite	CE	Bentonite	CE	Bentonite	CE	Bentonite	CE	Bentonite	CE	Bentonite	CE
F	29.38	10.82	29.77	10.996	51.85	11.55	143.38	31.54	59.49	46.45	305.59	100.396
p-value	0.00103	0.0217	0.000998	0.0211	0.000262	0.0193	2.15E-05	0.0025	0.000187	0.00104	3.29E-06	0.000169
F-crit	5.05	6.61	5.05	6.61	5.05	6.61	5.05	6.61	5.05	6.61	5.05	6.61

Table 3: Summary of ANOVA for OMC

Parameters	0% OPEFBA		2% OPEFBA		4% OPEFBA		6% OPEFBA		8% OPEFBA		10% OPEFBA	
	Bentonite	CE	Bentonite	CE	Bentonite	CE	Bentonite	CE	Bentonite	CE	Bentonite	CE
F	10.176	6.307	1013.37	131.0726	50.141	6.019	42.497	18.024	28.539	11.143	20.611	9.047
p-value	0.01179	0.05374	1.66E-07	8.91E-05	0.000284	0.0577	0.000425	0.008813	0.001104	0.0206	0.00238	0.0298
F-crit	5.05	6.61	5.05	6.61	5.05	6.61	5.05	6.61	5.05	6.61	5.05	6.61

3.4.2 Regression Analysis

Regression analysis was also carried out and the following results were obtained for MDUW and OMC (Tables 4 and 5) respectively.

Table 4: Results of Linear Regression Analysis for MDUW

Variables	Coefficients	t -Statistics	p-value	Regression parameters	
Intercept	16.159	31.844	1.377E-42	R-Squared	0.913
Bentonite	-0.0783	-25.818	7.325E-37	Adjusted R Squared	0.909
OPEFBA	0.009	0.591	0.5564	Overall F-Statistics	238.669
Log E	1.112	7.007	1.38E-09	Observations	72

For MDUW, the p-value for the bentonite was less than 0.05 which showed that application of bentonite in the mixture is statistically significant. The p-value for OPEFBA is greater than 0.05 which shows that application of OPEFBA in the mixture is not statistically significant. The p-value for log E (BSL, BSH) is also statistically significant on the mixture. The observed standard error was 0.4395 which showed that the errors are minimal. From the regression coefficients,

MDUW = 16.159 – 0.0783B + 0.009OPEFBA + 1.12 log E (1)

Table 5: Results of Linear Regression Analysis for OMC

Variables	Coefficients	t -Statistics	p-value	Regression parameters	
Intercept	20.1819	8.219	7.95E-12	R-Squared	0.57603
Bentonite	0.1367	9.210	1.24E-13	Adjusted R Squared	0.56375
OPEFBA	9.59826	6.4281	5.698	Overall F-Statistics	46.8754
Log E	-2.3196	-2.9872	0.0039	Observations	72

For the OMC, the p-value for the bentonite is less than 0.05 which shows that application of bentonite in the mixture is statistically significant. The p-value for OPEFBA is greater than 0.05 which shows that application of OPEFBA in the mixture is not statistically significant. The p-value for log E (BSL, BSH) is also significant on the mixture. The observed standard error is 2.1509 which shows that there are more errors when compared to MDUW. From the regression coefficients,

OMC = 20.1819 + 0.1367B +9.59826 OPEFBA – 2.3196 log E (2)

Figures 14 and 15 show the plot of predicted and measured values based on the regression analysis results.

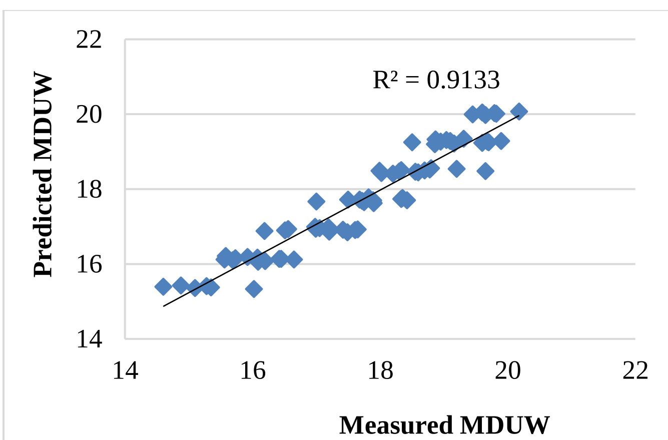

Figure 14: Predicted versus Measured values of MDUW

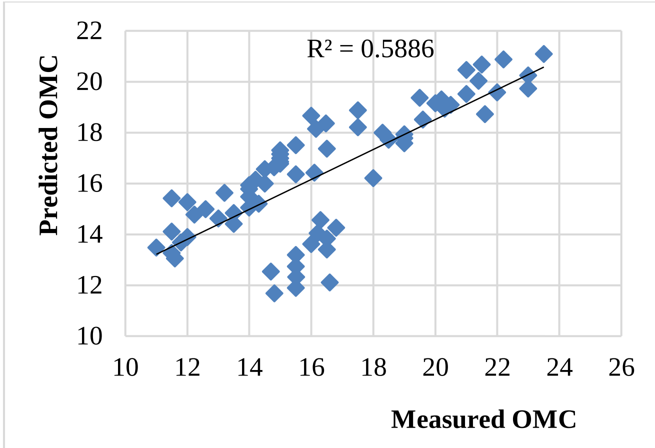

Figure 15: Predicted versus Measured values of OMC

4.0. Conclusion

Based on the result of the analysis, the following conclusion can be drawn from graphical representation of test results and regression analysis.

i. The increase in the percentage of bentonite in the mixtures affect the index properties of the soil such as the Atterberg limits incrementally. This is in agreement with Thakur and Yadar (2018) who showed continual increase in the liquid limit of sand-bentonite mixture from 21.18% at sand + 5% bentonite to 60.94% at sand + 25% bentonite. Also, the sand which is usually non-plastic become plastic at sand + 25% bentonite with a plastic limit of 29.02%.
ii. The linear shrinkage was observed to increase as the bentonite content and sand content increased.
iii. The addition of OPEFBA to the mixture affects the specific gravity in an undefined manner, caused reduction of plasticity index but increased the linear shrinkage mildly.
iv. The increase in bentonite affected the compaction characteristics of the mixture. The MDUW decreased in agreement with the work of Sobti and Sanjay (2017) who observed a decrease of MDUW from 16.86 to 16.27 kN/m^3 with increase in bentonite content from 5 to 40%.
v. The variation of OPEFBA does not have statistically significant effect on the compaction characteristics of sand-bentonite mixtures.
vi. Based on statistical analysis on compaction characteristics alone, it is evident that OPEFBA does not have significant effect on the MDUW and OMC of sand-bentonite mixtures. Regression equation developed could be viable to predict MDUW and OMC of sand-bentonite mixtures from independent parameters of bentonite, OPEFBA and log E. The R-sqaured values of 0.9133 for MDUW and 0.5886 for OMC were obtained. Removing the component of OPEFBA which is not presently statistically significant in the equation could give a better prediction accuracy. Though OPEFBA does not have significant effect on sand-bentonite mixtures, incorporating it into sand-bentonite mixtures can be an excellent way of disposing this waste.

5.0 Recommendation

Since the initial trial was not successful, it is recommended that experimental design should be carried out for the other possible combinations and investigated further. It is also recommended that shear strength tests, hydraulic conductivity and volumetric shrinkage tests should be carried out on such mix to ascertain its overall effect and suitability as additive in sand-bentonite mixtures for waste containment applications.

References

Agus, S.S., and Schanz, T., 2004. Swelling pressures and wetting-drying curves of a highly compacted bentonite-sand mixture. *In: Schanz, T. (ed.)*. From Experimental Evidence Towards Numerical Modelling of Unsaturated Soils, Springer, 241–256.

Amadi, A.A. and Eberemu, A.O., 2012. Delineation of compaction criteria for acceptable hydraulic conductivity of lateritic soil-bentonite mixtures designed as landfill liners. *Environmental Earth Sciences*, 67(4), 999-1006.

ASTM D854 – 14: Standard test methods for specific gravity of soils by water pycnometer.

Benson, C.H. and Trast, J.M., 1995. Hydraulic conductivity of thirteen compacted clays. *Clays and Clay Minerals*, 43 (6), 669-681.

BS 1377, 1990. Methods of tests for soils for civil engineering purposes. British Standards Institution, London.

Chapuis, R.P., 1981. Permeability testing of soil-bentonite mixtures. Proceedings of 10th International Conference on Soil Mechanics and Foundation Engineering, Stockholm, 4, 744-745.

Ghazi, A. F., 2015. Engineering characteristics of compacted sand-bentonite mixtures. Https://ro.ecu.edu.au/theses/1615.

Haug, M.D. and Wong, L.C., 1992. Impact of molding water content on the hydraulic conductivity of compacted sand-bentonite liner material. *Canadian Geotechnical Journal*, 29, 253-262.

Khalid, N., Mukri, M., Kamarudin, F., Abdul Ghani, A.H., 2020. Effect of compaction characteristics on hydraulic conductivity performance for sedimentary residual soil mixed bentonite as compacted liners. IOP Conference Series: Earth and Environmental Science, 498, 1-9. Doi:10.1088/1755-1315/498/1/012003.

Meier, A.J. and Shackelford, C.D., 2017. Membrane behavior of compacted sand–bentonite mixture. *Canadian Geotechnical Journal*, 54, 1284–1299. Dx.doi.org/10.1139/cgj-2016-0708.

Proia, R., Paolo, C., Mondoni, G., 2016. Experimental investigation of compacted sand-bentonite mixtures. VI Italian conference of researchers in geotechnical engineering. CNRIG 2016.

Sivapullaiah, P.V., Sridharan, A., Stalin, V.K., 2000. Hydraulic conductivity of bentonite-sand mixtures. *Canadian Geotechnical Journal*, 37(2), 406-413.

Sobti, J. and Sanjay, K., 2017. Strength and compaction analysis of sand-bentonite –coal ash mixes. IOP Conference series: Materials science and Engineering, 225, 012091.

Stoicescu,J. T.,Haug, M. D., Fredlund, D. G., 1998. The soil-water characteristics for sand-bentonite mixtures used for liners and covers. Proceeding of the Second International Conference on Unsaturated Soils, Beijing, China, August 27 - 30, 1, 143 -148.

Thakur, Y. and Yadav, R.K., 2018. Geotechnical characteristics of compacted sand-bentonite mixtures. International *Journal for Research in Applied Science & Engineering Technology (IJRASET)*, 6 (3).

Vanapalli, S.K., Lu, L. Infante Sedano, J.A., Oh, W.T., 2012. Swelling characteristics of sand-bentonite mixtures. DOI: 10.1007/978-3-642-31343-1_10.