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EVALUATION OF COMPACTION CHARACTERISTICS OF IRON ORE TAILINGS TREATED WITH BENTONITE

***Okoro, I. J.[1]; Amadi, A. A.[2]; Alhassan, M[3] & Agbese, E.[4]**
[1,2,3,4] Department of Civil Engineering Federal University of Technology, Minna
*Corresponding author email: isiuwaokoro@gmail.com

ABSTRACT

This paper reports the evaluation of compaction parameters (optimum moisture content and maximum dry density) of Iron Ore Tailings mixed with bentonite (IOT-bentonite mixtures) as a potential material for landfill liner purposes. Different percentages of bentonite (20, 25, 30, 35 and 40%) by dry weight of IOT were added to IOT and the mixtures evaluated in this study. Laboratory tests to evaluate the index properties and compaction characteristics of the mixtures were conducted. The index properties of the mixtures were also seen to improve with increase in bentonite content. The liquid limits of the mixtures containing 25 to 40% were seen to increase from 31 to 34.5% while their plasticity index also increased from 12.1 to 19.8%. These values satisfy the liquid limit and plasticity index requirements for landfill liners as reported in some regulatory codes. The mixtures were compacted using three compactive efforts namely British Standard Light (BSL), West African Standard (WAS) and British Standard Heavy (BSH) which simulates compaction efforts expected in the field. Findings show an increasing trend in the Optimum Moisture Content (OMC) and decreasing trend in the Maximum Dry Density (MDD) of the mixtures with increase in bentonite content. The OMC increased from 13.0 to 16.9% for BSL, 11.0 to 12.8% for WAS and 8.8 to 10.1% for BSH. While their MDDs decreased from 2.34 to 2.14 g/cm^3 for BSL, 2.47 to 2.38g/cm^3 for WAS and 2.5 to 2.42g/cm^3 for BSH..

Keywords: *Bentonite, Compaction characteristics, Iron ore tailings, Landfill liner.*

1 INTRODUCTION

Iron ore tailing (IOT) is the mining waste left over from the iron ore industry after the process of separating the valuable fraction from the worthless fraction of an ore. Increase in mining activities in the world has brought about tremendous generation of tailings which causes environmental pollution and also require a large portion of land for disposal. The composition of tailings is directly dependent on the composition of the ore and the process of mineral extraction used on the Ore (Adedeji and Sale, 1984).

Recent research works have been geared towards effective utilization of iron ore tailings as a partial replacement of other materials in construction and engineering works such as, landfilling, brick production and concrete production. In concrete production, it has been used as a partial replacement for other materials by several authors. Results obtained met the required design and in some cases more economical compare to the conventional materials used (Shetty *et al*., 2014; Ugama *et al*., 2014; Bakulamba *et al*., 2015 and Tiwari *et al.*, 2017). IOT mixed with other materials for land fill liner have also been studied by a few authors with their compaction characteristics reported (Manjunatha and Sunil, 2013; Umar *et al*., 2015).

The use of IOT alone as landfill liner is not feasible as a result of its properties especially its permeability which is the primary function of a landfill liner. Therefore, other materials such as bentonite with low permeability can serve as suitable admixture to enhance and complement the IOT for landfill liner application.

Bentonite is a montmorillonite type of clay having relatively small pore spaces occupied by water which leads to reduction in hydraulic conductivity. Hence, it is preferred as blended soil and it is widely used for landfill liner due to its low permeability (Nithi *et al.*, 2017).

Many engineers in a bid to predict the hydraulic conductivity of land fill liner carry out compaction test to study the interpretation of moisture content-dry density relationship. The relationship between dry density, moisture content and hydraulic conductivity is correctly interpreted for specific soil type in order not to mislead the engineers by the scattered values and manner of presentation (Wright *et al.*, 1996). It is also important to determine the index properties of landfill liner material in order to ascertain its suitability for the purpose. The liquid limit of landfill liner material is required to be between 30 to 60% and the plasticity index should be between 12 to 30% (Daniel, 1993).

Even though IOT-bentonite mixture is to be used as landfill liner, compaction by mechanical means is required to modify and improve its engineering properties. The main objective of compaction is to increase the soil density and reduce the air voids between the soil particles. OMC and MDD are compaction parameters required to evaluate the compaction characteristics of the mixture. These parameters are also important in other construction projects such as road and railway embankments, earth dams and backfills of retaining structure.

Most compacted earthworks, different molding moisture content often result in different dry densities under the same compaction energy. A constant value of energy applied to a particular type of soil, at optimum moisture content, leads to a maximum dry density. The MDD and OMC are unique for various types of soils and vary with the type of soils and the compaction energy (Jesmani *et al*., 2008). According to Umar *et al.* (2016), hydraulic conductivity generally decreases with increase in compactive effort.

Results obtained from several authors in the use of soil mixed with bentonite as liner materials has shown that increase in bentonite content in their mixtures resulted to an increase in optimum moisture content (OMC) and consequently decreases the maximum dry densities (MDDs) of the mixtures (Akgun *et al*. 2006; Amadi and Eberemu, 2012; Vijayan *et al*. 2016; Jaskiran and Sanjay, 2017; Nithi *et al.* 2017).

Manjunatha and Sunil (2013) carried out a research using polymetallic iron ore tailings, with lime and fly ash added as candidate material. The specific gravity of the mixture with the highest fly ash content of 40% was seen to be the least. The result obtained from the compaction characteristics of the mixtures containing IOT and flyash showed that the MDD decreased as the OMC increased with increase in fly ash content of the mixtures and this was attributed to the low specific gravities of fly ash as an additive blended with the tailings.

Khalid and Mukri (2017) stated that MDD and OMC were affected by the compaction energy applied to soil sample whether the soil was mixed or not with addition of bentonite. It was seen from their study that the increment in percentages of bentonite resulted in reduction of MDD and a consequent increase in OMC.

Jaskiran and Sanjay (2017) in their research on compaction characteristics of sand-bentonite mixtures reported a decrease in MDD as the OMC increases with increase in bentonite content. It was also reported that decrease in MDD may be attributed to the decrease in specific gravity, while the increase in OMC to the higher clay content requiring more water to hydrate the soil particles in the mix.

Jesmani *et al*., (2008) reported from their study that an addition of clay content (beyond 20%) to soil leads to decrease in MDD. This decrease in MDD was said to be due to increase in fine grains which causes the coarse grains to be away from each other and this changes the soil state from semi-buoyant to buoyant. Also, the OMC was said to increase due to the increase in clay content of the mixtures, since generally for obtaining MDD by increasing clay content, larger optimum water content is needed.

From the foregoing, several authors have carried out research on the compaction characteristics of soil-bentonite mixtures to determine their compaction parameters as well as the use of IOT as partial replacement of other materials for construction purposes. To the authors' knowledge there is no information about the index properties and compaction characteristics of IOT-bentonite mixtures with IOT as the major material treated with bentonite.

This paper therefore presents the study of index properties and compaction characteristics of bentonite added at different percentages by dry weight of IOT to iron ore tailings in geo-environmental engineering. The effect of compactive efforts on the IOT-bentonite mixtures was also analysed.

Iron ore tailings (IOT): The IOT used in this study was locally sourced from the National Iron Ore Mining Company (NIOMCO), Itakpe in Ajaokuta, Kogi state, Nigeria. The Itakpe Iron Mining Project is a ferruginous quartzite deposit of geological reserve amounting to 200 million tonnes (Olubami and Potgieter, 2005; Elinwa and Maichibi, 2014; Umar *et al*., 2015). The waste material from the processing was approximately 64% which translated into 3,072 tonnes per day (Ajaka, 2004). The mineralogical characterization of Itakpe iron Ore shows that it contains mainly hematite, magnetite and quartz (Adedeji & Sale, 1984; Olubami and Potgieter, 2005; Nwosu *et al*., 2013).

Bentonite: Bentonite used in this study was Na-bentonite and it is the same as those used by Amadi and Osinubi, (2017). It was locally sourced from commercial suppliers in Kaduna, Kaduna state, Nigeria.

2 METHODOLOGY

Sieve analysis was carried to determine the particle size distribution of the IOT, specific gravity tests, atterberg limit tests and compaction test of the IOT-bentonite mixtures were also carried out.

2.1 PARTICLE SIZE DISTRIBUTION ANALYSIS

The IOT was washed with water using sieve size of 0.75μm in order remove the fine portion of the sample after which the mass retained in the sieve was dried in the oven for 24 hours before carrying out the sieve analysis.

2.2 INDEX PROPERTIES

Index properties including consistency limits and specific gravities of the IOT-bentonite mixtures were determined in accordance with BS1377 standard procedures. The Atterberg limit test for determining the liquid limit was carried out using the cone penetrometer.

2.3 COMPACTION TEST

Pulverized air dried bentonite and iron ore talings was used to prepare the samples by adding 20, 25, 30, 35 and 40% bentonite by dry weight of IOT to IOT portion. The samples were first mixed in dried state; 3000g of each mixture was measured for the compaction test with water is added and mixing done simultaneously. Properties of the compaction test is summarised in Table I, with the different compaction energy produced from each compactive effort.

The five mixtures were compacted using British Standard Light (BSL), West African Standard (WAS) and British Standard Heavy (BSH) compactive efforts. The BSL (standard proctor) and BSH (modified standard proctor) compaction were carried out in accordance with the British Standards (BS1377: Part 4:1990), while the WAS was carried out in accordance with the Nigerian General Specification, (1997). A total of 15 samples were prepared for determination of moisture-density relationships of the mixtures.

Characteristics	Concentration
V_2O	0.02%
MnO	0.05%
Fe_2O_3	76.84%
pH	13.1%

Adapted from Umar *et al*., (2016).

TABLE 1 PROPERTIES OF COMPACTION

Type of compaction	Weight of rammer (kg)	Height of fall (m)	Number of blows	Number of layers	Compaction energy (KNm/m)
BSL	2.5	0.300	27	3	596.4
WAS	4.5	0.450	10	5	993.9
BSH	4.5	0.450	27	5	2683.7

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3 RESULTS AND DISCUSSION

The physio-chemical properties of IOT and bentonite are shown in Table 2 and 3. Their specific gravities were obtained as 3.1 and 2.34 respectively in accordance with BS 1377 and the specific gravities of the IOT-bentonite mixtures with bentonite in percentages of 20, 25, 30, 35 and 40 % gave values of 2.60, 2.67, 2.64, 2.62 and 2.55. This decrease in specific gravities was attributed to the increase in bentonite content as a result of its low specific graavity (Manjunatha and Sunil, 2013).

TABLE II: CHEMICAL CHARACTERISTICS OF IOT

Characteristics	Concentration
SiO_2	20.2%
K_2O	0.30%
CaO	0.53%
TiO_2	0.18%

TABLE III: CHEMICAL COMPOSITION OF BENTONITE

Chemical composition	Value (%)
SiO_2	58.14
Al_2O_3	21.73
Fe_2O_3	2.46
TiO_2	1.86
CaO	0.86
MgO	2.42
P_2O_5	0.119
Cr_2O_3	0.007
K_2O	0.52
Na_2O	2.08
MnO	0.07

Adapted from Amadi and Osinubi, (2017).

3.1 PARTICLE SIZE DISTRIBUTION

The result obtained from the sieve analysis shows that the IOT contains 98.8% sand and 0.6% gravel. The particle size distribution of IOT is shown in Figure 1.

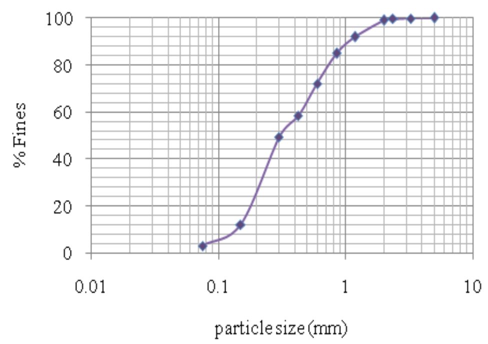

FIGURE 1: PARTICLE SIZE DISTRIBUTION CURVE (IOT)

3.2 INDEX PROPERTIES

The result obtained from the atterberg limit test shows that the liquid limit and plastic index increased with an increase in bentonite content. The liquid limit ranged from 27.0 to 34.5%, while the plastic index ranged from 8.5 to 19.48%. All other mixtures except that with 20% bentonite met the requirement of landfill liner according to Daniel, (1991) in the literature review. The liquid limit of mixtures containing 25 to 40% bentonite ranged from 31 to 34.5% and their plasticity index from 12.1 to 19.45%. Figure 2 shows the variation of consistency limits with bentonite content.

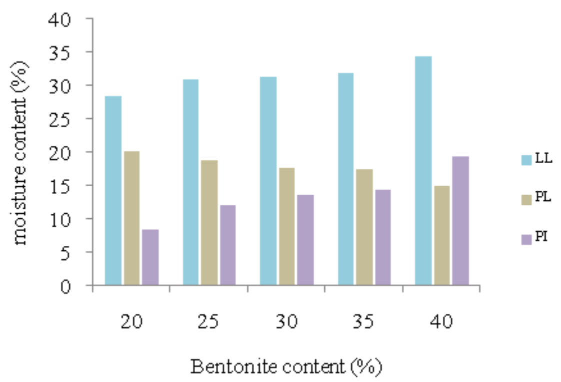

FIGURE 2: VARIATION OF CONSISTENCY LIMITS WITH BENTONITE CONTENT

3.3 COMPACTION CHARACTERISTICS

Figure 3 and 4 shows the effect of bentonite content on the MDD and OMC of the mixtures. It can be seen that the MDD decreased with higher bentonite content while the OMC increased with increase in bentonite content. The MDD ranged from 2.34 to 2.14g/cm^3 at 20 to 40% bentonite content for BSL, 2.47 to 2.38g/cm^3 % for WAS and 2.50 to 2.42 g/cm^3 for BSH. While the OMC ranged from 13 to 16.9% at 20 to 40 % bentonite content for BSL, 11.0 to 12.8% for WAS and 8.80 to 10.1% for BSH. This trend is similar to that found by Akgun *et al*. (2006); Jesmani *et al*. (2008); Vijayan *et al*. (2016); Amadi and Eberemu, (2012); Jaskiran and Sanjay, (2017) as well as Nithi *et al*. (2017). Jaskiran and Sanjay, (2017) explained that the decrease in MDD is attributed to the decrease in specific gravities of the mixtures as a result of increase in bentonite content which is also seen in the present study. The increase in fine grain fraction from bentonite led to a decrease in MDD, while the OMC of the mixtures increased with the increase in clay content as a result of more water needed to provide good lubrication. This is also similar to the report found by Jesmani *et al*., (2008).

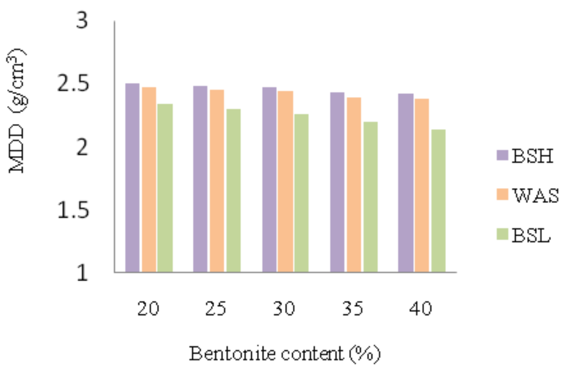

FIGURE 3: EFFECT OF BENTONITE CONTENT ON MDD OF MIXTURES.

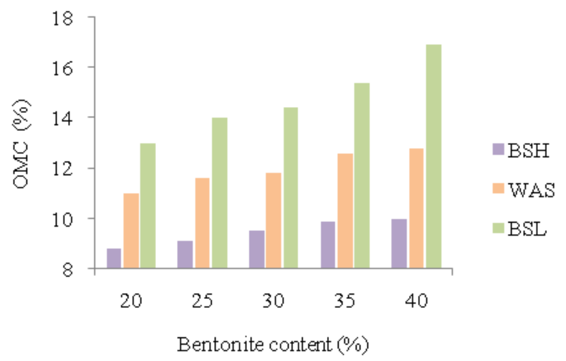

FIGURE 4: EFFECT OF BENTONITE CONTENT ON OMC OF MIXTURES

The effect of compaction energy on the MDD and OMC of the mixtures are presented in Figures 5 and 6. The result showed an increase in MDD and a decrease in OMC as compactive effort increased. The OMC ranged from 8.8 to 16.9% for the three compactive efforts used, while their MDD ranged from 2.14 to 2.50g/cm^3. This trend is consistent with the results reported in the literature review (Khalid and Mukri, 2017; Manjunatha and Sunil, 2013).

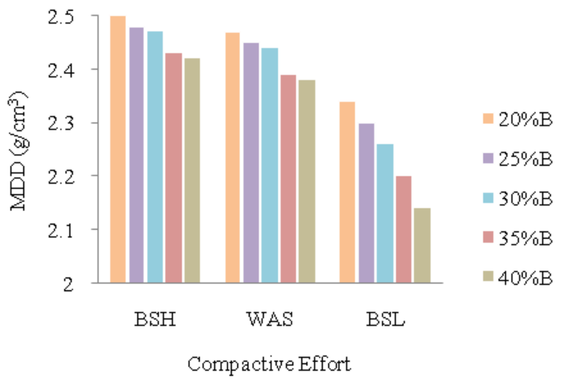

FIGURE 5: VARIATION OF MDD WITH THE DIFFERENT COMPACTIVE EFFORTS AT DIFFERENT PERCENTAGE OF BENTONITE CONTENT.

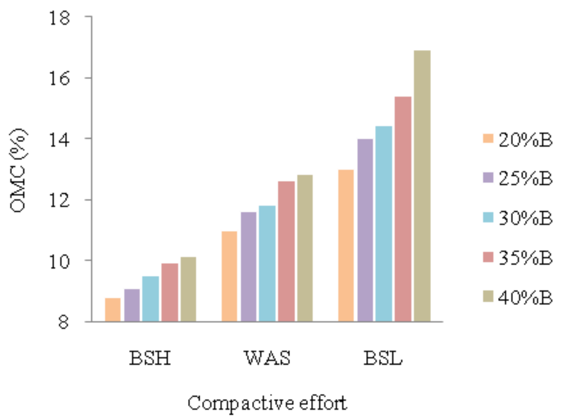

FIGURE 6: VARIATION OF MDD WITH THE DIFFERENT COMPACTIVE EFFORTS AT DIFFERENT PERCENTAGE OF BENTONITE CONTENT

4 CONCLUSION

The present study evaluated the compaction parameters of IOT treated with varying percentages of bentonite from the study, the following conclusions were drawn.

1. The liquid limit of IOT- Bentonite mixtures with 20 to 40% bentonite content is seen to increase gradually between 28.5 and 34.5%, while the plasticity index increases from 8.4 to 19.48%. All other mixtures except the mixture containing 20% bentonite content satisfied the requirements for landfill liner.
2. The specific gravities of the mixtures decrease with increase in bentonite content and this is attributed to the clay content found in bentonite.
3. With bentonite content of 20 to 40% by dry weight of IOT added as blending material to IOT, an increasing trend is found in the OMC while the MDD decreases. The increase in OMC was attributed to increase in bentonite content as more water is needed to lubricate the mixture. The MDD also decreased as a result of reduction in specific gravities with increase in bentonite content.
4. An increase in compactive effort increased the MDD while a decreasing trend was achieved for OMC. The decrease in MDD as a result of higher compactive efforts is said to give a lower hydraulic conductivity for landfill liner.

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