Novelty Journals

ISSN 2394-7357

International Journal of Novel Research in Civil Structural and Earth Sciences
Vol. 12, Issue 3, pp: (22-32), Month: September - December 2025, Available at: www.noveltyjournals.com

HYDRAULIC CONDUCTIVITY OF LATERITIC SOIL BENTONITE MIXTURE TREATED WITH RICE HUSK ASH FOR WASTE CONTAINMENT APPLICATION

Engr. F. I Ofondu[1], Bldr.J. O Emery[2], Engr. Dr. N.C. Mmowuba[3]

[1]Civil Engineering Dept.

[2]Building Technology Dept. Ogbonnaya Onu Polytechnic, Aba

Civil Engineering Dept. Chukwuemeka Odimegwu Ojukwu University, Uli Anambra State

DOI: https://doi.org/10.5281/zenodo.17176573

Published Date: 22-September-2025

Abstract: **The Natural Lateritic soil treated with up to 30% Bentonite and 20% Rice husk ash compacted using British standard light Compactive Effort, The effect of addition of Bentonite, Rice Husk Ash and Hydraulic Conductivity, were investigated to know if the Natural lateritic soil geotechnical properties can be improved to be suitable for liner in waste containment system. The results concluded that hydraulic conductivity were greatly reduced on increasing addition of bentonite and rice husk ash there by increasing the performance of natural lateritic soil in waste containment system.**

Keywords: **bentonite, rice husk, Hydraulic Conductivity and waste containment.**

1. INTRODUCTION

The challenges of solid waste management in most developing and under developed countries, has increased in recent times due to increase in population, industrialization, urbanization and globalization. Most developing countries spend huge amounts of financial resources on certain solid waste management aspects which does not necessarily lead to improvements in the quality of service. This trend is as a result of the consistent growth in the amount of Municipal Solid Waste (MSW), which is one of the main consequences of urban lifestyle. It is thus necessary for wastes to be managed properly and disposed in the most acceptable manner so as to reduce its resultant effect on humans, plants, animals and the environment (Ike, Ezeibe, Anijiofor, Nik-Daud, 2018).

Obviously, agricultural and industrial waste materials have attracted considerable interest in recent years for soil stabilization or construction. They have shown promising potentials that it could serve as a partial replacement/supplement for cement or as a filler material in soils for components of highway pavements, waste containment barriers or earth embankments. Huge quantities of mineral, agricultural, domestic and industrial waste materials are generated every day. Consequently, safe disposal and proper handling are increasingly becoming a major concern around the world. In the effort to solve the environmental problems associated with the increasing amount of wastes in many parts of the world, so much have been done to economically utilize them for useful purposes. More often, the wastes are recycled and re-used. However, this is difficult in most developing countries because of the complex nature of the composition of the waste materials. Sanitary landfill is one of the most cost-effective systems of disposal/handling solid wastes in most urban areas of developing and industrialized nations (Okonkwo, Arinze and Ugwu, 2018).

Effective liner system in landfills are essential in protecting groundwater from leachate contamination as communities depends on groundwater for consumption due to increasing contamination of available surface water sources. Engineered landfill are important sealing systems employed as containment strategy for waste disposal. It inhibits infiltration of precipitation, incidental discharge and leachate into the subsoil and groundwater. Engineered landfills is one of the best method of overcoming waste disposal crisis associated with groundwater contamination with leachate. Liner system in an engineered landfill acts as a barrier for leachate and prevents the transportation of contaminants to the surrounding pollution prone environment. Hence, liner system in a landfill becomes one of the critical design considerations (Olaoye, Afolayan, Oladeji, and Sani, 2019).

Furthermore, a barrier material (liner and cover) is usually subjected to imposed load from the waste and from machines during its active life, while the waste constitutes major load during the post closure period. It is required that the barrier material should not fail due to the weight of these imposed loads. It was therefore recommended that a liner material should have a minimum unconfined compressive strength (UCS) of 200kN/m2 to be able to withstand the stress from the waste and alternate wet/drying cycles (Ochepo, 2020).

Soil is one of the most important engineering materials. The geotechnical properties of a soil such as its grain-size distribution, plasticity, permeability and shear strength etc. can be assessed by proper laboratory testing. Soil alone has very specific properties that may not be appropriate for different types of constructions. Thus admixtures are necessary to improve the geotechnical properties of soil. Use of admixtures is one way of modifying soil properties (Pluming, Hussain, Basar and Nikang, 2016).

The use of bentonite can be very effective in increasing plasticity of a soil. Bentonite is a highly expansive soil. It exhibits a tendency of swelling on coming in contact with water and shrinks on removal of water. In case of bentonite, free swelling is up-to ten times to fifteen times to its original volume. Bentonite clay is a unique clay due to its ability to produce an electrical charge when hydrated. Upon contact with fluid, its electrical components changes giving it the ability to absorb toxins. Bentonite is known for its ability to absorb and remove toxins, heavy metals, impurities, and chemicals (Pluming et al., 2016). Due to its high swelling, lower hydraulic conductivity and containment adsorption capacity, bentonite forms an integral part of a liner and buffer material. The clay has been used extensively as soil amendment for compacted soil barrier in waste landfill barrier system. However, high compressibility, high desiccation shrinkage, low shear strength and low compaction density are reasons of concern (Srikanth and Mishra, 2016). Thus, Nigeria being the highest producer and consumer of rice in West Africa (Fabiyi et al., 2018). Disposal of Rice husk has encountered different constrains. The use of agricultural waste such as rice husk will considerably reduce the cost. Rice husk an agricultural waste obtained from milling of rice. About 108 tons of rice husk is generated annually in the world. Hence, use of Rice Husk for improvement of soil property should be encouraged (Pluming et al. 2016). Interestingly, the most widely used agricultural waste is rice husk, whose capabilities as a potential bio-adsorbent has been exploited since ages. Rice husk is made up of lignin, cellulose, hemicellulose, and mineral ash, as a result of which, it is chemically and mechanically stable as well as insoluble in water. Water containing heavy metals when treated with rice husk shows the removal of cadmium, copper, zinc, and chromium to a great extent. Various different factors can affect the adsorption rate of rice husk such as adsorbent concentration, temperature, pH, as well as size of particles. RHA (rice husk ash) produced from burning rice husk is a potential adsorbent for removing heavy metal such as Zn, Ni, and Pb. RHA main component is silica (80%, 89%), as a result of which it has been used to produce low-cost precursors and value-added silica (Soni, Bhardwaj, and Shukla, 2020). Burning of rice husk generates about 15-20% of its weight as ash. Rice husk is extremely prevalent in East and South-East Asia because of the rice production in this area. Meanwhile, the ash has been categorized under pozzolana, with about 67-70% silica and about 4.9% and 0.95%, alumina and iron oxides, respectively. And silica is a very good admixture to increase the soil strength. The high percentage of silicious materials in the RHA makes it an excellent material for soil stabilization. Also high percentage of silica reduces the plasticity of clayey soils (Pluming et al. 2016).

In this study effort was made to modify the properties of a lateritic soil which were poor and unsuitable for use as liner, by adding bentonite as well as varying percentage RHA content in order to improve the hydraulic conductivity, HC, as well as the strength, UCS, of the material for use as liner in engineered waste containment system.

The aim of this paper is to show the suitability of rice husk ash-modified lateritic soil- bentonite mixtures as waste containment liner materials which it is expected to help improve the compacted strength of the liner materials, reduce its hydraulic conductivity and its susceptibility to leakages.

Novelty Journals

ISSN 2394-7357

International Journal of Novel Research in Civil Structural and Earth Sciences
Vol. 12, Issue 3, pp: (22-32), Month: September - December 2025, Available at: www.noveltyjournals.com

2. MATERIAL AND METHODS

2.1 Materials

The materials used for the work were laterite, sodium bentonite and rice husk ash. The laterite was collected from Aba North Local Govermnent area of Abia State of Nigeria. Aba is well known city in Nigeria and West Africa for harbouring the largest Ariaria International market in the region. The sodium bentonite was bought from borehole materials suppliers at Ariaria International market. Rice husk were collected from rice farmers and rice husk producers at Agbazu and Eluama village in Bende local government area of Abia State.

2.2 Sample preparation

The laterite when collected was transported to the Geotechnics laboratory of Ogbonnaya Onu Polytechnic, Aba 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 adtilterated sodium bentonite products in the market, the sodium bentonite upon purchase was tested by appropriate means to ensure that it is original product. The rice husk (RA) collected from different rice processing sites.

The RA upon collection were sun-dried within one to two weeks to expel all entrapped water. Thereafter, they were burnt in an electronic kiln furnace at the temperature of 700°Cat Scientific Equipment Development Institute (SEDI), Enugu. After burning, the ash was sieved to remove large particles.

3. METHODS

3.1 Basic Characterization Tests

Soil index property and classification tests namely, natural moisture content, specific gravity, particle size distribution and Atterberg limits tests were performed on the lateritic soil. These tests were conducted at the Geotechnical Engineering laboratory, Ogbonnaya Onu Polytechnic, Aba according to British Standard Institute (1990) i.e. BS 1377:1990 as follows; moisture content (BS1377:1990 Part 2:3), Atterberg limit tests (BS1377:1990 Part 2:4 & 2:5), specific gravity (BS1377:1990 Part 2:8), density tests (BS1377:1990 Part 2:7), particle size distribution (BS1377:1990 Part 2:9).

3.2 Oxide composition.

The oxide composition of RHA was determined at defense industry cooperation of Nigeria (DICON), Kaduna, Nigeria, using the method of X-Ray Fluorescence (Nuclear Energy Test).

Table 1: Chemical Properties of Laterite, Bentonite, Rice Husk

Oxides	Concentration for Laterite (%)	Concentration bentonite (%)	Concentration for Rice Husk
SiO_2	80.539	53.139	75.969
V_2O_5	0.093	0.179	0.003
Cr_2O_3	0.069	0.036	0.014
MnO	0.042	0.093	0.37
Fe2O3	3.142	17.212	1.6
Co3O4	0.014	0.074	0.004
NiO	0.003	0.013	0.001
CuO	0.040	0.049	0.052
Nb2O3	0.009	0.031	0.005
MoO3	0.003	0.001	0.004
Wo3	0.006	0.000	0.003
P2O5	0.079	0.144	12.380
SO3	0.139	0.612	0.525
CaO	0.249	2.263	1.805
MgO	0.276	0	0
K2O	3.386	1.729	6.085
BaO	0.084	0.043	0.005

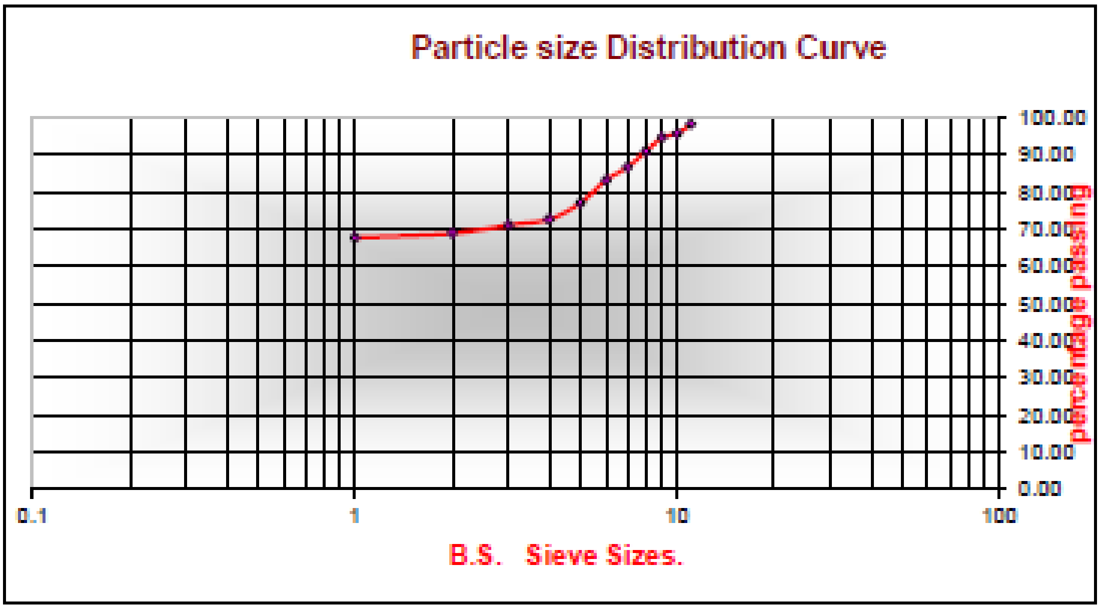
International Journal of Novel Research in Civil Structural and Earth Sciences
Vol. 12, Issue 3, pp: (22-32), Month: September - December 2025, Available at: www.noveltyjournals.com

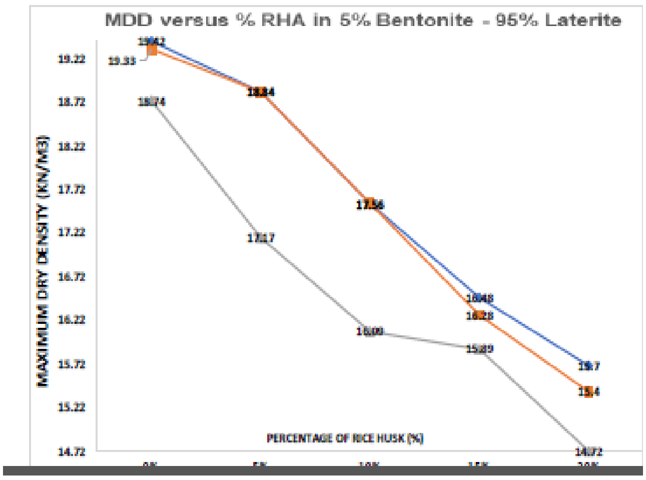
A12O3	9.135	19.304	0.358
Ta205	0.043	0	0.013
TiO2	1.570	2.714	0.105
ZnO	0.006	0.046	0.079
Ag2O	0.020	0.014	0.003
Cl	0.640	2.123	0.612
ZrO2	0.377	0.181	0.006
SnO2	0.034	0	0

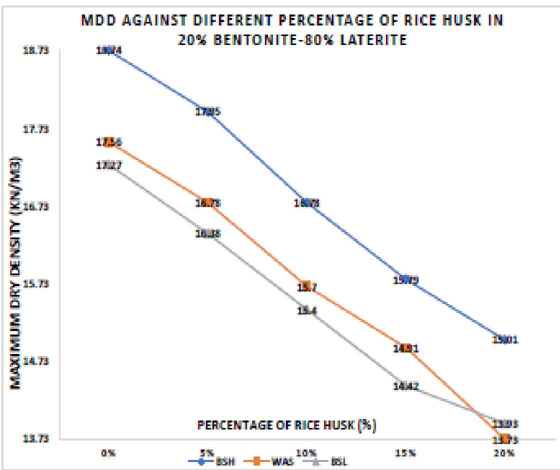
4. RESULT AND DISCUSSION

Table 2; Particle Size Distribution of Laterite

Total Weight of Dried Soil Sample Before Washing: 500g.





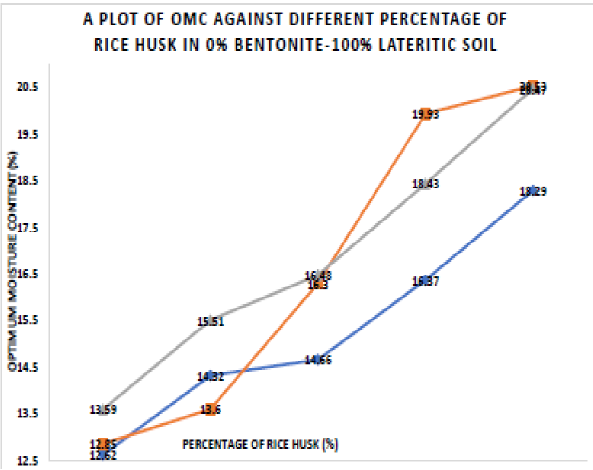


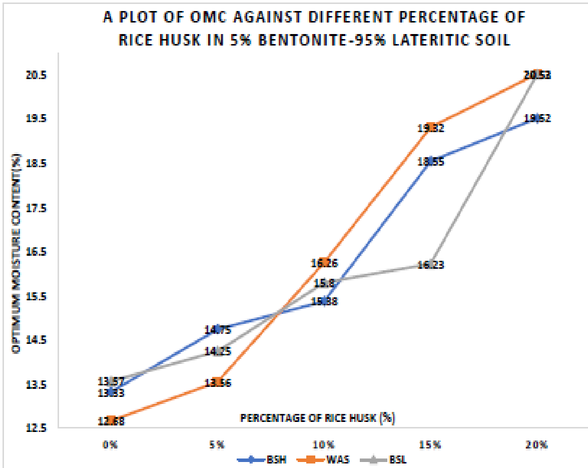
International Journal of Novel Research in Civil Structural and Earth Sciences
Vol. 12, Issue 3, pp: (22-32), Month: September - December 2025, Available at: www.noveltyjournals.com

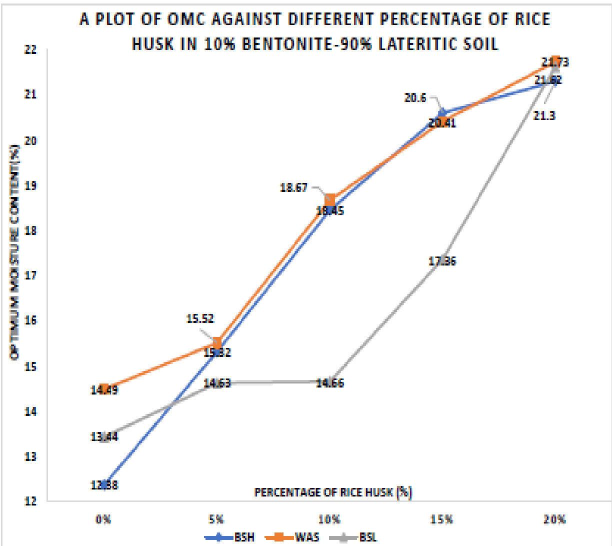
Highest maximum Dry Density (19.12KN/M3) occurred at 5% Bentonite-95% laterite with addition of 0% Rice husk ash. While the lowest MDD (Maximum Dry Density) occurred [13.15KN/M3] at 30% Bentonite 70% lateritic soil with addition of 20% Rice husk ash.

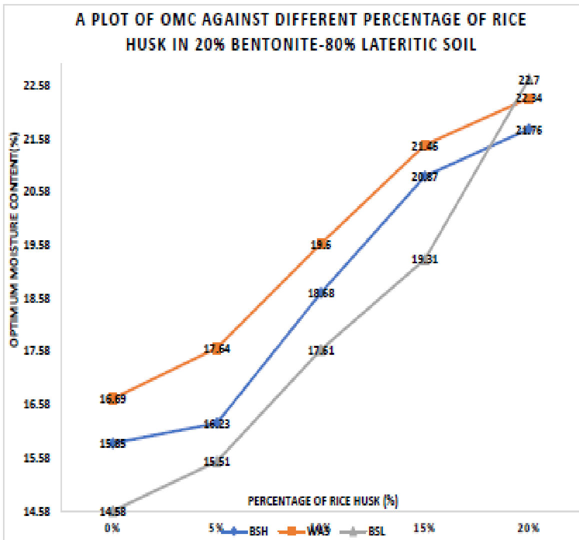
It can be observed generally that increase in Rice husk ash brought decrease in maximum dry density while increase in compactive effort [BSH, WAS, BSL] tend to increase maximum dry density. It can also be observed that up to 5% addition of Bentonite in laterite brought about increase in maximum dry density. Further increase in Bentonite brought about decrease in maximum dry density. Suggesting 5% Bentonite-95% laterite as optimal mix design for best performance in maximum dry density.

4.1.2 Results of Optimum Moisture Content during Compaction









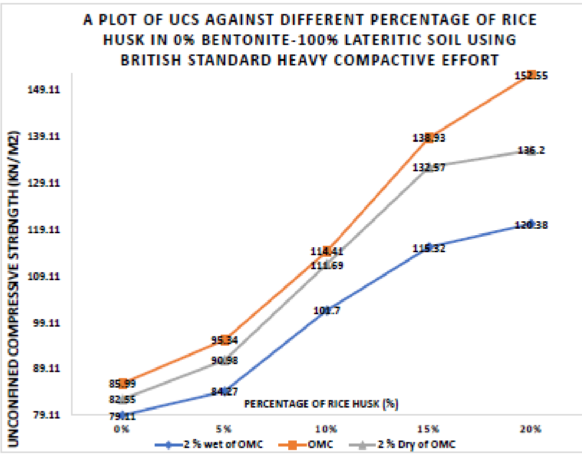
It can be observed that British Standard heavy gave the best performance in terms of optimum moisture content recording a maximum of 23.77% in 20% RHA-30% Bentonite-70% laterite while also a recording a lowest OMC of 12.38% in 5% Rice husk ash-10% Bentonite-90% laterite mixture. It can also be generally observed from the graphs that increase in Rice husk ash percentage in Bentonite laterite mixture brought about increase in optimum moisture content.

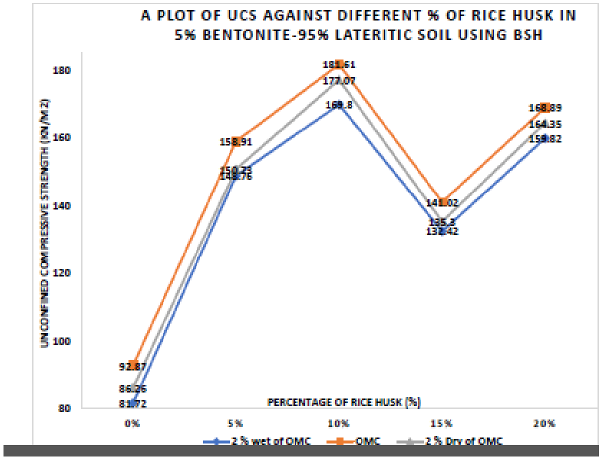
International Journal of Novel Research in Civil Structural and Earth Sciences
Vol. 12, Issue 3, pp: (22-32), Month: September - December 2025, Available at: www.noveltyjournals.com

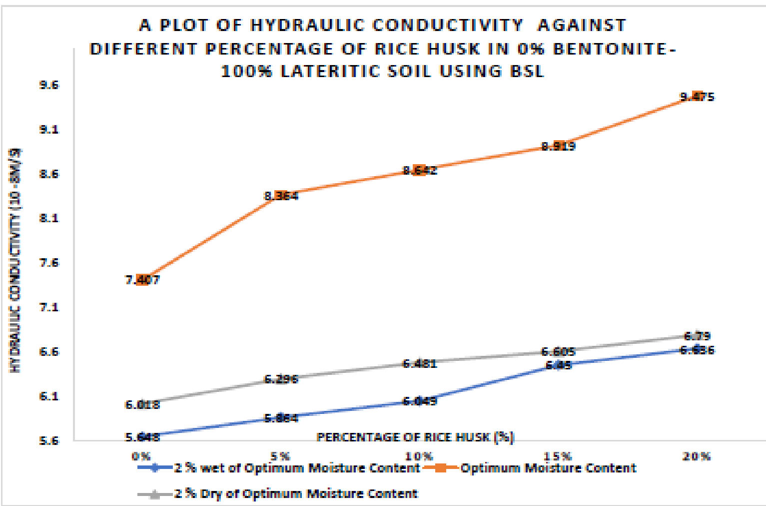
More so, increase in percentage of Bentonite also brought about increase in optimum moisture content. Also increase in Compactive Effort in this order, (BSL, WAS, BSH) brought about increase in optimum moisture content.

The optimal Mix for best performance in terms of optimum moisture content is 20% RHA 30% Bentonite and 70% laterite all compacted using British standard heavy. It can also be observed that as maximum dry density, decrease OMC is increasing.

4.1.3.1 Results of Unconfined Compressive Strength Using British Standard Heavy Compaction



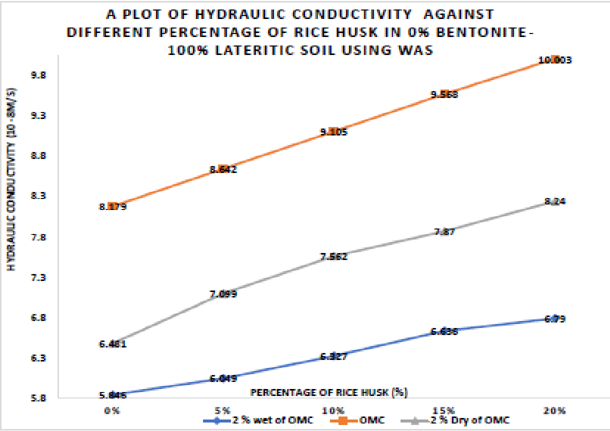


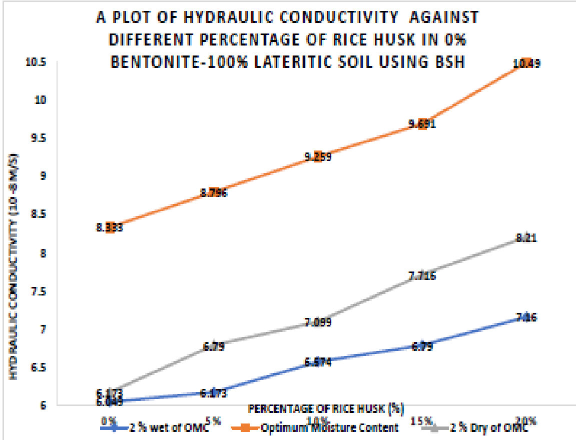


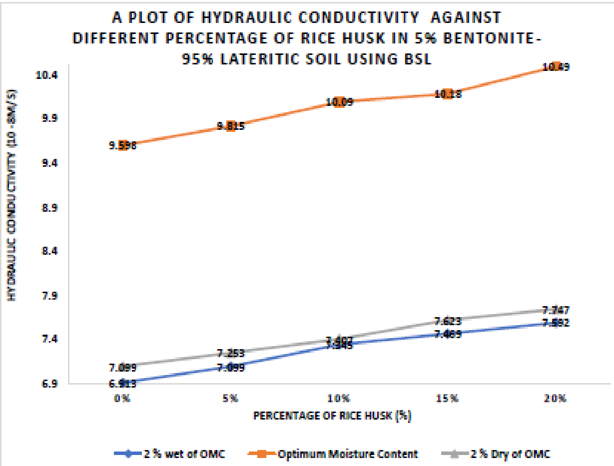
Increase in Bentonite after 5% also brought about decrease in Unconfined Compressive Strength of Bentonite-lateritic mixture. With 30% Bentonite-70% laterite give the maximum /best performance in Unconfined Compressive Strength. Compacting the RHA-Bentonite-laterite mixture with OMC gave the best or maximum performance in terms of Unconfined Compressive Strength followed by compacting at 2% Dry of OMC. Compacting at 2% wet of OMC gave the least performance in terms of UCS. The optimal mix or mix that gave highest unconfined compressive strength is 10% RHA-5% Bentonite 95% laterite compacted at optimum moisture content using West African Standard. While 0% RHA-0% Bentonite-100% laterite gave the lowest performance increase terms of Unconfined Compressive Strength.

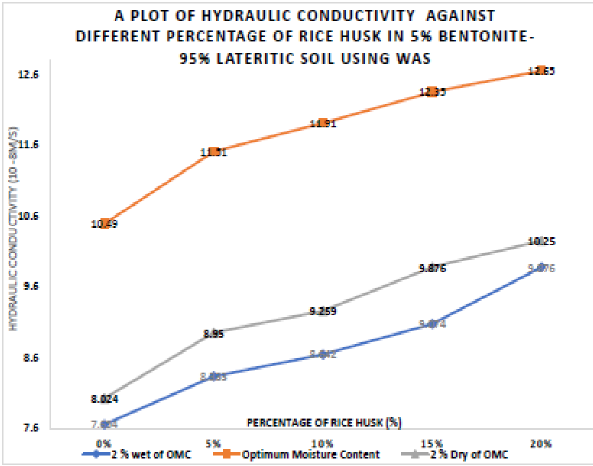
International Journal of Novel Research in Civil Structural and Earth Sciences
Vol. 12, Issue 3, pp: (22-32), Month: September - December 2025, Available at: www.noveltyjournals.com

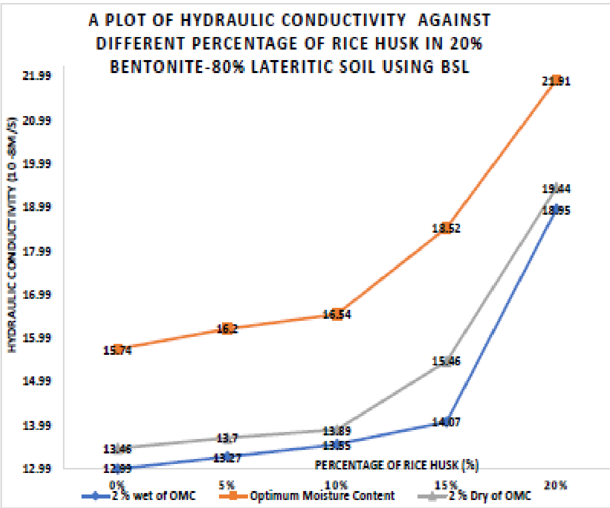
4.1.4.2 Results of Hydraulic Conductivity During Different Compaction

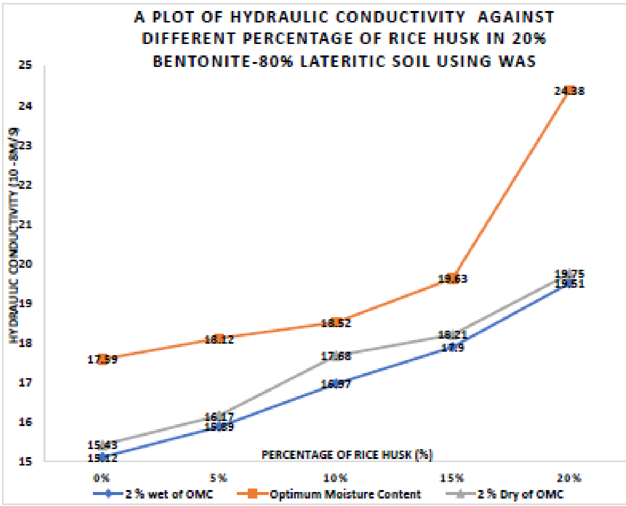


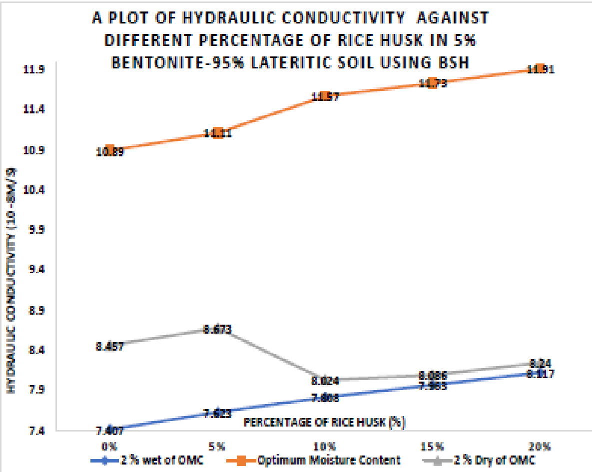


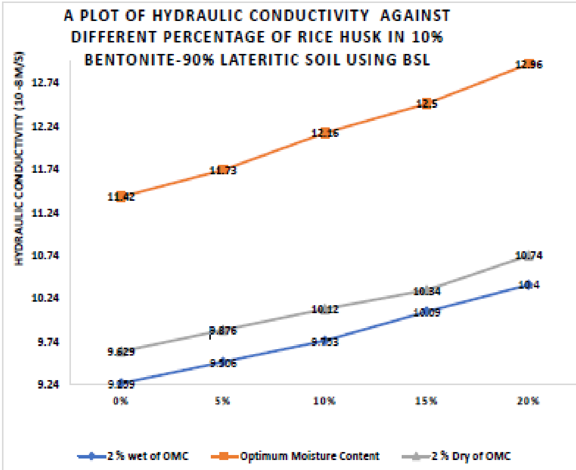


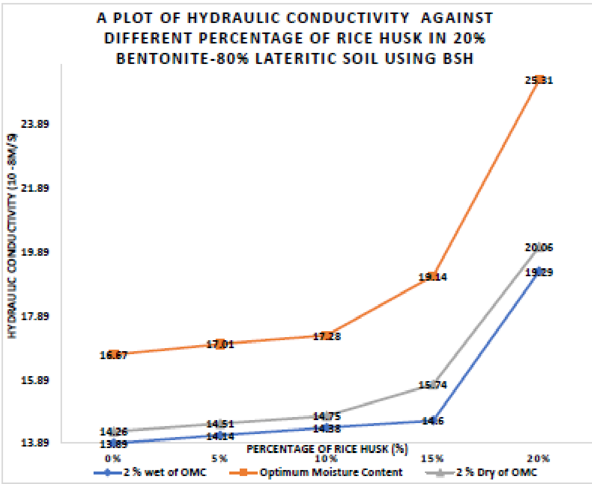


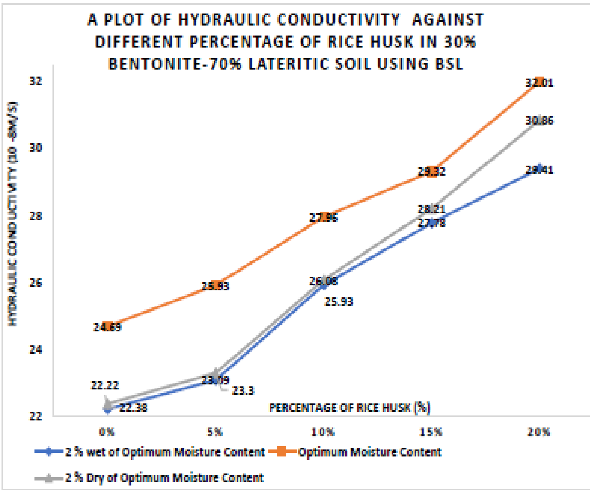


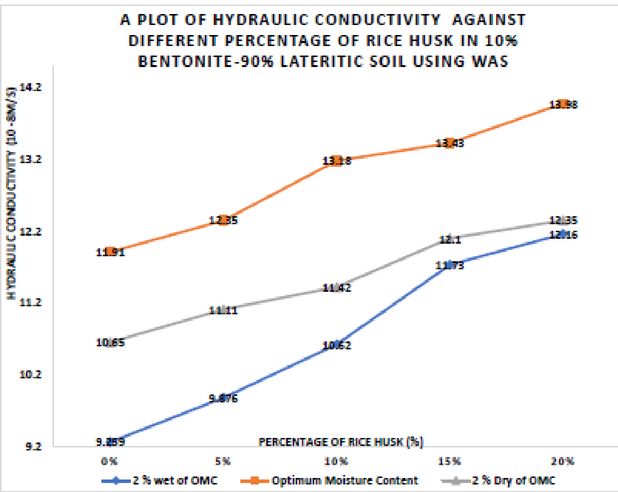


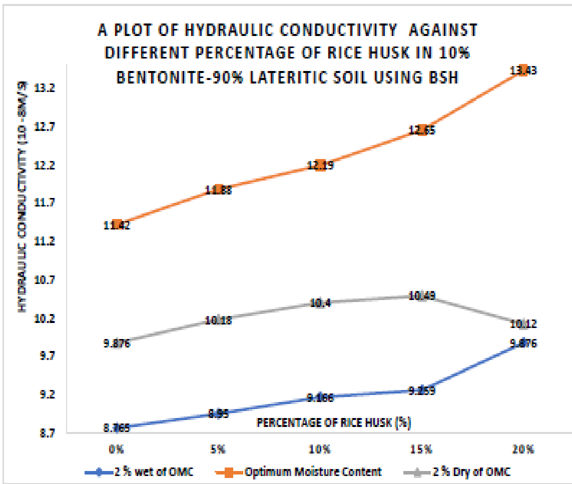

A PLOT OF HYDRAULIC CONDUCTIVITY AGAINST DIFFERENT PERCENTAGE OF RICE HUSK IN 5% BENTONITE-95% LATERITIC SOIL USING BSH
HYDRAULIC CONDUCTIVITY (10 -8M/S)
PERCENTAGE OF RICE HUSK (%)
2 % wet of OMC
Optimum Moisture Content
2 % Dry of OMC


A PLOT OF HYDRAULIC CONDUCTIVITY AGAINST DIFFERENT PERCENTAGE OF RICE HUSK IN 10% BENTONITE-90% LATERITIC SOIL USING BSL
HYDRAULIC CONDUCTIVITY (10 -8 M/S)
2 % wet of OMC
Optimum Moisture Content
2 % Dry of OMC


A PLOT OF HYDRAULIC CONDUCTIVITY AGAINST DIFFERENT PERCENTAGE OF RICE HUSK IN 20% BENTONITE-80% LATERITIC SOIL USING BSH
HYDRAULIC CONDUCTIVITY (10 -8M/S)
PERCENTAGE OF RICE HUSK (%)
2 % wet of OMC
Optimum Moisture Content
2 % Dry of OMC


A PLOT OF HYDRAULIC CONDUCTIVITY AGAINST DIFFERENT PERCENTAGE OF RICE HUSK IN 30% BENTONITE-70% LATERITIC SOIL USING BSL
HYDRAULIC CONDUCTIVITY (10 -8M/S)
PERCENTAGE OF RICE HUSK (%)
2 % wet of Optimum Moisture Content
Optimum Moisture Content
2 % Dry of Optimum Moisture Content


A PLOT OF HYDRAULIC CONDUCTIVITY AGAINST DIFFERENT PERCENTAGE OF RICE HUSK IN 10% BENTONITE-90% LATERITIC SOIL USING WAS
HYDRAULIC CONDUCTIVITY (10 -8M/S)
PERCENTAGE OF RICE HUSK (%)
2 % wet of OMC
Optimum Moisture Content
2 % Dry of OMC


A PLOT OF HYDRAULIC CONDUCTIVITY AGAINST DIFFERENT PERCENTAGE OF RICE HUSK IN 10% BENTONITE-90% LATERITIC SOIL USING BSH
HYDRAULIC CONDUCTIVITY (10 -8M/S)
PERCENTAGE OF RICE HUSK (%)
2 % wet of OMC
Optimum Moisture Content
2 % Dry of OMC

From The graphical Representation of Hydraulic Conductivity against percentage of Rice Husk in Different Bentonite-laterite Mixture. It has been observed that increment in Rice husk from 0% to 20% brought about decrement in Hydraulic Conductivity of Bentonite- Laterite mixture. 20% addition of rice husk recorded the maximum Hydraulic Conductivity in all different batches of Bentonite-Laterite Mixture. While 0% addition of rice husk recorded the least Hydraulic Conductivity in all different batches of Bentonite-Laterite Mixture

The hydraulic conductivity of the lateritic soil-bentonite mixtures decreased with increasing RHA content. This reduction in hydraulic conductivity can be attributed to the pozzolanic properties of RHA, which improve the microstructure and reduce the permeability of the mixture. The results showed that the addition of RHA up to an optimal content enhanced the effectiveness of the soil-bentonite mixture as a barrier for waste containment applications. The reduction in hydraulic conductivity observed in the lateritic soil-bentonite mixtures treated with rice husk ash (RHA) can be attributed to several factors. Firstly, RHA contains high amounts of amorphous silica and reactive compounds such as silica dioxide, which exhibit pozzolanic properties when in contact with water. These pozzolanic reactions result in the formation of cementitious compounds that improve the microstructure and reduce the permeability of the Mixture. Additionally, RHA has a high specific surface area, which promotes the formation of additional binding agents within the mixture. This leads to the development of a more interconnected network of particles, reducing the flow paths for water and further restricting the hydraulic conductivity. The finer particles of RHA also contribute to the densification of the mixture, increasing its resistance to water flow.

The Optimal content of RHA required to achieve the desired reduction in hydraulic conductivity may vary depending on the specific characteristics of the lateritic soil and bentonite used in the mixture. It is essential to conduct further testing and optimization to determine the most suitable RHA content for a given soil-bentonite combination

It is worth noting that the incorporation of RHA into the soil-bentonite mixture should not compromise other desirable engineering properties. The mechanical stability and compressibility of the mixture should be carefully evaluated to ensure that the addition of RHA does not adversely affect these properties. It is recommended to conduct additional laboratory tests, such as compaction tests and strength tests, to assess the geotechnical performance of the treated mixtures

5. CONCLUSION

In this study, evaluation of Hydraulic conductivity, Unconfined Compressive Strength, Maximum dry density and optimum moisture content of Rice Husk Ash-lateritic soil-Bentonite mix for their suitability in waste containment application was carried out. Analysis of data obtained indicated that the geotechnical properties investigated namely: hydraulic Conductivity, Unconfined compressive strength of the laterite soil were substaintly influenced by introduction of bentonile and rice husk ash.

Also, compacting at 2% wet of OMC, at OMC and +2% dry of OMC substantially affect the geotechnical properties of Natural soil investigated. Increase in Bentonite and Rice husk ash brought about increase in Optimum moisture contact but decrease in maximum dry density.

Moreso, increase in Bentonite and Rice husk ash brought about increase in Unconfined Compressive Strength. Increase in Bentonite and Rice husk ash brought about increase in hydraulic conductivity. Increase in bentonite.

Furthermore, increase in compactive effort brought about increase in max dry density, optimum moisture content, unconfined compressive strength but decrease in hydraulic conductivety. The study concludes that the addition of RHA can effectively reduce the hydraulic conductivity of the mixtures, improving their performance as barriers for waste containment. The findings contribute to the understanding of the influence of RHA on the engineering properties of soil-bentonite mixtures and provide insights into the potential use of RHA as a cost-effective and environmentally friendly additive for waste containment applications.Partial Replacement 20% Rice Hush Ash in all Bentonite-Laterite Mixtures considered gave the best results in terms of Hydraulic Conductivity. Also increment in percentage of Rish husk ASH added brought about Decrement in Hydraulic conductivity

Optimum Moisture Content During Compaction of RHA- Bentonite -Laterite Mixture gave the best results in terms of Hydraulic Conductivity. Also Increasing the compaction water content by 2% wet (+2%) of optimum Moisture Content brought about reduction in Performance in terms of Hydraulic Conductivity. Also decreasing the compaction water content by 2% dry (-2%) wet of optimum Moisture Content Gave the least result in terms of Hydraulic Conductivity.It should be noted that Lateritic soil considered alone will be suitable for the construction of a linear based on its hydraulic properties obtained. Moreso, Rice husk Ash-bentonite-Laterite is also suitable for the construction of a linear based on its hydraulic properties obtained, since all Hydraulic Conductivity results are less than the permissible value (1 × 10 -9M/S) as described by Daniel and Benson (1990). The utilization of rice husk ash as an additive in lateritic soil-bentonite mixtures for waste containment applications has shown promise in reducing hydraulic conductivity. The reactive silica content in RHA reacts with calcium hydroxide, leading to increased strength and reduced permeability. This development provides a sustainable and cost-effective approach to improving waste containment practices.

This indicate that the addition of rice husk ash (RHA) can effectively reduce the hydraulic conductivity of lateritic soil-bentonite mixtures, enhancing their performance as barriers for waste containment applications. The pozzolanic properties of RHA, including its high silica content and reactivity, contribute to the reduction in hydraulic conductivity by improving the microstructure and increasing the density of the mixture

6. RECOMMENDATIONS

The optimal content of RHA required to achieve the desired reduction in hydraulic conductivity should be determined based on the specific characteristics of the soil and bentonite used. It is crucial to balance the reduction in hydraulic conductivity with the preservation of other important engineering properties. The use of RHA as an additive in soil-bentonite mixtures offers potential benefits in terms of cost-effectiveness and environmental sustainability. Rice husk ash is a byproduct of the rice milling industry and its utilization can contribute to waste recycling and reduce the demand for traditional cementitious materials further research is recommended to explore the long-term performance and durability of the treated mixtures under different environmental conditions. Additionally, field-scale testing and validation should be conducted to assess the practical applicability of RHA-treated soil-bentonite mixtures for waste containment project. Overall, this research provides valuable insights into the use of rice husk ash as a potential additive for improving the hydraulic conductivity of lateritic soil-bentonite mixtures, thereby enhancing their effectiveness in waste containment application

REFERENCES

[1] Ab Aziz, N.N.S.N, Mukri, M., Hashim, S & Khalid N. (2015). Influence of compaction effort for lateritic soil mix with geopolymer in designing soil liner. EJGE, 20, 12353-12364.

[2] Abdel-shafy H.I, and Mansour M.S.M (2018). Solid waste issue: sources, composition, disposal, recycling and valorization. *Egyptian Journal of Petroleum* Vol 27, pp 1275-1290.

[3] Abila, B. and Kantola, J. (2013) Municipal Solid Waste Management Problems in Nigeria: Evolving Knowledge Management Solution. World Academy of Science, Engineering and Technology. *International Journal of Environmental and Ecological Engineering*, 7, 303-308.

[4] Aginam C.H, Nwakaire C., Nwajuaku A.I (2015). Engineering properties of lateritic soils form Anambra Central Zone, Nigeria. *International Journal of Soft Computing and Engineering* (IJSCE) (ISSN 2231-2307, vol. 4, Issue-6.

[5] Ahmad, S.Z, Ahamad, M.S & Yusoff, M.S (2014). Spatial effect of new municipal solid waste landfill siting using different guidelines. *Waste Management Resources*, 32, 24-33.

[6] Albrecht, B. A. and Benson, C. H. (2001). Effect of desiccation on compacted natural clays. *J. Geotech & Geoenviron.* Eng. ASCE, Vol. 127, No. 1, pp 67–75.

[7] Amadi A.A., and Odedede O., (2021). Attenuation of Contaminants in landfill leachate by lateritic soil enhanced with bentonite. Geomechanics and Geoengineering, *An International Journal*, Volume 16, Issue 5: Pp 348-358.

[8] Barkat, M., Chegrouche, S., Mellah, A., Bensmain B., Nibou, D., and Boufatit, M., (2014). Application of Algerian Bentonite in the removal of Cadmium (II) and Chromium (VI) from Aqueous Solutions. *Journal of Surface Engineered Materials and Advanced Technology*, Vol. 4, No, 4, pp 210-226.

[9] Beatrice Abila and Jussi Kantola (2013). Municipal Solid Waste Management Problems in Nigeria: Evolving Knowledge Management Solution. World Academy of Science, *Engineering and Technology International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering* Vol:7, No:6.

[10] Bello, A.A (2013). Hydraulic Conductivity of three compacted reddish brown tropical soils. KSCE Journal of Civil Engineering, 17, 939-948.

[11] Bharat, T. V. (2017). Selection and Configuration of Sorption Isotherm Models in Soils Using Artificial Bees Guided by the Particle Swarm. *Advances in Artificial Intelligence (16877470).*

[12] Bialowiec, A. (2011). Hazardous emissions from municipal solid waste landfills. *Contemporary problems of management and environmental protection*, Vol. 9, No. 9, pp 7-28.

[13] Chai, W., Huang, Y., SU S., Han G., Liu, J., and Cao, Y., (2017). Adsorption behavior of Zn(II) onto natural minerals in wastewater. *A comparative study of bentonite and kaolinite. Problems Mineral Processing*, 53(1). 264-278.

[14] Chen Y.M (2014). A fundamental theory of environmental geotechnics and its application. *Chinese Journal of Geotech Engineering*, Vol. 36, No. 1, pp 1-46.

[15] Chinade A.U, Yusuf U.S, and Osinubi K.J, (2017). Effect of Municipal Solid Waste Leachate On The Strength Of Compacted Tropical Soil for Landfill Liner. I*nternational Research Journal of Engineering and Technology* (IRJET) e-ISSN: 2395 -0056 Volume: 04 Issue: 06.

[16] Daniel, D.E (2012). Geotechnical practice of waste disposal, Springer Science and Business Media.

[17] David A. Rubinos & Giovanni Spagnoli (2018); Utilization of waste products as alternative landfill liner and cover materials – A critical review; Critical Reviews in Environmental *Science and Technology*. VOL. 48, NO. 4, 376–438 https://doi.org/10.1080/10643389.2018.1461495. ISSN: 1064-3389.