Nnamdi Azikiwe University Journal of Civil Engineering (NAUJCVE)
Volume-4, Issue-1, pp-63-71
www.naujcve.com
Research Paper Open Access

Consistency Limit And Compaction Properties Of Waste Marble Dust-Stabilized Lateritic Soil For Landfill Liner Application

Jechira, Benjamin Kuma[*1]; Godwin, Joel[1] and Umar, Murtala[2]

[1]Department of Civil Engineering, Joseph SarwuanTarka University, Makurdi, Benue State
[*]Corresponding Email: jechirabenjy@gmail.com
[2]Department of Civil Engineering, Bayero University, Kano, Kano State

[*]***Corresponding Author: jechirabenjy@gmail.com***

Abstract: *This study investigated the consistency limits and compaction characteristics of waste marble dust (WMD)-stabilized lateritic soil for use as landfill liner material. XRD analysis revealed that the unstabilised lateritic soil is predominantly kaolinite, while chemical analysis showed WMD is rich in CaO, indicating cementitious potential. Incorporating WMD reduced the liquid limit from 36.4% to 30.2% and increased the plastic limit from 12.0% to 24.0%, resulting in a lower plasticity index but maintaining values above the 7% threshold for liners. Maximum dry density (MDD) increased with WMD addition up to 9%, achieving 2.11 Mg/m³ under heavy compaction, while optimum moisture content (OMC) generally decreased, indicating improved compaction efficiency. These modifications are attributed to cation exchange, flocculation, and the filler effect of WMD. Overall, the WMD-stabilized lateritic soil meets typical geotechnical criteria for landfill liners, offering an effective and sustainable reuse of marble waste.*

Keywords: *Lateritic Soil, Waste Marble Dust, Consistency Limits, Compaction, Landfill Liner*

Date of Submission:07-10-2025 Date of acceptance:22-10-2025

1. INTRODUCTION

Municipal solid waste (MSW) management remains one of the most pressing environmental challenges in many developing countries, including Nigeria. Open dumping is still the most widely practiced method of waste disposal due to its simplicity and low immediate cost. However, it poses severe long-term environmental and public health risks. In Nigeria alone, it is estimated that over 250 metric tons of waste are deposited in uncontrolled dump sites (Sabat, 2012). These wastes often comprise a mix of industrial, chemical, and biological materials (Geeta Rani *et al.*, 2014) and frequently contain hazardous heavy metals such as chromium, nickel, zinc, and lead, which have been shown to adversely impact human health (Singh *et al.*, 2014). In urban centers like Kano, open dumpsites are commonly situated close to residential areas, thereby increasing the risk of direct human exposure and groundwater contamination through leachate infiltration. According to the World Health Organization (WHO, 2009), long-term exposure to contaminated environments can negatively affect up to 25% of the population living nearby (Chen and Idusuyi, 2015). Additionally, uncontrolled decomposition of organic waste generates methane, which not only contributes to greenhouse gas emissions but also creates a fire hazard, especially where scrap tyres - common at dump sites - serve both as fuel and as breeding sites for disease vectors. Fires involving tyres can release dioxins, known to cause reproductive and carcinogenic effects even at trace concentrations, while scavenging birds further exacerbate health risks by transmitting pathogens.

To mitigate these multifaceted threats, engineered sanitary landfills have become the global standard for safe waste disposal. A fundamental component of these landfills is the liner system, which acts as a barrier to restrict the downward migration of leachate, thereby protecting groundwater resources. Modern landfill liners include compacted clay liners (CCL), geosynthetic clay liners (GCL), geomembranes, and composite systems. However, synthetic liners like GCL significantly increase construction costs, often rendering them impractical for many developing economies (Amadi and Eberemu, 2012). Consequently, enhancing the properties of locally available soils through stabilization emerges as a practical, cost-effective alternative for constructing landfill liners. Stabilization techniques typically involve incorporating additives such as lime, cement, fly ash, quarry dust, or other industrial by-products to improve critical soil properties (Osinubi, 1995).

In selecting materials for landfill liners, key geotechnical criteria often call for a liquid limit greater than 30%, a plasticity index above 10%, fines content exceeding 50% (passing 0.075 mm sieve), and volumetric shrinkage below 4% (Frempongand Yanful, 2014; CGRM, 2007). Some lateritic soils, which are widely distributed in tropical regions like Nigeria, often falls short of these index property requirements limiting their direct suitability as landfill liner materials without modification.Waste marble dust presents a sustainable and economically attractive stabilizing agent for improving lateritic soils. Marble is extensively quarried for construction and decorative purposes, with notable examples such as the TajMahal in India (El Gammal*et al.*, 2011). During cutting and polishing operations, up to 20–30% of the marble block's weight is lost as fine waste dust (Alyamac and Ince, 2009). Improper disposal of this marble dust contributes to air pollution, alters landscapes, impedes groundwater recharge, and increases soil alkalinity, thereby reducing fertility (Montero *et al.*, 2009). Utilizing waste marble dust to stabilize lateritic soils offers a dual environmental benefit: it diverts a problematic waste stream from landfills and improves the engineering properties of indigenous soils to meet landfill liner requirements.

This study investigated the consistency limit and compaction properties of waste marble dust-stabilized lateritic soil, evaluating its potential suitability as a low-cost, environmentally friendly landfill liner material. By assessing critical parameters such as Atterberg limits, maximum dry density, and optimum moisture content, this research seeks to establish a scientific basis for the sustainable reuse of marble waste in geotechnical applications, thereby supporting safer waste disposal practices and promoting circular economy principles in Nigeria.

II. MATERIALS AND METHODS

2.1 Materials

The lateritic soil sample used were obtained from an area at Ungogo Local Government Area of Kano State, Nigeria (Latitude 11°57'16.7"N and latitude 8°27'16.4"E). The samples were collected at 0.5m to 1.2m using the method of disturbed sampling as shown in Plate 1. The collected samples were stored in a polythene bags to prevent loss of moisture content. The samples were then taken to the soil Mechanic Laboratory of the Department of Civil Engineering, Bayero University Kano. The sample was spread and allowed to air dry under laboratory condition before laboratory tests were carried out. The samples of waste marble dust were obtained from Deidei building materials market in Abuja where cutting and polishing of marble is being carried out as shown in Plate 2 which were packed in sacks and transported to the Soil Mechanic Laboratory of the Department of Civil Engineering, Bayero University Kano for testing. The Waste Marble Dust (WMD) was sieved through the British Standard Sieve No 200 before being used. The WMD proportions were varied by 0, 3, 6, 9 and 12% by mass of the dry soil sample.

Plate 1: Obtaining of Lateritic Soil

Plate 2: Obtaining of Waste Marble Dust

2.2 Methods

A series of laboratory tests consisting of Chemical Composition of WMD and Lateritic soil; Mineralogical Composition of Lateritic Soil; Consistency Limits; British Standard Light, British Standard Heavy and West African Standard Compaction were conducted in accordance with BS 1377(1990) and BS 1924(1990) on the natural soil and soil prepared with the significant quantities of WMD. The WMD proportions were varied at 0,3,6,9 and 12% by mass of the soil sample.

Compaction test was conducted to determine the relationship between the moisture content and the dried density of a soil for a specified conpactive effort. The sample tested were prepared by mixing the relevant of dry soil sample previously crushed to pass through BS No 4 sieve with 4.76 mm aperture as outline by Head (1992) as well as Albrecht and Benson (2001). The specimens were moulded at water content enough to mould it and different compactive efforts similar to those that might be achieved in the field. The compaction methods include the Standard Proctor Light (SP) or British Standard Light (BSL), Modified Proctor (MP) or British Standard Heavy (BSH) in accordance with BS 1377 (1990) and BS 1924 (1990) and the West African Standard (WAS) compaction as outlined in the Nigerian General Specification (1997).

III. RESULTS AND DISCUSSION

3.1Mineralogical and Chemical Composition

X-Ray Diffraction (XRD) analysis of the natural lateritic soil sample is shown in Figure 1. It was observed from the result that the soil sample contains illite, Calcite, Kaolinite and Quartz with Kaolinite being the dominant clay mineral.

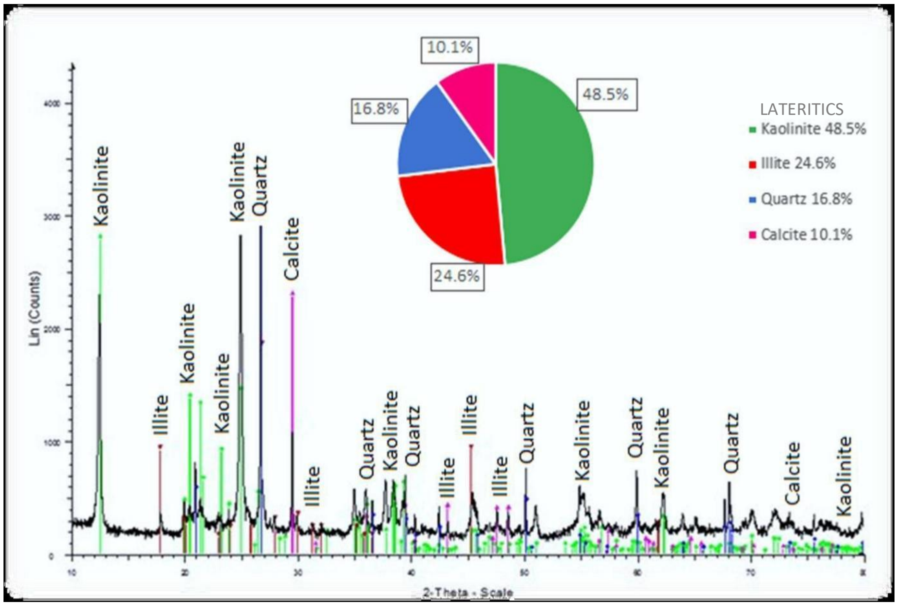

Fig. 1: Mineralogy of natural soil sample

The chemical composition of the WMD and the soil sample, as presented in Table 1, shows that the WMD is predominantly composed of lime (CaO), indicating its cementitious nature, while the soil sample is rich in silica (SiO_2). The calculated silica-to-sesquioxide ratio for the soil is 1.67, classifying it as lateritic in accordance with ASTM C618-12a (2013).

Table 1: Percentage Oxide Composition of Lateritic Soil and WMD

Elemental Oxide	% Composition	
	Lateritic soil	WMD
SiO_2	51.20	15.39
Al_2O_2	21.55	8.90
FeO_3	9.20	2.53
TiO_2	0.32	0.20
Cr_2O_3	0.65	0.56
MnO	0.70	0.60
MgO	4.30	2.8
CaO	6.99	59.07
Na_2O	0.56	0.47
K_2O	0.72	0.88
P_2O_5	0.83	0.90
LOI	5.04	7.78

3.2Index and Engineering Properties of the Natural Soil

The summary of index and engineering properties of the soil sample are presented in Table2. The soil is classified as A-6 according to AASHTO classification system (AASHTO, 1986) and as clay with low plasticity according to USCS (ASTM, 1992).

Table 2: The Index and Engineering Properties of the natural lateritic Soil

Property	Quantity
NaturalMoistureContent(%)	7.10
SpecificGravity	2.69
Gravel(%)	19.34
Sand(%)	29.20
SiltorClay(%)	51.45
LiquidLimit(%)	36.00
PlasticLimit (%)	24.00
PlasticityIndex(%)	12.00
LinearShrinkage(%)	8.30
PercentagepassingBSNo200Sieve	51.45
FreeSwell(%)	58
AASHTOClassification	A-6
USCSClassification	CL
OMC(BritishStandardHeavy) (%)	12.70
MDD(BritishStandard Heavy) (Mg/m^3)	2.00
OMC(BritishStandardLight)(%)	14.84
MDD(British Standard Light)(Mg/m^3)	1.86
OMC(WestAfricanstandard)(%)	13.83
MDD(West African standard)(Mg/m^3)	1.92
UCS(British StandardHeavy) (kN/m^2)	220
UCS(British StandardLight) (kN/m^2)	80
UCS(West African standard)(kN/m^2)	130
pHValue	6.8
Colour	Reddishbrown
DominantclayMineral	Kaolinite

3.3 Effect of Waste Marble Dust (WMD) on Atterberge Limits

The influence of Waste Marble Dust (WMD) on the Atterberg limits of the soil is shown in Figure 2. The Liquid Limit (LL) of the natural soil was initially 36.4%, decreasing progressively to 30.2% at 12% WMD content. This steady reduction is attributed to flocculation and agglomeration arising from cation exchange reactions, which reduce the soil's water holding capacity. These values are well below the commonly recommended maximum LL of 60% for landfill liners, indicating that both the natural soil and the WMD-treated soils comfortably satisfy this criterion (ASTM D2487, EPA guidelines). The Plastic Limit (PL) increased from 12.0% for the untreated soil to 24.0% at 12% WMD content, likely due to the higher specific surface area and cementitious reactions requiring more water. This increase suggests enhanced resistance to volumetric changes upon wetting. The plasticity index (PI) showed a decreasing trend with increased WMD content, reflecting reduced soil plasticity due to the flocculation effects from calcium ions in the WMD. Despite this reduction, the PI values remained above 7% throughout, meeting typical minimum requirements for compacted clay liners to ensure sufficient plasticity and low permeability. Thus, based on the Atterberg limits results—LL well below 60% and PI consistently above 7%—the WMD-stabilized lateritic soil meets established criteria for use as a landfill liner material.

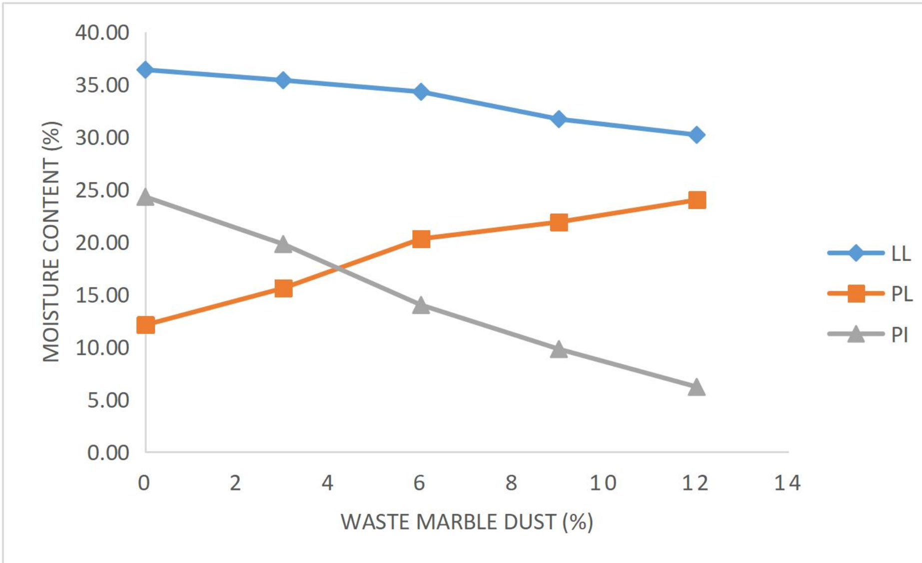

Fig. 2: Variation of Atterberg Limits with Waste Marble Dust Contents

3.5 Compaction Characteristics

The compaction behavior of the WMD-treated lateritic soil under three different compaction energy levels - British Standard Light (BSL), British Standard Heavy (BSH), and West African Standard (WAS) - was evaluated in terms of maximum dry density (MDD) and optimum moisture content (OMC) for varying WMD contents of 3%, 6%, 9%, and 12%. These results are summarized in Figures 11a and 11b, respectively.

As shown in Figure 3, the MDD increased with WMD addition up to 9% for both BSH and WAS efforts, rising from 2.00 Mg/m³ and 1.92 Mg/m³ for the natural soil to 2.11 Mg/m³ and 2.05 Mg/m³, respectively. However, a slight reduction in MDD was observed at 12% WMD content, likely due to the replacement of the higher specific gravity lateritic soil particles with the lower specific gravity WMD (Osinubi*et al.*, 2011). Under BSL compaction, MDD initially increased at 3% WMD, showed a slight decrease at 6%, and then reached its peak at 9% WMD. The overall increase in MDD with moderate WMD addition is attributed to the fine WMD particles filling soil voids and enhancing particle packing (Oriola and Moses, 2011).

Figure 4 illustrates the OMC trends for the three compaction energies. Generally, OMC decreased with increasing WMD content, dropping from 14.24%, 12.70%, and 13.83% for the natural soil to 13.09%, 9.52%, and 11.58% at 9% WMD for BSL, BSH, and WAS, respectively. This reduction is attributed to cation exchange leading to flocculation and agglomeration, which reduces the water needed for lubrication. However, slight increases in OMC at higher WMD contents may result from the additional water demand required for the formation of cementitious compounds like calcium hydroxide ($Ca(OH)_2$) (Moses and Osinubi, 2013).

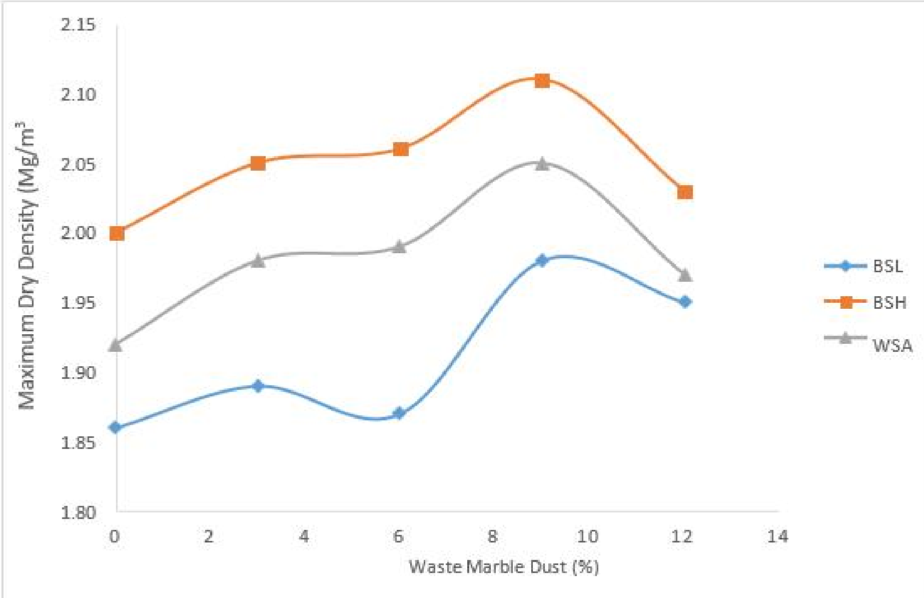

Fig. 3: Variation of Maximum Dry Density with Waste Marble Dust Treatment

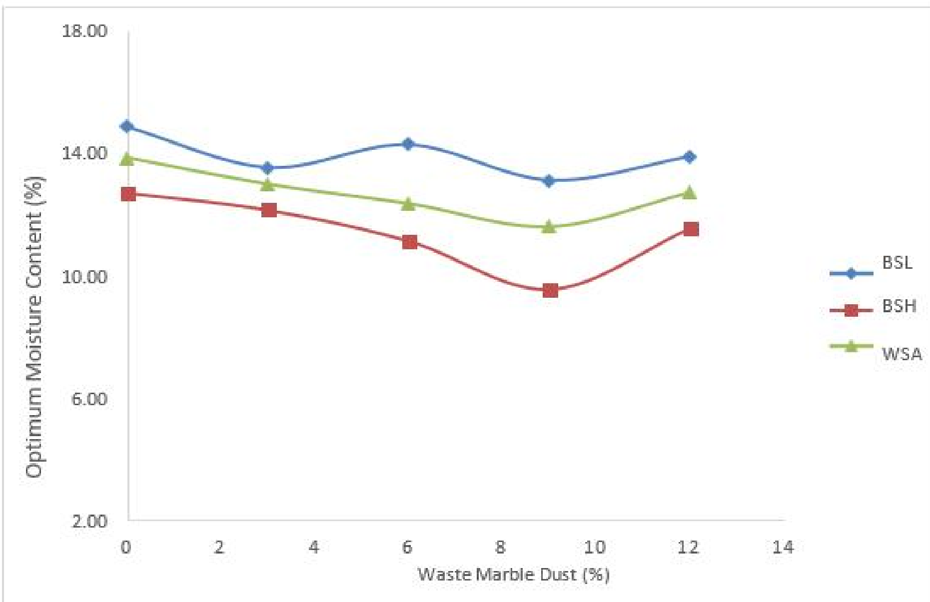

Fig. 4: Variation of Optimum Moisture Content with Waste Marble Dust Treatment

IV. CONCLUSIONAND RECOMMENDATIONS

The study has demonstrated that the incorporation of Waste Marble Dust (WMD) significantly modified the consistency limits and compaction properties of the lateritic soil, enhancing its suitability for landfill liner applications. The progressive decrease in liquid limit from 36.4% to 30.2% with increasing WMD content, alongside the corresponding increase in plastic limit from 12.0% to 24.0%, indicates improved workability and reduced susceptibility to volumetric changes. Despite the reduction in plasticity index, values remained above the typical minimum threshold of 7%, ensuring that the soil retained sufficient plasticity and low permeability required for effective liner performance. These results confirm that the WMD-stabilized soil comfortably satisfies established criteria

(ASTM D2487, EPA guidelines) for compacted clay liners, reflecting a balance of reduced plasticity and maintained impermeability.

Moreover, the compaction results revealed that the addition of WMD enhanced the maximum dry density (MDD) up to 9% WMD content under all compaction energies, with slight declines observed at 12% due to the lower specific gravity of WMD relative to the natural soil. The observed decrease in optimum moisture content (OMC) with increasing WMD is beneficial, indicating reduced water demand for achieving maximum compaction, except at higher WMD contents where minor increases suggest additional water required for cementitious reactions. These improvements in MDD and controlled OMC underscore the potential of WMD-treated lateritic soils to achieve dense, stable, and durable landfill liners, offering a sustainable alternative by recycling industrial waste while meeting geotechnical performance standards.

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