Analysis of Shear Strength of Compacted Lateritic Soils

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ABSTRACT

This paper presents the results of a laboratory investigation carried out on three compacted reddish brown tropical soils in order to define the ranges of the water content and dry unit weight at which compacted test specimens would have adequate shear strength.

Test specimens were compacted with British Standard light energy over a range of water content namely -4, -2, 0, 2 and 4% of optimum moisture contents. Specimens with dry density of 1.64Mg/m^3 prepared in the 13.9 - 18.1% molding water content range recorded unconfined compressive strength values equal to or greater than 200 kN/m^2 which is the minimum acceptable for materials to be used as hydraulic barriers in containment structures.

(Keywords: British standard light, containment structure, dry density, optimum moisture content, unconfined compressive strength)

INTRODUCTION

Hydraulic barriers used for waste containment structures in landfill design play a vital role in impeding fluid flow and attenuating inorganic contaminants. The structural integrity of these hydraulics barriers must be ensured by making sure that the constructed facility has adequate shear strength.

According to (Daniel and Wu, 1993; Edil et al., 1992; Stark and Poeppel, 1994; Osinubi and Bello, 2009, 2010) the material should have adequate shear strength (a minimum unconfined compressive strength of 200kN/m^2) and be durable to withstand destructive forces associated with alternating wet/dry and freeze/thaw cycles. This strength is the lowest value for very stiff soils based on the consistency classification according to (Peck et al., 1974). The unconfined compressive strength (UCS) value can be estimated using the following equations:

$$\sigma = \frac{RX\,C_R X 1000KN/m^2}{A} \quad \textbf{(1)}$$

and

$$A = \frac{100\,A_0}{100 - \varepsilon\%} \quad \textbf{(2)}$$

then,

$$\sigma = \frac{RC_R(100 - \varepsilon\%)}{100\,A_0}\,X\,1000KN/m^2 \quad \textbf{(3)}$$

where $A_0 = \pi D^2/4$, the initial area of cross-section (mm^2), ε% = x/L$_o$, ε% = axial strain percent, L$_o$ = initial length of specimen, D = initial diameter of specimen (mm), C_R N/division = mean calibration of load ring, R divisions = load ring reading at strain, ε; A (mm^2) = area of cross-section at strain,; RxC$_R$ Newtons = load on specimen at strain, ε ; σ = compressive stress at strain, ε,. The ring calibration C_R can be assumed to be constant.

Meanwhile, compacted liners are widely used as hydraulic barriers in landfills and other waste containment facilities, to impede migration of leachates into the subsurface groundwater. It is noteworthy that one of the serious and growing potential problems in developing countries like Nigeria is the shortage of land for waste disposal. Poor management of waste, be it human, biological, agricultural or industrial, may lead to severe soil and groundwater contamination as well as adverse health effects (Benson, 1999, 2000; Adewuyi, 2004; Bello, 2010). Although there are some efforts to reduce and recover waste, disposal of waste at landfills is still the most common method for facilities (beginning about three decades ago) with hydraulic barriers employed primarily to protect ground water quality (Osinubi, and Kundiri, 2008).

Containment facilities prevent the migration of leachates and gases to soil, groundwater, surface water, and air. Leachate is generated when liquids are disposed of directly as waste, when rainfall accumulates in the landfill before placement of a final cover, or when there is a flaw in the final cover that allows water to penetrate. Landfill gases are generated as organic waste biodegrades. Biodegradation primarily produces methane and carbon dioxide, but these gases can also contain some solvents.

A liner system functions to intercept leachates or gas migrating within a landfill and route it to a collection point where it can be removed or treated. For a compacted natural soil to be used as a hydraulic barrier it must possess a hydraulic conductivity of less than or equal to 1×10^{-9}m/s, volumetric shrinkage upon drying (maximum of 4%) and shear strength (minimum of 200 kPa). Further required characteristics of the liners and the total lining system are described in the European regulations and national document (Witt and Zeh, 2005; Zeh and Witt, 2005).

In spite of several research projects such as (Kraus et al., 1997; Abichou et al., 2000; Albrecht and Benson, 2001), some problems dealing with cover lining system are yet to be solved definitely. In this paper, shear strength obtained from unconfined compressive strength testing has been used to assess of the structural integrity of the containment facilities.

MATERIALS AND METHODS

Materials

The soil samples used in this research work are a natural material that is yellowish brown lateritic soil from borrow pits at Moniya, Ibadan, Southwestern, Nigeria (latitude $7^{o}27^{'}$ and longitude $4^{o}59^{'}$) using the method of disturbed sampling. The method of disturbed sampling was employed. The soil samples were obtained at depths of 0.80 – 2.90m designated as MP1, MP2 and MP3.

Methods

Index Properties: Laboratory tests were carried out to determine the index properties of the sample specimen in accordance with British Standards (BSI, 1990).

Compaction: The specimens were prepared by mixing the relevant quantity of dry soil samples previously crushed to pass through BS No.4 sieve (4.76 mm aperture) as outlined in BS 1377 (BSI, 1990) and Head of 1992. The specimens were prepared using moulding water content in the range 6.5 - 22.5%. The compaction method used is the British Standard light (BSL) described by (BSI, 1990 and Head, 1992) that is easily achieved in the field.

Unconfined compression test was carried out on soil specimens previously mixed with tap water and compacted at moulding water contents in the range 6.5 - 22.5% using BSL energy. Compacted specimens were sealed in plastic bags and allowed to stand for at least 24 hours before trimming and testing. At least three specimens (38 mm diameter by 76 mm high) per moulding water were used in the unconfined compression tests.

RESULTS AND DISCUSSION

Index Properties

The results of the index properties and compaction characteristic of the soil samples are summarized in Table 1. The particle size distribution curves are shown in Figure 1. The soils are classified as A-7-6 according to the Association of American States Highway and Transportation Officials Classification System (AASHTO). They are also classified as lean clay with sand (CL), according to the Unified Soil Classification System (USCS). The specific gravity of the soils is in the range 2.61 - 2.64, while the pH is in the range 6.30 – 7.00. The percentage passing BS No.200 sieve is 56.15 – 58.99.

The clay mineralogy of the soil samples which was quantitatively analyzed using X-ray diffraction (XRD) was determined to be kaolinite. The soil samples have activity values less than 1.

Table 1: Index Properties of Reddish-Brown Soils.

Properties	Soil Samples		
	MP1	MP2	MP3
Natural moisture content, %	5.2	5.9	5.6
Specific gravity	2.66	2.62	2.65
Liquid limit, %	43	48	44
Plastic limit, %	29	32	28
Plasticity index, %	14	16	16
Linear shrinkage, %	8.60	7.80	6.25
% Passing BS No. 40 sieve	80.1	77.25	81.55
% Passing BS No. 200 sieve	63.55	59.2	66.4
% < 2 μm	23.63	21.57	25.39
Maximum dry unit weight, kN/m^3	17.46	17.46	17.85
Optimum moisture content, %	17.8	15.4	15.1
AASHTO classification	A-7-6(8)	A-7-6(9)	A-7-6(8)
USCS	CL	CL	CL
Activity	0.55	0.68	0.74
Derived Parameters			
Grading modulus	0.61	0.67	0.60
Plasticity product	889.7	947.2	982.4
Plasticity modulus	1121.4	1236.0	1304.8

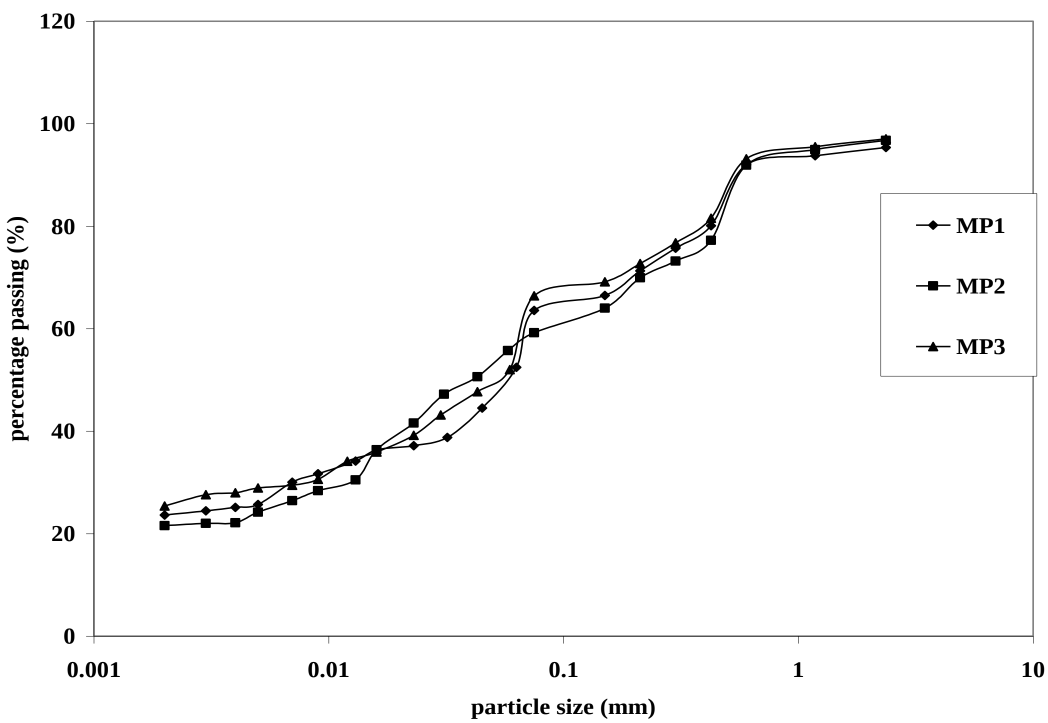


Figure 1: Particle Size Distribution Curves for the Three Reddish-Brown Tropical Soils.

The higher the activity of a soil the greater the clay fraction influences its properties. The fabric of a soil refers to the geometric arrangement of particles (Lambe and Whitman, 1979). The determination of the fabric was carried out by field emission scanning electrons microscopy (FESEM) at the Department of Material Science, International Islamic University, Malaysia. The micrographs shown on Plates 1 – 3 indicate that kaolinite flakes and halloysitic tubes are present in the fabric of the soils because there are visible flocs which seem to be sandy silt sized particles.

Chemical Composition

The chemical composition of the abandoned dumpsite soil and lateritic soils is summarized in Table 2. The concentrations of Fe_2O_3 are in the range 7.7 – 9.2% for soil samples in agreement with the findings of Bolarinwa (2001). The ferruginous soils contain free iron oxides which have been transformed to the active forms (Gidigasu, 1984; Malomo, 1983).

The pH values of the tested soils are in the range 6.10 – 6.20 that indicate acidic nature. The organic carbon content of the soil samples is low thus indicating low loss on ignition.

Effect of Compaction Moulding Water Content

The variation of unconfined compressive strength with moulding water content is shown in Figure 2. Unconfined compressive strength (UCS) generally increased with moulding water up to 17.5%, and thereafter decreased to minimum values for the three soils tested. UCS values recorded for specimens prepared within 12.5 – 19.2% moulding water content range are equal to or greater than 200kN/m^2 minimum required for a material to be used in waste containment applications.

It was observed that specimen MP2 that has the highest grading modulus, plasticity modulus and plasticity product recorded peak UCS values as shown in Table 1. This may be due to the fines fraction filling up the void spaces hence reducing compressibility and deformation, while increasing the shear strength characteristics. Such an increase in strength could also probably be due to the formation of very weak bonds between the soil particles and the available water molecules (Osinubi and Bello, 2009; Osinubi, et al., 2007).

Effect of Dry Density

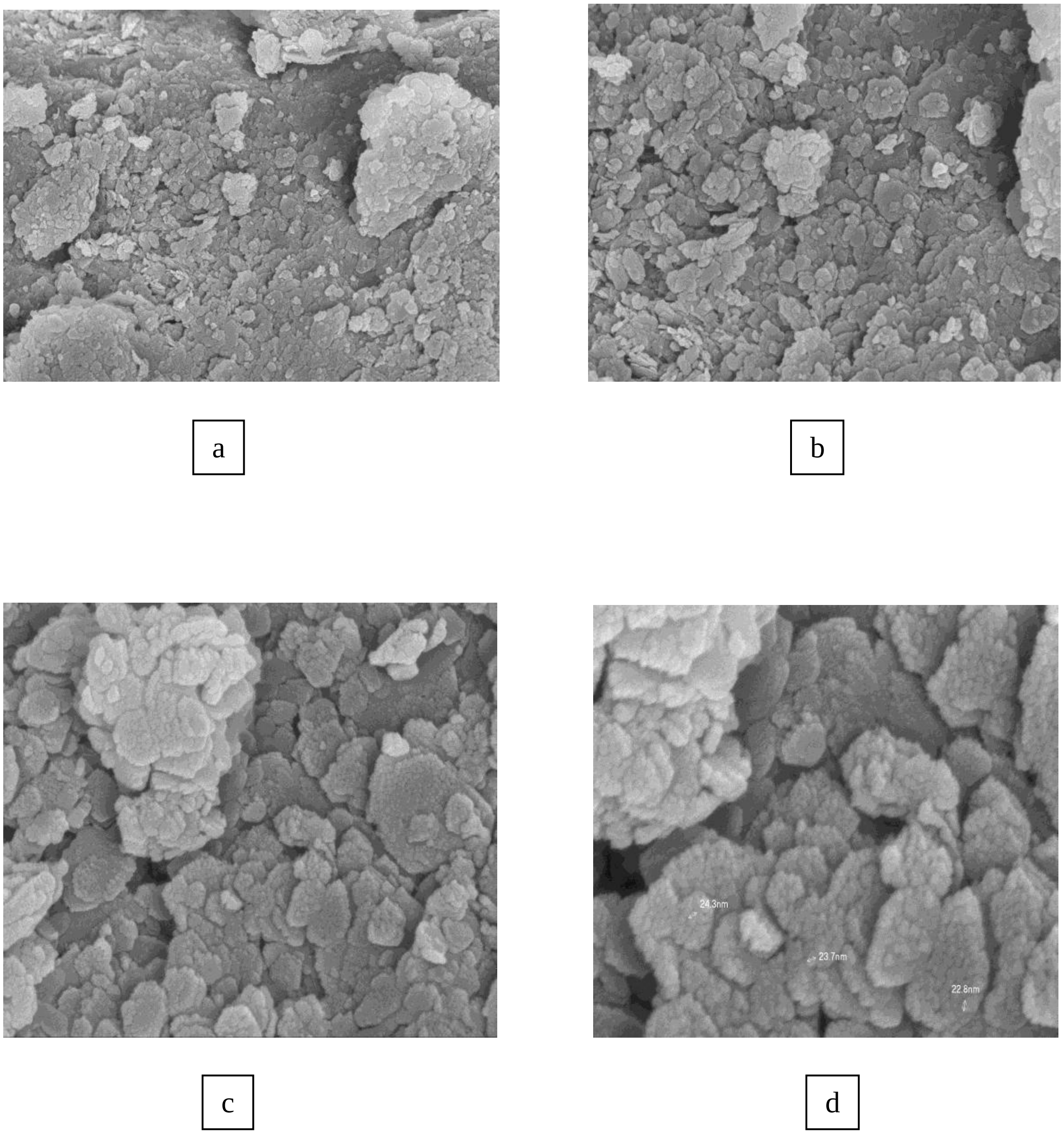
The variation of unconfined compressive strength with dry density is shown in Figure 3. Generally, UCS increased to a peak and decreased non-linearly with dry density. UCS values greater than 200kN/m ^{2} were recorded at dry unit weight greater than 1.64Mg/m^3. The findings are within the range of values reported by (Osinubi et al., 2007).

CONCLUSION

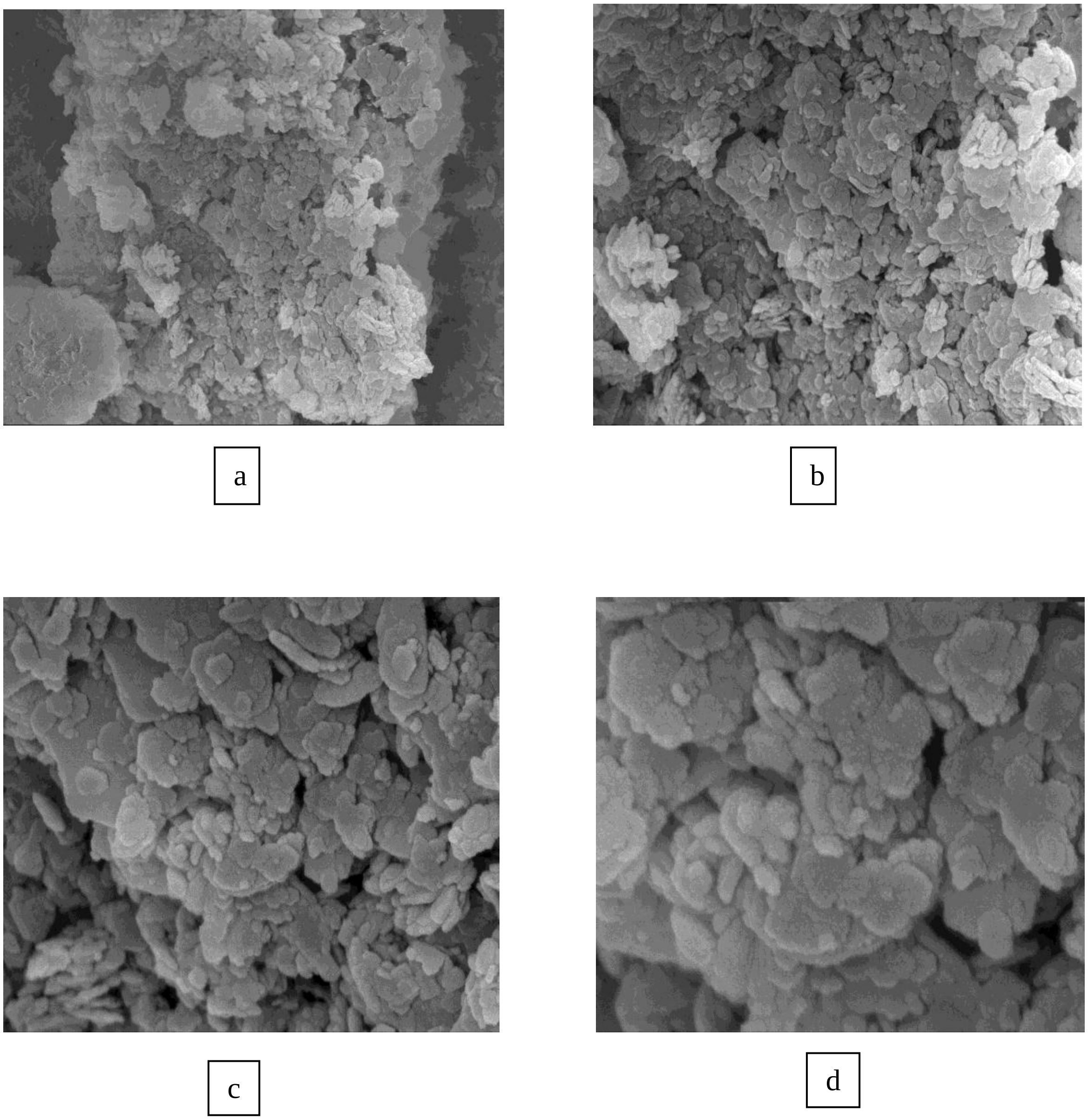
The reddish brown Tropical Soils from Ibadan, Southwestern Nigeria were classified as A-7-6 or lean clay with sand (CL) according to AASHTO and USCS. The soils were compacted using British Standard light energy to determine the effects of compaction water content and dry density on their shear strength when used in waste containment application.. .

Unconfined compressive strength (UCS) values of the soils generally increased to peak values at moulding water content of 16.5%, and thereafter decreased to very low values as water content increased. UCS values recorded in the 13.9 - 18.1% moulding water content range are equal to or greater than 200kN/m^2 minimum acceptable value required for containment structure. Generally, UCS values increased non-linearly to peak values and thereafter decreased with increase in dry unit weight.

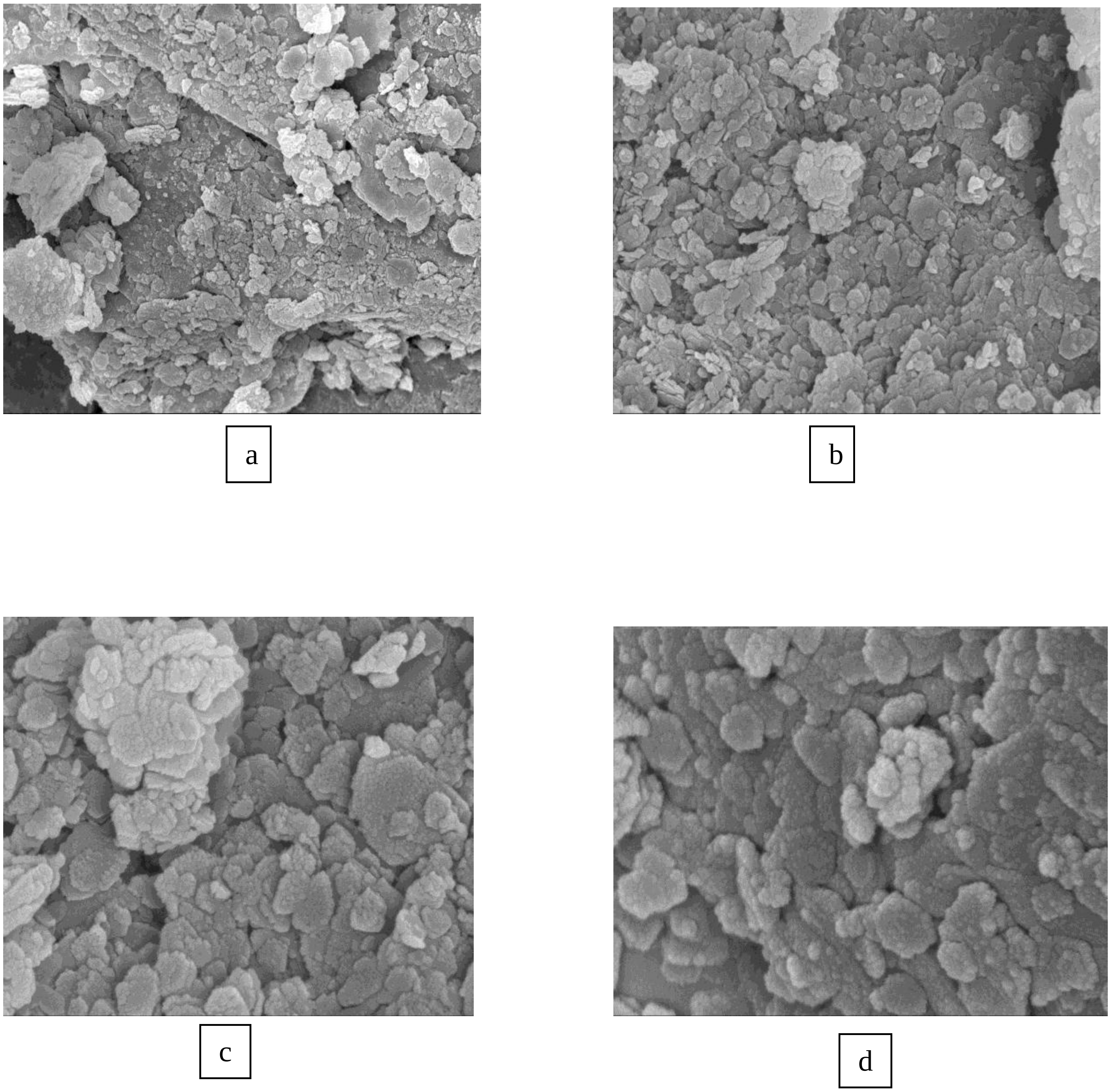
The study established that UCS values of tested soils greater than 200 kN/m^2 can be achieved when prepared at moulding water content in the range 13.9 - 18.1% and compacted to a dry density greater than 1.64 Mg/m^3 using British Standard light energy. Consequently, the soils can be used as hydraulic barriers in waste containment applications.



Plates 1 (a, b, c and d): Micrographs showing Kaolinitic and Halloysitic Flakes at 10,000, 20,000, 50,000 and 100,000 magnification using FESEM for MP1.



Plates 2 (a, b, c and d): Micrographs showing Kaolinitic and Halloysitic Flakes at 10,000, 20,000, 50,000 and 100,000 magnification using FESEM for MP2.



Plates 3 (a, b, c and d): Micrographs showing Kaolinitic and Halloysitic Flakes at 10,000, 20,000, 50,000 and 100,000 magnification using FESEM for MP3.

Table 2: Chemical Composition of Soil Samples.

Oxides	Concentration, %		
	MP1	MP2	MP3
Fe_2O_3	9.2	7.7	8.2
CaO	4.3	4.1	7.2
MnO_3	0.31	0.10	0.35
K_2O	1.0	0.6	1.6
Cr_2O_3	0.12	0.13	0.3
Al_2O_3	5.1	3.3	4.1
SiO_2	3.4	5.7	2.2
Organic Carbon	0.05	0.07	0.02
pH	6.10	6.20	6.20
EC µmhos/cm	0.29	0.26	0.16

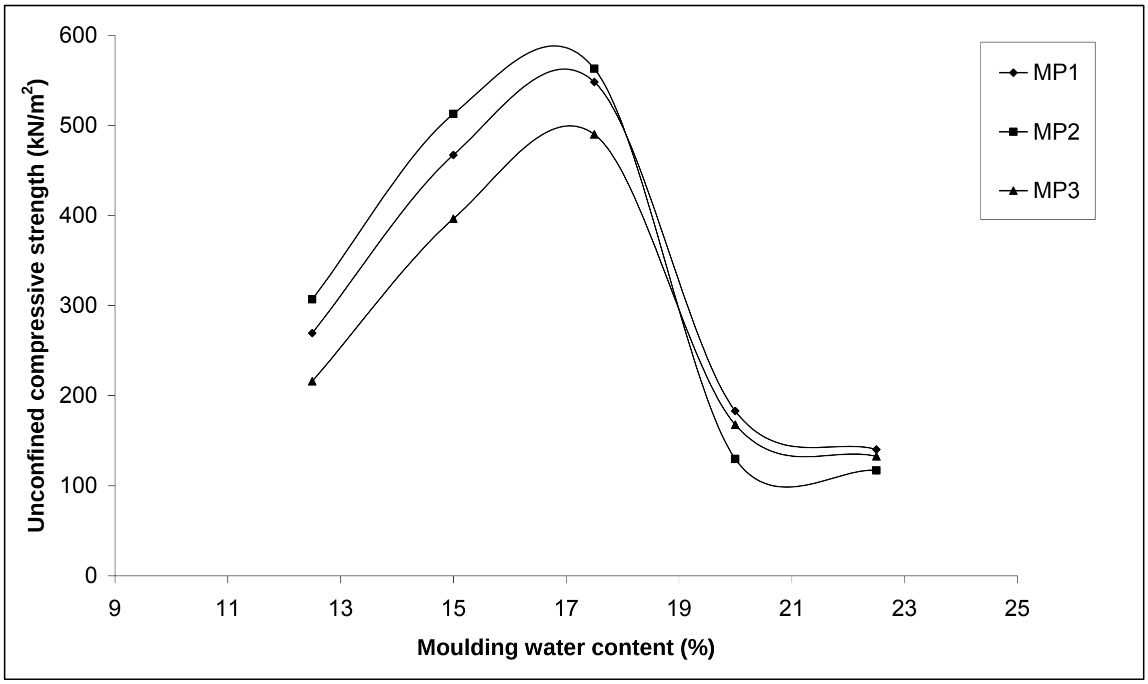


Figure 2: Variation of Unconfined Compressive Strength of Soils with Moulding Water Content.

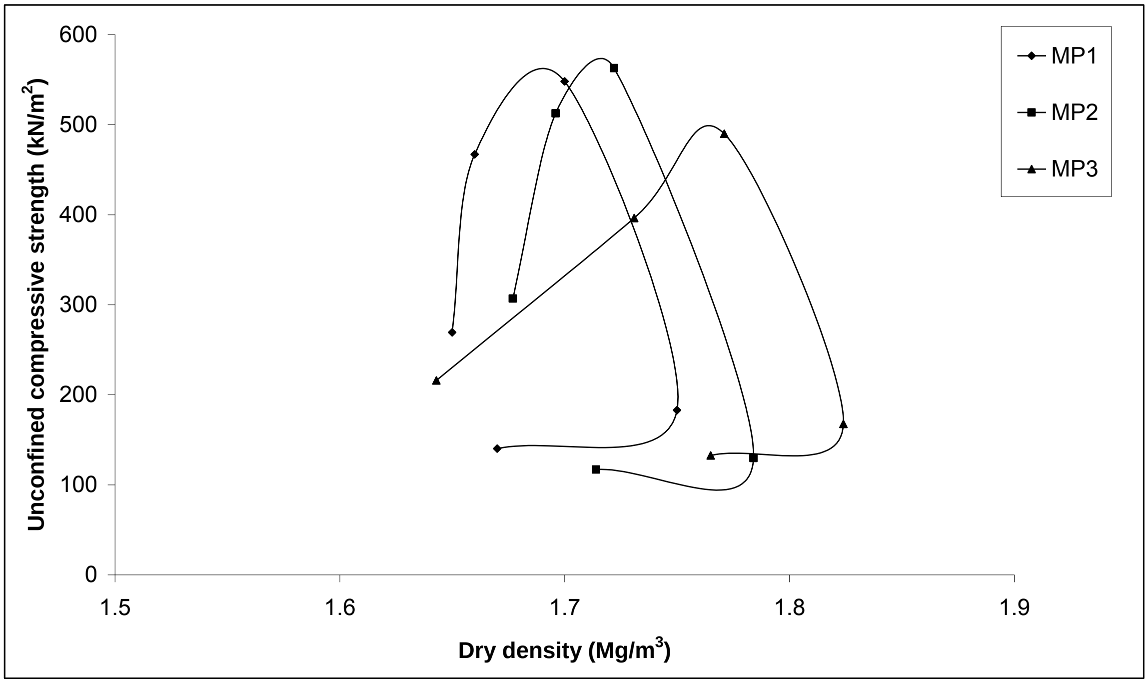


Figure 3: Variation of Unconfined Compressive Strength of Soils with Dry Unit Weight.

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