



# EFFECT OF FINES CONTENT ON THE ENGINEERING PROPERTIES OF RECONSTITUTED LATERITIC SOILS IN WASTE CONTAINMENT APPLICATION

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## Abstract

A lateritic soil reddish brown in colour was reconstituted with inclusion of fines content in 0, 20, 40, 60, 80 and 90% to form six (6) different soil mixes (S1, S2, S3, S4, S5 and S6, respectively). These soils were analysed to determine the effect of fines content on their engineering properties. Tests were carried out to determine index properties, compaction characteristics, strength properties (unconfined compressive strength (UCS) and undrained shear strength parameters) and hydraulic properties of the reconstituted soils. Specimens used for the determination of UCS, undrained shear strength parameters and hydraulic properties were prepared at the optimum moisture content (OMC) and compacted using the British Standard light, BSL (standard Proctor) energy. Reconstitution of the natural soil (0% fines content) yielded soil samples having fines content between 61 and 93%, and grading modulus that decreased with higher fines content. The specific gravity of the reconstituted soils decreased, while the Atterberg limits as well as derived plasticity parameters increased with higher fines content. The maximum dry density (MDD) and OMC decreased and increased, respectively, with higher fines content. The UCS and angle of shearing resistance generally decreased while cohesion increased with increase in fines content. The hydraulic properties improved with higher fines content. Test results indicate that the reconstituted lateritic soil samples meet the relevant requirements for materials to be used as hydraulic barrier in waste containment structures.

**Keywords:** compaction, derived plasticity parameters, hydraulic barrier, hydraulic conductivity, reconstituted lateritic soil

## 1. Introduction

Fine-grained soils are the most common materials used in the construction of compacted clay liners (hydraulic barrier) in waste disposal facilities because of their ready availability, good engineering properties when compacted and they are relatively economical. Significant pollutant retention capacity has also been observed for lateritic soils with a large percentage of fines [1-3].

For a lateritic soil to be effective as a barrier material in waste disposal facilities, it is expected to contain appreciable quantities of fines that enables the soil in its compacted state to yield low hydraulic conductivity values ( $k$ ) generally less than  $1 \times 10^{-9}$  m/s. Daniel [4] also stated that the minimum requirements recommended in achieving a hydraulic conductivity  $\leq 1.0 \times 10^{-9}$  m/s for most soil liner materials are as

follows: Percentage fines  $\geq 20 - 30\%$ ; Plasticity index  $\geq 7 - 10\%$ ; Percentage gravel  $\leq 30\%$ ; Maximum particle size: 25 - 50 mm. Compacted soils used for liners should also have adequate shear strength even when placed on the wet side of optimum. Some researchers [5] suggested that the minimum shear strength of the material should be 200 kPa (30 psi.) based on the lowest value for a very stiff clay soil [6].

Lateritic soils found in some areas in the tropics might not meet the properties listed for their use in waste containment applications and haulage distance of suitable material might not be economically viable; hence reconstitution of soil might be necessary to make the material useable for the intended purpose. The potential of reconstituted soil for use in construction of compacted soil liners and covers as well as their field performance would be greatly affected by the de-

gree of reconstitution with the fines content.

Several researchers have worked on the effect of fines on different engineering properties of soils. Research works have shown that fines content affect the compression and compaction behavior of soils [7, 8]. Also, its effects on instability and strength of soils have been investigated [9 - 11]. Furthermore, its influence on soils to be used as a highway material was investigated [12 - 14] but not much work has been done on the effect of fines on reconstituted lateritic soils for use as hydraulic barriers in waste containment systems. Hence, this study was aimed at the evaluation of the effect of fines content on the engineering properties of reconstituted lateritic soil to be used in waste containment applications.

## 2. Background

The geotechnical characteristics and field performance of reconstituted lateritic soils as well as their reaction to different stabilizing agents are better understood through their index properties. The interaction of the soil particles at the micro scale is reflected in the Atterberg limits of the soil that provides a better understanding of the strength, compressibility, swell potential of the soil or the water holding capacity of the soil and it is dependent on the type of clay mineral present along with the content.

Soil compaction is the mechanical process of increasing the density of a soil thereby eliminating the air voids within the soil matrix. The increase in density due to a reduction in void ratio, results in a substantial increase in shear strength of the soil and a marked decrease in its compressibility as well as permeability [15]. The reason for compaction test is to reduce the sensitivity of strength and volume change to environmental changes, especially those affected by moisture.

Field and laboratory experiments in the evaluation of compaction characteristics of lateritic soils indicate that two important factors influence the compaction test result of lateritic soils [16]. These are factors derived from processes of lateritic soil formation and factors derived from preparation and test method. In the first group, factors such as nature and mineralogical composition, grading characteristics, plasticity of fines and amount of clay size content in the fine-grained lateritic soil affect the MDD and OMC values and consequently permeability of the soil. In the second group, natural moisture content, method of drying and effect of fresh and reused (recompacted) sample have been shown to affect the value of MDD and OMC.

Furthermore, compaction characteristics are affected by their grading characteristics along with plasticity of the fines. Placement variables such as the moisture content, amount of compaction, type of compactive effort also affect the compaction characteris-

tics. Varying each of these placement variables has an effect on permeability, compressibility, swell potential, strength and stress-strain characteristics of the material.

## 3. Materials and Methods

### 3.1. Soil

The soil used in this study is a reddish brown lateritic soil which was collected from a borrow pit in Shika, Zaria (Latitude 11°15' N and Longitude 7°45' E), Nigeria, by method of disturbed sampling. A study of the soil and geological maps of Nigerian [17, 18] show that the soil samples from the borrow pit belong to the group of ferruginous tropical soils derived from acid igneous and metamorphic rocks [19, 20]. Soils from the study area contain kaolinite as the dominant clay mineral [21].

### 3.2. Reconstitution of the soil

The soil used in this study was air-dried and crushed by using a metal roller. Materials that passed through BS No 200 sieve (75µm aperture) were collected as fines. The natural soil was then mixed thoroughly with 0, 20, 40, 60, 80 and 90% fines content by weight of dry soil, to form six independent reconstituted soil samples S1, S2, S3, S4, S5 and S6, respectively.

### 3.3. Index properties

Tests carried out on the six reconstituted soil samples were in accordance with procedures outlined [22]. Sodium hexametaphosphate was used as dispersant during hydrometer tests. The grading modulus (GM), was computed by using equation (1):

$$GM = \frac{300 - \% \text{ passing } 2.4\text{mm} + \% < 0.425\text{mm} + \% < 0.075\text{mm}}{100} \quad (1)$$

% passing 2.4mm = Percentage of particle sizes passing sieve with 2.4mm aperture; % < 0.425mm = Percentage of particle sizes less than 0.425mm; % < 0.075mm = Percentage of particle sizes less than 0.075mm.

### 3.4. Derived plasticity parameters

Derived plasticity parameters such as plasticity modulus (PM), plasticity product (PP) and shrinkage modulus (SM) are used to represent the effective contribution of the plasticity of the fines to the performance of the whole material and they depend on the proportion of fines in the material [23].

Plasticity Modulus (PM) is defined as the product of plasticity index (PI) and percentage of soil fraction passing BS No 40 sieve (i.e., % < 425µm):

$$PM = PI \times (\% < 425\mu\text{m}) \quad (2)$$

$\% < 425\mu\text{m}$  = percentage of particle sizes less than 0.425mm.

Plasticity Product (PP) is defined as the product of plasticity index (PI) and percentage of fines less than BS No 200 sieve (i.e.,  $\% < 75\mu\text{m}$ ):  $\% < 75\mu\text{m}$  = percentage of particle sizes less than 0.075mm

$$PP = PI \times (\% < 75\mu\text{m}) \quad (3)$$

Shrinkage Modulus (SM) is defined as the product of linear shrinkage (LS) and percentage passing BS No 40 sieve (i.e.,  $\% < 425\mu\text{m}$ ):

$$SM = LS \times (\% < 425\mu\text{m}) \quad (4)$$

### 3.5. Compaction

Tests involving the moisture-density relationship, unconfined compression and hydraulic conductivity were carried out using air dried soil samples compacted with the BSL energy in accordance with BSI [22]. The reconstituted soil mixtures (S1 to S6) used for all the compaction tests were obtained by first thoroughly mixing dry predetermined quantities of pulverized soil with the respective fines contents to obtain uniform mixtures.

### 3.6. Unconfined compression

This test was carried out in accordance with BS 1377 [22]. Air dried reconstituted soils (S1 to S6) were compacted at their optimum moisture content using the BSL energy level in 1000 cm<sup>3</sup> mould. After compaction the specimen was extruded from the mould, placed in airtight polythene bags and kept in the humidity room for a period of 48 hours to allow for uniform distribution of moisture at a constant temperature of 24±2°C. After curing, the samples were trimmed into cylindrical undisturbed specimens that were placed in a load frame machine driven strain controlled at 0.10 %/min until failure occurred. Three specimens were used for each test and the average result taken.

### 3.7. Triaxial compression

The triaxial test was carried out in accordance with the procedure outlined in BS 1377 [22]. The same size of cylindrical specimen was prepared as explained under unconfined compression test. However, in this case, axial compression was applied on a set of three specimens A, B and C that were subjected to different confining cell pressures (103, 206 and 310 kN/m<sup>2</sup>) respectively, to obtain the undrained shear strength and its parameters.

Table 1: Basic geotechnical properties of the natural soil.

Property	Quantity
Natural moisture content, %	18.5
Percent passing BS No. 200 Sieve	60.9
Specific gravity	2.65
Liquid limit, %	45.85
Plastic limit, %	23.81
Plasticity index, %	22.0
Linear shrinkage, %	5.04
USCS	CL
AASHTO Classification	A-7-6 (11)
Maximum dry density, Mg/m <sup>3</sup>	1.686
Optimum moisture content, %	17.25
Shear strength, kN/m <sup>2</sup>	463
Cohesion, kN/m <sup>2</sup>	95
Angle of shearing resistance, degree	35°
Colour	Reddish-brown

### 3.8. Hydraulic conductivity

The hydraulic conductivity was measured using rigid wall permeameter under falling head condition [24]. The reconstituted soils (S1 to S6) were compacted at their respective BSL maximum dry density (MDD). After compaction, each sample with the mould was soaked in distilled water for a minimum period of 96 hours to allow for full saturation without vertical swelling. The fully saturated test specimen was then connected to a permeant liquid (distilled water). During permeation, test specimens were free to swell vertically (i.e., no vertical stress was applied). Hydraulic gradient ranged from 5 to 15. Tests lasted for 2 to 4 days and were only discontinued when steady flow was established.

## 4. Results and Discussion

### 4.1. Index properties

The natural soil is classified as fine-grained soils, inorganic lean clays of low to medium plasticity (CL) based on the Unified Soil Classification System (USCS). Based on AASHTO classification system, the soil is classified as A-7-6 (11). The basic geotechnical properties of the natural soil are summarized in Table 1. The particle size distribution of the natural and reconstituted soils is shown in Fig. 1.

Reconstitution of the natural soil yielded soil samples with varying fines contents. The percentage fines increased from 60.9 to 93.2% for S1 to S6, respectively. The relationship between the grading modulus (GM) determined using eq. (1) and fines content depicted in Fig. 2 shows that GM decreases with higher fines content. It implies that GM is inversely related to the fines content of the reconstituted soils.

### 4.2. Specific gravity

The variation of specific gravity with fines content is shown in Fig 3. A trend of decrease in specific gravity from 2.65 for S1 (natural soil with least amount of

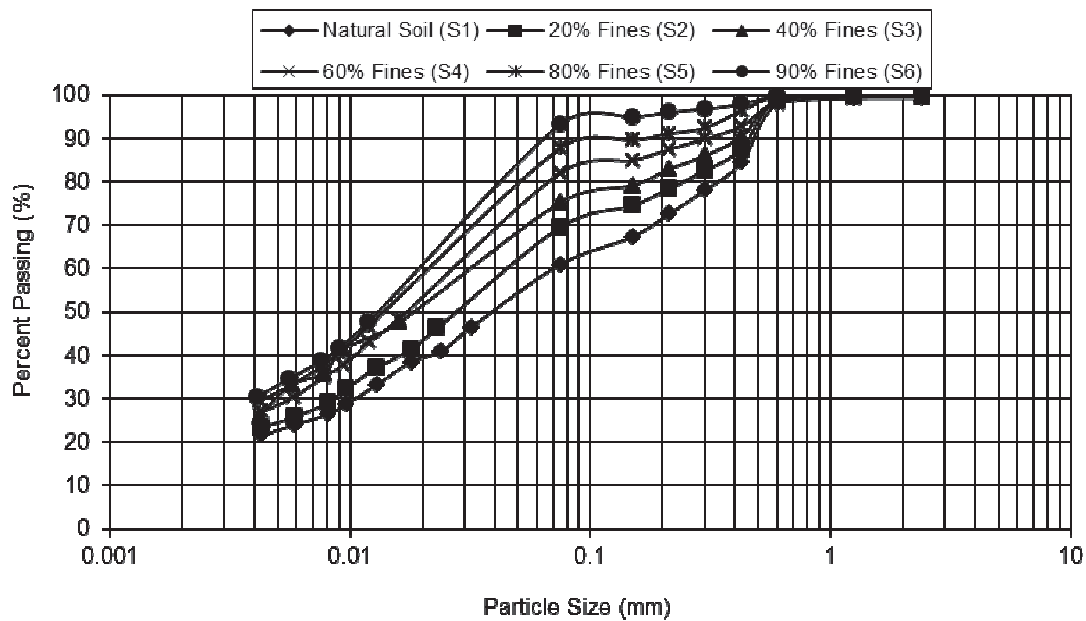


Figure 1: Particle size distribution curves of the natural and reconstituted soils..

fines) to 2.53 for S6 (reconstituted soil with maximum fines content) with higher fines content was observed. The observed trend was due to the increased replacement of particles of the natural soil with finer particles that were less dense.

#### 4.3. Atterberg limits

The variation of Atterberg limits (i.e., the liquid limit (LL), plastic limit (PL), plasticity index (PI) and linear shrinkage (LS)) of the reconstituted soils with fines content is shown in Fig. 4. Generally, the Atterberg limits of the samples obviously increased with higher fines content and this is in agreement with the results reported [25]. The results show that as the amount of fines increased, the resultant specific surfaces and activity of the material also increased, that was reflected in the increase in Atterberg limit values. This was so because the Atterberg limit values were proportional to the specific surfaces provided by the fines content [15].

The liquid limit and the plastic limit provide the most useful way of identifying and classifying the fine-grained cohesive soils [24]. Soils with high liquid limit generally have low hydraulic conductivity. It was recommended [26] that the liquid limit of a liner material be at least 20%. However, clay soils with too high liquid limit (LL) are more susceptible to desiccation cracking, whereas clay soils with too low plastic limit (PL) and plasticity index (PI) are less workable resulting in a higher probability of the existence of macropores and poor interlift bonding [27]. In general soils with very high liquid limit have poor volume stability and high shrink-swell potentials.

As long as it does not create any working problem (being workable and easy for machine to handle), soils with higher liquid limit are preferred for their low hydraulic conductivity in landfill liners [4]. High plasticity clays are more difficult to compact when used as fill material [24]; this is because they form hard lumps when dry and is difficult to break down during compaction thereby forming zones of higher hydraulic conductivity. More so, very high plasticity soil becomes sticky when wet and becomes difficult to work with in the field.

Linear shrinkage values ranged from 5 to 7% as shown in Fig. 4. The trend shows that shrinkage is highly dependant on the amount of fines in the soil. Linear shrinkage occurs as the water surrounding the individual soil particles of the specimens is removed, the soil particles move closer together. More movements are experienced in finer particles than coarser particles, which explain the trend. The shrinkage limit and shrinkage ratio of a clay soil, considered in relation to the field moisture content, can indicate whether it is likely to shrink on drying and if so, by how much [24]. Cracks provide pathways for moisture migration into a landfill cell, which increases the generation of leachate and ultimately increases the potential for the soil and ground water contamination.

#### 4.4. Derived plasticity parameters

These are used to represent the effective contribution of the plasticity of the fines to the performance of the whole material and they depend on the proportion of fines in the material. The variation of derived parameters such as plasticity modulus (PM), plasticity product (PP) and shrinkage modulus (SM) are shown

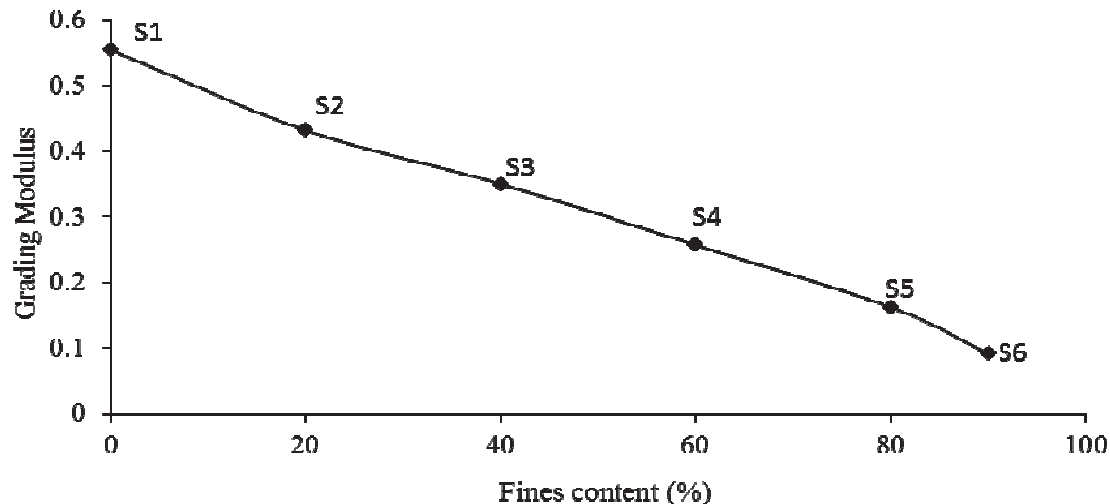


Figure 2: Variation of grading modulus with fines content.

in Fig 5. Generally, the derived parameters increased with higher fines content.

#### 4.5. Compaction characteristics

In the construction of soil liners, compaction is done to achieve a soil layer of improved engineering properties. Compaction of soils results into a homogenous mass that is free of large continuous inter-clods voids; increases their density and strength, and reduce their hydraulic conductivity. The variation of maximum dry density (MDD) and optimum moisture content (OMC) of the reconstituted soils with fines content is shown in Fig. 6. Generally, MDD decreased while OMC increased with increase in fines content. The MDD decreased because of decrease in specific gravity of the reconstituted due to increase in fines content. This result is consistent with the results other researcher [16] for fine-grained residual lateritic soils. On the other hand, the OMC increased due to increase in fines content resulting in increased total specific surface that required more water to achieve the mobilization of soil particles during the compaction process. The result is in agreement with the findings reported by other researchers [28–30].

#### 4.6. Strength characteristics

##### 4.6.1. Unconfined compressive strength

Durability and resistance to weathering is the quality of bonding in the material, which should be strong enough to withstand the destructive forces of environmental elements and equipment that will work over such materials; a minimum unconfined compressive strength of 200 kN/m<sup>2</sup> is required for a material to be suitable for use as a liner in waste containment systems [4, 5].

The variation of unconfined compressive strength (UCS) with fines content is shown in Fig. 7. The

UCS values ranged from 463 kN/m<sup>2</sup> for the natural soil to 359 kN/m<sup>2</sup> for reconstituted soil containing 90% fines. Generally, UCS of the soil samples decreased with higher fines content. The main factors responsible for the strength of soil are the cohesion and frictional resistance between the soil particles in contact. As the fines content increase, the soil matrix changes with the presence of excess fines; leading to a more slippery state and hence a reduction in the UCS of the soil.

Furthermore, this trend could be attributed to the reduction in density of the soil samples and the increased affinity for water by the increasing fines content, which results in loss of cementation between the particles leading to loss in strength (reduced cohesive resistance).

Regardless of the observed trend, even at 90% fines content, the UCS recorded is more than the minimum 200 kN/m<sup>2</sup> strength requirement for a liner material suggested [5].

##### 4.6.2. Undrained shear strength parameters

The relationship between cohesion ( $c$ ) and angle of shearing resistance ( $\phi$ ) of the reconstituted lateritic soil samples and fines content is shown in Fig. 8. Cohesion increased, from 95 to 200 kN/m<sup>2</sup> while angle of shearing resistance decreased from 35° to 16.5° for the natural soil and soil with 90% fines content, respectively. The basic intrinsic strength properties of soils are the cohesion and angle of shearing resistance. Increase in fine particles make soils to become less dense, increasing the inter particle bond between the particles due to larger surface area in contact and eventually increasing the cohesion.

Also, the angle of shearing resistance which depends on the grading, particle shape, void ratio but unaffected by the degree of saturation, decreases with increase in fines content because of the platy or fine na-

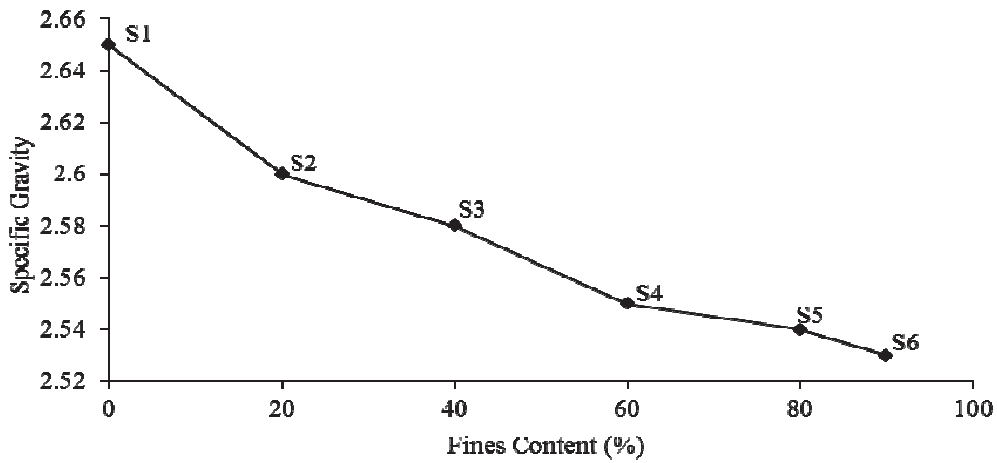


Figure 3: Variation of specific gravity with fines content.

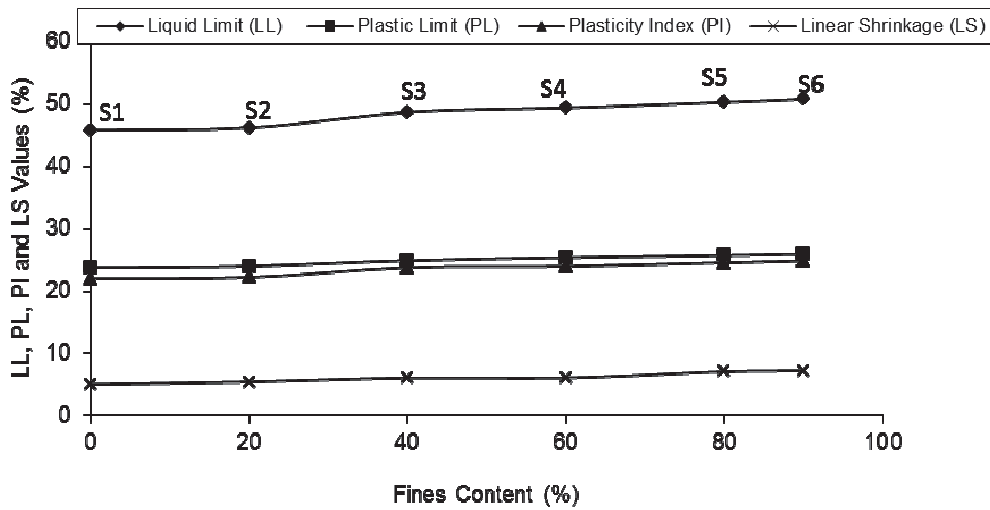


Figure 4: Relationship between Atterberg limit values and fines content.

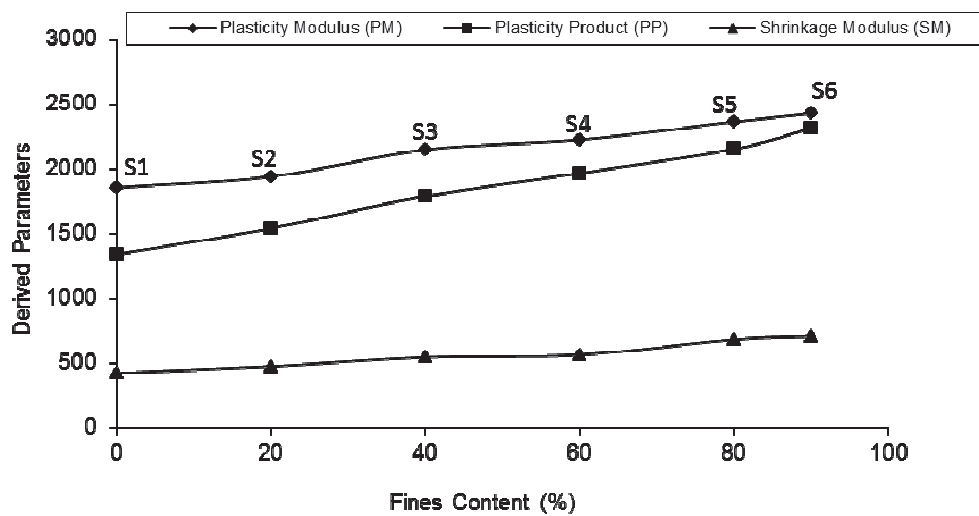


Figure 5: Variation of derived plasticity parameters of reconstituted soils with fines content.

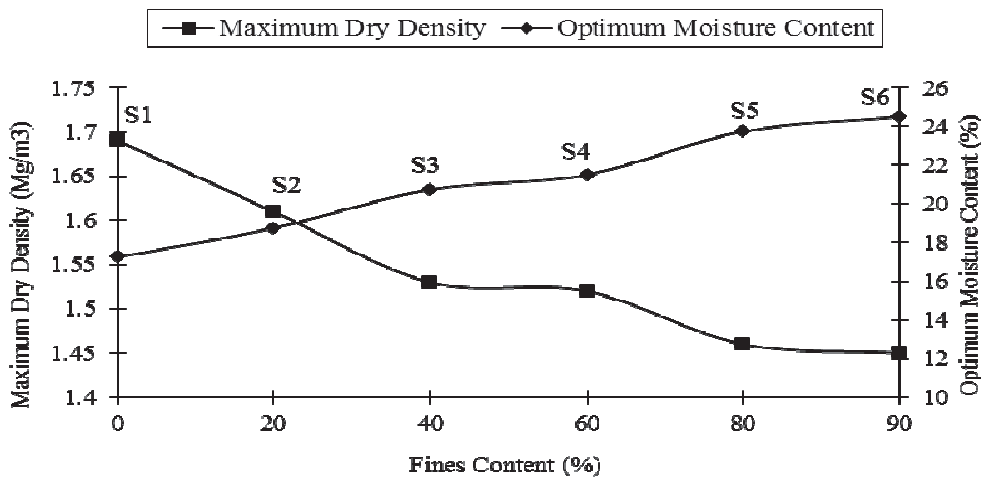


Figure 6: Variation of maximum dry density and optimum moisture content with fines content.

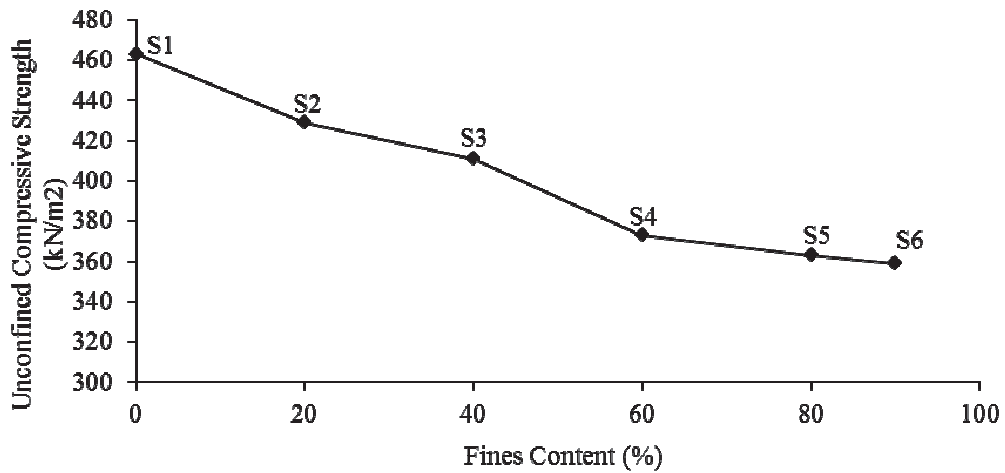


Figure 7: Variation of unconfined compressive strength (UCS) with fines content.

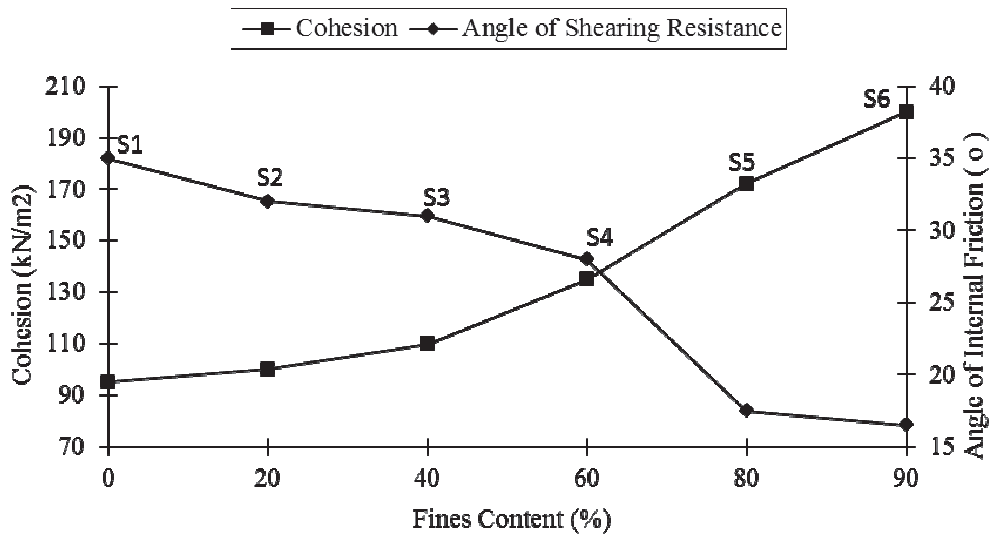


Figure 8: Variation of angle of cohesion and angle of shearing resistance with fines content.

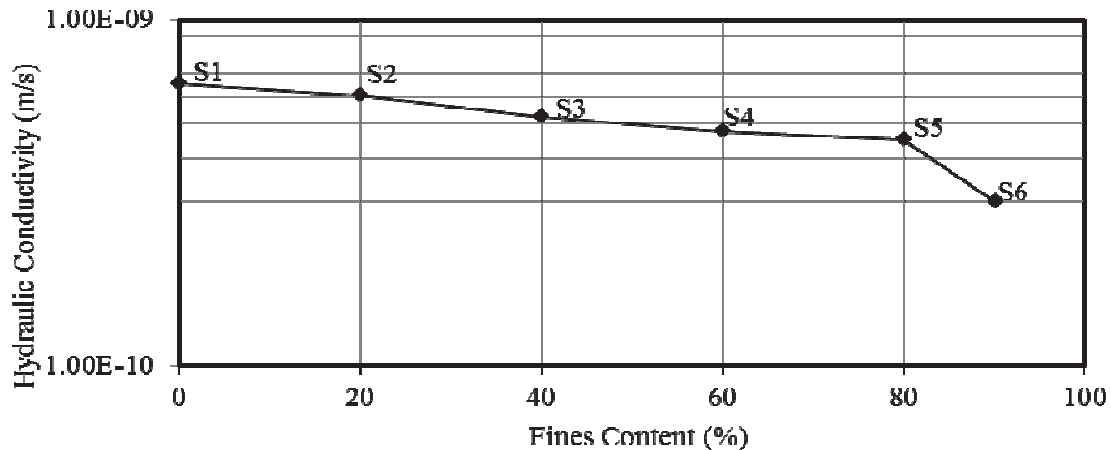


Figure 9: Variation of hydraulic conductivity with fines content.

ture of the soils, which reduces the interlocking forces between the particles [16].

#### 4.7. Hydraulic properties

Hydraulic conductivity is the key design parameter when evaluating the acceptability of a material in waste containment barrier application, since water retention is the primary aim of the containment barrier system. The impact of a waste disposal facility on ground water quality depends on the presence of a dominant flow path, and most importantly the nature of the barrier, which is intended to limit and control contaminant migration [31].

The variation of hydraulic conductivity with fines content is shown in Fig. 9. The coefficient of permeability ( $k$ ) (hydraulic conductivity) values decreased from 6.573E-10 m/s for the natural soil (S1) to 2.985E-10 m/s for soil with 90% fines content (S6). The hydraulic conductivity decreased between the natural soil (S1) and 20% fines content (S2) by 1.08 orders of magnitude; it decreased by 1.15 orders of magnitude between 20% fines content (S2) and 40% fines content (S3). Between 40% fines content (S3) and 60% fines content (S4), the hydraulic conductivity value decreased by 1.10 orders of magnitude; it further decreased by 1.06 orders of magnitude between 60% fines content and 80% fines content (S5). Finally it decreased by the highest margin of 1.51 orders of magnitude between 80% fines content (S5) and 90% fines content (S6). These results were expected, as the voids were filled with smaller particles (fines) that reduced the volume of voids present and flow of water through the interconnected voids. This is in agreement with the findings reported [32].

The relationship between the degree of saturation and fines content is shown in Fig. 10. The initial degree of saturation at compaction ranged from 78 to 92%, while the final degree of saturation (at the end of permeability test) ranged from 79 to 100%.

This trend shows that degree of saturation increased with higher fines content. This was due to increased capillary action of closely packed fine particles with higher matric suction ability, that had more contact areas and can easily absorbed water [33, 34].

The relationships between the hydraulic conductivity and the grading modulus as well as the plasticity characteristics (plasticity modulus and plasticity product) are shown in Figs.11 and 12 respectively. The hydraulic conductivity generally increased with increasing grading modulus (GM), which is so because increased (GM) is associated with less fines which will allow more flow to be conducted through the pore spaces. The hydraulic properties decreased with increased plasticity characteristics (plasticity modulus and plasticity product) values as expected for increased fines content, thus making the material better for use as hydraulic barrier in waste containment systems.

#### 5. Conclusion

A lateritic soil classified as CL under USCS was reconstituted with inclusion of fines content in 0; 20; 40; 60; 80; and 90% to form six (6) different soil mixes (S1, S2, S3, S4, S5 and S6, respectively). Tests on its engineering properties gave the following results:

The particle sizes of the reconstituted soils generally increased with increasing fines content resulting in a decrease in grading modulus. The specific gravity decreased with increased fines from 2.65 to 2.53. The Atterberg limits (plastic limit, liquid limit, plasticity index, and linear shrinkage) values increased with higher fines content. Also, the values of derived plasticity characteristics such as plasticity modulus, plasticity product, and shrinkage modulus increased with higher fines content.

For the reconstituted soils the maximum dry density decreased while the optimum moisture content



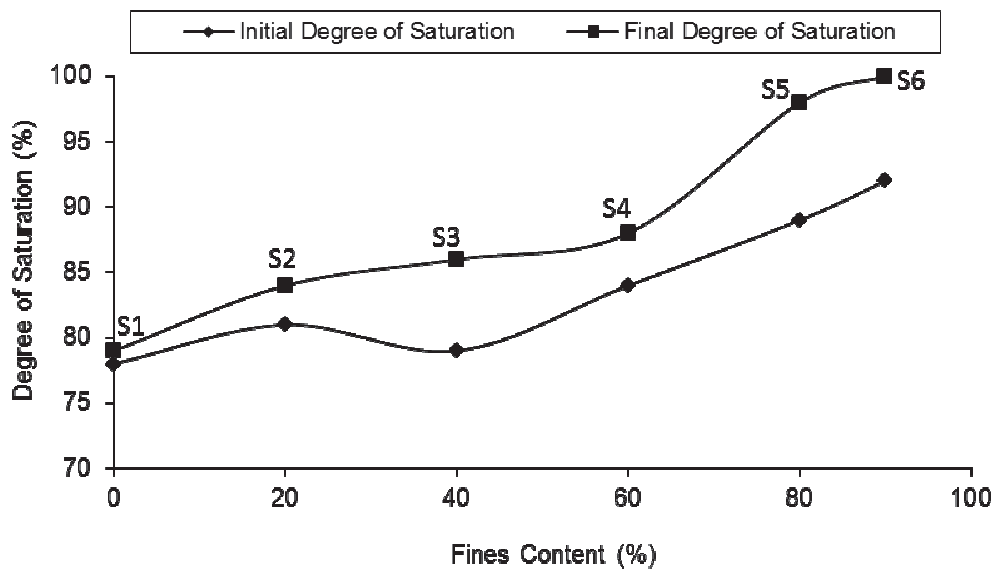


Figure 10: Variation of degree of saturation and fines content of reconstituted soil samples.

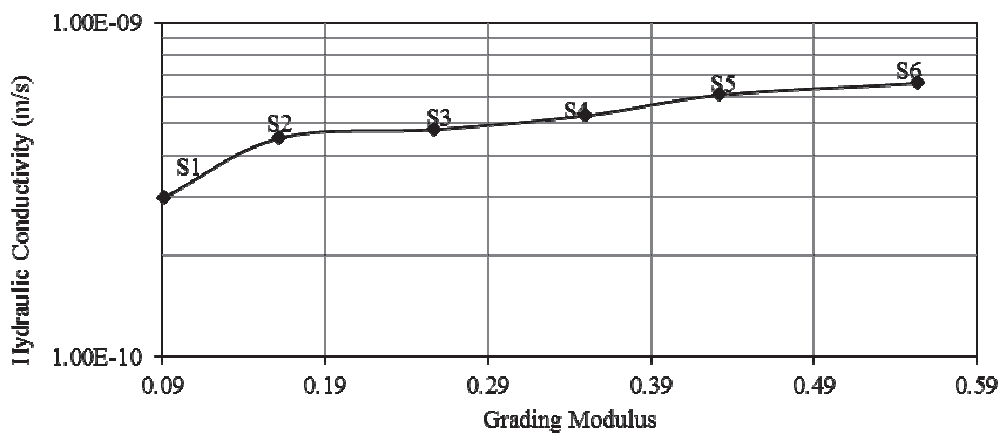


Figure 11: Variation of hydraulic conductivity with grading modulus.

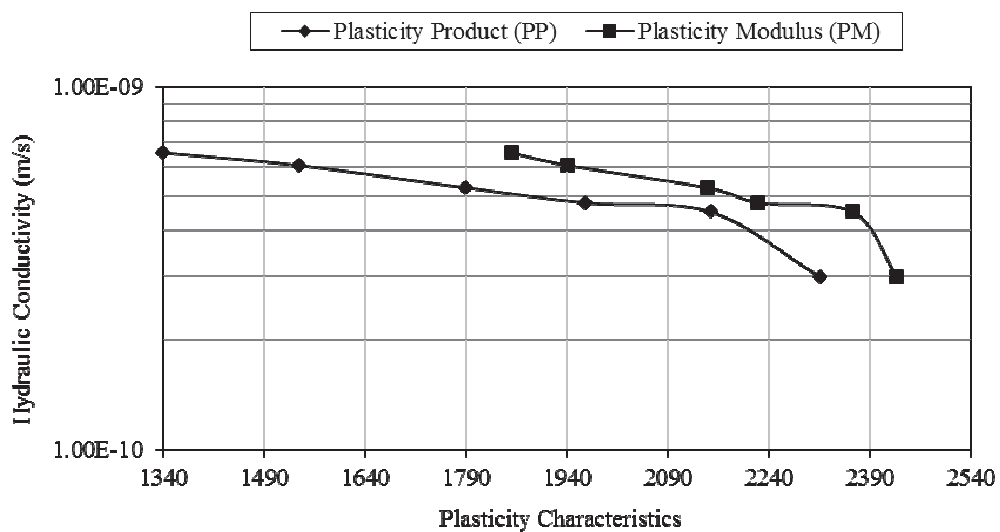


Figure 12: Variation of hydraulic conductivity with plasticity characteristics.

increased with higher fines content. The unconfined compressive strength decreased with higher fines content although recorded values are higher than the permissible 200 kN/m<sup>2</sup> required for hydraulic barriers. The cohesion increased while the angle of shearing resistance reduced with increase in fines content.

The hydraulic properties of the reconstituted soils improved with increased fines content up to 90% fines treatment. The initial degree of saturation at compaction and final degree of saturation after permeability test increased with higher fines content. Hydraulic conductivity increased with higher grading modulus which is associated with fewer fines while it decreased with increased plasticity characteristics (plasticity modulus, plasticity product) values.

The recorded test results of the reconstituted lateritic soils show that they can be used in constructing hydraulic barriers for waste containment facilities particularly in places where lateritic soil deposits do not meet the basic requirement for use as hydraulic barrier material.

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