Comparative Use of Cement and Katsi to Stabilize Laterite as a Liner in Containment Facility

Abdulrahman Haruna, Suleiman Abdulrahman, Idi Mamman Adamu

Abstract - Solid waste management has recently dominated the environmental scene in developing countries, everyday nearly three thousand tons of solid waste is generated in each state thereby causing environmental degradation. This research investigates the use of cement, and Katsi admixture to stabilize laterite used as a liner in containment facility. A trial pit of $1m^3$ at a waste disposal site was dug and soil sample were collected. The natural soil was subjected to test in accordance with BS 1377(1990). The sample was prepared by adding either cement or Katsi to the collected soil, at varying percentage. The geotechnical properties of unstabilized soil sample shows that the soil has a low to medium plasticity; its specific gravity of 2.44 indicates that the soil needs improvement for it to meet the range of value stipulated for clay minerals. Also the unconfined compressive strength UCS of the soil was observed to be 286.0 KN/m2, and coefficient of permeability K was found as 1.39 x 10-5 cm/s. Katsi was observed to have improved the Atterberg's Limit of the soil as the percentage of Katsi is increased explaining cationic exchange between the Katsi and laterite. And 7.5% Katsi content is recommended as convenient for laterite –Katsi mixture within the content of this study. This is because at 7.5% Katsi content the LL remained the same and the PI was at peak, implying that the greater the dry strength and toughness at plastic limit; the permeability, the rate of volume change and compressibility will remain the same.

Keywords: Katsi, Liner, Waste Disposal, Containment Facility, Stabilized Laterite.

1. INTRODUCTION

The uncontrolled and rampant disposal of municipal solid waste in Kano metropolis propelled the Government of Kano state to invest in proper disposal of these waste, but their effort almost failed due to un-proper containment facility that will contained these disposed waste without negative impact to the liner of the landfill or making the surrounding nasty, hazardous, and toxic. It also contaminates the soil and ground water through infiltration of leachate (bad water coming from decomposed solid waste) into the ground through the landfill.

This research is limited to the laboratory test and thus comparing the result between katsi stabilized laterite and cement stabilized laterite in making of liners for containment facility.

The significance of the study are;

i. To provide the society with hygienic environment.
ii. To provide an economical and cheap local material for line Containment facility.
iii. Safe and quality drinking water free from contamination as a result of infiltration of leachate from landfill.

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Waste material in waste containment facilities such as Land fill are made isolated from surrounding environments by providing liners or isolation barriers. Isolation barriers control or restrict the migration of pollutant from the landfill into the environment. Commonly used isolation barriers are composed of compacted natural inorganic clays or clayey soils. Disposing of waste in a landfill involves burying the waste and this remains a common practice in most countries. Old, poorly-designed or poorly-managed landfills can create a number of adverse environmental impacts such as wind-blown litter, attraction of vermin, and generation of liquid leachate. Another common by-product of landfills is gas (mostly composed of methane and carbon dioxide), which is produced as organic waste breaks down anaerobically. This gas can create odour problems, kill surface vegetation, and is a greenhouse gas.

These social wastes are the most significant source of subsurface, ground water, well water and other body of water contamination [1]. Rain water infiltrates into the waste and reacts physically, chemically and biologically with waste to produce leachates which infiltrates into the ground causing subsoil and ground water contamination. Leachate may contain toxic substances from discarded household materials, for instance materials like caustic cleaning products, used oil, batteries, paint thinner, etc. The leachate also contains dissolved bits of food, yard waste, paper and other biodegradable products. Bacterial action makes the leachate malodorous and unsuitable for release into the environment. In clean modern landfills, trash is dumped on site, compacted and covered with fresh soil cover which prevents release of odors, stops trash from bellowing around and discourages disease-carrying insects, rats, roaches, and other vermin. The effect of leachate has drawn the attention of the Federal environmental Agency (FEPA) law to foresee the sustainable development of Nigerian natural resources and environmental technology including initiation of policy related to environmental research and technology.

1.1 LITERATURE REVIEW

Hydraulic liner may be one or more layers of clay or a synthetic flexible membrane (or a combination of these). The liner effectively creates a bathtub in the ground. If the bottom liner fails, wastes will migrate directly into the environment. There are three types of liners: clay, plastic, and composite. To contain the inflow of leachate, impervious barriers or liners should be introduced in the landfill before the dumping of refuse begins [2]. Sadhu and Datta also outlined the following properties for the barrier i. very low permeability, ii. Should be flexible and remain intact under settlement of subsoil (beneath liners), iii. Should be durable for the design life of the landfill, iv. Should be strong enough to withstand stresses imposed by the filled waste, v. it should be easy to construct and maintained. Material(s) to be used as an impervious barrier in a containment landfill should be a composite barrier which is a combination of compacted clay liner and a thin polymetric sheet of High Density Polythens (HDPE), with the clay having the coefficient of permeability K, in order of 10-9 m/sec [2].

At some sites, suitable soils may not be available locally. In such cases, the barrier layer may be made of local soil (e.g laterite) mixed with low permeability additive such as Bentonite to give a mixture of amended soil (stabilized soil having a permeability in order of 10-9 m/sec). The amount of additive required is determined from laboratory tests. Typically10-15%, Bentonite is usually sufficient for silts, sand or silty sand [2]. Soil liners should have a hydraulic conductivity of at least 1 x 10^{-7}cm/s. Hydraulic conductivity is obtained at water content slightly (0.5 to 1.7%) wet of optimum water content. Generally the lowest hydraulic conductivity of laterite, clayey soils is achieved when the soil is compacted at water content slightly higher than the optimum water content [3]. Compacted soil liners are subject to frequent desiccation due to evaporative water losses, and desiccation lead to the development of shrinkage cracks. Cracks provide pathways for moisture migration into the landfill cell, which increases the generation of waste leachate, and ultimately increase the potential for soil and ground water contamination. Thus, the soil liner significantly losses its effectiveness as an impermeable barrier [3].

Physical properties (such as hydraulic conductivity, strength, and shrinkage potential) controlling the performance of soil liners are greatly influenced by water content, if the soil is too dry at the time of compaction, suitable low hydraulic conductivity may become unachievable. If the soil is too wet, a variety of problem may cause problem with construction equipment operating on soft, weak soils and potential slope instability caused by low strength of the soil. Kabir and Taha draw their conclusion that granite residual soil can be used as a suitable liner material for isolation waste materials in landfills, and its potential use as isolation barrier will enhance the waste management programme. Hydraulic containment (pumpard treat) is often performed when dealing with ground water contamination aid roles on pumping the contaminated ground water to the surface using a series of excavation wells Hydraulic containment system are used to control the movement of contaminated ground water, preventing the continued expansion of the contaminated zone. Although hydraulic containment and clean up can represent separate objectives, more typically remediation efforts are undertaken to achieve a combination of both [4].

Aim and Objectives of the Research

The aim of this project is to investigate into the use of cement admixed with Katsi to stabilize laterite as a liner in containment facility.

The objectives is to analyzed and make recommendations based on test results, if cement stabilized laterites and katsi stabilized laterite could be effectively used as liner in containment facilities, and also

i. To determine the engineering properties of the proposed laterite.
ii. To determine if the soil sample have properties that could prevent the infiltration of leachate in to ground from its land fill.
iii. To determine the effectiveness of treated sample when compared with control sample (untreated sample) in containment facilities.
iv. To determine the optimum percentage of Admixture needed to make the sample meet the minimum requirement of a landfill liner.

2. MATERIAL AND METHODS

2.1 LATERITE

The international society for soil mechanics and foundation Engineering (ISSMFE) Progress Report (1982/85) states that "a soil can be considered lateritic if it belong to horizon A or B of well drained profiles developed under buried tropical climates, its clay fraction are constituted essentially of the kaolmite group and of iron or aluminum hydrated oxides. These components are assembled in peculiar porous and highly stable aggregate structure". Lateritic soil is a category of residual soil formed from the weathering of igneous rock under conditions of high temperature and high rainfall such as those typically occurring in tropical regions. Laterites are mosttly reddish in color, but not all reddish tropical soils are lateritic. Extensive areas of Asia, South America, and Africa are blanketed with lateritic soil.

2.2 Cement

Portland cement is an additive intended to bind soil particles together. Cement is a powder that when mixed with water binds a stone–sand mixture into a strong material within a few days. Or in another world it is material required to bind the grains of sand together into a solid mass. The essential ingredients of portland cement are lime, Silica and Alumina. Fortunately, all three occur abundantly in nature as chalk. The amount of gypsum added to clinker during manufacture of a particular types of cement will also determine the setting time of the cement.

2.3 Katsi (Local Dye Residue)

The term "Katsi" is the Hausa name used in referring to the by-product residue of indigo dyeing process which is predominately carried out in Hausa land. As the dye looses it effectiveness, a dense deposit known in Hausa language as "dagwalo" is formed at the bottom of the dye pit, this 'dagwalo' is left to stand in the pit for about two days, and then the whole solution is removed from the pit leaving behind a dense deposit at the base The deposit is scrapped and removed from the pit and left to dry out completely. It is further burnt with open fire until a light grey ash is formed; this is pounded into powdered ash which is called Katsi or dye residue.

According to Ella, about 2 to 3 head pans (46 to 69kg) of Katsi are produced from a dye pit in a circle of dying process. An average of about 112 tons of Katsi is produced in the country annually. For the Chemical analysis of Katsi, see [5].

2.4 Sampling

The soil sample was obtained near a waste disposing site at Rijiyar zaki Kano State. A trial pit from which the sample was collected was dug at a width of 1m x 1m and a depth of 1m. After digging, the sample was collected into four separate bags and some relatively small portion of the collected samples was put in an air tight polythene bag. The natural soil was subjected to test in accordance with BS 1377 (1990). The laboratory tests conducted includes; Atterberg limit test, sieve analysis, compaction test, unconfined compressive strength test and Permeability test. The percentage of the cement and katsi used are (0%, 2.5%, 5%, 7.5% and 10%). Also katsi-cement mixture was used in the ratio of 2:1, to the laterite.

3. RESULTS AND DISCUSSION

The summary result of various test conducted in this study are reported here. Attempt is made after every presentation to discuss them in relation to result obtained.

Table 1: Geotechnical Properties of unstabilized Soil

Characteristics	Test Values /Description
Percentage of sand	86.57%
Liquid Limit (LL)	57.50%
Plastic Limit (PL)	52.00%
Plasticity index (PI)	5.5%
Linear shrinkage (LS)	9.29%
Colour	Reddish brown
Maximum Dry Density MDD	2.27Mg/m3
Optimum Moisture content OMC	12.1%
Specific gravity (Gs)	2.44
Coefficient of permeability	1.39x 10-5 cm/s
Natural Moisture Content %	10.59
UCS	286.0 KN/m2

The geotechnical properties of unstabilized soil sample were shown in table 1 above. Comparing the liquid limit value plastic limit and a plasticity index values, it implies that the soil has a low to medium plasticity [6]. The natural moisture content of the soil sample indicate that the soil is visibly wet at the time of collection while the specific gravity (Gs) of 2.44 indicates that the soil have to be improved for it to meet the range of value stipulated for clay minerals, the low Gs might be due to some fair amount of organic minerals present in the soil sample.

The maximum Dry Density MDD/optimum moisture content OMC relationship of the compacted sample of 2.27Mg/m3 and 12.1% indicates that when the soil is compacted slightly above OMC the compressibility would be better at relatively low stress levels [6] and the permeability of the soil will also decreased owing to the fact that the strong inter particles bonds in flocculated structure do not allow the particles to be displaced.

The unconfined compressive strength UCS of the soil was observed to be 286.0 KN/m2 which means the soil is stiff in terms of consistency. While coefficient of permeability K was found as 1.39 x 10-5 cm/s owing to the fact that the compaction of the soil sample at the OMC of 12.1% improved the coefficient of permeability of the laterite. Furthermore the grading curve of the laterite shows that the laterite falls in zone 3 based on BS882: part 2: 1973. Meaning, there is more medium sand than fine and coarse sand.

Table 2: Atterberg Limit test results for the stabilised soil

	Sample Type	Varying Percentage of Stabilisation				
		0%	2.5%	5%	7.5%	10%
Liquid Limit	Soil-Cement	57.5	46.2	42.0	46.0	43.0
	Soil-Katsi	57.5	41.0	48.0	46.2	30.0
Plastic Limit	Soil-Cement	52.0	35.0	29.2	31.2	32.7
	Soil-Katsi	52.0	17.8	21.6	19.3	8.3

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Plasticity Index	Soil-Cement	5.5	11.2	12.8	14.8	10.3
	Soil-Katsi	5.5	23.2	26.4	26.9	21.7
Linear Shrinkage	Soil-Cement	9.3	10.0	6.3	5.7	5.7
	Soil-Katsi	9.3	9.6	10.7	9.3	7.5

Effect of Cement on Atterberg's Limit of laterite

The variation of liquid limit, plastic limit, plasticity index and linear shrinkage with increase in the percentage of cement to weight of soil sample were shown in table 2 above. There was steady decrease of liquid limit at 0% to 5% cement content before it increased to 46.0 at 7.5% cement content and further reduced to 43.0 at 10% cement addition. The decrease in liquid limit between 0% and 5% addition of cement is due to the fact that cement has minimal effect on Atterberg's limits[7]. The increase in the liquid limit with increase in cement content from 5% to 7.5% is due to the fact that the cationic ions in both cement and soil sample cancels out leaving a net negative charge with a resultant high affinity for H+ ion in water. The variation in the linear shrinkage with different percentage of cement content can also be due to the cationic exchange of ions between the cement and the soil sample thereby causing a decrease in the shrinkage limit with increase in cement content.

Effect of Katsi on Atterberg's Limits of the Laterite

Similarly, the variation of liquid limit, plastic limit, plasticity index and linear shrinkage with increase in the percentage Katsi to weight of soil sample are shown in table 2 above. The liquid limit increases from 0% to 2.5% Katsi increase and decreased from 46.2 to 30.0 at 7.5% and 10% increase in Katsi content. The increase in the liquid limit between 2.5% and 5% Katsi can be due to the explanation referred in soil – cement liquid in the earlier section of this chapter while, the decrease in the liquid was due to the agglomeration and flocculation of the soil particles. In the same vein there was an increase in plastic limit from 17.85 to 21.62 at 2.5% and 5% Katsi content while a further decrease was observed at 7.5% -10% Katsi content from 19.3 to 8.3. The decrease and increase in the plastic limit can be related to the explanation of the observation given for liquid limit. The linear shrinkage was also observed to increase between 2.5% to 5% of Katsi content and further decreased from 7.5% to 10% of the Katsi content which tends to be a positive effect on the soil property.

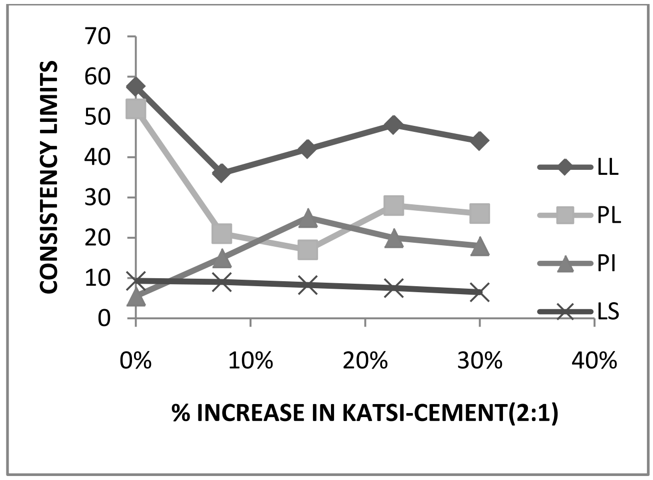
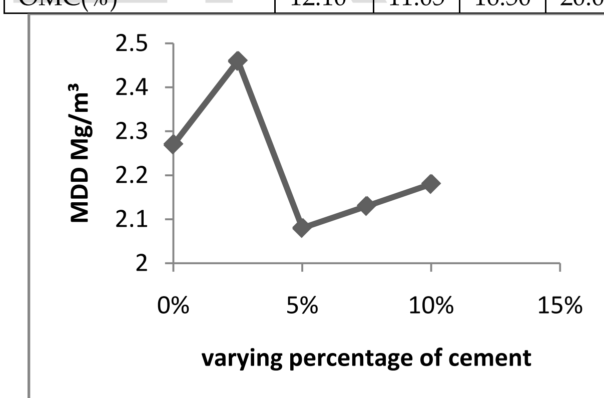


Fig. 1: Variation of consistency limits with varying concentration of Katsi-cement (%)

From figure 1 above, there was a decrease in liquid limit with increase in Katsi - cement content and subsequently begin to rise again, which are 57.50, 36.00,42.0, 48.0 and 44.0 for various concentration of Katsi and cement in 2:1 ratio. The decrease in liquid limit between the corresponding additions of Katsi-cement might be due to the minimal effect of cement on Atterberg's limits[7].

Table 3: Compaction test for Soil – Cement MDD/OMC relationship Results

Varying concentration of Cement	0%	2.5%	5%	7.5%	10%
MDD Mg/m³ OMC(%)	2.27 12.10	2.46 11.05	2.08 16.50	2.13 20.00	2.18 20.50



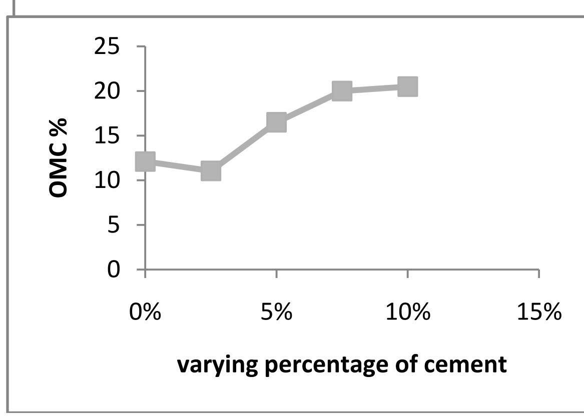


Fig 2: (a) MDD against concentration of cement.
(b) OMC with varying concentration of cement

Effect of Cement on Compaction test of the laterite

Table 3 and figure 2(a) and (b) above reflects the variation in the maximum dry density (MDD) and optimum moisture content (OMC).The gradual increase in MDD at 0% to 2.5% and further decrease from 5% to 10% is due to pozzolanic reaction between silica and alumina in cement which hydrates the alkalis in laterite. This forms larger aggregate and occupies more space and reduce the volume with increase in MDD, gradually the OMC decreased from 0% to 2.5% cement content and the increase in the OMC from 2.5% to 10% is due to the increased in amount of water required to support the pozzolanic reaction (hydration) between cement compounds and the soil.

Table 4: Soil – Katsi MDD/OMC relationship results

Varying concentration of katsi	0%	2.5%	5%	7.5%	10%
MDD Mg/m3	2.27	1.97	2.00	1.98	1.85
OMC (%)	12.10	15.86	10.00	9.80	6.00

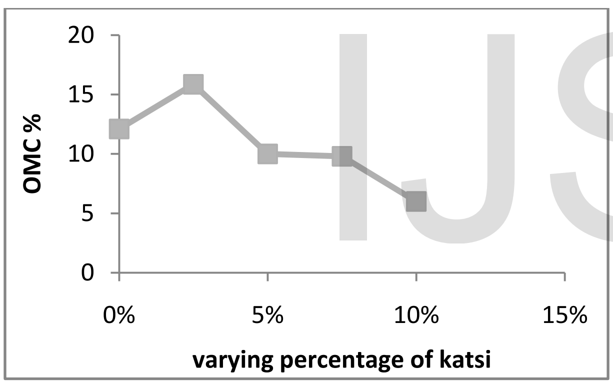


Fig 3: (a) MDD against concentration of Katsi
(b) OMC against varying concentration of Katsi

Effect of Katsi on MDD and OMC

The variation in the maximum dry density (MDD) and optimum moisture content (OMC) which were shown in table 4 and figure 3 (a) and (b) respectively. There was a decrease in the MDD with increase in Katsi at 2.5% Katsi content which later increase at 5% and constant decrease from 7.5% to 10% of Katsi content. The decrease in the MDD can be due to the cationic exchange of both Katsi and soil sample which reduce flocculation and agglomeration causing volumetric increase and a corresponding decrease in density.

Furthermore, the OMC increased at 0% to 2.5% Katsi content, further increase in Katsi content results in decreased OMC at 5% to 10%. This can be attributed to the reduction in the surface area cause by the flocculation and agglomeration of the complementary cationic exchange between the Katsi and the laterite soil. Thereby reducing the hydro affinity of the soil – Katsi mixture, implying that the greater the percentage of Katsi the lesser the water required to attain the maximum dry density in compaction [8].

Table 5: Unconfined Compressive Strength (UCS) Result

	Sample Type	Varying percentage of stabilisation				
		0%	2.5%	5%	7.5%	10%
UCS Value (KN/m2)	Soil + Cement	286.0	327.0	345.0	330.0	270.0
	Soil + Katsi	286.0	270.0	300.0	312.0	240.0
	Soil + Katsi+cement	286	326.0	295.0	280.0	195.0

Effect of Katsi on Unconfined Compressive strength (UCS) of laterite.

The reduction in UCS value between 0% and 2.5% Katsi (as shown in table 5 above) is due to the deflocculation induced by the disequilibrium in the cationic exchange reactions between the valence cations in Katsi and the lower valency ions in laterite structure.

While the further increase in UCS value at 5% and 10% Katsi content is due to the development of calcium silicate and calcium aluminates as the constituent of the Katsi reacts with the laterite minerals. These reactions are phased into the flocculation and agglomeration as the pozzolanic reaction stage. However, the combinations of Katsi-cement on the (UCS) only increased the strength when 5% Katsi and 2.5% cement are used.

Table 6: Permeability test Results for soil-cement

SAMPLE TYPE	Varying Concentration of cement (%)				
	0%	2.5%	5%	7.5%	10%
Soil + Cement (cm/s)	1.39x 10-5	1.33x 10-5	1.28x 10-5	1.26x 10-5	1.03x 10-5
Soil + Katsi (cm/s)	1.39x 10-5	1.36x 10-5	1.31x 10-5	1.24x 10-5	1.20x 10-5
Soil + Katsi + cement (cm/s)	1.39x 10-5	1.30x 10-5	1.28x 10-5	1.28x 10-5	1.24x 10-5

Effect of cement on Permeability test of the laterite

From the result obtained above, the coefficient of permeability "K" of the parent material decrease with increase in the percentage of cement content. This is as a result of the binding properties of cement which replaces the soil pore spaces thereby increasing the time of water movement and hence decreases the hydraulic conductivity.

However, the hydraulic conductivity (coefficient of permeability 'K') for the parent sample using the falling head method when Katsi was added to the laterite was 1.39

x 10-5 cm/s, while further increase in percentage of Katsi concentration further reduces the hydraulic conductivity of the sample. This reduction in K value can be attributed to the replacement of soil pore-space with Katsi requiring increase in compactive effort and increase in moisture content and decrease in hydraulic conductivity.

Effect of Katsi-cement on Permeability test of the laterite

The hydraulic conductivity (coefficient of permeability 'K') for the parent sample using the falling head method is 1.39 x 10-5 cm/s while further increase in percentage of Katsi - cement concentration gave a K – value of 1.3 x 10-5 cm/s, 1.28 x10-5 cm/s, 1.28x 10-5 cm/s, 1.24x 10-5 for various percentages of Katsi-cements. The reduction in the permeability is as a result of the reasons stated in above.

4. CONCLUSION

From the experiment conducted it was observed that the addition of Katsi and the addition of cement as stabilizers to the laterite have significantly improved its engineering properties respectively.

1. The Katsi was observed to have improved the Atterberg's Limit of the soil with a considerable reduction in the LL and PL and a considerable increase in the PI as well as continuous reduction in the linear shrinkage (LS) as the percentage of Katsi was increased explaining cationic exchange between the Katsi and laterite.

2. The MDD was also altered because it increased when compared to that of the unstabilized sample and reduced continuously as the percentage of Katsi increases while the OMC fluctuated though it was greater than that of the unstabilized sample at 2.5% and 5% with addition of Katsi to the soil sample

3. The aforementioned observation can also be said for cement – soil mixture though they were less pronounced when compared with soil–Katsi mixture. The PI values observed for soil-cement values are comparatively less than that of soil–Katsi mixture and which that of soil–Katsi mixture had a regular decrease as the percentage of Katsi increase, that of soil–cement mixture was irregular. Also in the case of Katsi-cement mixture there was a decrease in the MDD and the OMC.

4. There was steady decrease in the coefficient of permeability as the percentage of cement increased and also the coefficient of permeability also decrease with increase in the percentage of Katsi. While the UCS value increased as the percentage at certain percentage of additives.

4.1 RECOMMENDATION

Therefore 7.5% Katsi content is recommended as convenient for laterite–Katsi mixture within the content of this study. This is because at 7.5% Katsi content the LL remained the same and the PI was at peak, implying that, greater the dry strength and toughness at plastic limit; the permeability and rate of volume changed of the compressibility will remain the same. Also, at 5% and 7.5% of cement and Katsi respectively the Peak value for the UCS also attained.

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