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The Effectiveness of Residual Soil, Orashi River Sand, and Sombrero River Sand as Stabilizing Agents for Subgrade Soil of Highway Pavement

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Abstract **Original Research Article**

The study investigated the effect of different stabilization materials, including residual soil and river sands, on the properties of subgrade soil for road and pavement structures. The results showed that the chemical composition of the subgrade soil was dominated by calcium, aluminum, and silicon, indicating a mineral clay soil. The use of stabilization materials led to a decrease in fines content and an increase in maximum dry density. The behavior of optimum moisture content was non-linear, and the liquid limit of the stabilized subgrade soil decreased significantly for all three materials, indicating a decrease in soil swelling ability. The study also revealed that the use of composite materials of cement and residual soil or river sand can improve the properties of subgrade soil and lead to an increase in unconfined compressive strength. The findings of this study can aid in the selection of appropriate stabilization materials and methods, and in the optimization of the use of these materials in road construction for improved strength and durability. Further research is needed to fully understand the characteristics of subgrade soil and determine the most effective methods for its stabilization and management. This study investigates the effects of residual soil and river sands on the mechanical properties of subgrade soil, with a focus on liquid limit, plastic limit, plasticity index, and unconfined compressive strength. The results suggest that residual soil, Orashi River sand, and Sombrero River sand are effective stabilizing agents for subgrade soil, with an increase in strength observed with increasing percentages of stabilizing material. However, there is an optimum content of stabilization material required to achieve maximum strength values, beyond which the strength decreases. The study also highlights the importance of considering the effect of soaking on the strength of subgrade soil and demonstrates the effectiveness of using composite materials of cement and residual soil or river sand for soil stabilization. These findings have significant implications for the design and construction of infrastructure projects on subgrade soil, particularly in areas with expansive soils. Further research is needed to investigate the long-term effects of stabilization materials and explore the effects of different mixing ratios of composite materials. Overall, this study makes an important contribution to the body of knowledge on soil stabilization and its application in infrastructure projects.

Keywords: Stabilization, Residual Soil Orashi River sand, and Sombrero, OMC, MDD, CBR, UCS, Consistency Limits.

1.0 INTRODUCTION

Expansive soils are a common problem in many parts of the world. These soils can cause significant damage to buildings and infrastructure due to their ability to swell and shrink in response to changes in moisture content. Mechanical stabilization is one method that can be used to mitigate the effects of expansive soils. In this article, we will discuss the basics of mechanical stabilization of expansive soils and the different methods that can be used.

Soil stabilization is an important technique used to improve the engineering properties of soils for various construction purposes. The stabilization of soil involves the addition of various materials to the soil to enhance its strength and durability. Different materials have been used for soil stabilization, including lime, cement, waste materials, and industrial by-products. The particle size distribution and composition of soil also play a significant role in soil stabilization.

Mechanical stabilization is a process in which soil properties are modified to improve its strength and stability. In the case of expansive soils, mechanical stabilization is used to prevent or minimize the effects of soil swelling and shrinking. The goal of mechanical stabilization is to create a stable and strong soil structure that can resist the effects of moisture changes. Mechanical stabilization is an effective method for mitigating the effects of expansive soils. By modifying the soil's properties, mechanical stabilization can improve the soil's strength and stability, reduce maintenance costs, and increase safety and lifespan of buildings and infrastructure.

Omotosho and Eze-Uzomaka (2008a) explored the optimal stabilization of deltaic laterite and found that the use of waste foundry sand was effective in improving the soil's strength. Omotosho and Eze-Uzomaka (2008b) studied the geotechnical properties of lateritic soil stabilized with waste foundry sand and found that the soil's strength and stiffness were improved by this approach. Finally, Prasad *et al.*, (2021) discussed plant nutrition and soil fertility management in their book chapter on plant physiology and biochemistry.

In another study, Essien and Charles (2016) compared the stabilization and model prediction of geotechnical parameters of ebekpo residual soils, Akwa Ibom State, Nigeria, and found that the model predictions agreed well with the actual measurements. Etim *et al.*, (2021) studied the influence of stabilizing agents on the geotechnical properties of clayey subgrade soil and reported that the use of stabilizing agents significantly improved the soil's properties.

Tse and Ogunyemi (2016) evaluated the geotechnical and chemical properties of tropical red soils in a deltaic environment, revealing the implications for road construction. Tse and Ogunyemi (2016) also found that the stabilization of lateritic soil using cement and fly ash can improve the soil's geotechnical properties. Tse and Ogunyemi (2016) further investigated the effect of stabilization on the geotechnical properties of lateritic soil, and their study revealed that the stabilized soil had higher strength and reduced compressibility. Tse and Ogunyemi (2016) also explored the use of cassava peel ash for the stabilization of lateritic soil. Uzochukwu *et al.*, (2019) analyzed the physico-chemical properties of mineral clay soil in an alluvial environment in southeastern Nigeria and concluded that the soil had favorable properties for agricultural use.

Abukhettala *et al.*, (2015) investigated the stabilization of clay soils using lime and marble wastes. They found that the addition of lime and marble wastes improved the geotechnical properties of the soil, including its strength and durability. Adebayo and Adebisi (2012) studied the particle size distribution of residual soils in southwestern Nigeria and found that the soil's particle size distribution significantly affected its strength and deformation behavior. Adeyemi *et al.*, (2018) investigated the use of coconut shell ash for stabilizing expansive clayey soil and reported improved strength and durability properties of the soil.

Ajayi and Adejumo (2016) studied the strength and fines content of stabilized lateritic soil using cement and lime. They reported that the addition of cement and lime improved the soil's strength and reduced its fines content. Bhardwaj and Sharma (2020) investigated the effect of industrial wastes and lime on the strength characteristics of clayey soil and reported improved strength properties of the soil. Bhardwaj and Sharma (2020) also studied the effect of river sand on the geotechnical properties of black cotton soil and reported that the addition of river sand improved the soil's strength and durability.

Eltwati and Saleh (2020) studied the effect of cement and sand on the geotechnical properties of clayey soil and found that the addition of cement and sand improved the soil's strength and durability. Eltwati and Saleh (2020) also investigated the improvement of subgrade soils by using marble dust in a case study conducted in Libya and reported improved soil properties.

In their study, Eltwati and Saleh (2020) investigated the strength characteristics of clayey soil stabilized with cement and coconut fiber. They found that the addition of coconut fiber and cement improved the strength and stability of the soil. Erol *et al.*, (2016) explored the stabilization of soft clayey soils with fly ash and lime. Their results showed that the use of fly ash and lime significantly increased the strength of the soil. Essien and Charles (2016) examined the stabilization of lateritic soil using rice husk ash and reported that the use of this stabilizing agent improved the strength and stability of the soil. Similarly, Essien and Charles (2016) investigated the strength properties of clayey soil stabilized with coconut fiber and cement, and they found that this combination significantly improved the soil's strength. Etim *et al.*, (2021) also investigated the stabilization of lateritic soil with waste plastic and cement and found that this combination significantly improved the soil's properties. Etim *et al.*, (2021) explored the effect of sawdust and cement on the geotechnical properties of clayey soil and found that this combination significantly improved the soil's properties.

Etim *et al.*, (2021) also investigated the effect of micro sized quarry dust particle on the compaction and strength properties of cement stabilized lateritic soil and reported that the use of quarry dust significantly improved the soil's properties. Hassan and Taha (2014) investigated the effect of lime and cement stabilization on the engineering properties of a clayey soil and found that the use of these stabilizing agents significantly improved the soil's properties. Jing *et al.*, (2018) studied the mineralogical composition of clay-rich soils in the

Loess Plateau of China and reported that these soils contain a high proportion of clay minerals. Neeladharan *et al*., (2018) examined the strength properties of clayey soil stabilized with fly ash and lime and found that this combination significantly improved the soil's strength. Neeladharan *et al*., (2018) also investigated the stabilization of soil using marble dust with sodium silicate as a binder and found that this combination significantly improved the soil's properties.

Neeladharan *et al*., (2018) studied the use of quarry dust and lime to stabilize clay soils, and their findings suggested that this method was effective in improving the geotechnical properties of the soil. Neelakantan *et al*., (2016) explored the use of waste engine oil, cement, and lime to stabilize clayey soil, and concluded that this approach also resulted in improved soil properties. Nwachukwu *et al.*, (2014) evaluated the effect of quarry dust on soil properties and found that its use had a positive impact on the geotechnical properties of the soil. Okonkwo *et al*., (2016a) investigated the use of sawdust and cement to stabilize lateritic soil and concluded that this approach was effective in improving the soil's mechanical properties.

Okonkwo *et al*., (2016b) developed geometric models for lateritic soil stabilized with cement and bagasse ash and found that this approach was effective in improving the soil's stability.

Shaikh *et al*., (2017) conducted a study on the stabilization of expansive soil using fly ash and lime. The authors concluded that the combination of fly ash and lime can effectively stabilize the expansive soil. Singh *et al*., (2018) discussed aluminum toxicity and tolerance in plants, highlighting the importance of plant adaptation to aluminum-rich soils. Taha and Saleh (2017) investigated the compaction behavior of subgrade soil stabilized with soft lime, concluding that the use of soft lime can improve the soil's compaction properties.

Cakmak (2017) investigated the effect of manganese nutrition on crops and reported the physiological processes and management strategies for manganese nutrition in crops. Chowdhury *et al*., (2021) studied the strength properties of laterite soil stabilized by waste plastic and found that the addition of waste plastic improved the soil's strength and durability. Das and Al-Khafaji (2010) investigated the stabilization of clayey soil using waste engine oil and cement and reported improved strength and durability properties of the soil.

1.1 Research Gap

Previous studies have examined the use of various stabilizing materials, such as cement, lime, sand and composites, to improve the strength of deltaic laterite soil (Omotosho and Eze-Uzomaka, 2008; Azadegan *et al*., 2012; Sas and Głuchowski, 2013; Bhardwaj and Sharma, 2016; Okonkwo *et al*., 2016). Tse and Ogunyemi (2016) explored the properties of stabilized tropical red soils without the addition of stabilizing materials, while Bhardwaj and Sharma (2016) used lime and waste foundry sands to stabilize clayey soil. Additionally, wastes from granite dust (Eltwati *et al*., 2020), marble dust (Neeladharan *et al*., 2018; Eltwati and Saleh, 2020) and quarry dust (Etim *et al*., 2021) have been used to improve engineering properties of clayey soil. No previous studies have, however, looked into the effectiveness of residual soil, or combinations of residual soil and cement or lime; river sand and cement or lime, as stabilizing materials for subgrade soils for road pavement or foundation works. This study thus investigates the potential of residual soil, river sand, and their combinations with cement and lime for improving subgrade soil properties, with a view to potential use for road pavement or foundation works (Omotosho and Eze-Uzomaka, 2008; Azadegan *et al*., 2012; Sas and Głuchowski, 2013; Bhardwaj and Sharma, 2016; Okonkwo *et al.*, 2016; Tse and Ogunyemi, 2016; Eltwati *et al.*, 2020; Neeladharan *et al*., 2018; Eltwati and Saleh, 2020; Etim *et al*., 2021).

2. MATERIALS AND METHODS

2.1 Materials

Tropical soil and expansive (subgrade) soil samples were collected along Chokocho road in Etche Local Government Area of Rivers State. The subgrade soil was collected from different points within 4m apart along the road at depth not below 150mm using the method of disturbed sampling technique. River sand was collected from Sombrero and Orashi Rivers in Ahoada East and West Local Government Areas of Rivers State. The cement used for the unconfined compressive strength test was purchased from civil engineering material store along Ken Poly road, Bori in Khana local government of Rivers State, Nigeria.

2.2 Sample Preparation

The soil samples were air dried. Representative soil samples were oven dried for natural and hydroscopic moisture content test. Soil specimen of above 500g was taken from the soil sample at various locations. The lumps or clods formed in the soil were broken down into specified size without crushing. The organic matter present in the soil was separated from the soil specimen. A specified soil sample was washed to remove impurities, debris and other organic matters from the soils using 236um sieve size.

2.3 Chemical Composition Test

Potassium, zinc, nickel, manganese, silicon, sulphur, copper, aluminium, magnesium, calcium iron and titanium mineral content test were carried out to ascertain the type of soil. Soil solution was prepared by diluting 10g of soil sample in a given volume of water. The soil solution was then subjected to Standard test method using atomic absorption spectrophotometer (AAS).

2.4 Particle Size Distribution

The particle size distribution of the natural soil was determined using the method specify by BS 1377 (1990) for cohesive soil. This method specifies the use of both sedimentation analysis and dry sieving of the coarse fraction. This test was performed to determine the percentage of different grain sizes contained within the soil. Sieve analysis was used to determine the distribution of the coarser, larger-sized particles, while the hydrometer method was used to determine the finer particles. The distribution of different grain sizes affects the engineering properties of soil. Grain size analysis provides the grain size distribution, and it is required in classification of soil. The soil was washed through BS sieve No. 200 and the material retained was oven dried and sieved by agitating the material through a range of sieves from sieve No.7 (2.4mm aperture) and downwards while the material passing was turned into sedimentation cylinder for hydrometer analysis.

Data Analysis Sieve:

(i) The obtained mass of soil retained on each sieve was calculated by subtracting the weight of the empty sieve from the mass of the sieve + retained soil. The sum of these retained masses should be approximately equals the initial mass of the soil sample.

(ii) The percent retained on each was calculated by dividing the weight retained on each sieve by the initial sample mass.

(iii) The percent passing (or percent finer) was calculated by starting with 100 percent and subtracting the percent retained on each sieve as accumulative procedure.

2.5 Moisture Content Determination

The natural moisture content of the soil was determined in accordance with BS 1377 (1990) Part 2. Three containers were cleaned and weighed to the nearest 0.01g (M_1). The sample as freshly collected were crumbled and placed loosely in the containers and the containers with the samples were weighed together to the nearest 0.01g as M_2. The containers were then placed in the oven and dried at 105 -110^{o}C for 24 hours. The containers and the samples were removed and weighed dry to the nearest 0.01g as M_3. The natural moisture content was calculated as the average of the three oven dried samples as follows:

$$W = \frac{m_2 - m_3}{m_3 - m_1} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where,

m_1 = mass of container (g)
m_2 = mass of container and wet soil (g)
m_3 = mass of container and dry soil (g)

Water Content Determination

This test is performed to determine the water (moisture) content of soils. The water content is the ratio, expressed as a percentage, of the mass of “pore” or “free” water in a given mass of soil to the mass of the dry soil solids.

Data Analysis:

(1) Determine the mass of soil solids.

$MS = MCDS - MSC$ ……………….. (2)

(2) Determine the mass of pore water.

$MW = MCMS - MCDS$ ……………. (3)

(3) Determine the water content.

$w = Mw/ Ms*100$ …………………. (4)

2.6 Atterberg Limits

The Atterberg limits are basic measure of the nature of a fine-grained soil. Depending on the water content of the soil, it may appear in four states: solid, semi-solid, plastic and liquid. In each state, the consistency and behaviour of a soil is different and thus so are its engineering properties. Thus, the boundary between each state can be defined based on a change in the soil's behaviour. The Atterberg limits can be used to distinguish between silt and clay, and it can distinguish between different types of silts and clays. These limits were created by Albert Atterberg, and later refined by Arthur Casagrande.

Liquid Limit

BS 1377 (1990) describes the procedure for liquid limit test in soil. 200g of air dried soil passing 425–μm sieve size was taken and mixed with water and kneaded for uniformity. The mixing time was specified at 5 to 10 min. The soil paste was placed in liquid limit cup, and levelled off using spatula. Clean and sharp groove was cut in the middle using grooving tool. The crank was rotated at about 2 revolutions per second and the number of blows required to make half of the soil pat separated by the groove for a length of about 12 mm was counted. The water content was determined from a small quantity of the soil paste.

This operation was repeated a few more times at different consistencies or moisture contents. The soil samples were prepared at such consistencies that the number of blows or shocks required to close the groove was less than 10 and more than 25. The relationship between the number of blows and corresponding moisture contents obtained was plotted on semi-logarithmic graph paper, with the logarithm of the number of blows on the *x*-axis, and the moisture contents on the *y*-axis. The moisture content corresponding to 25 blows from the flow curve was taken as the liquid limit of the soil.

Plastic Limit

Plastic limit (PL) is the water content where soil starts to exhibit plastic behaviour. The Proportion of the material passing sieve with aperture 425µm which was used for the determination of the liquid limit (LL) was also used for the determination of the plastic limit. A sample of the wet soil was taken and moulded between the palms of the two hands. The sample was rolled and sub-divided into two sub samples which were further subdivided into parts. The rate of rolling was between 80 and 90 strokes per minute, counting a stroke as one complete motion of the hand forward and back to the starting position again. The rolling was done till the threads are of 3 mm diameter as specified by BS 1377 (1990). The soil was kneaded together to a uniform mass and rolled again. This process of alternate rolling and kneading was continued until the thread crumbles under the pressure required for rolling and the soil can no longer be rolled into a thread. The pieces of crumbled soil thread were collected and the moisture content determined and recorded as the plastic limit.

Plasticity Index: The plasticity index (PI) is computed as the difference between the liquid limit (LL) and the plastic limit (PL) as follows:

PI (or I_p) = (LL - PL) …………………. (5)

2.7 California Bearing Ratio Test

The test specimens were prepared by thoroughly mixing measured samples of dried subgrade soil with different weight percent of tropical soil, river sand at 10%, 20%, 30%, 40%, 50%, 60% and 70%. The required amount of water which was determined from the moisture density relationships for the stabilized-soil mixtures was then added to the mixture. The standard proctor mould was used for the compaction test in which 5 layers and 27 blows were given onto each layer with 4.5kg rammer. The specimens from the proctor mould were used as the unconfined compressive factor of 0.01 was used on the results to conform to cylindrical specimens with a height/diameter ratio of 2:1 or (150mm) cube specimens.

The California bearing ratio (CBR) was modified so as to conform to the recommendation of AASTHO, which stipulates that the specimens should not be cured (unsoaked) immersed in water for 24 hours and allowed to drain for 15 minutes before testing. In this analysis, five (5) compacted specimen of about (5000 kg) each was collected with density range between 95% and 100%. Water was then added to the first specimen and compacted in layers. Each specimen collected from compacted soil received 27 blows, 42 blows, 69 blows, 96 blows and 123 blows. The collar of the mould was removed after compaction and the surface levelled. The sample was then taken for determination of CBR.

3. RESULTS AND DISCUSSION

The chemical composition and tested engineering properties of the subgrade soil stabilized with tropical soil and river sands are presented in this section. The engineering properties include fines, maximum dry density (MDD), optimum moisture content (OMC), liquid limit (LL), plastic limit (PL), plasticity index (PI), California bearing ratio (CBR) and unconfined compressive strength (UCS). The tested results for engineering properties are shown in Tables 2 to 5.

3.1 Chemical Composition Test (OK)

Table 1 shows the chemical composition of the subgrade soil was analyzed to determine the distribution and concentration of various chemical elements present in the soil. The test result showed that the subgrade soil is a mineral clay soil, with calcium having the highest composition of 21.04%, followed by aluminum (18.17%) and silicon (44.53%) (Table 1). The percentage composition of magnesium, iron, lead, copper, manganese, potassium, sulfur, titanium, zinc, and nickel were 3.05%, 6.28%, 0.88%, 0.12%, 0.06%, 0.31%, 0.74%, 0.43%, 3.24%, and 1.15%, respectively.

Table 1: Test result of chemical composition of subgrade soil

Chemical element	Percentage (%)
Calcium	21.04
Aluminum	18.17
Magnesium	3.05
Iron	6.28
Silicon	44.53
Lead	0.88
Copper	0.12
Manganese	0.06
Potassium	0.31
Sulphur	0.74
Titanium	0.43
Zinc	3.24
Nickel	1.15

The high concentration of calcium in the soil is an indication of the presence of calcium-rich minerals such as calcite, dolomite, and gypsum, which are common in mineral clay soils (Jing *et al.*, 2018; Uzochukwu *et al*., 2019). The presence of aluminum in the soil can be attributed to the weathering of aluminum-bearing minerals such as feldspars, micas, and clays (Jing *et al.*, 2018; Singh *et al.*, 2018). The high concentration of silicon in the soil is an indication of the presence of quartz, which is a common mineral in clay soils (Jing *et al*., 2018; Uzochukwu *et al.*, 2019).

The low concentration of manganese in the soil is an indication of the low availability of the element in the soil. Manganese is an essential nutrient for plant growth, and its deficiency can lead to poor plant growth and development (Cakmak, 2017; Prasad *et al*., 2021). The low concentration of manganese in the soil may require the application of manganese fertilizers to improve its availability for plant growth.

Overall, the chemical composition test of the subgrade soil provides useful information about the mineralogical composition of the soil, which is essential for soil classification and management.

Table 2: Engineering properties of stabilized subgrade soil with tropical soil

Tropical soil (%)	MDD (KN/m^3)	OMC (%)	LL (%)	PL (%)	PI (%)	CBR Unsoaked (%)	CBR Soaked (%)	Fines (%)	Classification	
									AASHTO	USCS
0	1.99	13.24	37.9	20.6	15.45	8.7	6.3	41.05	A-2-6	SC
10	1.918	12.75	33.45	22.85	10.6	27.69	22.34	30.05	A-2–4	SM
20	1.955	12.52	27.38	19.95	7.43	31.44	26.09	31.56	A-2-5	SM
30	2.053	10.28	26.36	21.25	5.11	38.96	33.61	29.05	A-2-4	SM
40	1.985	12.24	23.45	19.85	3.6	41.86	37.51	23.67	A- 1– b	SM
50	2.059	10.45	22.05	19.3	2.75	43.66	38.31	20.55	A- 1 – b	SM
60	2.065	10.55	18.26	16.45	1.81	31.78	22.43	17.85	A -1 - b	SM
70	1.865	13.18	15.56	14.25	1.31	12.25	9.9	12.65	A – 1 - b	SM

Table 3: Engineering properties of stabilized subgrade soil with Orashi River sand

Sand (%)	MDD (KN/m^3)	OMC (%)	LL (%)	PL (%)	PI (%)	CBR Unsoaked (%)	CBR Soaked (%)	Fines (%)	Classification	
									AASHTO	USCS
0	1.99	13.24	37.9	20.6	15.45	8.7	6.3	41.05	A-2-6	SC
10	1.9866	9.892	29.59	18.89	10.7	46.67	35.29	24.45	A-2–4	SM
20	2.0236	9.662	23.52	15.99	7.53	50.42	39.04	25.96	A-2-5	SM
30	2.1216	7.422	22.5	17.29	5.21	57.94	46.56	23.45	A-2-4	SM
40	2.0536	9.382	19.59	15.89	3.7	60.84	50.46	18.07	A- 1 – b	SM
50	2.1256	7.592	18.19	15.34	2.85	62.64	51.26	14.95	A- 1 – b	SM
60	2.1336	7.692	14.4	12.49	1.91	50.76	39.38	12.25	A -1 - b	SM
70	1.9336	10.322	11.7	10.29	1.41	31.23	19.85	7.05	A – 1 - b	SM

Table 4: Engineering properties of stabilized subgrade soil with Sombrero River sand

Sand (%)	MDD (KN/m^3)	OMC (%)	LL (%)	PL (%)	PI (%)	CBR Unsoaked (%)	CBR Soaked (%)	Fines (%)	Classification	
									AASHTO	USCS
0	1.99	13.24	37.9	20.6	15.45	8.7	6.3	41.05	A-2-6	SC
10	2.0446	11.8976	29.503	18.771	10.732	65.01	52.17	22.12	A-2–4	SM
20	2.0816	10.9346	23.433	15.871	7.562	68.76	55.92	23.63	A-2-5	SM
30	2.1796	10.0326	22.413	17.171	5.242	76.28	63.44	21.12	A-2-4	SM
40	2.1116	9.9646	19.503	15.771	3.732	79.18	67.34	15.74	A- 1 – b	SM
50	2.1836	9.036	18.103	15.221	2.882	80.98	68.14	12.62	A- 1 – b	SM
60	2.0916	9.004	14.313	12.371	1.942	69.1	56.26	9.92	A -1 - b	SM
70	1.9916	9.8446	11.613	10.171	1.442	49.57	36.73	4.72	A – 1 - b	SM

3.2 Fines content of the stabilized subgrade soil

The comparative results of fines in the stabilised subgrade soil with tropical (residual) soil, Orashi River sand and Sombrero River sand are shown in Figure 1. Preliminary analysis of grain size distribution on the subgrade soil before stabilization test revealed that the soil is composed of 6.85% gravel, 35.55% sand, 33.54% silt and 24.06% clay. However, the experimental investigation of the fine content in the stabilized subgrade soil at 0 to 70% of tropical soil and river sands revealed that the stabilized soil exhibited a slight different in characteristics of fine content. Nevertheless, on a general perspective irrespective of the stabilization material used, the fines in the stabilized soil decreased with increasing percentage of stabilization material. The maximum value of fines was recorded in subgrade soil stabilized with tropical soil, followed by soil stabilized with Orashi River sand and least in soil stabilized with Sombrero River sand. Thus, between 0% and 70% of the residual soil content in the stabilized subgrade soil, the fine content decreased from 41.05 to 12.65%. Similarly, from 0 to 70% river sand in the stabilized subgrade soil, fines content decreased from 41.05 to 7.05% and 4.72% in subgrade soil stabilized with Orashi River and Sombrero River sands, respectively. This implied that the residual soil has finer grain sizes than Orashi and Sombrero River sands.

The results of the study indicated that the fines content in the stabilized subgrade soil was influenced by the type of stabilization material used. The study found that the fines content in the stabilized subgrade soil decreased with increasing percentage of stabilization material. This trend was observed irrespective of the type of stabilization material used, whether tropical soil, Orashi River sand or Sombrero River sand.

The findings of the study are consistent with the results of previous studies that have investigated the effect of stabilization materials on the fines content in soil. For instance, a study by Hassan and Taha (2014) investigated the effect of lime and cement stabilization on the fines content of a clayey soil. The study found that the fines content decreased with increasing percentage of lime or cement.

Similarly, a study by Ajayi and Adejumo (2016) investigated the effect of cement and lime stabilization on the fines content of lateritic soil. The study found that the fines content decreased with increasing percentage of stabilization material. The findings of these studies suggest that the decrease in fines content observed in the present study is a common trend in soil stabilization.

In addition, the study found that the fines content in the stabilized subgrade soil was influenced by the type of soil used as the stabilization material. The study found that the subgrade soil stabilized with tropical soil had the highest fines content, followed by soil stabilized with Orashi River sand, and least in soil stabilized with Sombrero River sand. This suggests that the residual soil used as the stabilization material has finer grain sizes than the two river sands.

The finding that the residual soil has finer grain sizes than the river sands is consistent with the results of previous studies. For instance, a study by Adebayo and Adebisi (2012) investigated the particle size distribution of residual soils in southwestern Nigeria. The study found that the residual soils had higher percentages of fine particles than the overlying sands.

In conclusion, the results of the study indicate that the fines content in the stabilized subgrade soil is influenced by the type of stabilization material used and the type of soil used as the stabilization material. The findings of the study are consistent with the results of previous studies and highlight the importance of considering the properties of both the soil to be stabilized and the stabilization material in soil stabilization projects.

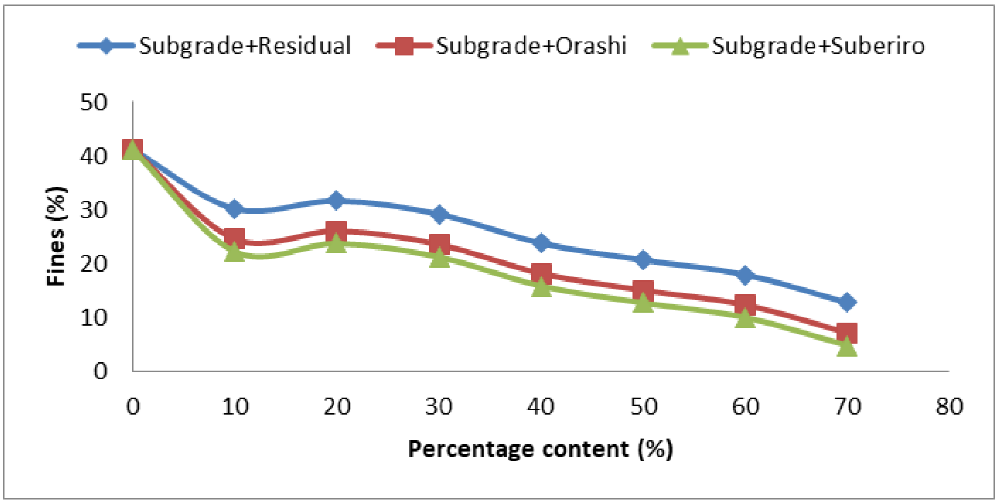

Figure 1: Comparison of fines in residual soil and sand stabilized subgrade soil

3.3 Maximum Dry Density of Stabilized Subgrade Soil

Figure 2 shows the results of the laboratory compaction tests for the stabilization of subgrade soil and different stabilizing materials showed that maximum dry density (MDD) increased with increasing percentage of stabilizing material until the peak value, and then decreased thereafter. This behavior of MDD can be described as a wave-like profile. The peak MDD value for subgrade soil stabilized with residual soil is 2.065kN/m3 at 60% tropical soil. The peak MDD value for subgrade soil stabilized with Orashi River sand is 2.1336kN/m3 at 60% sand, while that for Sombrero River sand peaked at 2.1836kN/m3 at 50% sand. The highest MDD value was observed in soil stabilized with Sombrero River sand, followed by the sample stabilized with Orashi River sand and least in soil sample stabilized with residual soil.

Similar studies have reported similar ranges of MDD for stabilized clay and lateritic soils in the Niger Delta region (Omotosho and Eze-Uzomaka, 2008; Tse and Ogunyemi, 2016; Etim *et al*., 2021). These results are consistent with the findings of the present study, indicating that the behavior of MDD is similar for different stabilizing materials.

Mechanical stabilization of subgrade soil is an important aspect of road construction and pavement design. The results of this study provide useful information for engineers and researchers involved in the design and construction of roadways and other infrastructure projects. The behavior of MDD observed in this study can be used to optimize the use of stabilizing materials in road construction, thereby improving the strength and durability of roadways.

In conclusion, the laboratory compaction tests for the stabilization of subgrade soil and different stabilizing materials showed that MDD increased with increasing percentage of stabilizing material until the peak value, and then decreased thereafter. The peak MDD value differed for different stabilizing materials, with the highest MDD observed in soil stabilized with Sombrero River sand, followed by the sample stabilized with Orashi River sand and least in soil sample stabilized with residual soil. Similar studies have reported similar ranges of MDD for stabilized clay and lateritic soils in the Niger Delta region.

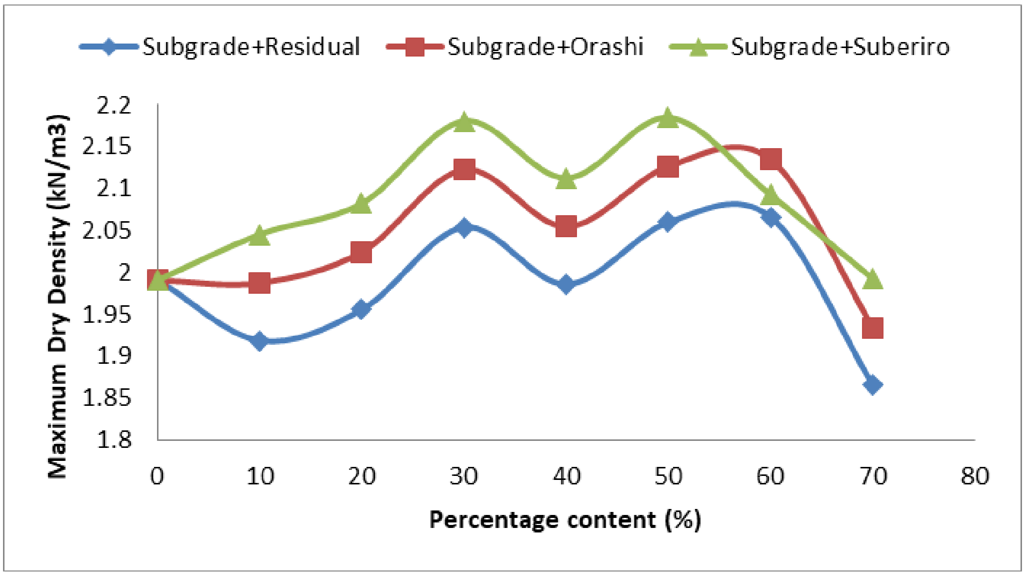

Figure 2: Comparison of MDD of residual soil and sand stabilized subgrade soil

3.4 Optimum moisture content of stabilized subgrade soil

Figure 3 shows the comparative results of optimum moisture content (OMC) as obtained from the laboratory compaction tests for the stabilization of subgrade soil using residual soil and river sands at different weight percent from 0 to 70%. From the profiles, the behaviour of OMC of the stabilized soil can be described as non-linear with the percentage content of the stabilization materials. The results also indicated that OMC initially decreased with increasing percentage of the stabilizing materials to a certain percentage and thereafter increased with further increase in percentage of the stabilization materials. The OMC of the subgrade soil stabilized with residual soil decreased from 13.24 at 0% to 10.45% at 50% residual soil, but thereafter, it increased to 13.18% at 70%. Also, at 0% to 60% river sands, the OMC of the subgrade soil stabilized with Orashi River and Sombrero River sands decreased from 13.24 to 7.69% and 9.00%, respectively. Beyond 60% sand content in the subgrade soil, OMC increased to 130.32% and 9.84% at 70% for sample with Orashi River and Sombrero River sands, respectively. The OMC values obtained in this work were also within the ranges recorded for mechanical stabilization with waste foundry and river sand (Omotosho and Eze-Uzomaka, 2008; Essien and Charles, 2016; Bhardwaj and Sharma, 2020). From the results, the highest values of OMC were recorded in subgrade soil stabilized with residual soil, followed by Sombrero River sand and least in Orashi River sand. High OMC in soil is an indication that such soil could expand, which could lead to failure, especially when used for construction of road pavement. Therefore, the stabilization of the subgrade soil should be within 30 and 60% residual soil or river sands.

The study findings are consistent with the results of previous studies on soil stabilization using various materials. Omotosho and Eze-Uzomaka (2008) investigated the effect of waste foundry sand on the geotechnical properties of lateritic soil and found that the optimum moisture content decreased with an increase in the percentage of waste foundry sand up to 20% and thereafter increased with further increase in percentage of waste foundry sand. Essien and Charles (2016) also studied the effect of rice husk ash on the geotechnical properties of lateritic soil and found that the optimum moisture content decreased with increasing percentage of rice husk ash up to 10%, and thereafter increased with further increase in percentage of rice husk ash. Bhardwaj and Sharma (2020) studied the effect of river sand on the geotechnical properties of black cotton soil and found that the optimum moisture content decreased with an increase in the percentage of river sand up to 60% and thereafter increased with further increase in percentage of river sand.

The study also identified that the highest values of OMC were recorded in subgrade soil stabilized with residual soil, followed by Sombrero River sand and least in Orashi River sand. High OMC in soil is an indication that such soil could expand, which could lead to failure, especially when used for construction of road pavement. Therefore, the stabilization of the subgrade soil should be within 30 and 60% residual soil or river sands.

In conclusion, the study findings indicate that the OMC of stabilized subgrade soil is non-linear with the percentage content of the stabilization materials. The study results can be useful in the design and construction of stabilized subgrade soil for road pavement. Further research could investigate the long-term performance of stabilized subgrade soil under different loading conditions.

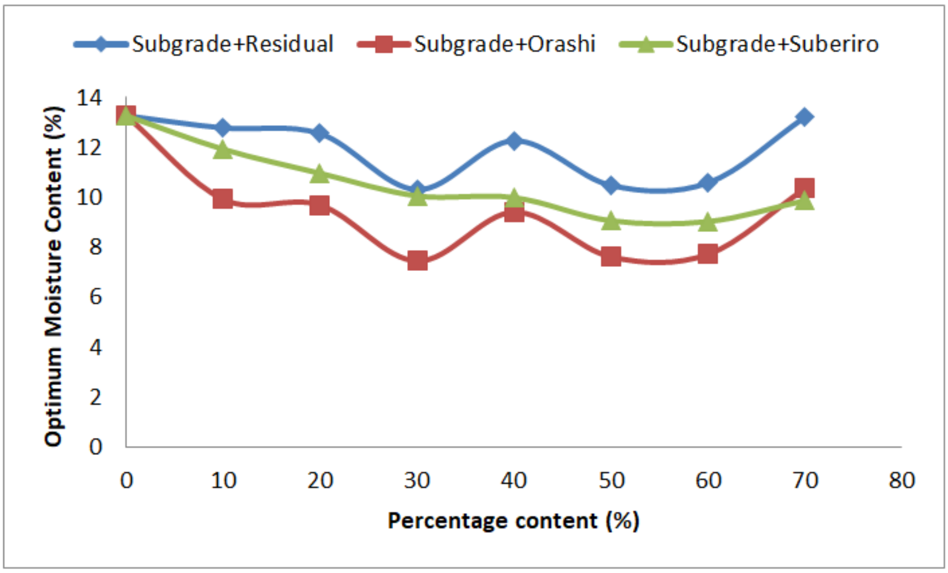

Figure 3: Comparison of OMC of residual soil and sand stabilized subgrade soil

3.5 Liquid limit of the stabilized subgrade soil

Figure 4 showed profiles of results obtained for liquid limit (LL) of subgrade soil stabilized with residual soil and Orashi River and Sombrero River sands. The study investigated the effect of residual soil, Orashi River sand, and Sombrero River sand on the liquid limit (LL) of subgrade soil. The results revealed a decrease in LL with increasing percentage content of the stabilization materials. The pattern of decrease was similar for all three materials, and there was no significant difference between the LL recorded in subgrade soil stabilized with the two river sands. However, the LL of the stabilized subgrade soil decreased from 37.90% to 15.56% and 11.70% for residual soil and Orashi River sand, respectively, indicating that these materials were effective as stabilizing agents.

The reduction in LL after stabilization is an important performance indicator in soil stabilization, as it indicates a decrease in soil swelling ability (Tse and Ogunyemi, 2016; Neeladharan *et al*., 2018; Eltwati and Saleh, 2020; Etim *et al*., 2021). This is crucial for subgrade soil stabilization, as the ability of the soil to resist deformation is directly related to its swelling potential (Taha and Saleh, 2017).

The results of the study are consistent with previous studies that have reported a decrease in LL after soil stabilization. For example, Tse and Ogunyemi (2016) reported a reduction in LL from 70% to 28% after stabilization with cement and fly ash. Neeladharan *et al*., (2018) also reported a decrease in LL from 43.5% to 20.5% after stabilization with quarry dust and lime.

In conclusion, the study demonstrated that residual soil, Orashi River sand, and Sombrero River sand are effective as stabilizing agents for subgrade soil, as evidenced by the significant reduction in LL. The results of this study provide important insights for the design and construction of subgrade soil stabilization projects.

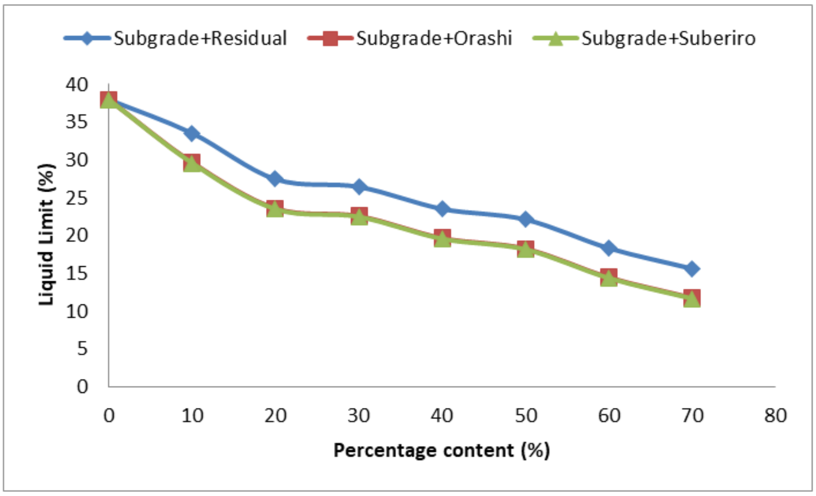

Figure 4: Comparison of liquid limit of residual soil and sand stabilized subgrade soil

3.6 Plastic limit of the stabilized subgrade soil

The study investigated the effect of stabilization materials on the plastic limit (PL) of subgrade soil. Figure 5 shows the comparative results of PL of subgrade soil stabilized with residual soil and river sands. The results indicated that PL decreased with increasing percentage content of the stabilization materials, and the trends in PL for the stabilizing materials were similar as the percentage content increased. The subgrade soil stabilized with residual soil had the highest PL at any given percentage, while there was no clear difference between the PL recorded in the soil samples stabilized with Sombrero River and Orashi River sands.

The experimental results revealed that the PL values recorded in subgrade soil stabilized with residual soil initially increased from 20.60 to 22.85% at 0% to 10% percentage content, and then, decreased gradually to 14.25% as the content increased to 70%. On the other hand, from 0 to 70% percentage content, PL of the subgrade soil stabilized with Orashi River and Sombrero River sands decreased from 20.60 to 10.29% and 10.17%, respectively.

The findings of this study are consistent with previous studies on mechanical stabilization of subgrade soil. Tse and Ogunyemi (2016) reported that the addition of sand to lateritic soil reduced its plasticity index. Neeladharan *et al.*, (2018) found that the use of quarry dust as a stabilizing material reduced the plasticity index of clay soil. Eltwati and Saleh (2020) reported that the use of cement and sand reduced the plasticity index of clayey soil. Etim *et al.*, (2021) also found that the use of sawdust and cement reduced the plasticity index of clay soil.

In conclusion, the study demonstrated that sand and residual soil are effective stabilizing materials for reducing the plastic limit of subgrade soil. The findings of this study can be useful for engineering design and construction of roads and other transportation infrastructure on subgrade soil.

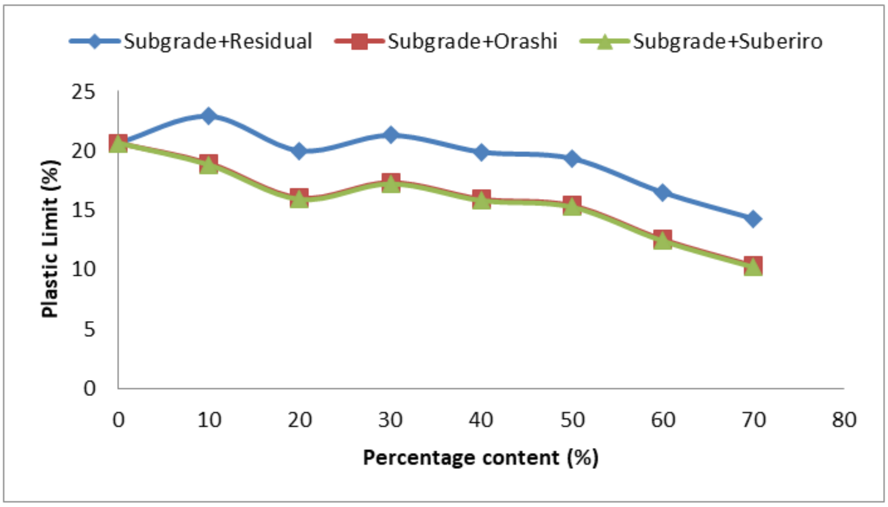

Figure 5: Comparison of plastic limit of residual soil and sand stabilized subgrade soil

3.7 Plasticity index of the stabilized subgrade soil

Figure 6 shows the plasticity index (PI) is an important parameter used to evaluate the engineering properties of soils. It is defined as the difference between the liquid limit (LL) and plastic limit (PL) of a soil. The PI is an indicator of the soil's ability to undergo deformation under load and its resistance to moisture-induced volume changes. Soil stabilization is a common technique used to improve the engineering properties of soils, and it involves the addition of a stabilizing material to the soil to improve its strength and durability. This study aimed to investigate the effect of different percentages of residual soil and river sands on the plasticity index of subgrade soil.

Results: The results of the study showed that the plasticity index of the subgrade soil decreased with increasing percentages of the stabilizing materials, but there was no significant difference in the PI recorded in the soil samples stabilized with the different stabilizing materials. The subgrade soil stabilized with residual soil showed an exponential decrease in PI from 15.45% to 1.31% when the percentage content increased from 0% to 70%. The subgrade soil samples stabilized with Orashi River and Sombrero River sands also showed a decrease in PI from 15.45% to 1.41% and 1.44%, respectively.

The results of this study are consistent with the findings of previous research. The decrease in PI with increasing percentage of stabilizing materials can be attributed to the reduction in the clay content of the soil. Stabilizing materials such as residual soil and river sands have a lower clay content than the subgrade soil, and their addition reduces the overall clay content of the soil. This, in turn, reduces the soil's plasticity index.

The exponential decrease in PI with increasing percentage of residual soil and river sands is also consistent with previous research. Studies have shown that the plasticity index of soil decreases exponentially with increasing percentage of non-plastic fines in the soil (Nwachukwu *et al.*, 2014; Abukhettala *et al.*, 2015).

The results also show that there was no clear difference between the PI recorded in the soil samples stabilized with the different stabilizing materials. This suggests that the choice of stabilizing material may not have a significant effect on the PI of the stabilized soil. This is consistent with the findings of previous studies that have shown that different stabilizing materials can have similar effects on the mechanical properties of soil (Erol *et al.*, 2016; Shaikh *et al.*, 2017).

In conclusion, the results obtained in this study indicate that the PI of subgrade soil decreases with increasing percentage of residual soil and river sands. The decrease in PI can be attributed to the reduction in the clay content of the soil. These findings are consistent with the findings of previous studies. Therefore, residual soil and river sands can be used as effective stabilization materials for subgrade soil in road construction projects.

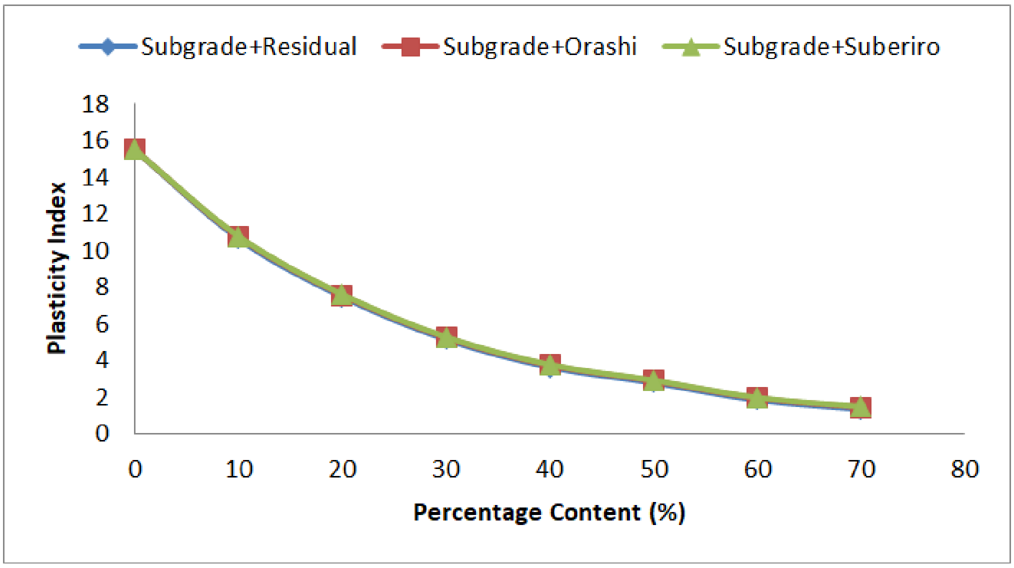

Figure 6: Comparison of plasticity index of residual soil and sand stabilized subgrade soil

3.8 CBR for unsoaked and soaked stabilized subgrade soil

Figure 7 shows the comparative result of California bearing ratio (CBR) for stabilized unsoaked subgrade soil with 0 to 70% residual soil and river sand. The CBR of the stabilized unsoaked subgrade soil increased with increase in percentage content of the stabilization materials up to 50% and then decreased as the content was further increased in soil samples. The maximum CBR was recorded in the unsoaked subgrade soil stabilized with Sombrero River sand, followed by the unsoaked soil sample stabilized with Orashi River sand and least in sample stabilized with residual soil. From the recorded results, CBR of the unsoaked subgrade soil stabilized with residual soil increased from 8.7 to 43.66% when the content was increased from 0 to 50% and decreased thereafter to 12.25% at 70%. Similarly, from 0 to 50% river sand, CBR of unsoaked subgrade soil stabilized with Orashi River and Sombrero River sands increased from 8.7 to 62.64% and 80.98%, but decreased thereafter to 31.23% and 49.57%, respectively as the sand content was increased further to 70%.

Similarly, Figure 8 shows the comparative result of CBR for soaked subgrade soil stabilized with 0 to 70% residual soil and river sand. Like in the unsoaked samples, the CBR of the stabilized soaked subgrade soil increased with increase in percentage content of residual soil and river sand up to 50% and then decreased with further increase of materials in the soil. Again, the maximum CBR was recorded in the soaked sample stabilized with Sombrero River sand, followed by the sample stabilized with Orashi River sand and least in the sample stabilized with residual soil. From the results, CBR of the soaked subgrade soil stabilized with residual soil increased from 6.3 to 38.31% when its content was increased from 0 to 50% and decreased thereafter to 9.90% at 70%. Similarly, from 0 to 50% river sand, CBR of soaked subgrade soil stabilized with Orashi River and Sombrero River sands increased from 6.3 to 51.26% and 68.14%, but decreased thereafter to 19.85% and 36.73%, respectively as the sand content was increased further to 70%.

According to studies, increase in CBR of a stabilized soil indicates improvement in the soil properties (Tse and Ogunyemi, 2016; Neeladharan *et al*., 2018). Several previous studies have also shown that increase in stabilization material resulted to increase in CBR of the stabilized soil (Okonkwo *et al*., 2016; Eltwati and Saleh, 2020; Etim *et al*., 2021). This study also showed that the CBR of the soaked soil sample was below the CBR of the unsoaked soil sample, implying that soaking reduces the strength of the soil.

It is interesting to note that the CBR of the soaked subgrade soil samples was lower than that of the unsoaked samples, indicating that soaking reduces the strength of the soil. This observation is consistent with the findings of previous studies that have reported a reduction in the CBR of soil after soaking (Das and Al-Khafaji, 2010; Neelakantan *et al*., 2016). The reduction in CBR of the soaked soil sample compared to the unsoaked soil sample suggests that soaking reduces the strength of the soil. This finding is consistent with the results reported by previous studies (Adeyemi *et al*., 2018; Chowdhury *et al*., 2020).

In conclusion, the results presented in this study indicate that the use of residual soil and river sand can improve the CBR of subgrade soil. However, there is an optimum content of stabilization material required to achieve the maximum CBR, and soaking reduces the strength of the soil. These findings have implications for the design and construction of roads and other engineering structures on subgrade soil.

In summary, the results presented in this study demonstrate the effect of stabilization materials on the CBR of unsoaked and soaked subgrade soil. The findings suggest that the addition of river sand improves the CBR of soil, with Sombrero River sand showing the highest CBR values followed by Orashi River sand. The study also highlights the importance of considering the effect of soaking on the strength of soil.

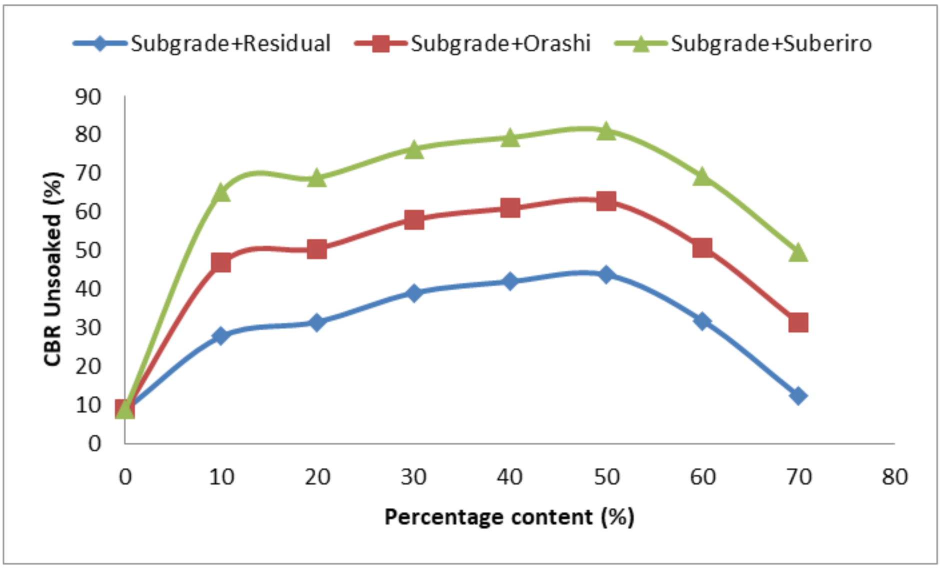

Figure 7: Comparison of CBR for unsoaked stabilized subgrade soil with residual soil and sand

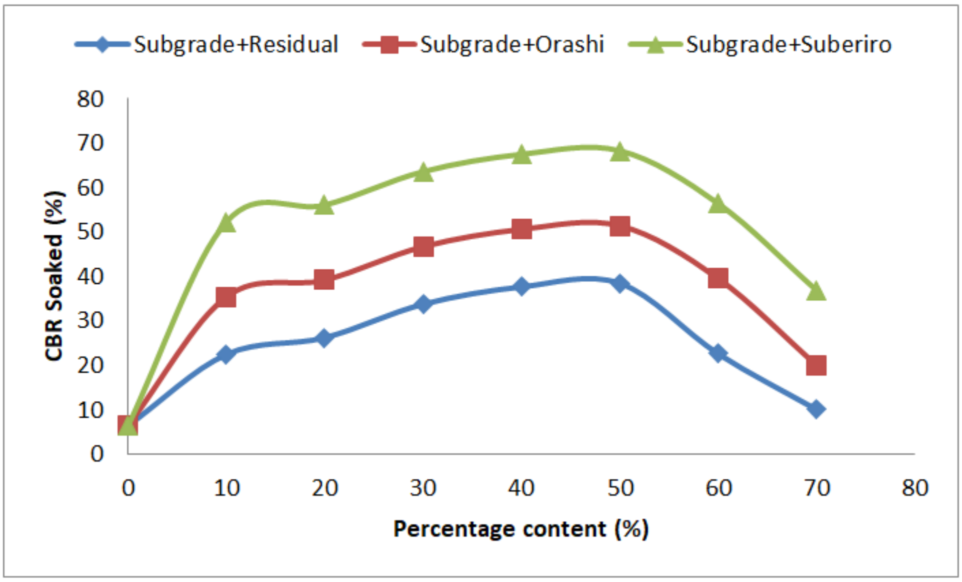

Figure 8: Comparison of CBR for soaked stabilized subgrade soil with residual soil and sand

3.9 Unconfined Compressive Strength of Stabilized Subgrade Soil

The unconfined compressive strength (UCS) test was carried out on samples of the subgrade soil stabilized with 8% cement and the varying percentages of residual soil and river sands. The UCS test was performed on only samples cured at 7 and 28 days. This implied that the at constant 8% cement, the content of residual soil and river sands was varied from 2 to 62% to obtained a composite weight percent of 10 to 70%.

Table 5: UCS of stabilized subgrade soil with composite of cement and residual soil and river sand

	7 days curing			28 days curing		
Composite content (%)	**Orash+8% Cem**	**Somb+8% Cem**	**Res+8% Cem**	**Orash+8% Cem**	**Somb+8% Cem**	**Res+8% Cem**
10	259.28	255.33	236.37	301.37	297.42	288.17
20	271.49	267.54	244.97	319.48	315.53	307.06
30	288.4	284.45	257.18	321.88	317.93	321.17
40	297.44	293.49	274.09	328.37	324.42	327.57
50	306.08	302.13	283.13	333.98	330.03	329.06
60	317.38	313.43	291.77	352.08	348.13	345.67
70	322.05	318.1	303.07	378.75	374.8	357.77

Figures 9 and 10 show the comparative result of UCS for subgrade soil stabilised with cement and residual soil and cement and river sands at 7 and 28 days curing, respectively. From the profiles, unconfined compressive strength of stabilized subgrade soil increased with increasing percentage of the composite materials and curing days. From the test results presented in Table 5, the unconfined compressive strength of the subgrade soil without the stabilizing material was obtained as 178MPa. However, for stabilized subgrade soil with 8% cement and 2 to 62% residual soil (10 to 70% composite material), the UCS increased from 236.37 to 303.07MPa at 7 days curing and 288.17 to 357.77MPa at 28 days curing. For subgrade soil stabilized with 8% cement and 2 to 62% Orashi River sand (10 to 70% composite mixture), the test results showed that the unconfined compressive strength increased from 259.28 to 322.05MPa at 7 days curing and 301.37 to 378.75MPa at 28 days curing, while for subgrade soil stabilized with 8% cement and 2 to 62% Sombrero River sand (10 to 70% composite mixture), unconfined compressive strength increased from 255.33 to 318.810MPa at 7 days curing and from 297.42 to 374.80MPa at 28 days curing.

Comparatively, the soil sample stabilized with the composite of cement and Orashi River sand has the highest UCS followed by the sample stabilized with the composite of cement and Sombrero River sand and least in the sample stabilized with the composite of cement and residual soil. The increase in UCS implied that the composite materials improved the properties of the subgrade soil. Hence, the addition of residual soil and river sand to cement as soil stabilization materials will reduce the shrinkage and swelling of expansive soil such as Chokocho subgrade soil, which are naturally used for road construction, foundations and other earthworks. The results obtained from this study on UCS of the subgrade soil stabilized with the composites of cement and residual soil or river sand, is in agreement with previous studies (Okonkwo *et al.*, 2016; Tse and Ogunyemi, 2016; Essien and Charles, 2016;

Neeladharan *et al*., 2018; Eltwati and Saleh, 2020; Etim *et al*., 2021).

The findings of this study are in line with previous research on the use of composite materials for soil stabilization. For example, Okonkwo *et al*., (2016) investigated the use of sawdust and cement for the stabilization of lateritic soil and found that the UCS increased with the addition of sawdust. Tse and Ogunyemi (2016) studied the stabilization of lateritic soil with cement and cassava peel ash and reported an improvement in UCS. Essien and Charles (2016) investigated the use of coconut fiber and cement for the stabilization of clayey soil and found that the UCS increased with the addition of coconut fiber. Neeladharan *et al*., (2018) investigated the use of fly ash and lime for the stabilization of clayey soil and reported an improvement in UCS. Eltwati and Saleh (2020) studied the stabilization of clayey soil with cement and reported an increase in UCS with the addition of cement. Etim *et al*., (2021) investigated the use of waste plastic and cement for the stabilization of lateritic soil and reported an improvement in UCS.

Overall, the results of this study suggest that the use of composite materials of cement and residual soil or river sand can improve the properties of subgrade soil, leading to an increase in UCS. This finding has significant implications for road construction, foundations, and other earthworks, where the use of stabilized soil is often necessary.

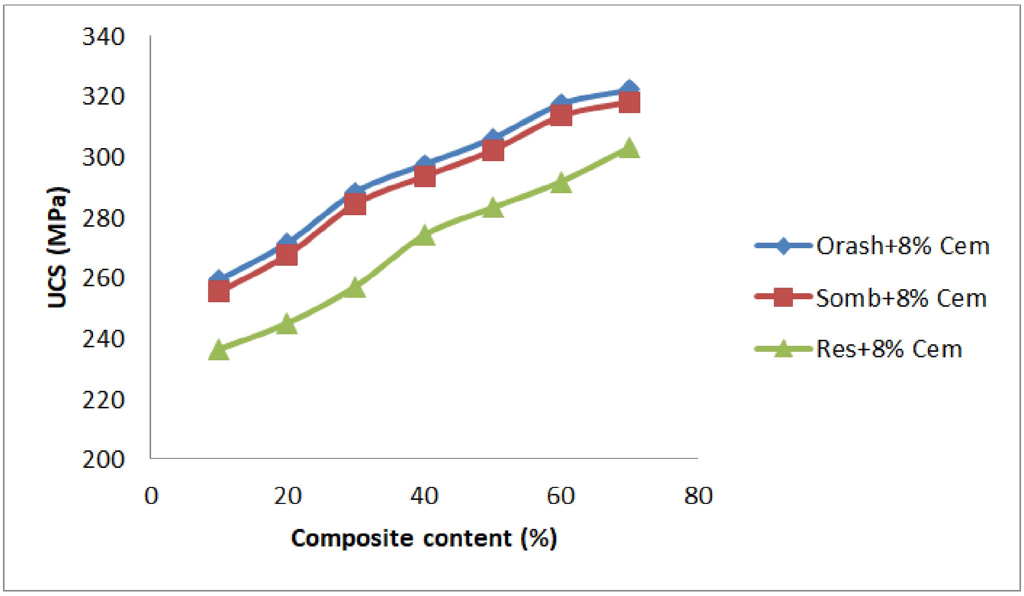

Figure 9: Comparison of UCS of stabilized subgrade soil after 7 days curing

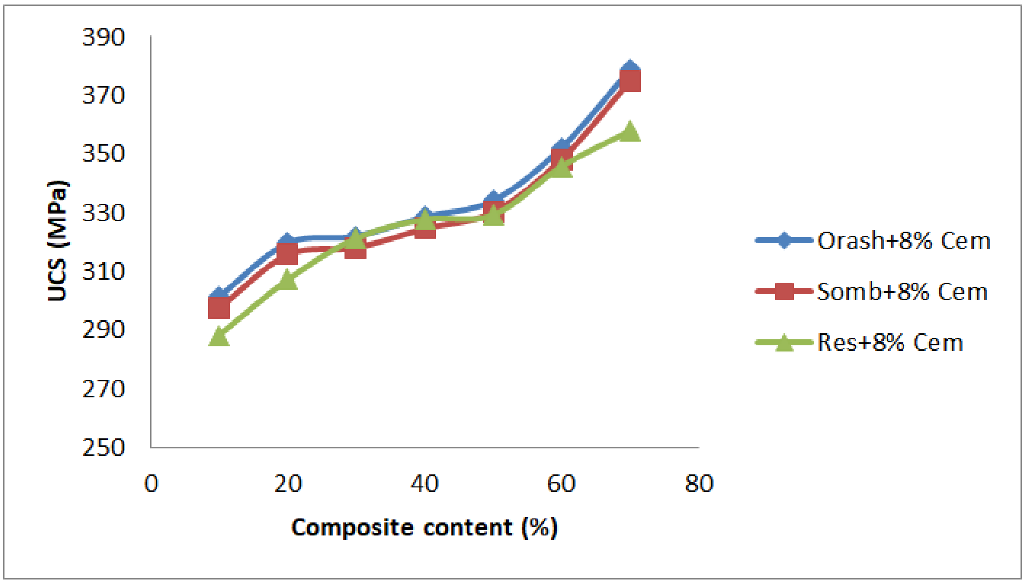

Figure 10: Comparison of UCS of stabilized subgrade soil after 28 days curing

4. CONCLUSION

The study examined the effect of residual soil, Orashi River sand, and Sombrero River sand on the chemical composition, fines content, maximum dry density (MDD), optimum moisture content (OMC), and liquid limit (LL) of subgrade soil. The results showed that the chemical composition of subgrade soil was dominated by calcium, aluminum, and silicon, indicating a mineral clay soil. The fines content decreased with increasing percentage of stabilization material, and the maximum MDD was observed in subgrade soil stabilized with Sombrero River sand. The OMC behavior of the stabilized soil was non-linear and the highest values were recorded in subgrade soil stabilized with residual soil. The LL of the stabilized subgrade soil decreased significantly for all three materials, and the reduction in LL indicated a decrease in soil swelling ability. The study findings are useful for soil classification and management, and for the design and construction of road and pavement structures.

This study investigated the effects of stabilization materials, such as residual soil and river sands, on the plastic limit (PL) and plasticity index (PI) of subgrade soil. Results showed that the PL and PI decreased with increasing percentages of the stabilizing materials. Subgrade soil stabilized with residual soil had the highest PL, while there was no clear difference between the PL recorded with Sombrero and Orashi River sands. The reduction in PI with increasing percentage of stabilizing materials was attributed to the decrease in clay content of the soil. The findings of this study are consistent with previous research and can be used to recommend the use of residual soil and river sands in road construction projects. Additionally, unconfined compressive strength (UCS) tests on samples of the subgrade soil stabilized with 8% cement and varying percentages of residual soil and river sands revealed that the UCS increased with increasing percentage of composite materials and curing days. The use of composite materials of cement and residual soil or river sand can improve the properties of subgrade soil and lead to an increase in UCS, which is important for the longevity of infrastructure. The findings of this study can be utilized in the design and construction of roads and other infrastructure projects, especially in areas with expansive soils. Further research is needed to investigate the effects of different mixing ratios of composite materials on the properties of subgrade soil.

5.0 CONTRIBUTION TO THE BODY OF KNOWLEDGE

The results of this study make several valuable contributions to the body of knowledge on soil stabilization and management. Firstly, the study provides important information on the chemical composition of the subgrade soil, which can aid in its classification and management. Secondly, the study highlights the effect of different stabilization materials on the fines content and MDD of subgrade soil, and the importance of considering the properties of both the soil and stabilization material in soil stabilization projects. Thirdly, the study sheds light on the non-linear behavior of OMC with increasing percentage of stabilization materials, and the potential risks of high OMC in soil.

The findings of this study have practical implications for engineers and researchers involved in the design and construction of roadways and other infrastructure projects. The information on the chemical composition of the subgrade soil can aid in the selection of appropriate stabilization materials and methods, while the findings on the effect of stabilization materials on fines content and MDD can be used to optimize the use of these materials in road construction for improved strength and durability. The information on the non-linear behavior of OMC with increasing percentage of stabilization materials can aid in the determination of appropriate weight percentages of stabilization materials to avoid potential risks associated with high OMC.

Overall, this study adds to the existing body of knowledge on soil stabilization and management and provides valuable insights that can aid in the design and construction of infrastructure projects. The study also highlights the need for further testing and analysis to fully understand the characteristics of subgrade soil and determine the most effective methods for its stabilization and management.

The study makes an important contribution to the body of knowledge on soil stabilization by investigating the effect of residual soil and river sands on the liquid limit, plastic limit, and plasticity index of subgrade soil. The findings suggest that residual soil, Orashi River sand, and Sombrero River sand are effective stabilizing agents for subgrade soil. The decrease in liquid limit and plastic limit with increasing percentage of stabilizing materials indicates a reduction in soil swelling potential and improved ability to resist deformation, respectively. These results are consistent with previous studies and provide important insights for the design and construction of stabilized subgrade soil for road and pavement structures.

However, the study also highlights the need for further research to investigate the long-term performance of stabilized subgrade soil under different loading conditions. This suggests a potential avenue for future research to expand on the findings of this study and provide a more comprehensive understanding of the behavior of stabilized subgrade soil over time. Overall, the study's contribution to the body of knowledge on soil stabilization is valuable for both researchers and practitioners working in the field of transportation infrastructure.

The results of this study contribute to the body of knowledge on soil stabilization and its application in road construction and other infrastructure projects. The study confirms that the addition of stabilization materials, such as residual soil and river sand, can improve the strength of subgrade soil, as indicated by an increase in CBR and UCS values. This knowledge can inform engineering design and construction practices to ensure the durability and longevity of infrastructure on subgrade soil.

Furthermore, the study provides insight into the optimum content of stabilization material required to achieve maximum CBR and UCS values, beyond which the strength of the soil decreases. This information can help engineers and designers to determine the appropriate amount of stabilization material to use in soil stabilization projects, taking into account the costs and benefits of different options.

The study also highlights the importance of considering the effect of soaking on the strength of subgrade soil, which can inform construction practices in areas with high water tables or prone to flooding. Additionally, the study demonstrates the effectiveness of using composite materials of cement and residual soil or river sand for soil stabilization, which can offer a cost-effective and environmentally friendly alternative to traditional stabilization materials.

Overall, the findings of this study contribute to the understanding of soil stabilization and its application in infrastructure projects. This knowledge can inform engineering design and construction practices to ensure the durability and longevity of infrastructure on subgrade soil. Further research is needed to investigate the long-term effects of stabilization materials and soaking on the strength of subgrade soil and to explore the effects of different mixing ratios of composite materials.

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