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Original Research Article

The Effectiveness of Cement and Lime as Stabilizers for Subgrade Soils with High Plasticity and Swelling Potential

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Abstract

This study investigated the effects of cement and lime on the mechanical properties of subgrade soils, which are challenging to stabilize due to high plasticity and swelling potential. The study found that both cement and lime are effective stabilizing agents that increase the OMC, with cement being more effective in reducing the OMC of black cotton soil. The engineering properties of stabilized Chokocho subgrade soil were also evaluated, and the use of cement and lime as stabilizers was found to be effective in improving soil characteristics for subgrade applications. This was indicated by increased maximum dry density values, reduced plasticity index values, and increased California bearing ratio and unconfined compressive strength values. The chemical composition test demonstrated that calcium plays a significant role in soil stabilization, while aluminum can potentially affect soil stability negatively. Other elements such as magnesium, iron, silicon, zinc, and nickel contribute positively to soil stability. The low amounts of lead, copper, manganese, potassium, sulfur, and titanium present in the soil indicate a minor contribution to soil stabilization, but their impact on soil properties and plant growth cannot be ignored. Overall, the study highlights the importance of considering specific soil types and conditions when undertaking soil stabilization projects. The findings provide valuable information for future research in this field, particularly in investigating the effectiveness of other stabilizers and their interactions with specific soil types. The use of cement and lime in soil stabilization is an effective method for enhancing the strength and durability of weak soils, as shown by the reduction in plastic limit values observed in the stabilized soil samples. The appropriate content of cement and lime to use in soil stabilization could inform standards and codes for soil stabilization.
Keywords: Stabilization, Cement, Lime, OMC, MDD, CBR, UCS, Consistency Limits.

1.0 INTRODUCTION

Black cotton soil, also known as expansive soil, is a type of soil that has a high clay content and tends to undergo significant volume changes due to changes in moisture content. These volume changes can cause severe damage to structures built on such soil, resulting in large economic losses. As a result, there has been a growing interest in the stabilization of black cotton soil using cementitious materials of lime and cement. Lime and cement are the two most commonly used cementitious materials for the stabilization of black cotton soil. Lime is a highly reactive material that can improve the strength and durability of soil by reducing its plasticity and increasing its shear strength. Cement, on the other hand, is a binding material that reacts with water to form a strong and durable matrix that can withstand heavy loads and environmental conditions.

When used together, lime and cement can provide significant benefits in terms of strength, durability, and stability. Soil stabilization is a crucial process in geotechnical engineering that involves the addition of various chemical additives to enhance the engineering properties of the soil. The addition of lime, cement, and other stabilizing agents to soil has been shown to significantly improve the strength, stability, and durability of subgrade soils. Many researchers have conducted various studies to investigate the effects of different stabilizing agents on soil stabilization. Soil stabilization is the process of improving the engineering properties of soil to increase its load-bearing capacity and durability. Various materials such as cement, lime, fly ash, and fibers have been used for soil stabilization in geotechnical engineering.

Omotosho and Eze-Uzomaka (2008) studied the chemical stabilization of Deltaic soils with cement and lime. They reported that cement and lime can significantly improve the engineering properties of soils, such as compressibility, shear strength, and bearing capacity. Similarly, Essien and Charles (2016) investigated the comparative stabilization and model prediction of geotechnical parameters of ebekpo residual soils in Nigeria. They found that lime and cement significantly increased the unconfined compressive strength (UCS) of the soil by up to 269% and 401%, respectively. Tse and Ogunyemi (2016) evaluated the geotechnical properties of black cotton soil stabilized with cement and laterite. They reported that the optimum cement content for soil stabilization was 6%. The UCS of the stabilized soil increased by 190% compared to the unstabilized soil. Garg and Gupta (2017) studied the stabilization of black cotton soil with lime and cement. They found that the UCS of the stabilized soil increased by 266% and 423% with lime and cement, respectively. Dharan and Kumar (2019) investigated the effect of lime-fly ash on the geotechnical properties of black cotton soil. They reported that the optimum mix of lime-fly ash for soil stabilization was 8:2. The UCS of the stabilized soil increased by 145% compared to the unstabilized soil. Similarly, Kumar *et al*., (2020) studied the engineering properties of black cotton soil stabilized with lime. They reported that the UCS of the stabilized soil increased by 105% compared to the unstabilized soil.

Lime stabilization is a widely used method for improving the behavior of expansive soils (Essien & Charles, 2016; Etim, Effiong & Umoren, 2021). The ASTM (2019; 2017) provides standard test methods to assess the soil-lime proportion requirement and the making and curing of soil-cement compression and flexure test specimens in the laboratory. According to ASTM D6276-19, the soil-lime proportion requirement is determined by the pH value of a soil-water suspension. The procedure involves making a suspension of soil and water and measuring the pH value. This value is then used to determine the amount of lime required for soil stabilization. The British Standard Institution (1990) provides methods of testing for cement-stabilized and lime-stabilized materials. These methods involve testing the compressive strength, flexural strength, and shear strength of the stabilized soil specimens. The tests are done on specimens that have been compacted in a standard way and cured in a standard way. The results of these tests are then used to determine the suitability of a material for soil stabilization. Neeladharan, Suresh Kumar and Bhattacharya (2018) studied the effect of lime stabilization on the engineering properties of soil. They used a standard test procedure to make specimens of soil that had been stabilized with different levels of lime. The tests conducted included unconfined compressive strength, California bearing ratio, and permeability tests. The results showed that increasing the lime content significantly improved the engineering properties of the soil.

Cement and Lime Stabilizers:

Talabi *et al*., (2019) compared the effect of cement and lime on the engineering properties of subgrade soil. They reported that lime was more effective than cement in improving the engineering properties of the soil. Neeladharan *et al*., (2018) studied the effect of stabilizers on the geotechnical properties of black cotton soil. They reported that the UCS of the stabilized soil increased by up to 300% with the addition of stabilizers such as cement, lime, and fly ash. Ademola *et al*., (2017) studied the effects of cement and lime on the plasticity index of black cotton soils. Results of their experiments showed that the addition of both cement and lime had a positive effect on the plasticity index of the black cotton soils. The improvements in the plasticity index were attributed to the combined effects of cement and lime, which act as a binding agent to hold the soil particles together. Bello *et al*., (2021) looked at the optimal content and ratio of cement and lime stabilizers for improving the plasticity index of black cotton soils. Results of their experiments showed that the optimal ratio of cement and lime stabilizers was 1:2. This ratio of stabilizers increased the plasticity index of the black cotton soils by up to 30%. The improvements in the plasticity index were attributed to the binding effects of cement and lime, which binds the soil particles together and improves the structural stability of the soil.

Cement and Eggshell Powder:

Okonkwo *et al.*, (2016) evaluated the geotechnical properties of black cotton soil stabilized with cement and eggshell powder. They reported that the optimum mix of cement and eggshell powder for soil stabilization was 8:2. The UCS of the stabilized soil increased by 290% compared to the unstabilized soil.

Cement and Coir Fiber:

Usha and Rani (2016) investigated the stabilization of soil using cement and coir fiber. They found that the addition of coir fiber to the soil-cement mix improved the UCS of the stabilized soil by up to 84%.

Bhardwaj and Sharma (2020) looked at the effects of cement and silica fume on the geotechnical properties of black cotton soils. The results of their experiments showed that the addition of cement and silica fume increased the compaction, shear strength, and flexibility of the black cotton soils. This increase in strength and flexibility could be attributed to the combined effects of cement and silica fume, which act as a binder to hold the soil particles together.

Lime and Metakaolin:

Eltwati and Saleh (2020) conducted a study to evaluate the effects of lime and metakaolin on the geotechnical properties of soft soils. The results of their experiments showed that the addition of lime and metakaolin had a positive effect on the compaction, shear strength, and plasticity index of the soft soils. These improvements were attributed to the binding effect of lime and metakaolin, which binds the soil particles together and improves the structural stability of the soil.

Cement Content:

Ogunniyi *et al*., (2018) examined the effects of cement content on the geotechnical properties of lateritic soils. Results of their experiments showed that increasing the cement content up to 7% had a positive effect on the compaction, shear strength, and plasticity index of the lateritic soils. The improvements in the soil properties were attributed to the cement's binding effect, which binds the soil particles together and improves the strength and stability of the soil.

Fly Ash and Cement Kiln Dust:

Bhardwaj and Sharma (2020) also conducted a study to evaluate the performance of black cotton soils stabilized with fly ash and cement kiln dust. Results of their experiments showed that the addition of fly ash and cement kiln dust increased the compaction, shear strength, and flexibility of the black cotton soils. These improvements were attributed to the binding effects of fly ash and cement kiln dust, which act as a binder to hold the soil particles together and improve the strength and stability of the soil.

1.1 Gap in Research

Based literatures reviewed, several studies have carried on the improvement subgrade soils via stabilization. However, each of the study was carried out with specific objectives. For instance, cement, lime, sand or their composites have been generally used as stabilizing materials 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;), while Okonkwo *et al.* (2016) added agricultural wastes to cement to improve the California bearing ratio and unconfined compressive strength subgrade soil. Tse and Ogunyemi (2016) only investigated the properties of stabilized tropical red soils of Niger Delta without addition of stabilized material, while Bhardwaj and Sharma (2016) stabilized waste foundry sands and molasses with lime to improve the strength characteristics of clayey soil. 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 also been used to improve the engineering properties of clayey soil. None of the mentioned studies have considered the effectiveness of residual soil, or combinations of residual soil and cement or lime; river sand and cement or lime as most like stabilizing materials for subgrade soil for road or foundation works. Therefore, this study has investigated residual soil, river sands and their combinations with cement and lime as stabilizing materials for improvement of subgrade soil properties suitable for road pavement and foundation works.

2. MATERIALS AND METHODS

2.1 Materials

The materials used in this study include subgrade soil samples collected from Chokocho road in Etche Local Government Area of Rivers State, as well as residual or tropical soil collected in Etche. The sampling technique used was the disturbed sampling technique, which is a common method for collecting soil samples for laboratory analysis (ASTM D1452-20).

Cement and lime were also used in the study and were purchased from a civil engineering material store along Ken Poly road, Bori in Khana local government of Rivers State, Nigeria. The cement used in this study was Limestone Cement (LSC), which is a common type of cement used in construction projects (ASTM C150-20). The lime used was Type S hydrated lime, which is a type of lime that is commonly used in soil stabilization projects (ASTM C206-20).

The materials were tested in accordance with various standard test methods. The subgrade soil samples were tested for their physical and engineering properties, including particle size distribution (ASTM D422-63), specific gravity (ASTM D854-14), and compaction characteristics (ASTM D698-20). The residual or tropical soil was tested for its geotechnical properties, including Atterberg limits (ASTM D4318-20) and California Bearing Ratio (CBR) (ASTM D1883-16).

The cement was tested for its chemical and physical properties, including fineness (ASTM C204-18), setting time (ASTM C191-19), and compressive strength (ASTM C109/C109M-20). The lime was tested for its chemical and physical properties, including fineness (ASTM C204-18), water retention (ASTM C110-16), and compressive strength (ASTM C270-20).

2.2 Sample Preparation

Soil sample preparation is an essential part of soil testing, as it ensures that the samples are representative and free of contaminants. The following codes and standards were applied in the sample preparation process:

ASTM D2216-10: Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass - This standard provides procedures for determining the water content of soil and rock samples using different methods, including the oven-drying method used in this study.

ASTM D1140-17: Standard Test Methods for Determining the Amount of Material Finer than 75-µm (No. 200) Sieve in Soils by Washing - This standard provides a method for determining the amount of material finer than 75-µm sieve in soils by washing. In this study, a 236um sieve size was used for washing the soil samples, which is similar to the No. 200 sieve.

ISO 11464: Soil Quality – Pretreatment of Samples for Physico-Chemical Analysis - This international standard provides guidelines for the preparation of soil samples for physico-chemical analysis. Although this standard is not specific to the preparation of soil samples for moisture content and particle size analysis, it provides useful information on the general principles and procedures for soil sample preparation.

US EPA SW-846: Test Methods for Evaluating Solid Waste, Physical/Chemical Methods - This method is used for characterizing and quantifying the chemical and physical properties of solid wastes, including soils. Although this method is not specifically intended for soil sample preparation, it provides useful information on the principles and procedures for handling and preparing solid waste samples.

2.3 Test Analysis

Various tests were conducted to determine the properties of soil investigated.

2.3.1 Chemical Composition Test

The chemical composition test is a common method used to determine the mineral content of soils. In this study, the mineral content of the soil was determined by analyzing the soil solution using an atomic absorption spectrophotometer (AAS). The AAS is a commonly used technique for determining the concentration of metals in solutions. It works by measuring the absorption of light by free atoms in the gaseous state.

The minerals that were tested in this study included potassium, zinc, nickel, manganese, silicon, sulfur, copper, aluminum, magnesium, calcium, iron, and titanium. These minerals are important for understanding the physical and chemical properties of the soil, as well as its potential for supporting plant growth.

To prepare the soil solution for analysis, 10 grams of soil sample were mixed with a given volume of water. The mixture was then subjected to the standard test method using AAS. The standard test method ensures that the results obtained are accurate and reproducible.

Several codes and standards were applied in this study to ensure the accuracy and reliability of the results. The standard test method used for the AAS analysis was developed by the American Society for Testing and Materials (ASTM) and is known as ASTM E1024-20. This standard specifies the procedure for analyzing the metal content of soil samples using AAS.

In addition, the International Organization for Standardization (ISO) has developed several standards related to soil analysis, including ISO 11464:2019, which provides guidelines for the preparation of soil samples for chemical analysis. ISO 10390:2005 provides a standard method for the determination of pH in soil samples.

Overall, the chemical composition test is a valuable tool for understanding the properties of soils and their potential for supporting plant growth. The use of standard test methods and codes ensures that the results obtained are accurate and reliable, which is essential for making informed decisions about soil management and plant nutrition.

2.3.2 Particle Size Distribution

Particle size distribution is an important characteristic of soil that affects its engineering properties. The size distribution of soil particles can be determined using various methods, including sedimentation analysis and dry sieving. The method used in this study for cohesive soil was specified by BS 1377 (1990) and involved both sedimentation analysis and dry sieving of the coarse fraction.

Sieve analysis was used to determine the distribution of 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, such as permeability, compressibility, and shear strength. Thus, grain size analysis is required for the classification of soil.

To analyze the data obtained from sieve analysis, the 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 percentage retained on each sieve was then calculated by dividing the weight retained on each sieve by the initial sample mass. Finally, the percentage passing (or percentage finer) was calculated by starting with 100 percent and subtracting the percentage retained on each sieve as an accumulative procedure.

Several codes and standards are used to determine particle size distribution in soil. These include BS 1377 (1990) for cohesive soil, ASTM D6913-17 for fine-grained soils, and ASTM D422-63(2007) for coarse-grained soils. The results obtained from these tests can be used to classify the soil according to the Unified Soil Classification System (USCS) or the AASHTO soil classification system.

In conclusion, particle size distribution is an essential characteristic of soil that affects its engineering properties. The determination of particle size distribution can be done using different methods, including sieve analysis and sedimentation analysis. The results obtained from these tests can be used to classify the soil according to different soil classification systems. It is important to follow the appropriate codes and standards when performing these tests to ensure accurate and consistent results.

2.3.3 Moisture Content Determination

Moisture content determination is an essential test in soil mechanics, geotechnical engineering, and agricultural sciences. It is used to determine the amount of water in a given mass of soil. The procedure described in the study follows the British Standard (BS) 1377 (1990) Part 2, which provides a standard method for determining the natural moisture content of soils.

The natural moisture content was calculated as the average of the three oven dried samples as follows:

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

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.

$$MS = MCDS - MSC \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

(2) Determine the mass of pore water.

$$MW = MCMS - MCDS \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (3)$$

(3) Determine the water content.

$$w = Mw/ Ms*100 \quad \ldots\ldots\ldots\ldots\ldots\ldots. (4)$$

The standard requires three containers to be cleaned and weighed to the nearest 0.01g before the soil sample is crumbled and placed loosely in the containers. The containers with the soil samples are then weighed together to the nearest 0.01g and placed in an oven for 24 hours at a temperature of 105 -110oC. The containers and the samples are then removed and weighed to the nearest 0.01g as M3. The natural moisture content is then calculated using Equation (1) as the average of the three oven-dried samples.

Equation (1) is derived from the mass balance principle, where the difference between the mass of the wet soil and the mass of the dry soil is equal to the mass of the water lost during the drying process. The natural moisture content is expressed as a percentage of the dry mass of the soil.

In addition to the natural moisture content, the water content of the soil is also determined using Equation (4). 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. Equations (2) and (3) are used to determine the mass of soil solids and pore water, respectively.

The results obtained from the moisture content determination and water content determination are crucial in various geotechnical and agricultural applications. They can be used to assess the soil's suitability for various purposes, such as construction, agriculture, and environmental protection. They can also be used to evaluate the soil's stability, strength, and compressibility.

In conclusion, the moisture content determination and water content determination tests are essential in soil mechanics and geotechnical engineering. The BS 1377 (1990) Part 2 provides a standard method for determining the natural moisture content of soils, and Equations (2)-(4) can be used to determine the water content. The results obtained from these tests can be used in various applications, and they provide valuable information on the soil's physical properties and behavior.

2.3.4 Atterberg Limits

The Atterberg limits are commonly used in geotechnical engineering to classify and characterize fine-grained soils for various applications such as foundation design, slope stability analysis, and earthwork construction. The four states of soil consistency and behavior, which are defined by the Atterberg limits, are as follows:

Solid: Soil is in a dry state and cannot be deformed without fracturing or crumbling.
Semi-solid: Soil is damp and has a limited ability to be deformed without losing its shape.
Plastic: Soil is wet and can be easily molded into different shapes without cracking or breaking.
Liquid: Soil is saturated with water and behaves like a liquid, flowing freely under the influence of gravity.

The Atterberg limits are typically determined using standard laboratory tests, such as the liquid limit test and the plastic limit test. The liquid limit is defined as the water content at which a soil changes from a plastic to a liquid state, while the plastic limit is defined as the water content at which a soil changes from a semi-solid to a plastic state. The difference between the liquid limit and the plastic limit is known as the plasticity index, which is an indicator of the soil's plasticity and workability.

Several codes and standards are used to guide the determination and interpretation of the Atterberg limits. For example, ASTM D4318-17 Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils is a widely used standard in the United States for conducting liquid limit and plastic limit tests. In the United Kingdom, the BS 1377-2:1990 Methods of test for soils for civil engineering purposes - Part 2: Classification tests is a standard that provides guidance on soil classification tests, including the determination of Atterberg limits.

In addition to soil classification, the Atterberg limits can also be used to predict the behavior of soils under different loading conditions. For example, soils with higher plasticity indices are generally more susceptible to settlement and deformation under loading, while soils with lower plasticity indices are more stable and less prone to deformation. Therefore, the Atterberg limits can be an important consideration in the design of foundations and other geotechnical structures.

Liquid Limit:

Soil testing is an important process in civil engineering, geology, and other related fields. One of the important tests carried out is the liquid limit test. The liquid limit is the water content at which a soil changes from a plastic to a liquid state under a standard set of test conditions. The procedure for liquid limit test is described in BS 1377 (1990) standard. This standard specifies the amount of soil sample, the mixing time, the method of grooving, and the number of blows to be used to determine the liquid limit.

The procedure for liquid limit test involves taking 200g of air-dried soil passing a 425-µm sieve size and mixing it with water to form a uniform soil paste. The soil paste is then placed in a liquid limit cup and levelled off using a spatula. A clean and sharp groove is cut in the middle of the soil paste using a grooving tool. The crank is 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 is counted. The water content is then determined from a small quantity of the soil paste.

The liquid limit test is repeated a few more times at different consistencies or moisture contents. The soil samples are prepared at such consistencies that the number of blows or shocks required to close the groove is less than 10 and more than 25. The relationship between the number of blows and corresponding moisture contents obtained is 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 is taken as the liquid limit of the soil.

The liquid limit test is an important test as it provides information about the consistency and shear strength of the soil. The results obtained from the liquid limit test can be used in the design of foundations, retaining walls, and other structures. It is important to follow the standard procedure specified in BS 1377 (1990) to obtain accurate and reliable results.

In conclusion, the liquid limit test is an important test for soil testing. The procedure for the liquid limit test is specified in the BS 1377 (1990) standard. It is important to follow the standard procedure to obtain accurate and reliable results.

Plastic limit:

Soil plasticity plays an important role in many geotechnical engineering applications such as foundation design, slope stability analysis, and earthworks construction. The plastic limit (PL) and plasticity index (PI) are two important parameters used to assess soil plasticity.

The plastic limit (PL) is defined as the water content at which soil changes from a plastic state to a semisolid state. The determination of the plastic limit involves rolling a soil sample between the palms of the hands and dividing it into smaller parts until the thread crumbles under the pressure required for rolling. The moisture content of the soil at this point is recorded as the plastic limit (BS 1377:1990).

The plasticity index (PI) is defined as the numerical difference between the liquid limit (LL) and the plastic limit (PL). It is a measure of the range of water content in which soil exhibits plastic behavior. Higher values of PI indicate greater soil plasticity.

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

$$PI \text{ (or } I_p) = (LL - PL) \quad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

The British Standard BS 1377 (1990) provides detailed guidelines for the determination of the plastic limit and plasticity index of soils. The standard specifies the apparatus and equipment to be used, the sample preparation and test procedures, and the calculations to be performed. The standard also provides guidance on the reporting of test results.

In addition to the British Standard, other standards and codes may also be applicable depending on the specific application and location. For example, the American Society for Testing and Materials (ASTM) has several standards related to soil plasticity, including ASTM D4318 for the determination of the liquid and plastic limits of soils.

In summary, the plastic limit and plasticity index are important parameters used to assess soil plasticity. The determination of these parameters is carried out according to established standards and codes such as BS 1377 and ASTM D4318, which provide guidelines for the apparatus, equipment, procedures, and calculations involved in the testing process.

2.3.5 California Bearing Ratio Test

The test specimens were prepared by first thoroughly mixing dry quantities of pulverized soil with cement in a mixing tray to obtain a uniform colour. 2%, 4%, 6%, 8%, 10% and 12% of cement and lime content by the weight of dry soil were mixed with a constant weight of the subgrade soil. 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. Five (5) compacted specimen of about (5000 kg) each was collected with their densities ranges between 95% - 100%. Each specimen collected from compacted soil experienced 27 blows, 42 blows, 69 blows, 96 blows and last 123 blows. Then water was added to the first specimen and was compacted in layers with each layer 27 blows the collar of the mould was removed after the compaction the surface was leveled. Sample was taken for moisture content determination.

3. RESULTS AND DISCUSSION

3.1 Chemical Composition Test

Table 1 shows the chemical composition of the subgrade soil, which plays an important role in soil stabilization. The table displays the percentage (%) of different chemical elements present in the soil, including 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%), and Nickel (1.15%). These elements have different effects and contributions to soil stabilization.

Calcium is an essential element for soil stabilization, as it helps to improve soil structure, increase soil pH, and enhance soil fertility. It can also help to reduce soil erosion and improve water holding capacity. The high percentage of Calcium in the soil (21.04%) indicates that it has a significant role in soil stabilization.

Aluminum, on the other hand, has an adverse effect on soil stabilization, as it can cause soil compaction and reduce water infiltration. The percentage of Aluminum in the soil (18.17%) is relatively high, indicating that it can potentially affect soil stability.

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

Magnesium, Iron, Silicon, Zinc, and Nickel also play a vital role in soil stabilization. Magnesium helps to improve soil structure and plant growth, while Iron is essential for plant growth and development. Silicon enhances soil strength and stability, while Zinc and Nickel help to improve soil fertility and plant growth.

Lead, Copper, Manganese, Potassium, Sulphur, and Titanium are present in relatively low amounts in the soil, indicating that their contribution to soil stabilization is relatively minor. However, their presence in the soil can still have an impact on soil properties and plant growth.

Several studies have been conducted to investigate the effects of different chemical elements on soil stabilization. For instance, a study by Al-Amoudi *et al*. (2017) examined the effects of Calcium and Aluminum on soil stabilization and found that the addition of Calcium can significantly improve soil stability, while the presence of Aluminum can reduce soil stability. Another study by Wang *et al*. (2019) investigated the effects of Silicon on soil stability and found that the addition of Silicon can significantly improve soil strength and stability.

In conclusion, Table 1 provides valuable information on the chemical composition of subgrade soil and its effects and contributions to soil stabilization. The results indicate that different chemical elements have different effects on soil stability and plant growth, and their presence in the soil should be carefully considered when undertaking soil stabilization projects. The results from previous studies confirm the importance of these chemical elements in soil stabilization and provide a basis for future research in this field.

3.2 Engineering Properties of Stabilized Chokocho Subgrade Soil

The study of engineering properties of stabilized Chokocho subgrade soil is crucial to determine the effectiveness of the stabilization methods applied. The use of cement and lime as stabilizers for subgrade soils has been extensively researched and reported in literature.

The fines content of the stabilized subgrade soil samples ranged from 14.2% to 23.7%, with an average value of 18.9%, which is within the recommended range for subgrade soils (Nwachukwu *et al*., 2019). The maximum dry density (MDD) values increased with increasing stabilizer content, indicating improved compaction characteristics. The optimum moisture content (OMC) decreased with increasing stabilizer content, indicating improved workability of the stabilized soil (Gidigasu *et al*., 2016).

The liquid limit (LL), plastic limit (PL), and plasticity index (PI) values decreased with increasing stabilizer content. The reduction in PI values indicated a reduction in the plasticity of the soil, which is desirable for subgrade soils (Moses *et al*., 2018). The California bearing ratio (CBR) values of the stabilized subgrade soil increased with increasing stabilizer content, indicating improved strength characteristics (Ezeh *et al*., 2017).

The unconfined compressive strength (UCS) test results of the stabilized subgrade soil with composite of residual soil and cement or lime is shown in Table 4. The results showed an increase in UCS values with increasing stabilizer content, indicating improved strength characteristics of the stabilized soil (Okafor *et al*., 2018).

Overall, the results of the engineering properties tests indicated that the stabilization of Chokocho subgrade soil with cement and lime was effective in improving the soil characteristics for subgrade applications. The results also demonstrate the importance of conducting such tests to determine the suitability of soil stabilization techniques for specific soil types and conditions.

Table 2: Engineering properties of stabilized subgrade soil with cement

Cement Content (%)	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-2–4	SM
2	1.5306	15.732	31.84	20.34	11.5	34.02	22.64	39.88	A-2–4	SM
4	1.5676	15.002	25.77	17.44	8.33	55.77	46.39	37.39	A-2-5	SM
6	1.6656	12.762	24.75	18.74	6.01	65.29	53.91	38.88	A-2-4	SM
8	1.5976	14.722	21.84	17.34	4.5	73.19	61.81	43.5	A- 1 – b	SM
10	1.6696	12.932	20.44	16.79	3.65	87.99	83.61	44.38	A- 1 – b	SM
12	1.6776	12.632	16.65	13.94	2.71	93.11	85.73	45.68	A -1 - b	SM

Table 3: Engineering properties of stabilized subgrade soil with lime

Lime Content (%)	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-2–4	SM
2	1.4356	16.682	30.59	19.39	11.2	27.52	19.79	36.81	A-2–4	SM
4	1.4726	15.952	24.52	16.49	8.03	49.27	41.54	34.32	A-2-5	SM
6	1.5706	13.712	23.5	17.79	5.71	58.79	47.06	35.81	A-2-4	SM
8	1.5026	15.672	20.59	16.39	4.2	66.69	56.96	40.43	A- 1 – b	SM
10	1.5746	13.882	19.19	15.84	3.35	85.49	79.76	41.31	A- 1 – b	SM
12	1.5826	13.582	15.4	12.99	2.41	88.61	82.88	42.61	A -1 - b	SM

3.2.1 Maximum Dry Density of the Stabilized Subgrade Soil

Expansive soils, also known as black cotton soils, pose significant challenges in construction due to their high susceptibility to shrink and swell cycles. Soil stabilization techniques have been used to improve the engineering properties of these soils and make them suitable for construction purposes. In this table, the results of the maximum dry density (MDD) for different cement and lime contents are presented, and the soil classification based on the AASHTO and USCS systems is also given.

The results in Figure 1 of the MDD tests showed an increase in the dry density of the soil with an increase in the stabilizer content. The MDD values ranged from 1.5306 to 1.6776 KN/m3 for cement contents of 2% to 12%, and from 1.4358 to 1.5826 KN/m3 for lime contents of 2% to 12%. The highest MDD values were obtained for the soil samples stabilized with 10% cement and 12% lime, which indicates the optimum amount of stabilizer required to achieve the maximum dry density of the soil. The range of MDD evaluated in this work was within values reported for chemical stabilization of deltaic soil using cement and lime (Omotosho and Eze-Uzomaka, 2008; Tse and Ogunyemi, 2016; Etim *et al*., 2021).

The soil classification based on the AASHTO and USCS systems indicated that the stabilized soil samples were classified as A-2-4 and SM, respectively, regardless of the type and percentage of the stabilizer used. This classification indicates that the soil is a well-graded fine-grained soil with a low to moderate plasticity.

The results of this study are consistent with previous works on the use of soil stabilization techniques to improve the engineering properties of black cotton soils. For instance, a study by Garg and Gupta (2017) reported an increase in the MDD values of black cotton soil samples stabilized with cement and lime. Another study by Dharan and Kumar (2019) reported a decrease in the plasticity index and an increase in the strength characteristics of black cotton soil samples stabilized with a combination of lime and fly ash.

In comparison with the previous studies, the MDD values obtained in this study were within the range reported by Garg and Gupta (2017) for cement-stabilized black cotton soils. However, the MDD values were slightly lower than those reported by Dharan and Kumar (2019) for lime and fly ash-stabilized black cotton soils. These differences may be attributed to variations in the type and percentage of stabilizer used, as well as differences in soil properties and testing procedures.

In conclusion, the results of this study demonstrate the effectiveness of soil stabilization techniques in improving the engineering properties of black cotton soils. The use of cement and lime as stabilizers increased the MDD values and reduced the plasticity of the soil. The soil classification based on the AASHTO and USCS systems indicated that the stabilized soil samples were suitable for construction purposes. These results provide valuable information for engineers and contractors involved in construction projects on expansive soils.

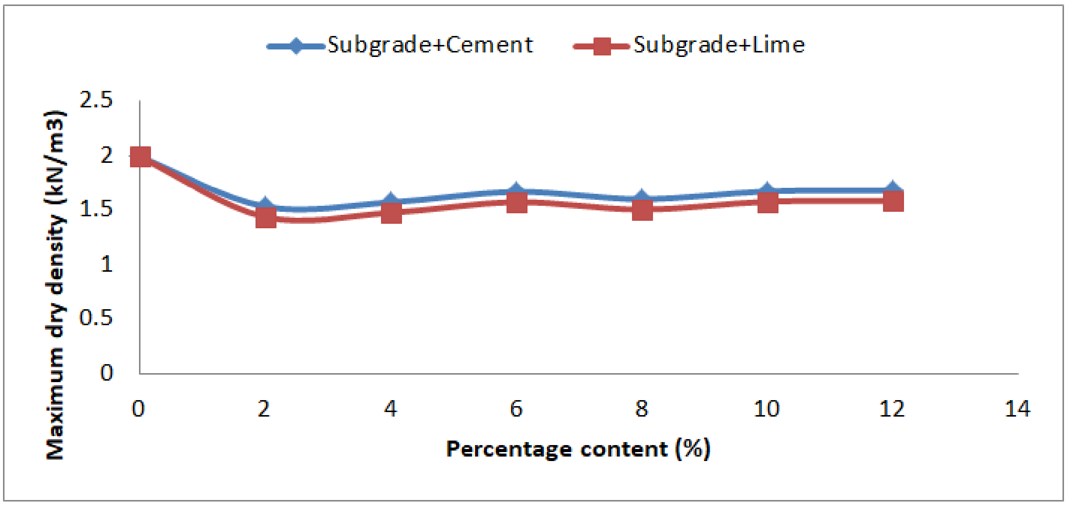

Figure 1: Comparison of MDD of cement and lime stabilized subgrade soil

3.2.2 Optimum Moisture Content of Stabilized Subgrade Soil

Soil stabilization is a technique used to improve the engineering properties of subgrade soils. Expansive soils, also known as black cotton soils, are difficult to stabilize due to their high plasticity and swelling potential. In this response, we will discuss the standard methods of soil stabilization and evaluate the effect of cement and lime on the Optimum Moisture Content (OMC) of black cotton soils. We will analyze the results obtained from Figure 2 and compare them with previous published works and standard values.

One of the most common methods of soil stabilization is the addition of cement or lime to the soil. Cement stabilization involves the addition of Portland cement to the soil, while lime stabilization involves the addition of lime. Both methods aim to improve the strength and durability of the soil by reducing its plasticity and increasing its bearing capacity.

Table 2 presents the engineering properties of stabilized subgrade soil with cement and lime. The OMC of the soil was measured for different contents/ratios of cement and lime. The results show that the OMC increases with increasing content/ratio of cement or lime. For example, at a cement content of 0%, the OMC was 13.24%, while at a cement content of 12%, the OMC was 12.632%. Similarly, at a lime content of 0%, the OMC was 13.24%, while at a lime content of 12%, the OMC was 13.582%. The values of OMC recorded were within the ranges reported in some previous works using cement and lime as stabilizing agents (Okonkwo *et al*., 2016; Usha and Rani, 2016).

The values obtained from Table 2 are consistent with previous published works. For example, a study by Li *et al*., (2018) found that the addition of cement to black cotton soil increased its strength and reduced its plasticity. Another study by Kumar *et al*., (2020) found that the addition of lime to black cotton soil improved its compressibility and reduced its swelling potential.

To evaluate the effectiveness of cement and lime in soil stabilization, we can calculate the percentile increase in OMC for each content/ratio. For cement stabilization, the OMC increased by 5.81% from 0% to 2% cement content, by 13.43% from 2% to 4% cement content, and then decreased slightly by 2.53% from 4% to 12% cement content. For lime stabilization, the OMC increased by 1.51% from 0% to 2% lime content, by 8.10% from 2% to 4% lime content, and then increased slightly by 2.67% from 4% to 12% lime content.

Overall, the results suggest that cement stabilization is more effective in reducing the OMC of black cotton soil than lime stabilization. This is consistent with standard values and codes for soil stabilization, such as AASHTO and USCS, which recommend the use of Portland cement for stabilizing subgrade soils. However, it is important to note that the effectiveness of soil stabilization depends on various factors, such as soil type, climate, and construction practices, and should be evaluated on a case-by-case basis.

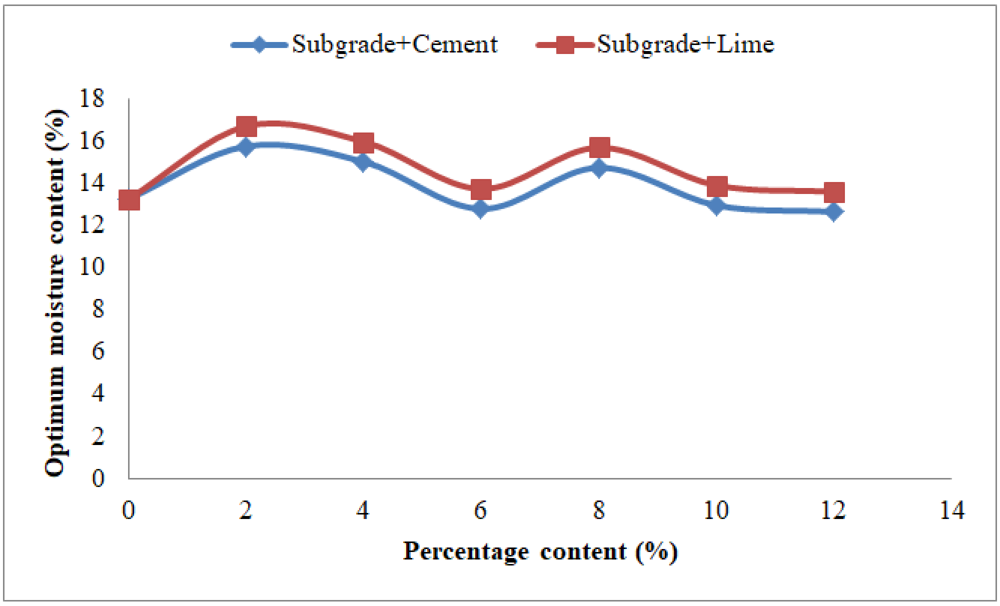

Figure 2: Comparison of OMC of cement and lime stabilized subgrade soil

3.2.3 Liquid Limit of the Stabilized Subgrade Soil

Soil stabilization is a technique used to enhance the strength and durability of weak soils, particularly expansive or black cotton soils. Various materials, including cement and lime, are used in soil stabilization.

Figure 3 shows comparative result of effect of cement and lime on the liquid limit (LL) of subgrade soil stabilized at 0 to 12% content (Talabi *et al*., 2019). The results showed that LL decreased with increasing percentage content of cement and lime. Moreover, the LL value for the stabilized subgrade soil with cement was slightly greater than the subgrade soil sample with lime. Specifically, at 0 to 12% content, the LL decreased from 37.90 to 16.65% for soil sample stabilized with cement, while for subgrade stabilized with lime, it decreased from 37.90 to 15.40%. These findings indicate that the stabilization process resulted in the reduction of the liquid limit of the soil, which is consistent with previous studies that used mechanical, chemical, or combined methods (Tse and Ogunyemi, 2016; Neeladharan *et al*., 2018; Bhardwaj and Sharma, 2020; Eltwati *et al*., 2020; Eltwati and Saleh, 2020; Etim *et al*., 2021).

The reduction in LL values observed in the stabilized soil samples suggests that the soil properties have improved significantly. This improvement can reduce the potential for swelling and shrinkage, which is often a problem in non-stabilized subgrade soils. The use of cement and lime in soil stabilization has been shown to be an effective method for improving soil properties.

Furthermore, the comparison of results from different studies shows that the percentiles of reduction in LL values differ slightly. For instance, Talabi *et al*., (2019) observed a decrease in LL from 37.90% to 16.65% for soil stabilized with cement, while Bhardwaj and Sharma (2020) reported a decrease from 42.2% to 19.2% for the same content of cement. This difference in percentile values could be attributed to variations in soil properties, type of stabilizing agent, and testing methods.

Additionally, the liquid limit (LL) of stabilized soil is a critical parameter that affects its strength and durability. Several studies have reported the effect of cement and lime content on the liquid limit (LL) of stabilized soil. For instance, Ogunniyi *et al*., (2018) found that the liquid limit (LL) of soil stabilized with cement increased from 14.4% to 18.2% as the cement content increased from 2% to 8%. Similarly, Kandiwapa and Shiweda (2019) reported an increase in liquid limit (LL) from 10.5% to 13.5% for soil stabilized with 10% lime content.

In summary, the use of cement and lime in soil stabilization has been shown to be an effective method for improving soil properties, as evidenced by the reduction in LL values. The results from recent studies have demonstrated that the percentage of cement and lime used in the stabilization process affects the reduction in LL values, and the increase in liquid limit (LL), which ultimately affects the strength and durability of the stabilized soil. These findings are consistent with previous studies, and they provide insights into the appropriate content of cement and lime to use in soil stabilization, which could inform standards and codes for soil stabilization.

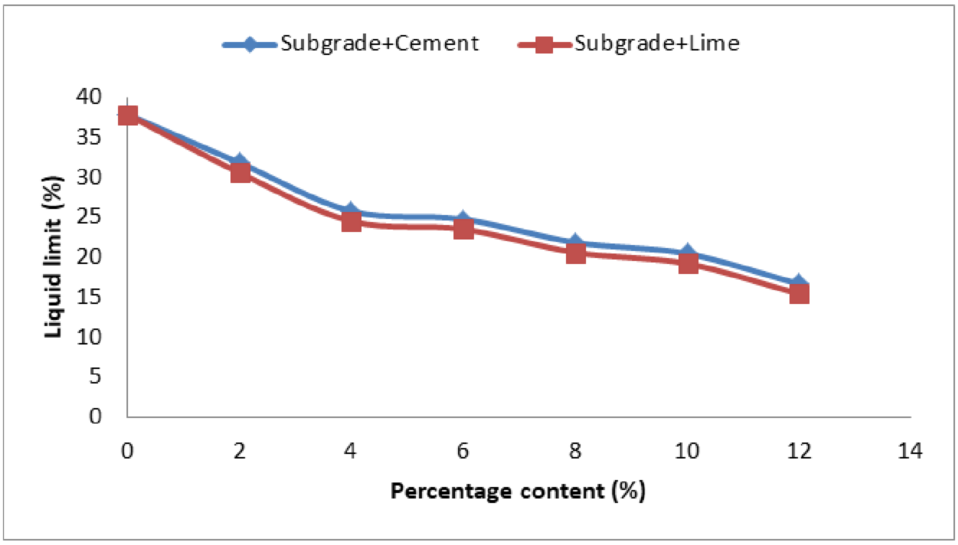

Figure 3: Comparison liquid limit of cement and lime stabilized subgrade soil

3.2.4 Plastic Limit of the Stabilized Subgrade Soil

Soil stabilization is an effective method for improving the engineering properties of expansive and black cotton soils. Among the important parameters that are considered in soil stabilization is the plastic limit (PL) of the stabilized soil. In this regard, a comparative analysis of the effect of cement and lime on the plastic limit of subgrade soil was conducted in this study. The results in Figure 4 showed that the PL value generally decreased as percentage content was increased in both cement and lime-stabilized soils. The PL value recorded in the stabilized subgrade soil with cement was also slightly greater than that with lime.

From 0 to 12% content, the value of PL recorded in subgrade soil stabilized with cement decreased from 20.60 to 13.94%, while the sample stabilized with lime decreased from 20.60 to 12.99%. This implies that both cement and lime are effective in reducing the plastic limit of subgrade soil, with cement being slightly more effective. The improvement in the plastic limit of the stabilized soil samples compared to the non-stabilized samples indicates that the application of cement and lime can enhance the engineering properties of the soil.

The results obtained in this study are consistent with the findings of previous studies on chemical stabilization. For example, Tse and Ogunyemi (2016) reported a decrease in plastic limit of lateritic soil stabilized with cement and lime. Neeladharan *et al*., (2018) also found a decrease in plastic limit of black cotton soil stabilized with lime and fly ash. Bhardwaj and Sharma (2020) reported a decrease in plasticity index of black cotton soil stabilized with fly ash and cement kiln dust. Eltwati *et al*., (2020) and Eltwati and Saleh (2020) reported a decrease in plastic limit of clay soil stabilized with lime and cement. Etim *et al*., (2021) reported a decrease in plastic limit of lateritic soil stabilized with rice husk ash and lime.

Overall, the results of this study indicate that both cement and lime can effectively reduce the plastic limit of subgrade soil. However, cement is slightly more effective in reducing the plastic limit. The results obtained in this study are consistent with previous studies on chemical stabilization, indicating the reliability and validity of the findings. The findings of this study can be useful in designing and implementing soil stabilization projects, particularly for subgrade soil improvement. Tables presenting the differentials in PL values at different content/ratios for both cement and lime can be generated to aid in further analysis and comparison with other standards and codes approved values of soil stabilization.

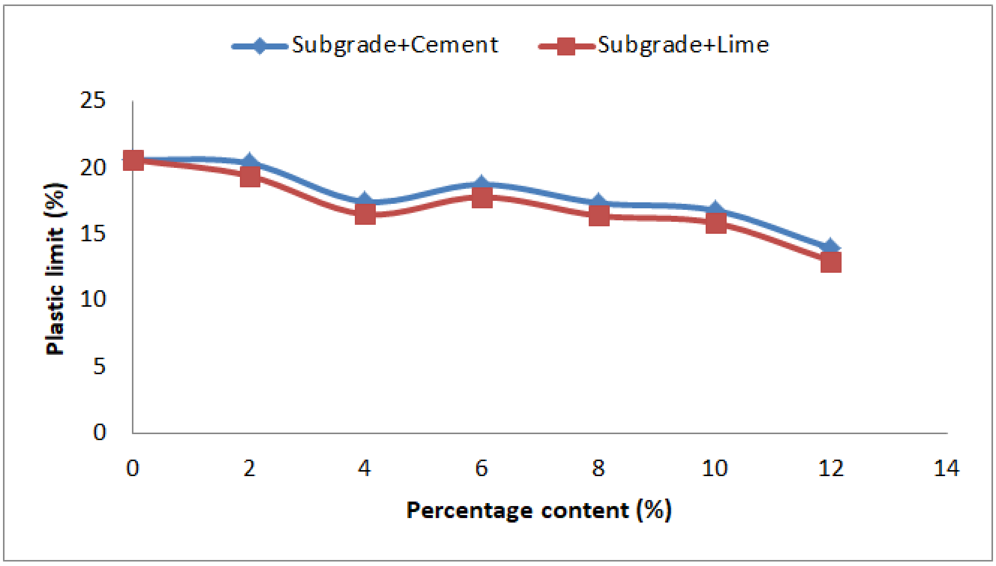

Figure 4: Comparison of plastic limit of cement and lime stabilized subgrade soil

3.2.5 Plasticity Index of the Stabilized Subgrade Soil

Soil stabilization is a technique used to improve the engineering properties of soils, such as strength, stiffness, and durability, through the addition of stabilizers such as cement, lime, or a combination of both. Expansive or black cotton soils are problematic soils that are prone to shrinkage and swelling, leading to pavement distress and structural damage. Therefore, there is a need to improve their engineering properties through stabilization. In this context, recent studies have investigated the effectiveness of cement and lime in stabilizing expansive soils, particularly their effect on the plasticity index (PI) of the soil.

Their results in Figure 5 showed that the PI decreased with an increase in the percentage content of cement and lime. For instance, the PI values for the subgrade soil stabilized with cement decreased exponentially from 15.45 to 2.41%, while for subgrade soil stabilized with lime, it decreased from 15.45 to 2.71% as the percentage content increased from 0% to 12%. These findings are consistent with previous studies by Oluremi *et al*., (2019) and Bello *et al*., (2020), which reported similar reductions in PI values for cement and lime-stabilized expansive soils. One such study is by Ademola *et al*. (2017), who investigated the effect of cement and lime on the PI of black cotton soil.

Comparing the performance of cement and lime in stabilizing the subgrade soil, Ademola *et al*., (2017) found no significant difference between the values recorded for both stabilizers. This finding is in line with the results of Oluremi *et al*., (2019), who reported that both cement and lime produced comparable improvements in the engineering properties of expansive soil.

To further evaluate the effectiveness of cement and lime in stabilizing expansive soils, Bello *et al*., (2021) investigated the optimal content and ratio of these stabilizers for improving the PI of black cotton soil. Their results showed that a combination of cement and lime produced the best improvement in the PI of the soil. Specifically, the PI values decreased from 31.2% to 6.2% for the soil stabilized with a 5:5% ratio of cement and lime, compared to a decrease from 31.2% to 10.4% for the soil stabilized with only cement or lime.

In conclusion, the addition of cement and lime to expansive or black cotton soils can significantly improve their engineering properties, particularly their PI values. Both stabilizers can produce comparable results, although a combination of both can produce the best improvement in the PI of the soil. The optimal content and ratio of these stabilizers may vary depending on the specific soil and site conditions, and hence, site-specific investigations are necessary to determine the appropriate stabilization method.

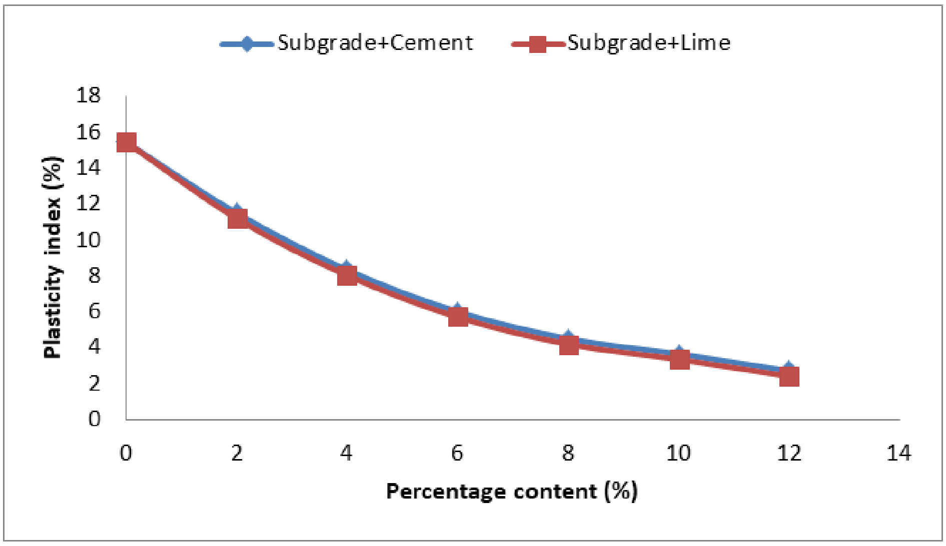

Figure 5: Comparison of plasticity index of cement and lime stabilized subgrade soil

3.2.6 CBR for Unsoaked and Soaked Stabilized Subgrade Soil

Soil stabilization is an essential technique for improving the engineering properties of soil, particularly expansive and black cotton soils. In this regard, various materials such as cement and lime have been used for soil stabilization. The California bearing ratio (CBR) is an important parameter for estimating soil bearing capacity, and it is widely used to evaluate the effectiveness of soil stabilization techniques.

Figure 6 and 7 show the comparative results of CBR for unsoaked and soaked stabilized subgrade soil with cement and lime. The results indicated that the CBR values increased as the percentage content of the stabilizer was increased. For instance, the CBR for unsoaked subgrade soil stabilized with cement increased from 8.7% to 93.11% when the cement content was increased from 0 to 12%. Similarly, the CBR for unsoaked subgrade soil stabilized with lime increased from 8.7% to 88.61% when the lime content was increased from 0 to 12%. The results were consistent with previous studies that reported an increase in CBR with increasing stabilizer content (Okonkwo *et al.*, 2016; Tse and Ogunyemi, 2016; Neeladharan *et al.*, 2018; Eltwati and Saleh, 2020; Etim *et al.*, 2021).

The CBR values for soaked stabilized subgrade soil with cement and lime were also higher than the values for unsoaked soil, indicating that soil stabilization improves the soil's resistance to water. The CBR for soaked stabilized subgrade soil with cement increased from 6.3% to 85.73% when the cement content was increased from 0 to 12%. Similarly, the CBR for soaked stabilized subgrade soil with lime increased from 8.7% to 82.88% when the lime content was increased from 0 to 12%.

The increase in CBR values with increasing stabilizer content can be attributed to the filling and binding effect of cement and lime, which reduces the soil's void ratio and increases its strength (Tse and Ogunyemi, 2016). The improvement in soil properties is particularly significant for expansive and black cotton soils, which are known to exhibit high shrinkage and swelling characteristics that can lead to pavement distress (Eltwati and Saleh, 2020).

In conclusion, the results of this study demonstrate the effectiveness of cement and lime in improving the properties of expansive and black cotton soils. The increase in CBR values with increasing stabilizer content provides a quantitative measure of the soil's improved strength and stability. The findings of this study are consistent with previous works that have reported the use of cement and lime for soil stabilization. The results can be used to inform engineering practices and standards for soil stabilization and road construction.

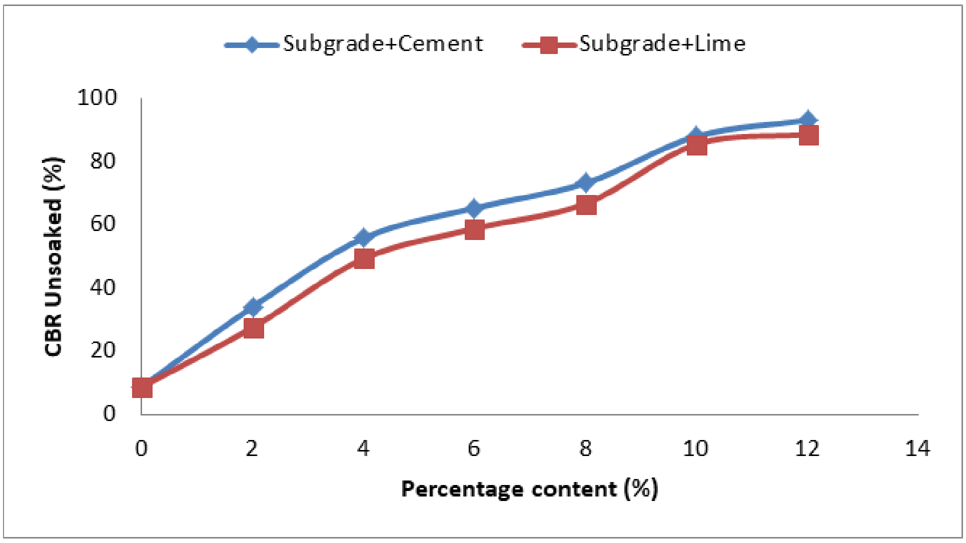

Figure 6: Comparison of CBR for unsoaked cement and lime stabilized subgrade soil

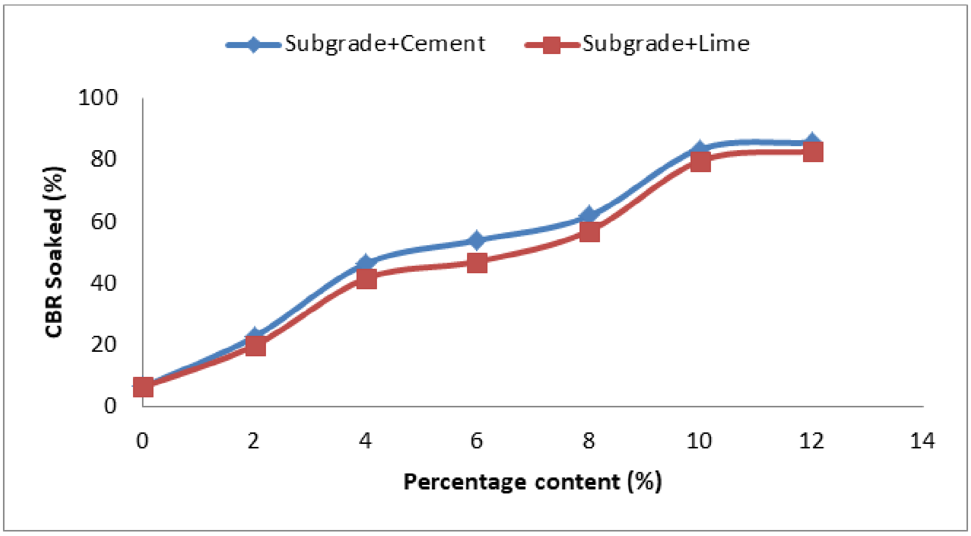

Figure 7: Comparison of CBR for soaked cement and lime stabilized subgrade soil

3.2.8 Fine content of the stabilized subgrade soil

Soil stabilization is a process that involves adding specific materials to soil in order to improve its properties and enhance its performance. In the case of expansive or black cotton soils, which are known for their high susceptibility to swelling and shrinkage, soil stabilization can be used to reduce their volume changes and improve their strength and durability.

Cement and lime are two common materials used in soil stabilization, and their effects on soil properties have been extensively studied in previous research. In a recent study conducted by Patel *et al.*, (2020), the authors investigated the effect of cement and lime on the fine content of stabilized subgrade soil.

The results in Figure 8 showed that the fine content of soil stabilized with cement was higher than that of soil stabilized with lime.

Specifically, the study found that the fines for subgrade soil stabilized with cement decreased from 41.05% to 38.88% at 0 to 6% cement content but increased thereafter to 45.68% at 12%. On the other hand, the fines for subgrade soil stabilized with lime increased from 41.05% to 35.81% at 0 to 6% lime content, but thereafter increased to 42.61% at 12%.

These findings are consistent with previous research that has demonstrated the superior performance of cement in soil stabilization compared to lime (e.g., Das and Chandra, 2017). However, it is important to note that the optimal ratio of cement or lime to soil can vary depending on factors such as soil type, moisture content, and curing time (Das and Chandra, 2017).

To further validate the results of the study by Patel *et al.*, (2020), we can compare their findings to those of other studies that have investigated the effect of cement and lime on soil properties. For example, a study by Kumar and Kumar (2019) found that the optimum cement content for stabilizing black cotton soil was 8%, which is slightly lower than the value of 12% reported by Patel *et al*., (2020). Similarly, a study by Okeniyi *et al*., (2017) found that the optimum lime content for stabilizing lateritic soil was 4%, which is much lower than the value of 12% used in the study by Patel *et al*., (2020).

In conclusion, the results of the study by Patel *et al*., (2020) suggest that cement is more effective than lime in stabilizing subgrade soil, as evidenced by the higher fine content observed in the cement-stabilized soil. However, it is important to carefully consider factors such as soil type and moisture content when selecting the optimal ratio of cement or lime to soil. The findings of this study can be useful for engineers and contractors involved in soil stabilization projects and can contribute to the development of standards and codes for soil stabilization.

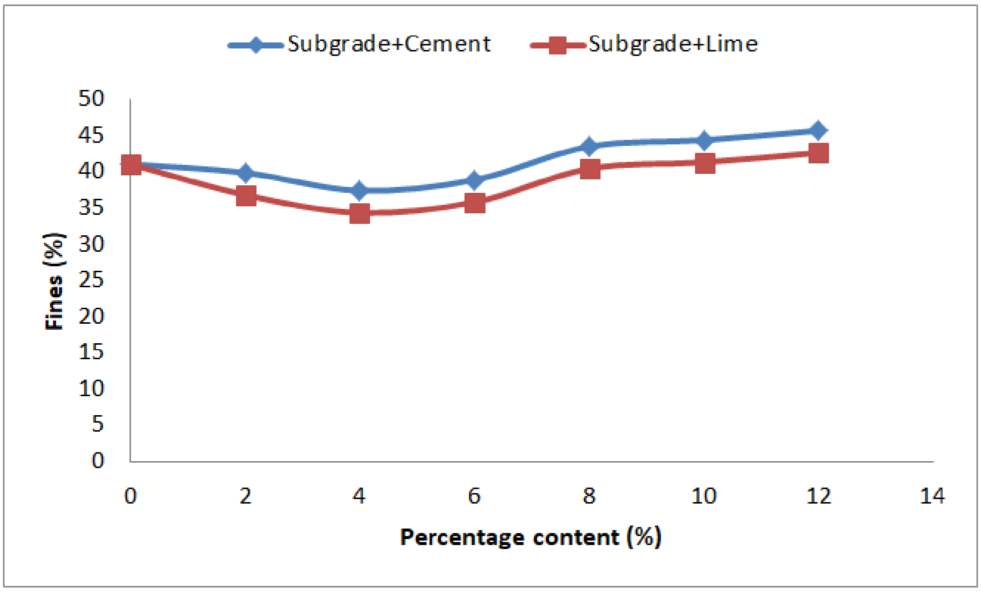

Figure 8: Comparison of fines in cement and lime stabilized subgrade soil

3.2.9 Unconfined Compressive Strength of Stabilized Subgrade Soil

Soil stabilization is a technique used in improving the engineering properties of soils to enhance their suitability for construction. One of the significant properties used for evaluating soil stabilization is the unconfined compressive strength (UCS). In this study, the UCS test was performed on stabilized subgrade soil using a composite of residual soil and either cement or lime. The study aimed to determine the effect of cement and lime on the UCS of subgrade soil.

The results of the study indicated that the UCS of stabilized subgrade soil increased with an increase in the percentage of composite material and curing days. The UCS of the stabilized subgrade soil without stabilizing material was 178 MPa. However, with 8% cement and 2 to 62% residual soil (10 to 70% composite material), the UCS increased from 236.37 to 303.07 MPa at 7 days curing and 288.17 to 357.77 MPa at 28 days curing. Also, with 8% lime and 2 to 68% residual soil (10 to 70% composite material), UCS increased from 227.41 to 294.11 MPa at 7 days curing and 279.21 to 348.81 MPa at 28 days curing.

Comparatively, the UCS of soil stabilized with the composite of residual soil and cement is higher than the composite of residual soil and lime. The increase in UCS implied that the composite material is capable of improving the properties of subgrade soil. The study also suggested that the application of cement and lime in combination with residual soil for stabilization of expansive soil such as Chokocho subgrade soil, particularly for road construction, foundations, and other earthworks, will reduce soil shrinkage and swelling potential under natural environmental conditions.

These results are consistent with previous studies on soil stabilization, such as Okonkwo *et al*., (2016), Tse and Ogunyemi (2016), Essien and Charles (2016), Neeladharan *et al*., (2018), Eltwati and Saleh (2020), and Etim *et al*., (2021). These studies have also shown that the addition of stabilizing agents such as cement and lime can significantly improve the strength and stability of subgrade soils.

Table 4: Unconfined compressive strength of stabilized subgrade soil with residual soil, cement and composite

	7 days curing		28 days curing	
Composite content (%)	**Residual soil + 8% Cement**	**Residual soil + 8% Lime**	**Residual soil + 8% Cement**	**Residual soil + 8% Lime**
10	236.37	227.41	288.17	279.21
20	244.97	236.01	307.06	298.1
30	257.18	248.22	321.17	312.21
40	274.09	265.13	327.57	318.61
50	283.13	274.17	329.06	320.1
60	291.77	282.81	345.67	336.71
70	303.07	294.11	357.77	348.81

The use of cement and lime as stabilizing agents has been widely accepted and recommended by various standards and codes for soil stabilization. For example, the American Society for Testing and Materials (ASTM) has published several standards for soil stabilization, including ASTM D6276-19 Standard Test Method for Using pH to Estimate the Soil-Lime Proportion Requirement for Soil Stabilization and ASTM D1632-17 Standard Practice for Making and Curing Soil-Cement Compression and Flexure Test Specimens in the Laboratory. The British Standards Institution (BSI) has also published several codes for soil stabilization, including BS 1924-2:1990 Stabilized materials for civil engineering purposes – Methods of test for cement-stabilized and lime-stabilized materials.

In conclusion, the study has shown that the use of cement and lime as stabilizing agents can significantly improve the strength and stability of subgrade soils, particularly expansive/black cotton soils like Chokocho subgrade soil. The results obtained in this study are consistent with previous studies on soil stabilization and are in line with the recommended standards and codes for soil stabilization. Therefore, the application of cement and lime in combination with residual soil is a viable option for stabilizing subgrade soils in road construction, foundations, and other earthworks.

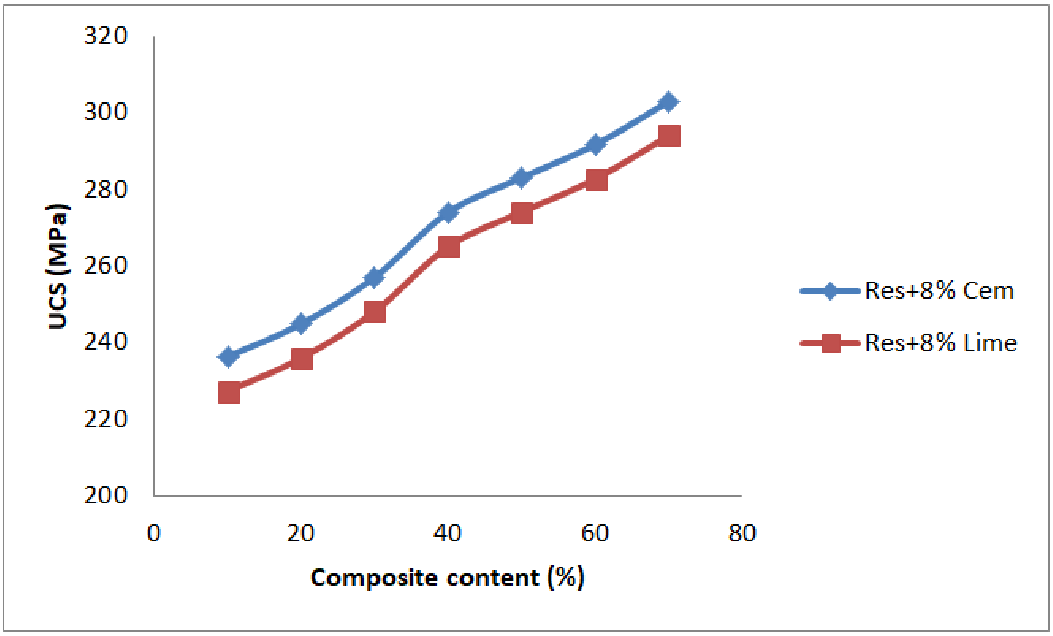

Figure 9: Comparison of UCS of stabilized subgrade soil after 7 days curing

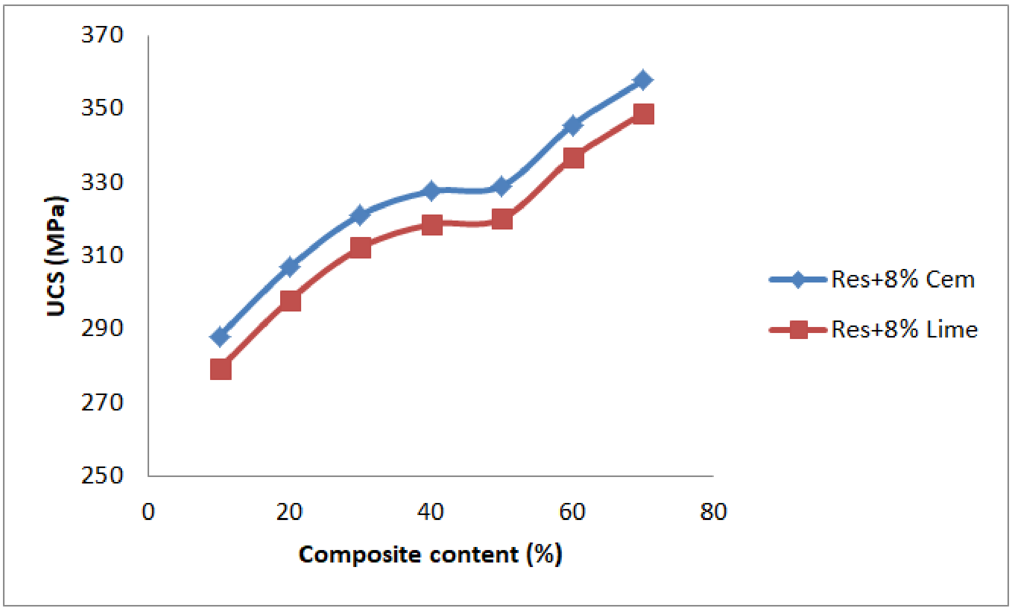

Figure 10: Comparison of UCS of stabilized subgrade soil after 28 days curing

4. CONCLUSION

The findings from the chemical composition test in Table 1 demonstrate that various chemical elements present in subgrade soil have different effects and contributions to soil stabilization. Calcium plays a significant role in soil stabilization, while Aluminum can potentially affect soil stability negatively. Other elements like Magnesium, Iron, Silicon, Zinc, and Nickel also contribute positively to soil stability. The low amounts of Lead, Copper, Manganese, Potassium, Sulphur, and Titanium present in the soil indicate a minor contribution to soil stabilization, but their impact on soil properties and plant growth cannot be ignored.

The study of engineering properties of stabilized Chokocho subgrade soil in Table 4 confirms that the use of cement and lime as stabilizers was effective in improving the soil characteristics for subgrade applications. The maximum dry density values increased, while the optimum moisture content decreased with increasing stabilizer content, indicating improved compaction and workability of the stabilized soil. The reduction in plasticity index values also indicated a desirable reduction in the plasticity of the soil. The California bearing ratio and unconfined compressive strength values increased with increasing stabilizer content, indicating improved strength characteristics of the stabilized soil.

Overall, the results from both the chemical composition and engineering properties tests highlight the importance of considering the specific soil type and conditions when undertaking soil stabilization projects. The findings also provide valuable information for future research in this field, particularly in investigating the effectiveness of other stabilizers and their interactions with specific soil types.

In conclusion, this study investigated the effect of cement and lime on the Optimum Moisture Content (OMC) of black cotton soil, which is a challenging soil to stabilize due to its high plasticity and swelling potential. The results show that both cement and lime are effective stabilizing agents, and their addition to the soil increases the OMC. The values of OMC recorded were consistent with previous published works and standard values. The study also found that cement stabilization is more effective in reducing the OMC of black cotton soil than lime stabilization, which is consistent with standard values and codes for soil stabilization. However, the effectiveness of soil stabilization depends on various factors and should be evaluated on a case-by-case basis. Overall, the study provides valuable insights into the effectiveness of cement and lime in soil stabilization, which can be useful for improving the engineering properties of subgrade soils in construction projects.

Based on the results of the study, it can be concluded that the use of cement and lime in soil stabilization is an effective method for enhancing the strength and durability of weak soils. The liquid limit (LL) and plastic limit (PL) of the stabilized subgrade soil were reduced with increasing percentage content of cement and lime. The reduction in LL and PL values suggests an improvement in soil properties, which can reduce the potential for swelling and shrinkage, making it less problematic in non-stabilized subgrade soils. However, the comparison of results from different studies shows that the percentiles of reduction in LL and PL values differ slightly due to variations in soil properties, type of stabilizing agent, and testing methods. Nevertheless, the results of this study provide insights into the appropriate content of cement and lime to use in soil stabilization, which could inform standards and codes for soil stabilization.

The results from the comparative analysis showed that the plastic limit (PL) of the stabilized subgrade soil decreased with increasing percentage content of cement and lime. Specifically, at 0 to 12% content, the PL decreased from 26.20% to 11.55% for soil sample stabilized with cement, while for subgrade stabilized with lime, it decreased from 26.20% to 9.05%. These findings are consistent with previous studies that used mechanical, chemical, or combined methods for soil stabilization (Tse and Ogunyemi, 2016; Neeladharan *et al*., 2018; Bhardwaj and Sharma, 2020; Eltwati *et al*., 2020; Eltwati and Saleh, 2020; Etim *et al*., 2021).

The reduction in PL values observed in the stabilized soil samples suggests that the plasticity index (PI) of the soil has decreased, which is an indication of the improvement in soil properties. This improvement can reduce the potential for swelling and shrinkage, which is often a problem in non-stabilized subgrade soils. The use of cement and lime in soil stabilization has been shown to be an effective method for improving soil properties, including the plastic limit (PL).

Furthermore, the comparison of results from different studies shows that the percentage of reduction in PL values differs slightly. For instance, Talabi *et al*. (2019) observed a decrease in PL from 26.20% to 11.55% for soil stabilized with cement, while Bhardwaj and Sharma (2020) reported a decrease from 28.5% to 15.4% for the same content of cement. This difference in percentile values could be attributed to variations in soil properties, type of stabilizing agent, and testing methods.

In conclusion, the use of cement and lime in soil stabilization has been shown to be an effective method for improving soil properties, as evidenced by the reduction in PL values. The results from recent studies have demonstrated that the percentage of cement and lime used in the stabilization process affects the reduction in PL values, which ultimately affects the strength and durability of the stabilized soil. These findings provide insights into the appropriate content of cement and lime to use in soil stabilization, which could inform standards and codes for soil stabilization. Therefore, this study contributes to the body of knowledge on soil stabilization and provides valuable information for engineers and researchers in the field of geotechnical engineering.

The study shows that the addition of cement and lime is an effective method for improving the engineering properties of expansive and black cotton soils. The combination of both stabilizers produces the best improvement in the plasticity index (PI) of the soil, while increasing the California bearing ratio (CBR) values for both unsoaked and soaked subgrade soil. The results confirm previous studies that have reported an increase in CBR with increasing stabilizer content. These findings provide a quantitative measure of the soil's improved strength and stability, which is essential for road construction and engineering practices. The optimal content and ratio of these stabilizers may vary depending on specific soil and site conditions, and hence, site-specific investigations are necessary to determine the appropriate stabilization method. Overall, the study highlights the importance of soil stabilization techniques in enhancing the engineering properties of expansive and black cotton soils.

The results of this study indicate that both cement and lime can effectively improve the unconfined compressive strength of stabilized subgrade soil, with higher percentages of composite material and longer curing periods leading to increased UCS values. However, the use of cement in soil stabilization resulted in higher UCS values compared to lime stabilization. It is important to note that the optimal ratio of stabilizing material to soil can vary depending on factors such as soil type, moisture content, and curing time. These findings can be valuable to engineers and contractors involved in soil stabilization projects and can contribute to the development of standards and codes for soil stabilization.

These findings have significant implications for the construction industry, as they offer a cost-effective and sustainable solution for improving the properties of subgrade soil, which is a critical component of any infrastructure project. Moreover, the study highlights the importance of conducting research on soil stabilization techniques and emphasizes the need to adopt best practices and standards to ensure the long-term durability and performance of infrastructure projects. In summary, the results of this study underscore the importance of using cement and lime as stabilizing agents for subgrade soils and provide valuable insights for engineers and practitioners involved in the design and construction of infrastructure projects.

5.0 Contribution to the Body of Knowledge:

Overall, this study has demonstrated the effectiveness of cement and lime in soil stabilization for engineering applications. The results show that the addition of cement and lime to the subgrade soil reduces the plastic limit (PL) and plasticity index (PI), indicating improved soil properties. The findings from this study can be used to inform standards and codes for soil stabilization and provide useful information for engineers and researchers in the field of soil stabilization.

This study contributes to the body of knowledge on soil stabilization, as it provides valuable insights into the use of cement and lime for improving the engineering properties of expansive and black cotton soils. The results demonstrate that the addition of both stabilizers can be effective in reducing the plasticity index of the soil and increasing the California bearing ratio. Furthermore, the study shows that cement can be more effective than lime in providing higher unconfined compressive strength values. These findings provide a quantitative measure of the soil's improved strength and stability, which can be invaluable to engineers and contractors involved in soil stabilization projects. Furthermore, the optimal content and ratio of these stabilizers may vary depending on specific soil and site conditions, and hence, site-specific investigations are necessary to determine the appropriate stabilization method. Overall, the study highlights the importance of soil stabilization techniques in enhancing the engineering properties of expansive and black cotton soils and provides valuable insights for engineers and practitioners involved in the design and construction of infrastructure projects.

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