Evaluation of Structural Stability by Characterization of Lateritic Soils with Rock Flour along Ibadan-Iwo-Osogbo Highway, Southwestern Nigeria

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Abstract. Failures of different categories of roads shortly after being opened to traffic have necessitated the need for sustainable alternative road building materials. This study determines the potential of rock flour on the geotechnical properties of lateritic soils with a view to establish the optimum content of the rock flour required for effective stabilization and proffer lasting remediation measures to the incessant road failures. Ten bulk lateritic soil samples were collected from ten trial pits at depths of 1.5 m in different locations of the study area. Index and engineering property tests were performed on the soils, both in their natural and stabilized states by adding 2, 4, 6, 8 and 10% rock flour contents. In addition, CBR – UCS model was used to establish a third order polynomial to correlate the soil-rock flour mix. The results show that the plasticity and linear shrinkage of the soils decreased with increase in rock flour contents. The MDD of rock flour stabilized soils increase with the maximum improvement observed at 10% by weight of rock flour with the corresponding decrease in OMC. The load bearing capacities (LBC) of the soils increase with the stabilization mix. It was observed that the values meet the requirements for good quality subgrade, subbase materials and some of the soils for base materials in road construction. The results also reveal the improvement of the soil properties. This is further confirmed by the increase in UCS and shear strength of the soils which optimally improved on addition of 8% rock flour. Moreover, the addition of more than 8% by weight of rock flour caused reduction in UCS and shear strength. These results show the stabilizing potentials of rock flour on lateritic soils especially when added at the optimum level. The CBR - UCS models established are in form of third order polynomial \(ax^3 - bx^2 + cx + d\) with the \(R^2\) values, 0.672 and 0.528 which indicate positive correlation of the soil-rock flour mix. Therefore, rock flour can potentially stabilize lateritic soils solely with addition of 8% recommended as an optimum content for stabilizing lateritic soils for road constructions.

Keywords: Rock flour, lateritic soil, stabilization, geotechnical properties, CBR - UCS models, road construction
1. Introduction

Failures of engineering structures including roads, buildings, bridges and dams have become a common phenomenon throughout the nation. Lateritic soils are the most common surface deposits occurring in the tropical and subtropical regions of the world, enriched in iron and aluminium and develop by intensive and long lasting weathering of the underlying parent rock. In Nigeria, laterites serve as the perfect soil materials to solve all construction problems especially in construction of earth dams, highways, embankments, airfields and foundation materials to support structures without considering its actual field geotechnical performance. Lateritic soils are used as road making material and they form the subgrade of most tropical road. They are used as sub-base and bases for low cost roads which carry low to medium traffic. The relationship between engineering structures and their foundation soils play a vital role as stable and strong foundation support the weight and transmit the load of the structure to the underlying soils or rocks [1]. Road failures in Nigeria are generally due to poor geotechnical properties of the underlying soils which constitute the entire road pavement [2].

Lateritic soil in Nigeria usually contain large content of clay, therefore, there is need for stabilization before they are use as construction material especially as highway construction material. Stabilization involves the different methods employed for modifying the properties of a soil to improve its engineering performance. It is a process which basically involves changing the chemical properties of soft soils by adding binders or stabilizers, either in wet or dry conditions to increase the strength and stiffness of the originally weak soils. Recently, soil stabilization have developed into new ways of using local available environmental and industrial waste materials to improve the engineering properties of weak or clayey soil for their appropriate performance. Replacement of natural soils aggregates and cement with solid industrial by-product is highly desirable. The use of solid wastes in civil engineering constructions has undergone considerable development over a period of time.

Rock flour is the waste materials produced from rock crushing plant during quarrying activities. Usually, quarry waste is used extensively as a surface finishing material in highways. [3] studied the effects of rock dust and pebble as aggregate in cement and concrete. They concluded that crushed stone dust can be used to replace natural sand in concrete. About 20% of rock is converted into rock flour while crushing rock into aggregate at stone crushing plants. Rock flour can be used as fine aggregate instead of river sand in concrete. This results in increase of compressive strength split tensile strength and modulus of rupture. It is good in reinforcing soil in construction, especially in earth retaining walls, soil beds and flexible pavements as a fill material because of its stability, free draining nature and good frictional characteristics. [4] investigated the effect of pyroclastic rock dust on the geotechnical properties of expansive soils. The results show significant reduction in plasticity and linear shrinkage of expansive soil with increasing amount of pyroclastic rock dust. The maximum dry density, optimum water content, shear strength and CBR, all increased with increasing pyroclastic rock dust content. This improvement in the geotechnical properties of the expansive soils with pyroclastic rock dust shows that rock dust is a good stabilizing agent for swelling soil. [5] used this waste as the main
construction material for the base layer of flexible pavement and observed its satisfactory performance under field conditions. [6] used quarry waste as a substitute of sand in construction materials and concluded that it would resolve the environmental problems caused by the large-scale depletion of the natural sources of river and mining sands. [7] investigated the effect of rock flour on the geotechnical properties of lateritic soils. The results show significant reduction in plasticity, linear shrinkage and increase in strength indices (maximum dry density, CBR and shear strength) with increasing amount of granite rock flour content.

High construction cost and signs of distress (failures) developed on various categories of roads in the country shortly after being opened to traffic necessitated the need for sustainable alternative road building materials. This study examines the potential of varying quantities of rock flour on the geotechnical properties of lateritic soils in the study area for road construction. This, with a view to determine the optimum content of the rock flour required for effective stabilization and proffering lasting solution to the continuous road failures across the country resulting to the needless loss of lives and property from accidents.

2. Location and Geological setting of the study area

Ibadan-Iwo-Osogbo highway is located in the southwestern Nigeria. It is situated within geographic co-ordinates of Latitudes N7° 37.50’ to N7° 48.18’ and Longitudes E4° 10’ to E4° 30’ or between N845000 – N862735 m and E628638 – E665459 m in the Universal Traverse Mercator (UTM) Minna Zone 31 co-ordinates. The road is about 86 Km long and trends approximately southwest – northeast (Fig. 1). It is a major and an important access road linking many states in southwestern Nigeria and this contributes to the heavy traffic along the highway. Along this major highway are linear settlements. The drainage pattern of the study area is dendritic with rivers like River Oba, River Osun, River Eyinle, River Orufu, River Aro, River Awon and many other tributaries. They generally flow southwards to join the coastal lagoon. Streams flow through a North-South direction, parallel or sub-parallel to the strike of the rock; its tributaries form a dense dendritic drainage pattern. Stream directions in the study area appear to be largely structurally controlled, especially by fractures on resistant rocks and they are mainly perennial while majority of the tributaries are seasonal. In the study area, the high rate of annual rainfall is primarily responsible for the recharge of the groundwater. The aquifer units in the area and other similar basement complex environment are believed to be derived essentially from the weathered rocks [8].
Figure 1: Location map of the study area

Geologically, the study area is underlain by the Precambrian Basement Complex rocks of Nigeria. The Basement Complex rocks comprise of gneisses and migmatites with supracrustal relics, which are Archean (c. 2700 Ma) to Proterozoic (c. 2000 Ma) in age [9]. The Basement Complex rocks of Nigeria forms a part of the African Crystalline Shield which occurs within the Pan African mobile belt that lies between the West African and Congo Cratons and South of the Tuareg Shield which were affected by the Pan-African orogeny [10; 11]. The Basement Complex of Southwestern Nigeria is located in a triangular portion of the Nigerian basement, an extension of the Dahomeyide Shield of the West African Craton. Rocks of the region include Migmatite-Gneiss Complex (MGC) that is characterised by (a) grey foliated gneiss, (b) ultramafic rocks and (c) felsic component comprised of pegmatite, aplite and granitic rocks [12]. The MGC in
Southwestern Nigeria is affected by three major geotectonic events ranging from Early Proterozoic of 2000 Ma to Pan African events of ~600 Ma [13; 14]. The rocks of the basement have been affected by medium pressure Barrovian metamorphism [14; 15]. The attitudes of tectonic structures in the Nigerian Basement have been documented in terms of orientation and magma-induced veins and dykes such as quartz veins and pegmatites [15]. Deformation of the Nigerian basement complex occurred in two phases, a ductile phase, which is responsible for the formation of planar structures (foliations) and a brittle phase resulting in jointing and fractures, many of which have been filled with quartzo-feldspathic veins, dolerite dykes, pegmatite and aplite veins and dykes [15]. The highway cuts across some rock units namely gneiss/migmatite to schist pegmatite, quartzo-syenite, charnockite, pegmatite, meta-intrusives and fine-medium grained granite (Fig. 2). Gneisses are migmatized in places and characterized by predominantly medium-sized grains with well defined bands of quartzo-feldspathic minerals alternated with ferromagnesian minerals [16].

Figure 2: Geological map of the area around Ibadan-Iwo-Oshogbo Highway
3. Materials and Methods

3.1 Materials

The materials used for this study are lateritic soil samples, rock flour and water.

3.1.1 Lateritic Soils

This study was conducted on ten bulk lateritic soil samples collected from ten test pits at different locations at depth of 1.5 m each from the study area. The samples were obtained at that sampling depth in order to obtain true representative samples of the subgrade which is the placement level of flexible highway pavement. On the field, the rock and soil exposures were observed and described. The sample collection was done systematically to ensure proper collection of samples and total coverage of the study area. A global positioning system (GPS) was used at each sampling point to measure coordinates of the station and heights above sea level. All the soil samples were carefully labeled in sample bags and then taken to the laboratory in sealed polythene bags to prevent contamination and loss of moisture.

3.1.2 Rock flour

Rock flours are the bye products of crystalline rocks such as granite and gneissic rocks. It is the finely divided and powdery form of these rocks. In this study, rock flour, waste material produced from granite rock crushing plant was collected from a quarry site. The rock flour was used as the stabilization agent and was systematically examined through series of index and engineering tests to assess its suitability as fill material in the study area for road construction. This work therefore focused principally on the response of the soils in the study area to varying quantities of chemical stabilizer; rock flour in road construction. This is an attempt to determine, the effects of increasing quantities of rock flour by weight on the strength, CBR, compaction parameters and the optimum content required for effective stabilization above which further addition of rock flour will not make any appreciable difference or may lead to a decline in the geotechnical properties.

3.1.3 Water

The water used for this study was obtained from a borehole. The water was clean and free from any visible impurities. It conformed to the requirements of [17].

3.2 Test Methods

The soil samples were air dried at the laboratory for two weeks at room temperature before the analyses. The basic index properties of soil including Atterberg limits and linear shrinkage were determined in accordance with [18] standard procedures. In order to effect adequate segregation of the grains of the soil for sieve analysis, each soil sample was soaked in weak calgon solution for 24 hours and regularly agitated before wet sieving. The soil samples were later compacted at the West African level of compaction before stabilization with 2%, 4%, 6%, 8% and 10% by
weight of rock flour in order to determine the influence of quantity of rock flour on the basic index and engineering properties of the soils in the study area. The optimum moisture content (OMC) obtained from the compaction test of each varied percentage of rock flour (RF) was used for the engineering property tests. The soil mixtures were thoroughly mixed with various moisture contents and allowed to equilibrate for 24 hours prior to compaction. The test which is to determine the optimum moisture content (OMC) and the maximum dry density (MDD) were conducted at the standard Proctor energy level. The compaction tests were carried out on the natural soils and the stabilized soils (in different percentages of rock flour). The compaction properties of the stabilized soils with varying amounts of rock flour were determined according to [19]. California Bearing Ratio, CBR (soaked and unsoaked), Unconfined Compressive Strength, UCS and shear strength were determined at each increase in rock flour contents to ascertain the effect of the addition of varying quantities of rock flour on the geotechnical properties of the soils. The procedure of unconfined compressive strength test was defined as cylindrical specimen of cohesive soil where a steadily increasing axial load was subjected to the soil specimen until failure occurs. The specimen was placed centrally on the lower platen of the compression testing machine. The force was applied with a controlled strain rate of approximately 1 mm/minute. The force was recorded during the test until the specimen failed. From the unconfined compressive strength, the unconfined shear strength of all the soil samples was calculated. These laboratory analyses were carried out according to British Standard Methods of test for soils for civil engineering purposes [18].

3.3 Soil-Rock flour mixtures

Rock flour was added to the soil in 2, 4, 6, 8 and 10% proportions by dry weight of the soils. Index properties and strength tests were performed on soil-rock flour mixtures. The influences of rock flour as stabilizing agent on the samples were determined. The various tests were carried out in accordance with [18; 19] procedures.

4. RESULTS AND DISCUSSION

The results of the index tests of the addition of varying contents by weight of rock flour to the different soil samples are shown in Figs. 3 – 5. The values of the specific gravity of the lateritic soils with the average of 2.68 ± 0.04 is an indication that the lateritic soils contain high proportion of clays, which might be the cause of the degree of instability witnessed along the highway of the study area, thus, the soil must be stabilized in order to improve their properties [2].

4.1 Plasticity characteristics

Plasticity index tends to have influence on the activity of the subgrade. The plasticity indices of some of the soils are higher than 12% and hence, they are not suitable for use as subgrade and practically subbase materials for roads and bridges as specified by [20]. The influence of rock flour on the consistency limit of the soils is shown in Figs 3 and 4. Addition of between 2% and
10% by weight of rock flour to the different soil samples in the study area reduced the liquid limit and plasticity index of rock flour stabilized soil. The effect of addition of different percentages of rock flour on the liquid limits of the soils is shown in Fig. 3. The decrease in liquid limit and plasticity index may be attributed to aggregation of particles to produce denser soil with rock flour mixes. The liquid limit decreases at all soil-rock flour mixes (Fig. 3), the stabilized soils are therefore suitable as subgrade and subbase materials for road pavement construction.

The relationship between plastic index and rock flour is shown in Fig. 4, the plastic index generally decreased with increase in rock flour content. Increase in percentage by weight of rock flour reduced the plasticity index from 7.00% to 5.70% by 18.57% reduction in sample 1A, 17.45% to 12.60% by 27.79% reduction in sample 1B, 13.35% to 9.05% by 32.21% reduction in sample 1C. The plasticity index of rock flour stabilized soil samples 3A and 3B were reduced by as much as 63.92% and 53.01% respectively upon addition of 10% rock flour. The plasticity index of the soil samples 5A, 5B, 5C, 8A and 8B were reduced to 2.20%, 6.65%, 4.95%, 11.40% and 9.10% respectively on addition of 10% of rock flour. The plasticity index of the soil samples 1A, 1B, 1C, 2A, 2B, 2C, 3A, 3B, 4A, 5A, 5B, 5C, 6A, 6B, 6C, 7A, 7B, 8A, 8B were reduced by 15.05%, 20.00%, 25.00%, 30.00%, 35.00%, 40.00%, 45.00%, 50.00%, 55.00%, 60.00%, 65.00%, 70.00%, 75.00%, 80.00%, 85.00%, 90.00%, 95.00%, 100.00% respectively on addition of 10% of rock flour. The percentage reduction has increased with increase in percentage of rock flour, indicating strong influence of the variation in percentage of stabilizer on the plasticity index. This trend may be attributed to the replacement of the finer soil particles by rock flour as a result of the reduction in the clay content and plasticity index. However, the plasticity index of the soils are lower than 12% on addition of 10% rock flour, hence, will be suitable for use as sub-base materials for roads and bridges as specified by [20] except Sample 1B with the plasticity index of 17.45% but with the addition of 10% rock flour decreased to 12.60% with percentage reduction of 15.05%. The increase in rock flour content decreased the plasticity index of the soil. This indicates that the activity of the mixture is reduced with the addition of rock flour. The reduction in the plasticity index would reduce the potential of the soil to shrink under moisture change. This can be attributed to the reduction in the quantity of silt and clay fraction forming coarser materials with larger surface areas. The influence of rock flour on the plasticity indices of the samples is shown in Fig. 4. The plasticity index generally decreased with increase in rock flour contents, which makes stabilized soils much better for use as construction materials. These reductions in plasticity indices are indications of soil improvement with response to a more stable soil with enhanced workability. These values indicate strong influence of rock flour as stabilizer for improving plasticity of weak soils.

4.2 Linear Shrinkage

Figure 5 shows the influence of rock flour on the linear shrinkage of the soils. The figure reveals that some of the soils have linear shrinkage higher than 8% recommended by [21] for highway sub-base materials thus the need for stabilization of the soil. Increase in rock flour quantity in the soil was accompanied by a consistent reduction in linear shrinkage. Addition of 10% by weight of rock flour is required to reduce the linear shrinkage of soils in the study area to a value less than what was suggested by [21]. Progressive increase in the percentage of rock flour used in
stabilizing the soil samples 8A and 8B progressively led to increasing percentage reduction in linear shrinkage, reducing by 0% on addition of 2% rock flour to 15.05% percentage reduction on addition of 10% rock flour with the linear shrinkage value reduced from 9.3% to 7.9% for sample 8A and reducing by 0% on addition of 2% rock flour to 19.72% on addition of 10% flour from 7.1% to 5.7% for sample 8B. Generally, addition of 2% of rock flour led to 0% reduction in all the samples of the study area except samples 1A and 1B while further increase in percentage of rock flour resulted in a decrease in the percentage reduction of linear shrinkage with the optimal percentage reduction observed on addition of 10% rock flour. Addition of 10% rock flour to the soils have linear shrinkage values between 2.1% and 7.9% indicating that the soils possess moderate or no swelling, while soil with linear shrinkage range between 10% and 12% is poor and may crack and cause differential settlement in foundation. This is responsible for the distresses/failure observed on highways. These values indicate a strong influence of rock flour as a stabilizer for improving the linear shrinkage of soil in the study area as reduction in linear shrinkage of the soil-rock flour mixture will enhance volume stability of the soil.

Figure 3: Influence of rock-flour on the liquid limit of the soils.
4.3 Compaction Characteristics

Compacting soils for roads and airfields requires attaining a high degree of density during construction to prevent detrimental consolidation from occurring under an embankment’s weight or under traffic. In addition, compaction reduces the detrimental effects of water.
4.3.1 Optimum Moisture Content (OMC)

The results of the influence of addition of varying quantities of rock flour by weight on the optimum moisture content (OMC) of the soils at the West African level of compaction are shown in Fig. 6. The stabilization of the soil with rock flour resulted in gradual reduction of the optimum moisture content by as much as 11.11% to 19.64% reduction from the initial unstabilized soil to sample stabilized with 10% by weight of rock flour for all the samples (Fig. 6). The decrease in percentage reduction in OMC when 10% by weight of rock flour was employed for stabilization of the soil (Fig. 6) suggests that it is necessary to stabilize the soils with 10% by weight of rock flour because the addition of 10% rock flour produced the soil with the lowest OMC. The OMC generally reduced correspondingly in all the soil samples with the addition of increasing percentages of rock flour. This corresponding reduction in OMC of the soils is an indication of the soil improvement, as this enhances the workability of the soils. The reduction in optimum moisture content is suggested to be as a result of the absorption capacity of the rock flour due to its porous properties. Rock-flour enhanced lateritic soils can be a profitable alternative to river or mining sands in construction, subgrade in highways and production of concretes [7]. This result shows that rock flour can be used as main construction material in highway pavement because the lower the OMC, the better the workability of good soils.

![Figure 6: The influence of rock flour on optimum moisture content of the soils.](image)
4.3.2 Maximum Dry Density (MDD)

The influence of addition of varying quantities of rock flour by weight on maximum dry density of the soils at the West African level of compaction is shown in Fig. 7. Increase in percentage by weight of rock flour from 2% to 10% used in stabilization of the soils resulted in increase in density and possibly strength of the soils of the study area. The addition of 2% by weight of rock flour led to progressive decrease in the maximum dry density of some of the soils. The addition of between 4% and 10% by weight of rock flour led to progressive increase in the maximum dry density (MDD). The MDD increased from 1745 kg/m$^3$ to a maximum of 1807.7 kg/m$^3$ for sample 8A and from 1749 kg/m$^3$ to a maximum of 1811.6 kg/m$^3$ for sample 8B upon addition of 10% by weight of rock flour, representing a percentage increase of 3.59% and 3.58% for samples 8A and 8B respectively. An increase in MDD was observed for all the soil samples tested as the rock flour content was increased from 2% to 10% (Fig. 7). Addition of rock flour increase the dry densities of all the soils, which is an indication of improvement in the soil properties. Thus, this shows that rock flour stabilization has generally improved the soils and enhanced their workability. The strong and positive impact of addition of rock flour on lateritic soils proves that it is an effective stabilizer for enhancing the geotechnical properties of lateritic soils [7]. The increase in MDD is an indication that increase in percentage by rock flour content has strong and positive effects on the soils density and always on the soils strength. Thus, rock flour stabilization has generally improved the soils and enhanced their workability. The good values of compaction properties possessed by these stabilized soils make them good engineering construction materials.

![Figure 7: The influence of rock flour content on the maximum dry density of the soils.](image-url)
4.4 Strength Characteristics

The strengths of engineering soils have a vital role in design, construction and long-term stability of structures on and with soil materials. The shear strength of the soil samples increased considerably with the addition of rock flour.

4.4.1 California Bearing Ratio (CBR)

The CBR is a semi-empirical test for evaluating highway subbase/subgrade soils. The soaked CBR test is a simulation of the condition that soils are exposed to in-situ upon ingress of water. Stabilization of the soil with rock flour also resulted in the increase in both unsoaked and soaked CBR, with the optimal values obtained upon the addition of 10% rock flour (Figs. 8 and 9). The increase in value ranging from 13.70% to 39.13% with the unsoaked CBR value increasing gradually from 73% to 83% and from 23% to 32% (Fig. 8), while the percentage increase of the soaked CBR ranges from 26.92% to 48.08% with the soaked CBR value increasing gradually from 26% to 33% and from 52% to 77% for the samples 1, 3 and 5. Also, addition of 10% rock flour produced the optimum percentage increase of the unsoaked CBR ranging from 22.58% to 27.59% with the value increasing gradually from 31% to 38% and 29% to 37% while the optimum percentage increase of the soaked CBR of the rock flour stabilized samples range from 45.00% to 47.37% with the soaked CBR increasing from 20% gradually to 29% and from 19% to 28% for samples 8A and 8B (Fig. 9). Addition of 10% rock flour optimally improved the CBR of the soils for both the soaked and unsoaked CBR. This is an indication of a stronger positive influence of rock flour on the strength measured in terms of soaked and unsoaked CBR. This indicates that the load bearing capacities of all the soils increased with the stabilization mix. The values of CBR (unsoaked and soaked) showed the effects of the stabilizer on properties of the soils. The minimum CBR requirements for subgrade, subbase and base courses are 10% (soaked), 30% (soaked) and 80% (unsoaked) respectively [22]. All the soils are suitable as subgrade/fill, subbase materials and only soil samples 3A and 3B are suitable as base course in their stabilized state. Whereas only 3A, 3B and 5B met the requirement for use as subbase and none of the soils met the minimum value of unsoaked CBR for base course in their unstabilized state. These are indications that rock flour is an effective soil stabilizer. It can be deduced from the results that rock flour produces solid and stronger positive effects on the strength measured in terms of unsoaked and soaked CBR. It can further be confirmed that rock flour serves as a good and more effective stabilizer of the soils and 10% by weight of rock flour is optimally required for the stabilization of the soils from all the locations of the study area. These improvements in the CBR values of all the samples satisfy the minimum requirements that guarantee the soils as subgrade and subbase road construction materials. Also, the improved values of CBR give reduction in thickness of pavement which results to low cost of construction.
4.4.2 Unconfined Compressive Strength (UCS) and Shear Strength

CBR, UCS and shear strength are often used to estimate the bearing capacity of highway subgrade and subbase soils. The UCS and shear strength were observed to increase with the increase in rock flour content for all the soil samples. There is a strong positive correlation between the results obtained for UCS and shear strength as the shear strength of the rock flour
stabilized soils increase with increase in percentage by weight of rock flour employed for the stabilization. The addition of 2% rock flour decreased the unconfined compressive strength and shear strength of the soils (Figs. 10 and 11). However, significant increase in strength was noticed on addition of 4, 6 and 8% rock flour and gradual reduction in the strength indices were observed at 10% rock flour. Addition of 8% rock flour optimally improved the UCS and shear strength of the soils. These results show the stabilizing potentials of rock flour on lateritic soil especially when added at the optimum level. Rock flour improves the soil properties and enhances the workability of the lateritic soils much better than when the soils are used in their natural state. Poor subgrade materials are characterized by low stiffness and resistance to deformation which results in pavement failure due to inability to support a high amount of loading. Unconfined compressive strength of soil between 100 – 200 kN/m² indicates stiff soil [23]. Change from the initial stiff soil to very stiff soil of the study area on addition of 8% rock flour has greatly improved the UCS and shear strength of the soils. Therefore, low UCS and shear strength of the soils indicating low strengths have been improved by rock flour stabilization and categorized as very stiff to support traffic load (Figs. 10 and 11). The increase in percentage by weight of rock flour employed for stabilization is accompanied by a corresponding increase in unconfined compressive strength and shear strength of all the soil samples. This indicates positive influence of addition of rock flour to the strength of the soils in the study area.

Strength indices tests results (CBR and UCS results) were used in model formulation as shown in Figures 12 and 13 with their respective equations (equations 1 and 2) and R-squared values. This serves as a template in predicting the relationship between the indices in estimation of results with little laboratory work. The CBR – UCS models developed were of the third order polynomial in form ax³ - bx² + cx + d, with the values of R² indicating the degree of correlation between CBR (unsoaked and soaked) and UCS at various stabilizer contents. It was observed that a positive correlation of 0.672 and 0.528 were obtained for CBR (unsoaked and soaked) and UCS at rock flour content. The results indicate good correlation between CBR and UCS of the soil-rock flour mix.
Figure 10: Influence of rock flour content on Unconfined compressive strength of the soils

Figure 11: The influence of rock flour content on the shear strength of the soils
Figure 12: UCS_{Rock flour} Vs Unsoaked CBR

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\text{UCS}_{\text{Rock flour}} = 0.002 \text{CBR}_{\text{Un}}^3 - 0.392 \text{CBR}_{\text{Un}}^2 + 19.20 \text{CBR}_{\text{Un}} - 110.6 \ldots \ldots (1)
\]

\[R^2 = 0.672\]

Where: \(\text{UCS}_{\text{Rock flour}}\) = Unconfined Compressive Strength at rock flour content, \(\text{CBR}_{\text{Un}}\) = Unsoaked California Bearing Ratio at rock flour content.

Figure 13: UCS_{Rock flour} Vs Soaked CBR
UCS (Rock flour) = 0.002 CBR_S^3 - 0.366 CBR_S^2 + 14.11 CBR_S + 16.02 \ldots \ldots \ldots (2)

R^2 = 0.528

Where: UCS (Rock flour) = Unconfined Compressive Strength at rock flour content, CBR_S = Soaked California Bearing Ratio at rock flour content.

5. Conclusion

Rock flour reduced the plasticity indices of the lateritic soils, a considerable reduction is achieved at 10% rock flour stabilized soils. This is an indication that the activity of the mixture was reduced with marked reduction in swelling nature of the soils. It also indicates a more stable soil with increased workability on addition of rock flour. The reduction in activity of the soils with changes in moisture content also reduces the linear shrinkage of the soil-rock flour mix. This enhances volume stability of the soils. The MDD of rock flour stabilized soils increase with the maximum improvement observed at 10% by weight of rock flour with the corresponding decrease in OMC. The increase in MDD is an indication that increase in percentage by rock flour content has strong and positive effects on the soils density and always on the soils strength. Conversely, the reduction in OMC of the soils is an indication of the soil improvement, as this enhances the workability of the soils. The CBR values of all the soils increased with rock flour, hence, improved the lateritic soils greatly to the satisfaction of meeting the minimum requirements that guarantee the soils as subgrade, subbase materials and even some of the soils as base course in the construction of highway pavement. This indicates that the load bearing capacities of the soils increase with the stabilization mix. This is an evidence of a stronger positive influence of rock flour on the soils strength measured in terms of soaked and unsoaked CBR. UCS and shear strength of the soils optimally improved on addition of 8% rock flour. Addition of more than 8% by weight of rock flour caused reduction in UCS and shear strength. These results show the stabilizing potentials of rock flour on lateritic soils especially when added at the optimum level. Reduction in plasticity indices, linear shrinkage, optimum moisture content and increase in strength indices indicate an improvement of the soil properties. Third order polynomial relationships established between CBR (unsoaked and soaked) and UCS with R^2 values indicate good correlation of the soil-rock flour mix. Thus, rock flour can potentially stabilize lateritic soils solely. Utilization of soil-rock flour mix would serve as profitable alternative to river or mining sands and prevent continuous failures of lateritic soils in constructions.

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