2nd International Civil Engineering Conference (ICEC 2020)
Department of Civil Engineering
Federal University of Technology, Minna, Nigeria

# Evaluation of Consistency Limits and Compaction Properties of Lateritic Soil-Rock Flour Mixtures to be used as Road Pavement Subgrade

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**ABSTRACT**
The study reported in this paper evaluated the consistency limits and compaction properties of lateritic soil stabilized with 0, 3, 6, 9 and 12% rock flour by dry weight of soil and compacted using British Standard Light (BSL), West Africa Standard (WAS) and British Standard Heavy (BHS) compactive efforts. Results show that the lateritic soil sample used for this study is classified as A-7-6 according to American Association of State Highway and Transportation Officials (AASHTO). The formulated mixtures from the A-7-6 soil and rock flour show an improvement in the index properties of the mixtures with increasing rock flour. The Liquid limit and Plasticity index reduced from 42 - 32% and 29.30 - 13.48% respectively as rock flour increased from 0 – 12%, while plasticity index of A-7-6 soil with rock flour shows considerable reduction in plasticity indices of mixtures with increasing content rock flour content. 1.802, 1.820 and 1.870g/cm³ were obtained as MDD values and 12.40, 11.90 and 11.60% as OMC values for the natural soil using BSL, WAS and BSH compaction efforts respectively. Also, at 12% of rock flour content, the MDD increased to 1.85, 1.870 and 2.010g/cm³ while the OMC increased to 14.80, 14.40 and 13.90% using the same compaction efforts. Based on results obtained, MDD result shows a progressive increase with higher rock flour content as well as higher compaction effort. The increase in MDD values suggest that the increase in rock flour content has positive influence on the strength and density of tested mixtures. In terms of consistency limits, the mixtures did not achieve the required threshold values for subgrade specified as LL < 35 and PI < 12% in local codes suggesting the use of higher rock flour contents to enhance these parameters. To optimize their structural strength for subgrade application, the mixtures should be compacted to 100% of the MDDs.
**Keywords:** *Lateritic soil, A-7-6 soil, rock flour, road pavement subgrade*

## 1.0 INTRODUCTION

Lateritic soil is a predominant surface deposit found in the tropical and sub-tropical regions, it is rich in iron and aluminium which are developed through weathering of the underlying parent rock (Ademila, 2019). Lateritic soil is highly weathered material, having rich oxides of iron, aluminium or both, possessing little or no basic primary silicates and may contain large quantity of quartz and kaolinite (Zaid *et al*., 2017; Adunoye *et al*., 2018). It is the major material used for pavement subgrade and sub-base courses in places where they occur (Mustapha *et al.*, 2019). Sometimes, lateritic soils with appreciable strength parameters are used as base course in low traffic highways. According to AASHTO (1986) soil classification system, lateritic soils vary in its suitability for subgrade material; from excellent to poor. A-7 soils are regarded as poorest performer for subgrade due to high content of clay it possesses. This class of soil is either sandy clay or silty clay, possessing high plasticity index. A-2 soils on the other hand are generally regarded as an excellent performer for subgrade construction, possessing clayey or silty gravel and soil. Generally, the quality of soil for pavement subgrade construction reduces from A-1 through A-7.

Clays are considered as geological materials having particle size <2µm. Clay contains minerals such as silica, alumina or magnesia and sometime both as well as water. Iron, potassium, sodium and calcium are commonly present as well. Some mineral compositions in clay such as kaolinite, hallosite nacrite and dickite impart its Engineering properties such as plasticity, shrinkage, swelling and cohesion (Ochieng, 2016). The challenges associated with instability of clay often stems from swelling of expansive clay material thereby making the soil unsuitable for construction in foundation of buildings, highway pavement, railway or any other engineering structures (Ogunribido and Abiola, 2015). The inherent properties of clayey soil such as high plasticity, low strength, low permeability, poor workability and tendency to retain moisture limit its application in specific engineering projects. Therefore, the natural soil specimen being studied needs to be stabilized to improve its engineering properties.

Continuous increase in axle load and vehicular volume justifies the need to have roads that are very stable, durable without escalating the construction cost (Athanasopoulou and Kollaros, 2011; Afolayan and Abidoye, 2017). Several researches have been carried out to improve the index, geotechnical and engineering properties of poor/problematic grades of lateritic soil such as A-7-6. Poor lateritic soil having high plasticity, low CBR value and poor workability especially A-7-6 soil does not meet requirements for use as subgrade material according to NGS (1997).

Developed and developing countries produces rock flour as an industrial waste while processing coarse aggregate from rock in crusher plants. It is also an effluent material when drilling through rock. Rock flour as the name implies is in powdery form, having angular constituent particles and non-plastic materials. Rock flour is a stable material at different degree of moisture content, they contain mineral such as quartz, silica and feldspar (Reddy and Moorthy, 2002). It has varying applications in its use for infrastructure developments such as a fill material in Highway construction or retaining material without reinforcement (Satyanarayana et. al., 2013). The stability of rock flour at varying degree of moisture content is an indication of its prospects as a good stabilizing agent for materials such as clay which are susceptible to volumetric changes under the influence of water.

The need for soil stabilization has gained high acceptance in geotechnical engineering hence it is inevitable in road construction, especially in areas with problematic soils. Soil stabilization is aimed at improving the performance of poor soils by increasing its strength parameters, reducing its water retaining ability, reducing soil tendency to swelling and increasing workability. Bisrat and Satyendra (2019) defines stabilization as the process by which soil characteristics are improved with the sole aim of ensuring that the stabilized soil meets construction requirements. Soil stabilization can be achieved using different methods. These methods are broadly classified into mechanical and chemical stabilization. Mechanical stabilization is a physical process that is achieved by altering the physical nature of natural soil particles either by inducing vibrations or compaction or by incorporating reinforcements such as nailing, while chemical stabilization involves the use of stabilizer such as cementitious material to initiate chemical reactions between the stabilizing agent and soil minerals (pozzolanic materials) to achieve the desired improvement required (Saad et al., 2017: Fitsum, 2018: Bisrat and Satyendra, 2019).

The consistency limits provide a means of describing the degree and form of cohesion and adhesion between the soil particles as related to the resistance of the soil to deform or rupture. For example, the liquid limit (LL) defines the state whereby fine grain soil no longer flows like liquid. It is determined as the moisture content, expressed as a percentage of the weight of oven dried soil at the boundary between liquid and plastic states of consistency Similarly, Plastic limit (PL) of a soil is the moisture content at which a soil begins to behave as a plastic material Lastly, Plasticity index (PI) is obtained as the numerical difference between liquid limit and plastic limit of soil. These index parameters plays prominent role in the classification of soils.

Compaction is the densification of soil by direct application of mechanical load with the sole aim of reducing the air voids between the soil particles. Upon compaction, compacted soil sample experiences reduction in volume. To achieve the maximum dry density (MDD), water must be applied at optimum quantity that is; Optimum Moisture Content (OMC). The art of ensuring Optimum Moisture Content is attained at the site is critical in having satisfactory compaction. Soil compaction ensures that the soil particles form a strong matrix capable of withstanding axle load throughout the pavement design life span. Three energy level are mostly used in Nigeria and in countries across Africa which are; British Standard Light (BSL), British Standard Heavy (BSH) and West African Standard (WAS), which imparts 595.95, 993.26 and 2681.80 kJ of energy respectively on specimens. The compaction characteristic of soil achieved in the laboratory governs the values of Maximum Dry Density (MDD) and corresponding Optimum Moisture content (OMC) expected in the field with minimal deviation (Oluyemi and Uduebor, 2019).

The aim of this research work is to evaluate the consistency limits and compaction characteristics of lateritic soil mixed rock flour for subgrade pavement. To achieve this, Liquid Limit, Plastic Limit and Plasticity Index of the natural and stabilized soil will be determined. Also, compaction characteristics of mixtures will be determined using British Standard Light, West Africa Standard and British Standard Heavy compaction efforts.

## 2.0 MATERIALS AND METHODS

### 2.1 Study soil

Lateritic soil sample for this study is a dark brownish soil, collected as disturbed samples from identified borrow pit at depths varying between 1 – 2m in Agaie local government, Niger state (Latitude 906658 N and longitude E 636958) Nigeria.

Rock flour for this research work was obtained as an effluent of drilling process of a crystalline basement rock at a borehole drilling site in Tunga. Chancahaga local government, Minna, Niger state, Nigeria. It is a powdery whitish non-plastic material. Only fractions passing through BS sieve No. 200 (75µm) were used for the testing.

Water for the test was obtained from borehole at the Federal University of Technology, Minna Civil Engineering laboratory. The water used is colourless, odourless and free from visible impurities.

### Soil-Rock flour mixtures

Rock flour was added to the natural soil at 3, 6, 9 and 12% by dry weight of the soil sample. The Plastic Limit (PL), Liquid Limit (LL) and Plasticity Index (PI) were determined for the natural soil sample and the rock flour stabilized specimens. Compaction characteristics of the natural soil and rock flour stabilized samples were also obtained using three energy levels that is; BSL, BSH and WAS, following procedures outlined in BS 1924-2: 1990 and NGS (1997).

### 2.2 Test Methods

The laboratory analysis was carried out in accordance with British Standard methods of test for soil; While BS 1377: 1990 was used for the natural soil sample, BS 1924-2: 1990 was used for the stabilized soil samples. On the other hand, WAS compaction effort followed procedures outlined in NGS, (1997).

### Particle size distribution

This test was carried out to determine the particle size distribution of the soil sample in accordance with BS 1377-2:1990. A representative sample of mass 600g was used for this test. This test was carried out using set of sieves. The sieves were cleaned and arranged orderly from sieve No. 4 at the top and sieve No. 200 at the bottom just before the collection pan. Dry weight of the sample was recorded before pouring it into the sieve assemblage. The mechanical shaker was turned on for 10 minutes. Thereafter, weight retained in each sieve and the collection pan was obtained.

### Consistency Limits (Liquid Limit and Plastic Limit)

Soil sample passing through 425µm sieve, weighing 200g was mixed with clean water to form a homogenous paste which was used for the determination of Liquid Limit (LL). The homogenous paste was placed in the Casangrade's apparatus, a groove was made in the paste and the number of blows made to close up the groove was obtained. Also, Plastic Limit (PL) was obtained using soil sample passing through 425µm sieve, weighing 200g mixed with clean water to form a homogenous paste. The paste was moulded into a ball shape before rolling in on a glass plate. Rolling of the sample on the glass plate continues until the thread cracks at approximately 3mm diameter is achieved. The plastic limit was determined by placing the 3mm diameter sample in oven at $105^0$C for 24 hours to determine the moisture content.

Plasticity index (PI) is the numerical difference between liquid limit and plastic limit of soil as shown in equation 1

$$PI = LL - PL \quad (1)$$

### Compaction Test

Compaction test was done in accordance with BS 1377: 1990. The soil sample was air dried and thoroughly pulverized so that it passes through BS sieve No. 4 (4.75mm). Test specimens were obtained by mixing reasonable quantity of dry soil with 3%, 6%, 9% and 12% rock flour (by dry weight of soil). The optimum moisture content (OMC) and maximum dry density (MDD) for the natural soil and mixtures of soil and rock flour were obtained using the three energy levels adopted in this study for the natural soil sample and the stabilized specimens.

## Results and Discussion

### Index properties

Result of particle size distribution and summary of index properties of the natural soil are presented in Fig.1 and Table 1 respectively. The natural soil has 36.1% of silt – clay material passing through sieve No. 200, Liquid Limit (LL) of 42%, Plastic Limit (PL) of 12.70% and Plasticity index of 29.30% .Therefore, the soil is classified under A-7-6 according to AASHTO soil classification system and as Sandy Clay (SC) according to Unified Soil Classification System (USCS).

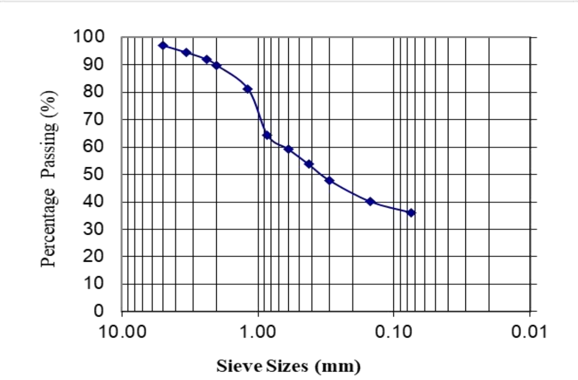


Figure 1: Particle size distribution curve of Natural Lateritic Soil

Table 1: Index Properties of Natural Lateritic Soil

| Property | Value |
|---|---|
| Percentage passing BS sieve No. 200 | 36.1% |
| Liquid Limit | 42% |
| Plastic Limit | 12.70% |
| Plasticity Index | 29.3% |
| AASHTO Classification | A-7-6 |
| USCS classification | SC |
| Specific Gravity | 2.65 |
| Colour | Brownish |

### Consistency Limits

Figure 2 shows the relationship between consistency limits of the natural soil and stabilized soil specimens using rock flour at 3, 6, 9 and 12%. Liquid limit of the natural soil decreased from 42% at 0% rock flour content to 32% upon adding 12% rock flour to the unstabilized specimen. Also, the Plastic Limit progressively increased from 12.70% for the natural soil to 18.52% when stabilized with 12% rock flour while the Plasticity Index reduced significantly from 29.30% to 13.48% in the same sequence of rock flour treatment. Although the addition of rock flour to A-7-6 soil improved the consistency limits of mixtures, they however failed to meet the requirements for subgrade materials which is specified as; LL < 35 and PI < 12% according to NGS (1997). The failure of mixtures to meet the required threshold values for consistency parameters suggests that higher rock flour contents are needed to achieve the specification requirements. Improvement in consistency limits occurred due to non-plastic nature of rock flour, which thereby, reduces the plasticity index of stabilized specimens (Satyanarayana *et al.,* 2013; Garata *et al.*, 2014).

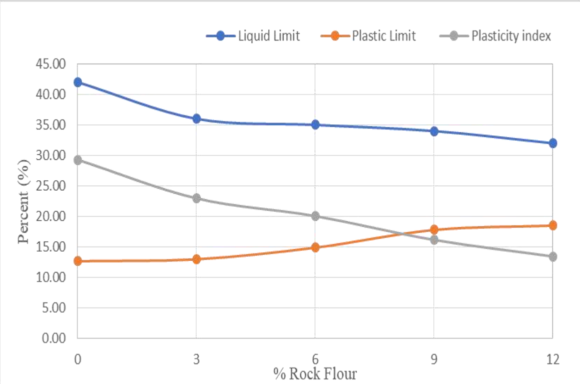


Figure 2: Variation of Atterberg limits of soil mixtures with rock flour content.

## Compaction Parameters

### Maximum Dry Density

Figure 3 shows how the maximum dry density changes with the addition of rock flour for BSL, BSH and WAS compaction. Generally, MDD increased from 1.870g/cm³ to 2.010g/cm³ for BSH, from 1.820g/cm³ to 1.87g/cm³ for WAS while BSL increased from 1.802 g/cm³ to 1.850g/cm³ as the rock flour content increased from 0 – 12%. British Standard Heavy gave highest set of results, having a MDD values ranging from 1.87 – 2.010g/cm³ as rock flour content increased from 0 – 12% as indicated in Fig. 3. The increase in MDD values suggest that the increase in rock flour content has positive influence on the strength and density characteristics of tested mixtures (Satyanarayana et. al., 2013: Ademila, 2019).

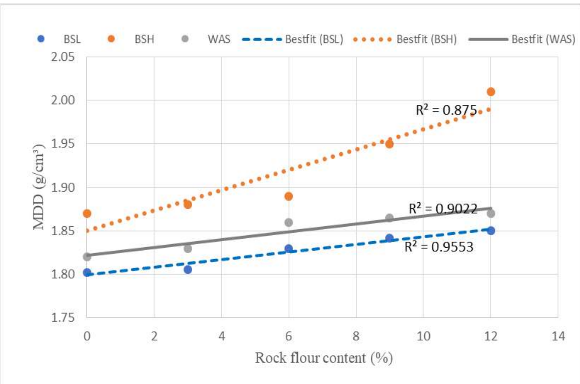


Figure 3: Variation of MDD with Rock flour content for BSL, WAS and BSH compaction efforts.

### Optimum Moisture Content

Figure 4 shows how the Optimum Moisture Content changes with the addition of rock flour for BSH, WAS and BSL compaction. In general, OMC increased from 11.60% to 13.90% for BSH, from 11.9% to 14.40% for WAS while BSL increased from 12.40% to 14.80% as the rock flour content increased from 0 – 12%. Decrease in OMC values for BSH compaction on tested mixtures occurred due to the replacement of silt and clay constituent with rock flour particles in the specimens, which therefore, reduced moisture intake (Satyanarayana et. al., 2013).

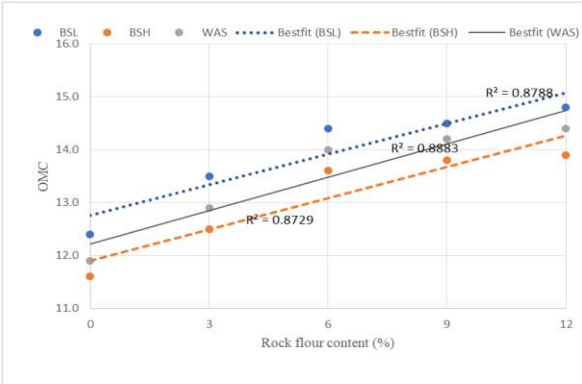


Figure 4: Variation of OMC with Rock flour content for BSL, WAS and BSH compaction efforts.

## SUMMARY AND CONCLUSIONS

This study evaluated the impact of adding up to 12% rock flour on the consistency limits and compaction characteristics of lateritic soil sample. Soil mixtures for compaction tests were compacted using British Standard Light (BSL), West Africa Standard (WAS) and British Standard Heavy (BSH) compactive efforts. The following conclusions were drawn from the study;

1. The natural soil classified as A-7-6 according to AASHTO classification system and SC under Unified Classification System.
2. The Liquid Limit and Plasticity Index reduced with increasing percentage of rock flour while the Plastic Limit increased with increasing rock flour content. Consistency limits results failed to meet the requirements for subgrade material, which is specified as; LL < 35 and PI < 12% according to (NGS, 1997).

3. The Maximum Dry Density (MDD) shows an increase with higher compaction effort.
4. Increasing rock flour content from 0 – 12% in the stabilized soil mixtures indicate a progressive increment in the MDD values for BSL, WAS and BSH. BSH gave the highest values of MDD which ranges between of 1.870 – 2.010 g/cm³ and corresponding OMC values between 11.60 – 13.90% for mixtures tested.

This research work therefore, established the potentials of using rock flour to improve the consistency limits and moisture – density properties of A-7-6 soil for use in road pavement subgrade.

## RECOMMENDATION

1. A-7-6 soil stabilized with rock flour content above 12% can be investigated to determine if the mixture meets consistency limits requirements for subgrade material as specified in local codes.

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