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Research Article

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Special Issue
A Themed Issue in Honour of Professor Clement Uche Atuanya on His retirement.

This themed issue pays tribute to Professor Clement Uche Atuanya in recognition of his illustrious career in Metallurgical and Materials Engineering as he retires from Nnamdi Azikiwe University, Awka. We celebrate his enduring legacy of dedication to advancing knowledge and his impact on academia and beyond through this collection of writings.

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Geotechnical Properties of Some Earth Materials Used for Road Pavement Construction in Anambra State

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Abstract
This research project was carried out to investigate the geotechnical properties of some earth materials used in road pavement construction in Anambra State of Nigeria. Laboratory tests including particle size distribution analysis, specific gravity, Atterberg limits, compaction using the British Standard Light (BSL) and the British Standard Heavy (BSH) compactive efforts, and California Bearing Ratio (CBR) tests were conducted on the soil samples gotten from Agu-Awka, Nawfia and Ugwuoba designated LAT 1, LAT 2 and LAT 3 respectively. From the results obtained from the tests and using the liquid limit, plastic limit and plasticity index the soil samples fall into A-2-4 of the AASHTO classification and SC (Clayey Sand) using the USCS classification. The compaction characteristics of the samples were found to be 21.21KN/m³, 21.77KN/m³ and 21.23KN/m³ for maximum dry unit weight and 12.5%, 13.5% and 11% for optimum moisture content for LAT 1, LAT 2 and LAT 3 respectively. The California Bearing Ratio (CBR) results after 48 hours soaking is 23.5%, 25.7% and 24.2% for LAT 1, LAT 2 and LAT 3 respectively. These results obtained indicate that the samples meet requirements for sub-base since the Federal Ministry of Works and Housing specifies CBR values greater than 20% for subbase type 2 with low traffic loads.

Keywords: California Bearing Ratio, compaction, geotechnical properties, road pavements, subbase

1. Introduction

Earth materials are generally defined as the naturally occurring materials found on the earth that constitute the raw materials upon which our global society exists. Earth materials include minerals, rocks, soil, water and metals (Kalev and Toor, 2017). They support life, agriculture and industrialization. Engineering soils are the major earth materials used for lower layers of road pavements. They are of key interest in this study. Soils are sediments or other unconsolidated accumulation of solid particles produced by the physical and chemical disintegration of rocks, and which may or may not contain organic matter. Soil constitutes the primary material for the foundation, sub-grade, or even the other layers of pavement (Mezie et al., 2023). Since all traffic loads are to be transmitted to the earth, it then serves as the foundation of the pavement (Nwakaire et al., 2016). Hence, a detailed study of soil engineering properties is always necessary for pavement construction applications. The geotechnical properties of soils are very essential parameters to be analysed because they influence the stability and lifespan of engineering structures (Ubani et al., 2023). They are also essential for the safe design and planning construction techniques for the intended structure(s).

A highway (road) pavement is a structure consisting of superimposed layers of processed materials above the natural soil sub-grade, whose primary function is to distribute the applied vehicle loads to the sub-grade (Nwakaire et al., 2020). The pavement surfacing should be able to provide a surface of acceptable riding quality, adequate skid resistance, favourable light reflecting characteristics, and low noise pollution (Nwakaire, et al., 2021). But beyond these, it is expected to transmit the vehicular wheel loads to the lower pavement layers. The main aim of the lower pavement layers is to ensure that the transmitted stresses due to wheel load are sufficiently reduced, so that they will not exceed the bearing strength of the sub-grade soil (Nwakaire et al., 2016; Aginam et al., 2014). For this reason, the engineering properties of earth materials used for construction of pavements are very important factors to be ascertained.

Ayodele and Falade (2016) investigated some geotechnical properties of selected sub-base materials used for road construction. In their study, they collected soil samples from three known locations and subjected them to laboratory investigations. Based on the index properties of the soils, they were classified as fair to poor and the CBR results of 5% to 12% revealed that they were not suitable as subbase materials. The study showed that the poor properties of the material was a major factor to the failures recorded in pavements constructed with materials from those locations. Tse and Ogunyemi (2016) focused their studies on tropical red soils. The geotechnical properties of the soils were used to ascertain their suitability and implications for use as road construction materials. Their study concluded that poor materials can lead to compromise on the integrity of road construction. It was from this backdrop that Abija (2019) conducted a detailed assessment on both subgrades and subbase materials revealing a spatial variation in the properties of residual soils and emphasizing the need for regular laboratory investigation on these materials for the purpose of quality control. Hence, it is expedient to continuously study to ascertain the properties of any material in use as road construction material in order to ensure compliance to standard requirements.

In this study, soil samples gotten from borrow pits used for pavement construction in Anambra State of Nigeria were investigated to evaluate their suitability for different aspects of pavement applications. The essence is to inform construction companies of the degree of variability in soil properties around the State and emphasize the need for careful studies and investigations of soil strength indicators before such soils are utilized for pavement constructions. This will guide companies both within and outside this state on the need for careful selection of earthwork materials for pavement construction. Laboratory tests including particle size distribution analysis, specific gravity, Atterberg limits, compaction using the British Standard Light (BSL) and the British Standard Heavy (BSH) compactive efforts, and California Bearing Ratio (CBR) tests were conducted on the soil samples to ascertain their suitability as pavement construction materials. Based on these tests, the soils were characterized and assessed.

2.0 Material and methods

The materials employed in this research include three lateritic soil samples from Agu-Awka, Nawfia and Ugwuoba (designated LAT 1, LAT 2 and LAT 3 respectively). The methods employed in the testing procedures and sample preparation were all in accordance with BS 1377 (1990) parts 1, 2 and 4. The soils were classified using the Unified Soil Classification System (USCS) and the American Association of State Highway and Transportation Officials (AASHTO). The tests conducted include specific gravity test, sieve analysis test, consistency limits test, and compaction test and C.B.R test.

Three disturbed lateritic soil samples were collected from selected borrow sites in the geological location of Anambra state and Oji local government in Enugu state because these areas are used to source road pavement construction materials by the construction companies in the environs. The samples were taken after the top soil was excavated to a depth of 250 to 300 mm. The samples were then transported to the laboratory for testing.

3.0 Results and Discussions

The results of the series of tests conducted on the samples of lateritic soils collected from Agu-Awka, Nawfia and Ugwuoba designated LAT 1, LAT 2 and LAT 3 respectively are provided in this chapter. The summary of the results obtained are shown in Table 1.

Table 1: Index properties of the soil samples

Property	LAT 1	LAT 2	LAT 3
Specific gravity	2.64	2.66	2.71
Liquid limit (%)	28	26.5	29.7
Plastic limit (%)	12.17	19.25	12.63
Plasticity Index (%)	15.83	7.25	17.07
Coefficient of uniformity (Cu)	4.3	4	5.5
Coefficient of curvature (Cc)	1.4	2.3	1.6
D10	0.07	0.05	0.1
D30	0.17	0.15	0.3
D60	0.3	0.2	0.55
Maximum dry unit weight (KN/m^3)	21.21	21.77	21.23
Optimum moisture content (%)	12.5	13.5	11
C.B.R value (%) (48 hrs soaked)	23.5	25.7	24.2
Unified Soil Classification System (USCS)	SC	SC	SC
American Association of State Highway and Transportation Officials (AASHTO) classification	A-2-4	A-2-4	A-2-4

From the table above, the results suggest that the soils collected from Agu-Awka, Nawfia and Ugwuoba were formed from the same weathering process.

3.1 Particle size distribution test results and analysis.

The results obtained from the test aided in the classification of the soil samples. Little amounts of gravel were recorded from all sites, not exceeding 10%. The particles that predominate in all samples from all sites are sand particles reaching as much as 92% as seen from the test results. According to USCS, the soils were classified as SC (Clayey Sand) soils which shows that the samples contain both clay and sand particles predominantly. The samples can also be classified as A-2-4 soils according to AASHTO classification. The coefficient of uniformity (Cu) of LAT 1, LAT 2 and LAT 3 samples are 4.3, 4 and 5.5 and their coefficient of curvature (Cc) are 1.4, 2.3 and 1.6 respectively as shown in Table 1. The curve shapes (Figure 1) show that the soil particles are poorly graded as the particles do not show a gradual distribution of all sizes.

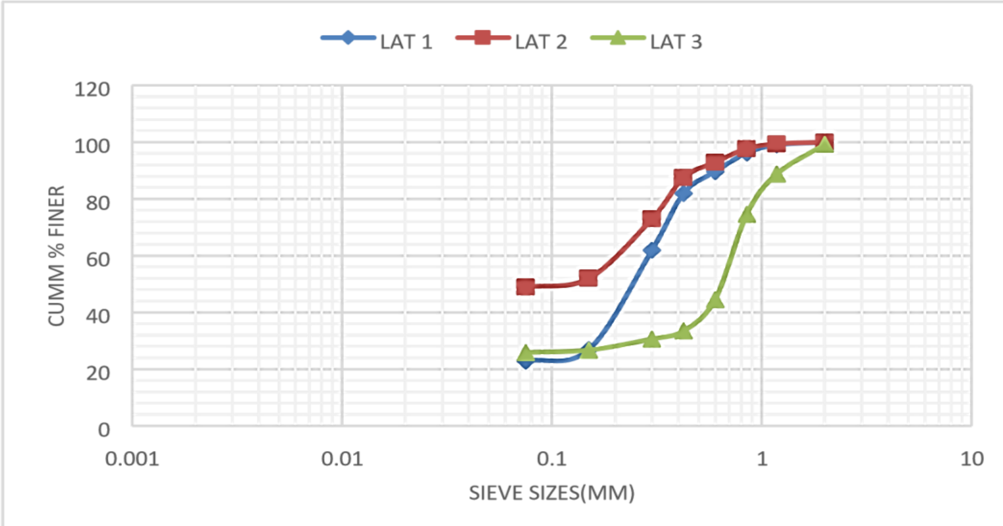

Figure 1: Particle size distribution for the soil samples.

3.2 Specific gravity test results and analysis.

The specific gravity of the soil is intensively used in soil engineering applications in determining other parameters such as void ratio, particle size distribution using hydrometer analysis & degree of saturation. For LAT 1, LAT 2, and LAT 3, the average specific gravity of the samples tested are 2.64, 2.66 and 2.71 respectively. The range of specific gravity from 2.60 to 2.80 suggests the presence of inorganic soils which actually can be of advantage at the sub-grade and sub-base levels of road construction.

3.3 Atterberg limits test results and analysis

The Atterberg limits test shows that the soil samples have an average plasticity index of 15.83, 7.25, 17.07 for LAT 1, LAT 2 and LAT 3 respectively, therefore the samples are judged to be of medium plasticity. The samples also have a liquid limit of 28%, 26.5% and 29.7% respectively. The Nigerian Federal Ministry of Works standard specifications states that the liquid limit and plasticity index of sub-grade materials should not exceed 80% and 55% respectively, therefore the soil samples can be used as sub-grade material. Figure 2 shows the Liqiud limit curves.

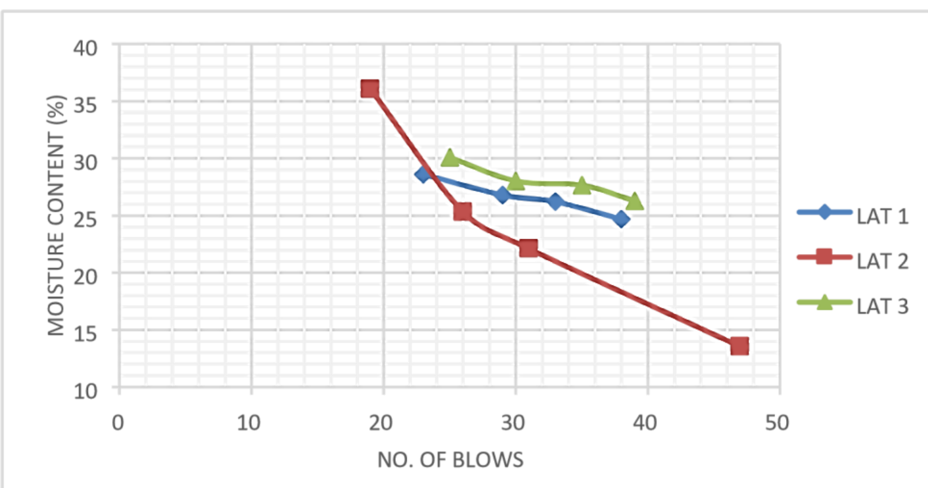

Figure 2: Liquid limit curves for the soil samples.

3.4 Compaction test results and analysis

Compaction densifies the soils, increasing dry unit weight with the addition of water. This decreases the settlement effect, decreases permeability and also increases shear strength. The highest limitation when water helps in maximizing the dry density is the maximum dry density beyond which the soil loses its density. The corresponding moisture content is the optimum moisture content (OMC) for that particular soil. The compaction curves for the three soil samples are shown in Figure 3. The maximum dry densities of the soil samples designated LAT 1, LAT 2 and LAT 3 are 21.21 g/cm³, 21.77 g/cm³ and 21.23 g/cm³ while their optimum moisture content is 12.5%, 13.5% and 11% respectively. From the results obtained, LAT 2 has the best compaction quality being that it achieved the highest maximum dry unit weight at the same compactive effort (CE).

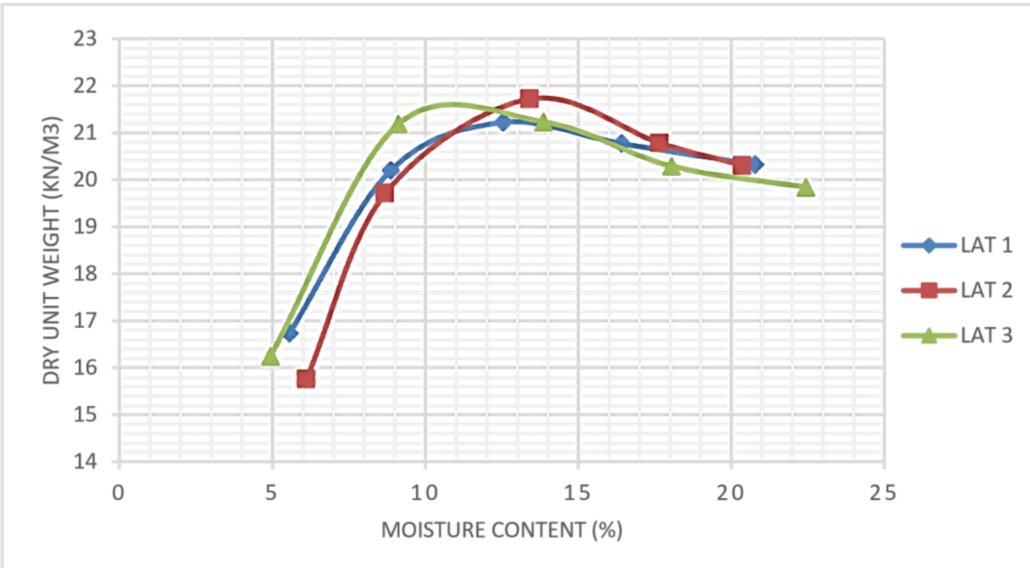

Figure 3: Compaction curves for the soil samples.

3.5 California bearing ratio (CBR) test results and analysis

CBR has been adopted in tropical areas for highway construction applications using laterites and other tropical soils as construction materials. As such, this test has been proven very useful for evaluation of nearly all lateritic soils. The CBR test results for the samples LAT 1, LAT 2 and LAT 3 after 48 hours soaking is 23.5%, 25.7% and 24.2% respectively. Since the three samples have CBR values less than 80%, they are not suitable for use as road base materials. The results obtained show also that the three samples have a minimum CBR values of 20% and are suitable to be used as “sub-base type 2” and sub-grade materials as specified by the Federal Ministry of Works standard specifications. The CBR test plots are shown in Figure 4.

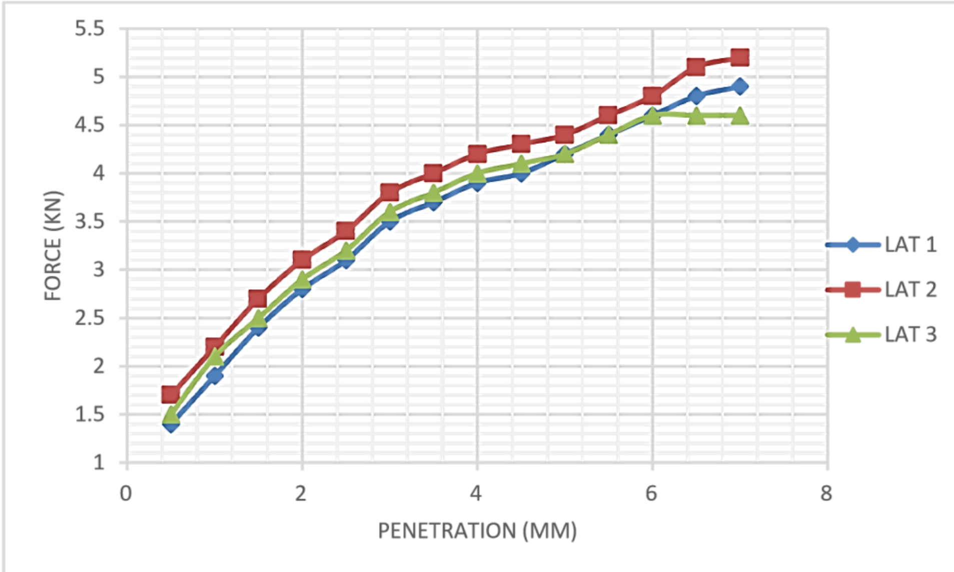

Figure 4: California Bearing Ratio (CBR) curves for the soil samples.

4.0. Conclusion

In this study, the geotechnical properties of three earth materils collected from borrow pits where road construction matreials are sourced within Anambra State have been subjected to geotechnical tests and analyses. The results obtained from the laboratory investigations were useful for the classification of the. From the particle size distribution, it was discovered that the particles that predominate in all samples from all sites are sand particles reaching as much as 92%. The specific gravity of the soils ranged from 2.60 to 2.80 which is typical of inorganic soils suitable for engineering applications. With this it was clear that the soils can perform satisfactrorilly as capping layers to strengthen weak subgrades. Based on the Atterberg limits tests, the soil samples can be judged to be of medium plasticity. The Plasticity indices ranged from 7.25 to 17.07 and liquid limit ranged from 26.5% to 29.7%. These values are typical of good subgrades.

According to the USCS (Unified Soil Classification System), the lateritic soils collected are classified in the group SC (Clayey Sand). Based on the USCS classification, these soils can be used as good subgrade materials. They are also suitable for sub-base of low trafficed roads, however, they are unsuitable as base layer materials for road pavement construction. The samples are also classified as silty or Clayey gravel and sand according to AASHTO (American Association of State Highway and Transportation Officials) classification.

The maximum dry densities (MDD) of the soil samples ranged from 21.21 g/cm³ to 21.77 g/cm³. whereas their optimum moisture content OMC ranges from 11% to 13,5%. is 12.5%, 13.5% and 11% respectively. This confirms the trend that OMC reduces with higher MDD. The CBR test results for the samples LAT 1, LAT 2 and LAT 3 after 48 hours soaking is 23.5%, 25.7% and 24.2% respectively. Since the three samples have CBR values less than 80%, they are not suitable for use as road base materials. The results obtained show also that the three samples have a minimum CBR values of 20% and are suitable to be used as “sub-base type 2” and sub-grade materials as specified by the Federal Ministry of Works standard specifications.

The use of materials from these borrowpits as base materials or subbase type 1 (for heavily trafficed roads) is discouraged. The properties of these materials can be improved to meet the requirements for “sub-base type 1” as mentioned in the above specifications. This can be achieved by applying soil stabilization techniques such as addition of lime, cement, fly ash or improving the grading of the materials by adding certain particle sizes that will boost the mechanical stability of the soil. These results are suitble to guide stakeholder within and outside of

Anambra state on the need for continous investigations to ascertain geotechnical properties of soils used for pavement construction works. Relying on a predetermined test would be missleading as the properties of these materials in their natural state vary in time and space.

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