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A Preliminary Geotechnical Assessment of Residual Tropical Soils around Osogbo Metropolis as Materials for Road Subgrade

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Abstract

Failure of roads is common in most part of the tropical region of the world. Majority of which can be attributed to poor selection of soil materials for road construction and climate. This study is aimed at investigating the properties of lateritic soil as material for road construction. Following an initial visit to the study area, soil samples were taken and subjected to geotechnical analyses such as particle size analysis, natural moisture content, Atterberg limits, compaction test, California Bearing Ratio (CBR), and direct shear test. All the tests were carried out according to the BS standard 1377 (1990). Results revealed a well graded fairly coarse soil with natural moisture content varying from 6.2-29.4 %. Atterberg limits shows a medium plasticity soil with medium compressibility and the soils classified within the $A-2$, $A-6$ and $A-7$ of the AASHTO classification scheme. In terms of soil strength, the maximum dry density (MDD) and optimum moisture content varies from 1210-1520 kg/m^3 and 13-24 %, respectively while California Bearing Ratio (CBR) value varied between 2.27- 45.32 % at 2.5 mm and 3.01 - 44.59 % at 5.0 mm. The shear strength of the samples ranged from 31.28-186.41 kN/m^2. Based on the results, the study concluded that the clayey nature of the soils was responsible for poor geotechnical properties which were generally below the specifications of the Federal Ministry of Works and Housing (FMWH), hence mostly not suitable in its present condition but could be improved to satisfy the conditions for use as sub-grade and sub-base soil in road construction.

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1. Introduction

All engineering structures such as roads, buildings, bridges, are founded on the ground. The majority of failed roads in the tropics can be attributed to geotechnical factors such as poor selection of sub-grade and sub-base materials [1, 2, 3] . The problem of premature failure of roads have been of great concern. Most of the roads are placed on laterite (sub-grade) and laterite has also been used as part of their construction materials. It is therefore, important to study the properties of these residual soils on which the road is constructed.

Road failure is most time responsible for a greater percentage of road accidents in Nigeria, this failure is often caused by poor selection sub-grade soils with invariably poor geotechnical properties such as high natural moisture and optimum moisture contents (NMC and OMC), high plasticity index, low maximum dry density (MDD), poor bearing capacity, high compressibility and poor mineralogy [4, 5, 6, 7, 8] . For a material

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to be used as either a base course or sub-base course depends on its strength in transmitting the axle-load applied on it [4, 5, 9].

Roads are generally founded on natural soil (sub-grade) and are constructed with geological materials (rocks or soils), whose properties influence their durability and performances as transport medium. Another factor that influences the performance of road especially in the south-western part of Nigeria is the climatic factor, particularly temperature fluctuations, rainfall intensity and acid rain attacks; these have been adjudged to reduce the strength of the road base materials [10, 11, 12] .

The laterite soil's mineralogical composition determines geotechnical parameters such as specific gravity, shear strength, Atterberg limits, and petrographic properties [13, 41] . The rapid cracking and damage to roads is worrying. The goal of this study is therefore to investigate the suitability of soils used as sub-grade or sub-base materials for the construction of new ring roads in and around Osogbo, thus enhancing their durability.

Therefore, this current research work is focused on the preliminary assessment of the geotechnical properties of a proposed road, this is with the aim of establishing the background values which are intended to be followed up subsequently over a period of time. The paper presents the preliminary report of the geotechnical evaluation as a feasibility study for road construction.

2. Location, Accessibility and Physiography

The new ring road is located within Osogbo Metropolis. Situated in the south-western part of Osun State. Geographically, it is bounded between latitudes N7°44′0′′ - N7°48′0′′ and longitudes E4°32′0′′ - E4°36′0′′. The area can be accessed through Oke-baale road, from Osogbo. It is less than 3 km away from Osun State University Osogbo campus and less than 1 km away from Oja Oba market. It is very close to Ilesa garage.

Landform influences the formation and characteristics of tropical soils, especially lateritic soils [3, 14, 15, 16] . The physical settings of the study area and geology are shown in Figure 1. The topography of the area can be described as undulating and the altitude of sampling points within the study area ranges from 333.0 - 346.2 m.

The major river in the area is the Osun River. The drainage pattern of the study area is dendritic. The area is well drained and a good number of streams exist as tributaries to the major rivers. The drainage map of the study area is shown in Figure 2.

3. Geology of the Study Area

The study area (Osogbo) is underlain by gneisses of the Basement Complex of Nigeria which are Precambrian in age [20, 21] . These gneisses are mostly weathered, but several

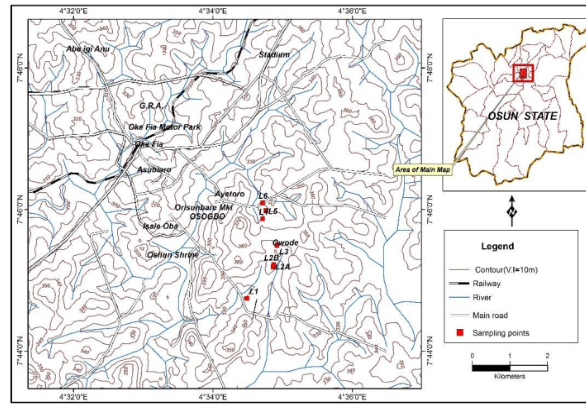

Figure 1: Topographic map of Osogbo (adapted from Nigerian survey of Iwo sheet, 1964)

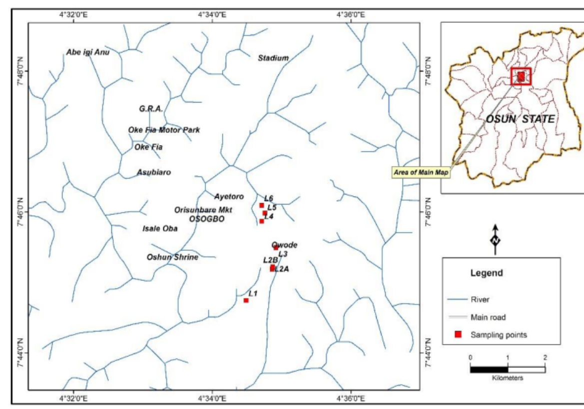

Figure 2: Drainage map of Osogbo (adapted from Nigerian survey of Iwo sheet, 1964)

road-cuts through these rocks still show features such as relict banding, quartz veins and quartz bands and including several pegmatites. Although the pegmatites are wide spread, they are weathered [21, 22] . Bodies of tonalite intruded into the gneisses, and the imprints from the gneisses probably formed relict bands on the tonalite. Dolerite occurs as dykes within the tonalite, and locally causing colour changes within the tonalite near their contact. Quartzites (massive and foliated) occur mainly as bands apparently sandwiched within the gneiss complex. The gneisses appear to be the oldest rocks, and it is on these that the metasediments (quartzites and possibly schist) were probably emplaced [20, 21, 22, 23] .

The gneisses are formed from regional metamorphism of the pre-existing crustal rocks that were in place at the time. The sediments overlying the crustal rocks were metamorphosed in this process to produce the metasediments. Tonalites are believed to represent diapiric emplacements of homogenized and mobilized basement [21, 22] . The pegmatites associated with the tonalite probably originated from the residual fluid phase of the tonalitic magma. Some of the pegmatites present within the gneisses may be of replacement origin [20] . The dolerite, a basic igneous body intruded the pre-existing rocks in form of dyke. Figure 3 shows the geological map of Osun state.

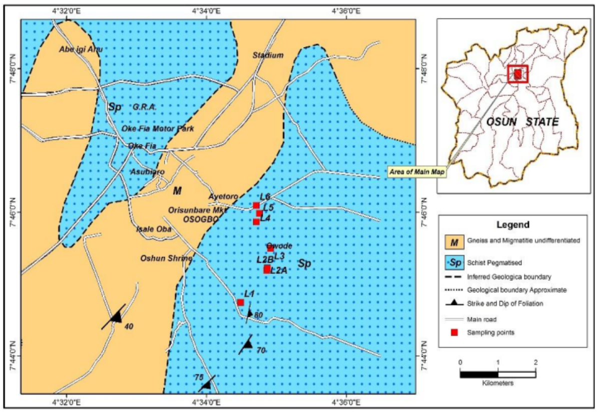

Figure 3: Geologic map of Osogbo (adapted after [40])

4. Materials and Methods

The research involved collection of soil samples and laboratory analyses of the collected samples. Six bulk disturbed samples were collected each at depths below 2m along the southern part of the new ring road, Osogbo. Proper labelling (OBO 1 – 6) was done to avoid mix up and human error. Samples collected were to the Civil Engineering Department laboratory, Osun State University, Osogbo and Soil laboratory of the Federal Polytechnic Ado-Ekiti for both index and engineering property analyses. Index properties include natural moisture content, grain size analysis and Atterberg limits while engineering properties test include compaction, California Bearing Ratio (CBR) and direct shear tests. All tests were carried out according to the BS 1377 [24] specification for soil tests.

5. Results and Discussions

5.1. Mineralogical Characteristics

The summary of the analytical results of the mineralogy of soils from the study area is presented in Table 1. It revealed the following minerals present in terms of abundance: kaolinite, goethite, quartz, muscovite, haematite and anatase. Kaolinite is by far the most abundant mineral present in the soil with percentage as high as 94% in some of the sampled pits. This indicates the prevailing conditions within environment of decomposition with specific leaching and drainage conditions favouring kaolinite as the stable mineral [8, 25] .

The lateritic nature of the soil samples is reflected in the percentage of kaolinite present, while the low percentages of haematite, quartz and goethite reflects the possible weak nature of the soil as previously stated [8] . Generally speaking, the results of mineralogy reflect in particular the influence of underlying lithology, that is, parent rock of the soils derived. For instance, soils derived from pegmatite will have higher percentage of feldspar and mica which often decompose into clay particles like kaolinite as reflected in the present study.

Table 1: Minerals present in the sampled soil.

Location no	Minerals present	Weight (%)
OBO1	Anatase	7.79
	Hematite	2.99
	Kaolinite	88.64
	Quartz	2.58
OBO2	Anatase	1.64
	Hematite	4.46
	Kaolinite	72.93
	Muscovite	10.64
	Quartz	10.34
OBO3	Anatase	2.97
	Goethite	16.01
	Hematite	3.9
	Kaolinite	40.96
	Quartz	36.15
OBO4	Goethite	11.87
	Hematite	2.23
	Kaolinite	77.93
	Quartz	7.97
OBO5	Hematite	1.08
	Kaolinite	94.27
	Muscovite	2.25
	Quartz	2.40
OBO6	Hematite	0.82
	Kaolinite	89.4
	Muscovite	5.99
	Quartz	3.79

5.2. Index properties of soil (Grain size distribution and Atterberg limits)

Results of the particle size distributions as presented in Table 2 indicate that the soils are well graded with clay content ranging from 14%-62%. The percentage fine and coarse components of the soil samples from OBO 1- OBO 6 range from 14-62% and 38-86%, respectively. The grain size distribution curves are presented in Figure 4.

According to the Federal Ministry of Works and Housing (FMWH) [26] specification, the fine content (clay + silt) for sub-grade, sub-base and base materials must not exceed 35%. Based on this specification, OBO 3 and OBO 6 are the only fair soils for sub-grade, sub-base and base materials. High clay content in soil will be responsible for instability of road pavements in the area. Nonetheless, soils with fines of less than 50% are expected to have stronger engineering properties, while those with fines of more than 50% are expected to result in compaction problems in the field when used either as base course or as sub-base materials [27] .

Consequently, in terms of the amount of fines, OBO 1 and OBO 2A are not appropriate for use in road construction as sub-base or base course materials, because they may present problems. [28] and [29] noted that the sand particles contribute to the mechanical strength while the clay colloid content provides the plasticity or workability required. Based on this specification, OBO 2B-OBO6 has higher mechanical strength than OBO1 and OBO2A. This variation is apparently due to the difference in mineralogical composition of the parent rocks from which the soils were derived.

Based on the American Association of State Highways and Transportation Officials (AASHTO) [30] soil classification, OBO 3 (A-2-6(0)) and OBO 6 (A-2-4(0)) are classified as good soils for sub-grade and sub-base, OBO 2B and 5 are fair with GI of 4 and 5, respectively. The group index (GI) are useful in evaluating the quality of soil as highway sub-grade material. It gives an indication of the load carrying capacity of a subgrade soil within the AASHTO classification. The higher the GI number the lower the bearing capacity of the soil [12, 31] .

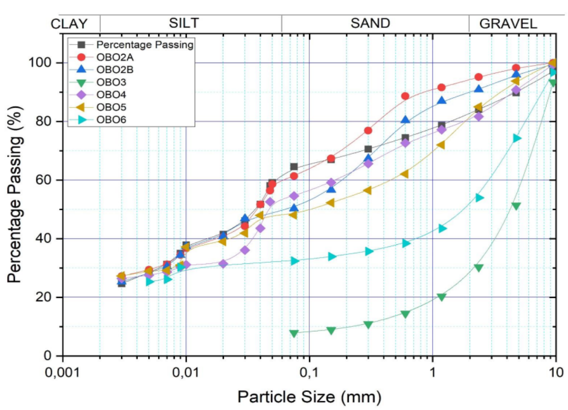

Figure 4: Grain Size Distribution Curves

Atterberg limits involves the determination of the liquid limit and plastic limit, and can be used to estimate the strength and settlement/compressibility characteristics of soils for road construction. The liquid limit and plastic limit ranges between 32.0%-47.2% and 19.7%- 25.9%, respectively (Table 2). Liquid limits of 40-60 % and above are typical of clay soils while values of 25-50% are typical of silty soils as illustrated in [24] . Figure 5 shows the soil plasticity chart in the area under study. Soils with liquid limits of ¡ 30 per cent are considered poor in plasticity and compressibility, those with liquid limits between 30 percent and 50 percent show medium plasticity, whereas those with liquid limits of > 50 per cent show high plasticity and compressibility. Plasticity chart shows that OBO 1-6 falls within medium plasticity. Accordingly, [32] recommended a maximum liquid limit of 45% for base course materials with 15 for plasticity index. More recently, [26] , recommended 50%, 30% and 20% maximum for liquid limits, plastic limits and plasticity index respectively for use as sub-grade, sub-base and base materials. According to the new specification, all the samples were acceptable in terms of liquid and plastic limits. Equally, all the soil samples except 2 (OBO1 and 4) were found suitable based on PI.

The average plasticity index which is the difference between the liquid limit and plastic limit was found to be 16.46. The plasticity index ranges between 10.1%-22.2%. According to [33] , laterite soils having a liquid limit above 30% and plasticity index above 12% are rated poor for use under bituminous surfacing. Therefore, the samples can be rated poor for subgrade material. The average linear shrinkage for the samples is 3.16%. The linear shrinkage values for the soils ranged from 2.14%-4.29%. These values are within the limits of 8% maximum as specified by the [26].

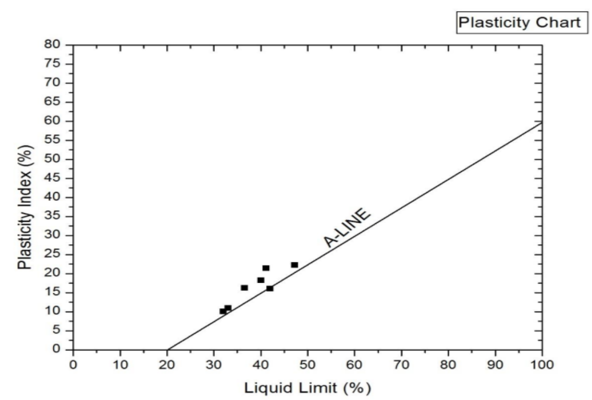

Figure 5: Plasticity chart for soils in the study area.

5.3. *Engineering Properties of Soil (Compaction, CBR and Strength Parameters)*

5.3.1. *Natural moisture content (NMC)*

NMC is one of the most common parameters for soil. Low moisture indicates that the soil is a dry one, whereas high moisture content indicates a wet soil. The study area has moisture content ranging from 6.2% -29.4% (Table 2). Some of these values are higher than the [26] recommended 5-15 percent range. Samples with high NMC indicates poor response to ingress of water and weaker subgrade. Only three samples, OBO 3, 4 and 5 are suitable soils while the rest are not suitable for road construction [34, 12] . High NMC values have been found to negatively influence the shear strength of soils and are not generally suitable for road constructions [11] .

5.3.2. *Compaction Test*

The higher the maximum dry density and the lower the optimum moisture content, the better the soil sample for construction work. Maximum dry density and optimum moisture contents were derived from compaction tests conducted at 95% modified AASHTO (Modified Proctor), the maximum dry density (MDD) ranges from 1210 kg/m^3 to 1520 kg/m^3, while the optimum moisture content (OMC) ranges from 13.0% to 24% (see Table 3). According to [35] , samples classified as

Table 2: Index Properties of Sample Soils

Sample No	% Gravel	% Sand	% Silt	% Clay	% Finer	% Coarse	Liquid Limit %	Plastic Limit %	Plasticity index	Linear Shrinkage %	FMWH (1997)	AASHTO	GI	USCS	Remarks
OBO1	18	26	32	24	56	44	47.2	25	22.2	2.86	Not suitable	A-7-6	10	ML	Sandy silt
OBO2A	6	32	36	26	62	38	42	25.9	16.1	3.57	Not suitable	A-7-6	9	ML	Sandy silt
OBO2B	11	41	23	25	48	52	36.5	20.3	16.2	2.86	Not suitable	A-6	4	ML	Sandy silt
OBO3	66	20	2	12	14	86	33	22	11	3.57	Suitable	A-2-6	0	ML	Sandy silt with gravel
OBO4	12	40	24	26	48	52	41.1	19.7	21.4	2.86	Suitable	A-7-6	6	ML	Sandy silt
OBO5	18	36	18	28	46	54	40	21.8	18.2	2.14	Suitable	A-6	5	ML	Sandy silt
OBO6	51	17	4	28	32	68	32	21.9	10.1	4.29	Suitable	A-2-4	0	ML	Sandy silt with gravel
Range	6-66	17-41	2-36	12-28	14-62	38-86	32.0-47.2	19.7-25.9	10.1-22.2	2.14-4.29					
Average	26	30.29	19.86	24.14	43.71	56.29	38.83	22.37	16.46	3.16					

Table 3: Engineering Properties of Sampled Soils

Sample No	Moisture content (%)	Optimum moisture content % @ MA	Maximum dry density (kg/m^3) @ MA	CBR value (%)	CBR Rating (FMWH, 2010)	Cohesion (C)	Angle of shearing resistance (ϕ)	Shear Strength (kN/m^2)
OBO1	29.4	22.8	1370	4.01	Poor (S2 subgrade)	30	7	31.28
OBO2A	17.9	24	1260	3.01	Poor (S2 subgrade)	50	5	50.87
OBO2B	13	19.2	1460	30.06	Good (S6 subbase/ subgrade)	60	5	60.87
OBO3	6.2	15	1520	44.59	Good (S6 subbase/ subgrade)	185	8	186.41
OBO4	13	21.8	1210	42.59	Good (S6 Subbase/ subgrade)	98	11	99.94
OBO5	11	18.2	1410	26.55	Good(S5 subgrade)	80	10	81.76
OBO6	17.8	13	1340	26.05	Good(S5 subgrade)	120	8	121.41
Range	6.2-29.4	13.0-24.0	1210-1520	3.01-44.59		30-185	5-11	31.28-186.41
Average	15.47	19.14	1367.14	25.27		89	7.71	90.36

sub-base and sub-grade materials with high value of maximum dry density and low optimum humidity content are great.

Also, [36] specified optimum moisture content (OMC) less than 18% and minimum 1700kg/m^3 MDD for both sub-base and sub-grade materials. Based on these specifications, most of the soil are not suitable as sub-base and sub-grade material especially for a high load carrying flexible pavement. [37] , stated that for a good soil, the lower the optimum moisture content, the better its workability and that increase in dry density is an indicator of improvement. According to [38] , soils with MDD greater than 1610 kg/m^3 are suitable for use as landfill barrier materials. None of the samples conform to the specification.

5.3.3. California Bearing Ratio (CBR)

The CBR values vary from 3.01% to 44.59% (Table 2). Recommendation from the Federal Ministry of Works and Housing [36] for use as: sub-grade, sub-base and base materials are: approximately 10%, approximately 30% and approximately 80 %, respectively for unsoaked soil. This means that OBO 1 and OBO2A with values below 10 percent are excellent CBR-based sub-grade materials; OBO 1, 2A, 5, and 6 having values below 30 percent are decent sub-base materials. All areas have less than 80 per cent of their unsoaked CBR values, which is the overall acceptable value for soils to be used as base materials [36] . By interpretation in terms of the strength of the soils, they are adequate for use as a sub-grade or sub-base road construction materials. OBO 1 and OBO 2A with poor CBR are not likely to provide a stable sub-grade material. The rating of soil according to CBR and their corresponding use has been classified according to [26] is presented in table 3.

5.3.4. Shear strength characteristics

The shear strength has been defined as the maximum resistance of a soil to shear stress before failure and it is an important mechanical property of soil which controls its stability under load. Shear strength is dependent on the nature of the soil, inter-particle frictional resistance, force of attraction (cohesion) and fluid pressure within its pores [39] . The strength parameters from the tested soils (OBO 1- OBO 6) shows that the cohesion varies between 30-185 kN/m^2, angle of shearing resistance between $5-11°$ and the shear strength between 31.28-186.41 kN/m^2 . From the result shown in Table 2, the impact of percentage fine and percentage coarse affected the strength of the soils. For instance, OBO 1 and OBO 2A contain a higher percentage of fine and lower percentage of coarse while OBO 2B- OBO 6 contain lower percentage of fine and higher percentage of coarse. The influence is reflected in the strength parameters as OBO 1 and 2A have lower strength compared to OBO 2B- OBO 6 with higher strength value. OBO 3 has the lowest value of moisture content with 6.2 and it has the highest shear strength 186.41 kN/m^2 .

Figures 6-8 illustrates the relationships CBR and PL, shear strength and liquid limits. A negative correlation exists between CBR against plastic limits and liquid limits while a fairly strong correlation exists between CBR and shear strength.

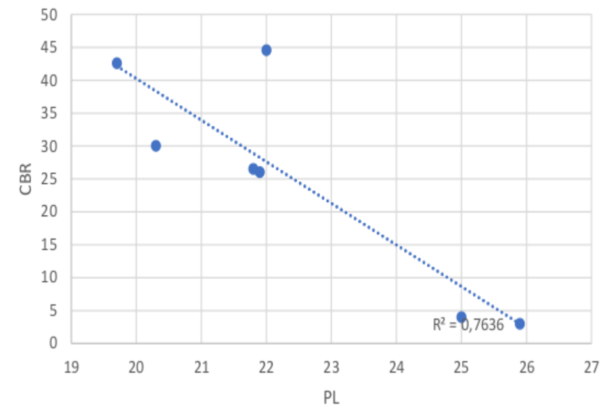

Figure 6: Relationship between CBR and PL

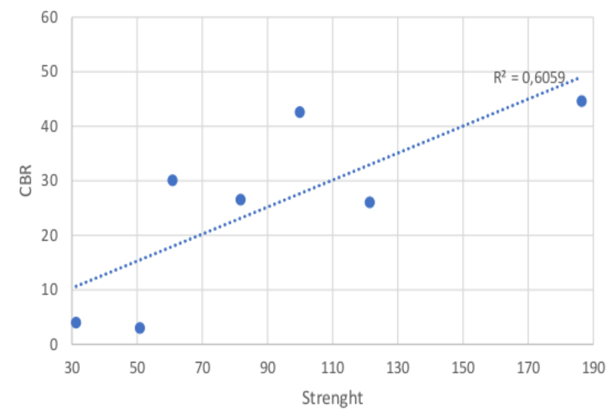

Figure 7: Relationship between CBR and Shear Strength

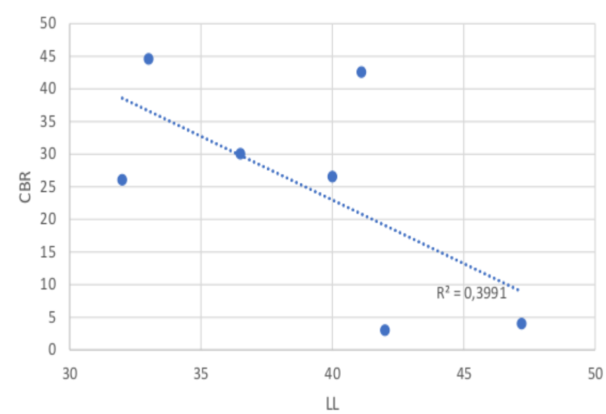

Figure 8: Relationship between CBR and liquid limits

6. Conclusions and Recommendations

The subgrade investigation of the south-east (SE) section of the new ring road in Osogbo metropolis has been undertaken. The result revealed a well-graded inorganic sandy silt soils, with fair compaction characteristics and good drainage. The study reveals that the soil samples are mostly wet soil based on the prevailing hydrological and climatic conditions of the study area and hence, would require an adequate drainage structure to maximise the potentials of the soil as subgrade material. Atterberg limits reflected a subgrade with appropriate LL, PL and PI according to specifications. Engineering properties of the soils revealed mostly cohesive soil with reduced strength, whereas, some of the sampled soil possess a good strength parameter especially those with low moisture contents. CBR classified the samples between poor and good subgrade categories (S2-S6) with 3 samples meeting the CBR conditions for use as subbase and subgrade materials (S5 and S6). Meanwhile, the weak nature of the soil have been attributed to the mineralogy of soil as derived by the parent rock material, this is evident in the low amounts of minerals like SiO_2, Fe_2O_3 and FeO(OH). In conclusion, investigated soils from the study area have shown the very important role of the parent rock in dictating the index and engineering properties of soil. Equally, mineralogy of tropical residual soils was found to be related to the strength or otherwise of the soil samples and the presence of some minerals with high specific gravity may as well enhance the strength of soils for subgrade in road constructions. Finally, mechanical stabilisation may be considered in improving the strength parameters of the soil samples under study for enhanced performance as subgrade soil for road pavement construction.

It is recommended based on the results of NMC and OMC that the improved subgrade soils be raised well above the local water table to prevent soaking and saturation especially during the peak precipitation.

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