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Strength Characteristics of Lateritic Soil Stabilized with Recycled Concrete

Olufikayo Aderinlewo[1], Benjamin Adele[2]
[1,2]Civil Engineering Department, Federal University of Technology Akure, Nigeria
([1]oluade2010@gmail.com)

Abstract- This study investigates the use of recycled concrete as a stabilizing agent for lateritic soil. The pulverized recycled concrete was added to the soil in varying proportions of 2, 4, 6, 8, 10 and 12% by weight of the lateritic soil samples. The compaction test on the modified soil showed that the Maximum dry density (MDD) increased by 5.07% from the initial MDD value of 1732.18 kg/m^3 when the soil sample was stabilized with 10% recycled concrete. Increase in the recycled concrete to 12% by weight of the soil sample had a percentage increase of 4% from the initial MDD value. The unsoaked California Bearing Ratio (CBR) value of the soil increased by 111.2% from the initial CBR value of 23.1% when the soil sample was stabilized with 10% recycled concrete. An increase in the recycled concrete content to 12% by weight of the soil sample gave an increase of 94.4% from the initial CBR value. The Unconfined Compressive Strength (UCS) experienced an increase of 62.5% from the initial UCS value of 190.77 kN/m^2 when the soil sample was stabilized with 10% recycled concrete by weight of the soil sample. Increase in the recycled concrete content to 12% by weight of the soil sample gave a percentage increase of 57.4% from the initial UCS value. The 10% recycled concrete (by weight of soil sample) produced the peak values of 310.08kN/m^2 and 48.8% for the unconfined compressive strength and California bearing ratio respectively.

Keywords- *Recycled Concrete, Maximum Dry Density, California Bearing Ratio*

I. INTRODUCTION

The need for adequate provision of transportation facilities is enormously increasing with increase in population. Highway engineers are faced with the problem of providing very suitable materials for highway construction. Owing to this fact, research is on-going by various organizations on ways to improve the engineering properties of soils most especially lateritic soils which are unstable soils. Hence, these soils have to be treated in order to improve their properties. The process of treatment is called stabilization which is any treatment applied to soil to improve its strength and reduce its vulnerability to water. If the treated soil is able to withstand the stresses imposed on it by traffic under all weather conditions without excessive deformation, then it is generally regarded as stable.

Several highway pavements in Nigeria are failing due to lack of the use of soil with adequate engineering strength. Many soils, in their initial state, lack strength and/or dimensional stability which render them unsuitable to the requirements of construction. Therefore, the Engineer has the choice of accepting the limitations imposed by the in situ soil properties, replacing the available soil by another one which complies with the specified requirements or improving the properties of the existing soil by stabilization so as to fulfill the design criteria. The ability to blend the naturally abundant lateritic soil with some chemical reagent to give it better engineering properties in both strength and waterproofing has been of paramount importance to transportation engineers. In a bid to improve the engineering properties of soil to make it suitable for road construction, several researches on soil stabilization have been carried out [1-5].

From an engineering point of view, laterite or lateritic soil is a product of tropical weathering with red, reddish brown and dark brown colour, with or without nodules or concretions and generally found below hardened ferruginous crusts [6]. Generally, the degree of laterization is estimated by the silica to sesquioxides (S-S) ratio (SiO_2/ (Fe_2O_3 + Al_2O_3)). A Silica-Sesquioxide (S-S) ratio less than 1.33 is indicative of laterites, between 1.33 and 2.00 is indicative of lateritic soils and greater than 2.00 is indicative of non-lateritic soils. Lateritic soils are widely employed as imported filling material for the prepared sub grade on different kinds of road projects. Lateritic soils are often stabilized to enhance durability of such roads. Some of the important goals of soil stabilization include increase in strength and stiffness of soils, increase in durability, enhancement of workability, reduction of compressibility, reduction of permeability and reduction of volume instability

Developments in the country have awakened the sense of economical resource management in the populace. People are being inspired to go back and take a closer look at the resources which they have earlier condemned, so as to find ways through which they could put such materials to use again. This is mainly because there is an increased competition for available materials as multiple uses of such resources are being discovered, and the cost of acquiring these suitable materials increases alongside. Major steps have therefore been taken to conduct researches that put abandoned materials into full use again. Moreover, various studies are being carried out to discover better ways of achieving this goal; ways that will cost less and would be more economical when compared to using materials that naturally meet required standards.

Recycled concretes are formed when structures made of concrete are demolished or renovated. Concrete recycling is an increasingly common method of utilizing the rubble which was once routinely trucked to landfills for disposal. Recycling has a number of benefits that have made it a more attractive option in this age of greater environmental awareness with the desire to keep construction costs down. These benefits include keeping concrete debris out of landfills thereby saving landfill space, reducing the need for gravel mining, and reducing the pollution involved in trucking material

The government of Ondo state in the year 2010 approved the contract for the dualization of Arakale road which covers a total length of 2.25 kilometres and having 9.2 metres wide asphalt pavement on each side of the two way road as well as a 2.4 metre wide concrete pedestrian walkway on either side of the road. The project which was awarded at a cost of N2.8 billion also included the cost of compensation to the owners of about 338 buildings that were demolished, cost of demolishing the building and cost of transporting the demolished wastes. The samples of the concrete debris were collected, recycled and used as stabilizing agent in this study with the aim of assessing the strength characteristics of lateritic soil thereby stabilized. The underlying objectives are to evaluate and compare the strength characteristics of the lateritic soil stabilized with recycled concrete and lateritic soil stabilized with cement; and assess the suitability and effectiveness of recycled concrete as a lateritic soil stabilizer.

II. BACKGROUND LITERATURE

Over the years, cement and lime have been the two main materials used for stabilizing soils. These materials have rapidly increased in price due to the sharp increase in the cost of energy required for their production since the 1970s [7]. The over dependence on the utilization of industrially manufactured soil improving additives (such as cement and lime) have kept the cost of construction of stabilized roads high. Hence, soil stabilization is the process by which the engineering properties of soil layers can be improved or treated by addition of other soil types, mineral materials or by mixing the appropriate chemical additive into the pulverized soil and then carrying out compaction [8]. It is aimed at improving the soil density, increasing its cohesion, frictional resistance and reducing its plasticity index. However, it is a must to obtain adequate relevant information concerning the ground condition and soil properties relating to the grading of the soil. Soil stabilization is used mainly in construction of earth dams, embankments, sub grade, sub base, bases, run ways and pavements [9].

The two general methods of stabilization are mechanical and chemical stabilization. In mechanical method of soil stabilization, improvement of soil engineering properties is carried out by the addition of other soil particles which are missing from its natural grading. In ground improvement projects, this normally leads to soil compaction, both deep and superficial. The soil as a material is densified by mechanical means and is used as fill in the construction of embankments, earth dams and subgrade of roads [10-11]. The increase in density is achieved by decreasing the air voids content while the water content remains approximately the same. Soil stabilization through compaction is mostly carried out by field compaction which involves the use of different compacting equipment [8]. In the chemical method of soil stabilization, a manufactured commercial product is added to the soil in adequate quantities such aswill improve the quality of the soil. These products include Portland cement, lime, lime-cement-fly ash and bitumen. The selection of these products depends upon the soil classification and degree of improvement in soil quality desired.

The soil name "laterite" was coined by Buchanan in 1807 in India, from a Latin word "later" meaning brick. This first reference is from India, where this soft, moist soil was cut into blocks of brick size and then dried in the sun. The blocks became irreversibly hard by drying and were used as building bricks. Soils under this classification are characterized by forming hard, impenetrable and often irreversible pans when dried [12]. They are characterized by the presence of iron and aluminum oxides or hydroxides, particularly those of iron, which give the colors to the soils. However, there is a pronounced tendency to call all red tropical soils laterite and this has caused a lot of confusion. The term laterite may be correctly applied to clays, sands, and gravels in various combinations while “lateritic soils” refer to materials with lower concentrations of oxides.

Stabilization of soil is employed when it is more economical to overcome a deficiency in a readily available material than to bring in one that fully complies with the requirements of specification for the soil [1]. It has been regarded as a last resort for upgrading substandard materials where no economic alternative is available. A continual reference to economy here denotes a careful consideration of all costs that would be incurred by importation of a compliant soil and comparing this to the cost of improving the properties of an unstable but readily available soil. Interest in the art of soil stabilization grew with a better appreciation of the cyclic loading effects of heavy traffic which creates a need for stronger pavements that often cannot be provided by realistic thickness of unbound granular materials, and the availability of purpose built - in – situ stabilization equipment that improves homogeneity of mix.

The compaction characteristics of laterite are determined by their grading characteristics and plasticity of fines [12]. These in turn can be traced to genetic and pedological factors. Placement variables (moisture content, amount of compaction and type of compaction effort) also influence the compaction characteristics. Varying each of these placement variables has an effect on permeability, compressibility, strength and stress-strain characteristics [13]. The significant characteristics of lateritic soil are the influence of the strength of the concretionary coarse particles on compaction. Most laterite soils contain a mixture of quartz and concretionary coarse particles, which may vary from hard to very soft. The strength of these particles has major implications in terms of field and laboratory compaction results and their subsequent performance in road pavements. Weak coarse fractions break down under rolling and traffic loading with a resulting increase in fines of the soil. The degree to which the materials break down is related to the content of iron oxide and the degree of dehydration. For example, soils compacted on the dry side of the optimum moisture content swell more that soils compacted on the wet side because the soil compacted on the dry side has greater moisture deficiency and a lower degree of saturation. On the other hand, soils compacted on the wet side of the optimum moisture content will shrink more on drying than soils compacted on the dry side [13].

The California bearing ratio (CBR) is a strength-based method of pavement design which uses the load-deformation characteristics of the roadbed soils, aggregate subbase, and base materials, and an empirical design chart to determine the thicknesses of the pavement, base, and other layers. The test originated with the California Division of Highways, although this agency now uses the Hveem stabilometer method. The CBR value is an estimate of the quality of the material as compared to that of an excellent base material, for which the CBR is assumed to equal 100 percent.

A. Recycled Concrete

The potential of recycled concrete in a range of specific engineering applications have been shown by a number of earlier research works [14-15]. The Commonwealth Scientific and Industrial Research Organization (CSIRO) in 2002 reported that Class 1A recycled concrete, which is a well graded, good quality recycled concrete with no greater than 0.5% brick content, had the potential for use in a wide range of applications, subject to appropriate tests or performance requirements. Applications include partial replacement (up to 30% of coarse recycled concrete) of virgin material in concrete production for non-structural work such as kerbs and gutters.

It was suggested that Class 1A recycled concrete could be incorporated into 30 to 40 MPa concrete exposed to benign environments but with some penalties in mix adjustment, permeability and shrinkage properties [16]. There were no visual detrimental effects in the concrete and it was expected that the cost of the increase in cement content could be offset by the lower cost of recycled concrete. Concrete from back-fill or road sub-base materials in pavements were used as recycled aggregates in some other works [17]. The maximum coarse aggregate size was 16 mm. He compared reinforced concrete with natural aggregates and with recycled aggregates. His results showed that compressive strength of concrete with natural aggregates was 35% higher than compressive strength of concrete with recycled aggregates.

One study showed that the construction industry produced 83 million tons of construction waste per year of which, 35 million tons was related to concrete waste [18]. 30% to 50% of a poor soil was replaced with recycled coarse aggregates from a building that has been erected 30 years age and obtained 32.6-35.8 MPa compressive strength after 28 days with standard curing condition. Another study revealed the workability of virgin concrete and discovered that it is higher than that of the recycled concrete, when the water/cement ratio is same. The compressive strength of recycled concrete is to some extent less than that of virgin concrete, when the water/cement ratio is low. However, at higher ratios, the compressive strength of recycled concrete is similar to that of virgin concrete [19].

III. METHODOLOGY AND MATERIALS

The lateritic soil samples were collected from a site located beside the Electrical Engineering workshop on the campus of the Federal University of Technology, Akure (FUTA) Ondo State, Nigeria. The recycled concrete was produced by crushing clean demolition waste of buildings demolished at Arakale, Akure, Nigeria. Figure 1 shows a sample of the pulverized recycled concrete. The method used in the sample collection of the lateritic soil is the trial pit method. One undisturbed block sample and several disturbed samples were collected from one location at the site. A trial pit is simply a hole dug in the ground that is large enough for a ladder to be inserted, thus permitting a close examination of the sides. With this method, relatively undisturbed samples of soils were collected. The depth of the trial pit was 1.2m (4ft) and about (1.2m) 4ft long and (1.2m) 4ft wide. The pit was sunk by hand excavation with the aid of spade and digger.

Thereafter, the stabilizing material was added to the lateritic soil specimens in percentages of 2, 4, 6, 8, 10 and 12% by weight of the soil. These quantities fall in the range of those used in previous studies [11]. Cement stabilized lateritic soil samples were also prepared using the above proportions which served as a basis for comparison since cement is considered to be the best soil stabilizer.

Figure 1. A sample of the pulverized recycled concrete.

The following tests were performed on the soil with and without the recycled concrete on one hand and with and without cement on the other hand:

- Moisture content test according to BS1377:1990 Part 2:3
- Atterberg limits test according to BS1377:1990 Part 2:4 and 2:5
- Density test according to BS1377:1990 Part 2:7

- Specific gravity test according to BS1377:1990 Part 2:8
- Particle size distribution (or sieve analysis) test according to BS1377:1990 Part 2:9
- Unconfined compressive strength test according to BS1377:1990 Part 7:7
- Compaction test according to BS1377:1990 Part 4:3
- California Bearing ratio (CBR) test according to BS1377:1990 Part 4:7
- X-ray fluorescence analyzer was used for the elemental analysis of the soil sample in order to determine percent composition of the elements present. The test was carried out at Rolab Research and Diagnostic Laboratory, Challenge, Ibadan, Nigeria.

IV. DISCUSSION OF RESULTS

A summary of the results of the basic geotechnical and elemental composition tests conducted on the lateritic soil without the pulverized recycled concrete are shown in table 1.

TABLE I. SUMMARY OF THE PRELIMINARY ANALYSIS ON THE SOIL SAMPLE

Engineering & Physical Properties	VALUES
Cation Exchange Capacity (meq/100g)	13.24
pH	6.3
Specific Gravity	2.74
Liquid Limit, LL (%)	51.2
Plastic Limit, PL (%)	21.4
Plasticity Index, PI (%)	29.8
Natural Moisture content (%)	20.8
Linear Shrinkage (%)	11.5
Bulk Density (g/cm^3)	1.64
Organic Matter (g/kg)	6.2
AASHTO Classification	A-2-7 (4)
Chemical/Elemental composition	VALUES (%)
Aluminum (Al)	91.20
Titanium (Ti)	0.89
Silicon (Si)	2.10
Iron (Fe)	5.55
Zinc (Zn)	0.01
Zirconium (Zr)	0.05
Molybdenum(Mo)	0.04
Manganese (Mn)	0.13

Based on table 1, the natural moisture content of the soil without the recycled concrete was 20.8%, Atterberg limits consisting of Liquid limit and Plastic limit were 51.2% and 21.4% respectively, plasticity index of the lateritic soil sample was 29.8% which indicated that the soil was medium plastic. Specific gravity, pH and CEC for the lateritic soil sample were 2.74, 6.3 and 13.24 meq/100g respectively. The organic matter present in the soil was 6.2g/kg. According to AASHTO classification, the soil was classified into group A-2-7 with a group index of 4. The X-ray fluorescence tests were used to determine the elemental composition of the lateritic soil, the main constituent elements were Aluminum and Iron which were 91.2% and 5.55% respectively.

Figure 2 shows the particle size distribution curve for the lateritic soil in which approximately 34% of the soil passed through Sieve No 200 while figure 3 shows the particle size distribution curve of the crushed recycled concrete in which approximately 5% of the crushed recycled concrete passed through Sieve No 200.

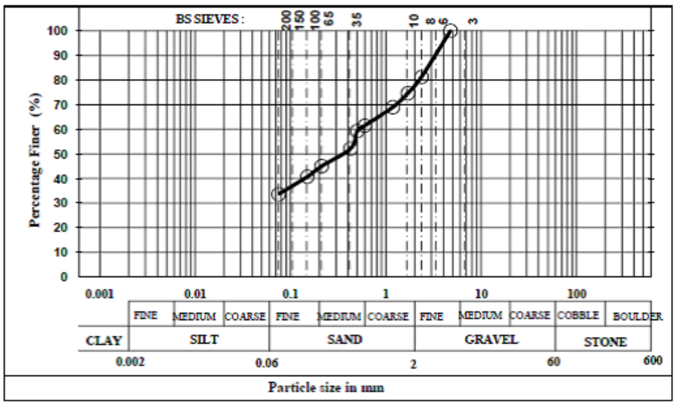

Figure 2. Particle size distribution curve for the lateritic soil sample

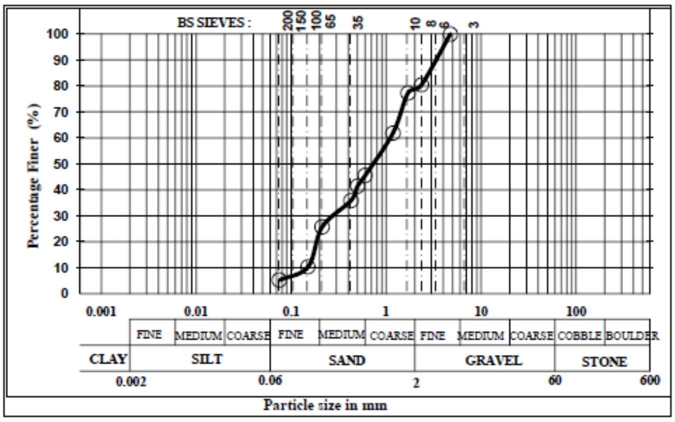

Figure 3. Particle size distribution curve for the recycled concrete

The elemental composition of the recycled concrete is shown in Table 2. The main constituent elements in the recycled concrete were Calcium, Aluminum, Iron and Silicon which were 31%, 24.4%, 20.93% and 12.1% respectively.

TABLE II. ELEMENTAL COMPOSITION OF THE RECYCLED CONCRETE

Elemental Composition of Recycled Concrete	VALUES (%)
Calcium (Ca)	31.00
Aluminum (Al)	24.40
Iron (Fe)	20.93
Silicon (Si)	12.10
Potassium (K)	5.80
Magnesium (Mg)	1.47
Sodium (Na)	0.45

A. *Compaction Test Results*

The British Standard Light (BSL) compactive effort was adopted for this study. The graph of the dry densities and the moisture contents of the soil sample stabilized with recycled concrete is shown in Figure 4 while that of cement is shown in Figure 5. Both figures showed that with increase in the recycled concrete and cement content there was an increase in the maximum dry density (MDD) and the optimum moisture content (OMC). This is evident from the upwards and right side shift of the compaction curves of the lateritic soil sample containing 0% stabilizer.

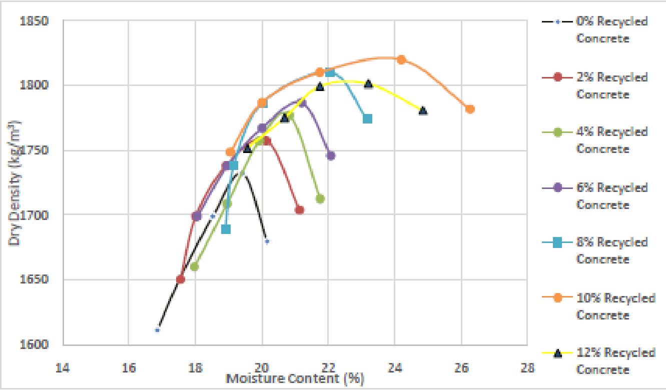

Figure 4. Compaction curves for the lateritic soil stabilized with varying quantities of recycled concrete

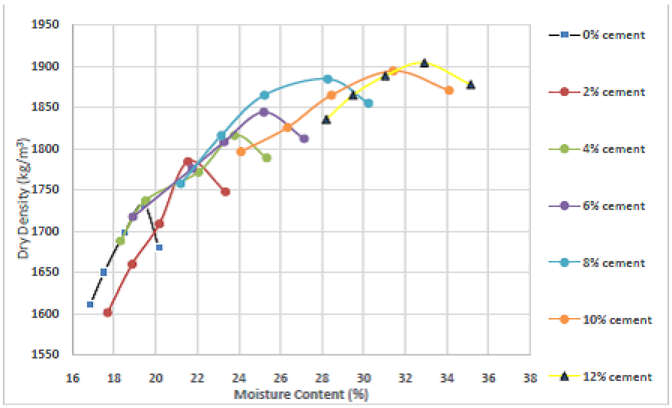

Figure 5. Compaction curves for the lateritic soil stabilized with varying quantities of cement

Figure 6 shows the overall values of maximum dry densities obtained for the lateritic soil with and without the recycled concrete and cement.

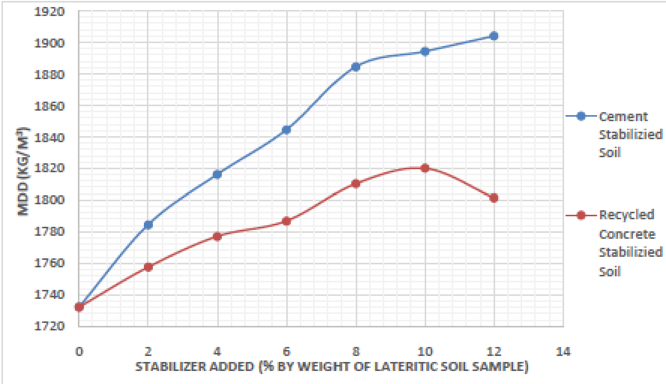

Figure 6. Maximum Dry Density (MDD) values of lateritic soil stabilized with recycled concrete and cement

Figure 6 shows that there was a percentage increase of 9.92% in the MDD value for samples stabilized with cement as the cement quantity was increased to 12% by weight of the soil sample. For the recycled concrete, as the quantity of the recycled concrete was increased to 10% by weight of the soil sample there was a percentage increase of 5.07% in the MDD value which subsequently decreased to 4% as the quantity of the recycled concrete was increased to 12% by weight of the soil sample. The addition of 10% (by weight of the soil sample) recycled concrete content produced the highest dry density value in the lateritic soil samples from the varying quantities of recycled concrete tested. Figure 7 shows the overall corresponding values of optimum moisture contents obtained for the lateritic soil with and without the recycled concrete and cement.

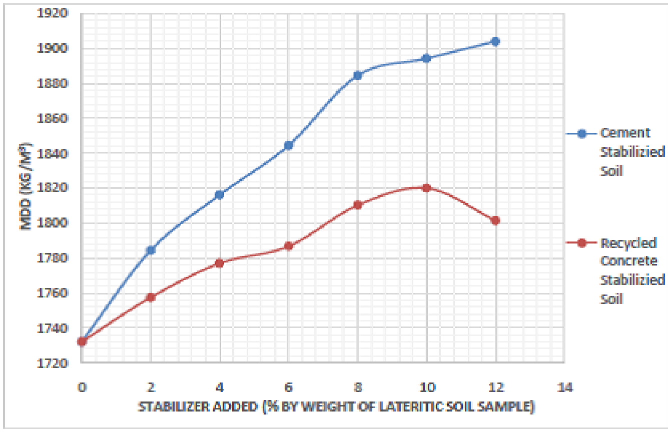

Figure 7. Optimum moisture content values of lateritic soil stabilized with recycled concrete and cement

Figure 7 shows that there was a percentage increase of 32.93% in the OMC value for samples stabilized with cement as the cement quantity was increased to 12% by weight of the soil sample. For recycled concrete, as the quantity of the recycled concrete was increased to 10% by weight of the soil sample there was a percentage increase of 24.19% in the OMC value which subsequently decreased to 23.20% as the quantity of the recycled concrete was increased to 12% by weight of the soil sample. The addition of 10% (by weight of the soil sample) recycled concrete produced the highest Optimum Moisture Content (OMC) value in the lateritic soil samples from the varying quantities of recycled concrete tested.

B. California Bearing Ratio (CBR) Test Results

The effects of addition of varying quantities of cement and recycled concrete by weight of the soil sample on the soaked CBR of the lateritic soil sample are illustrated in Figure 8.

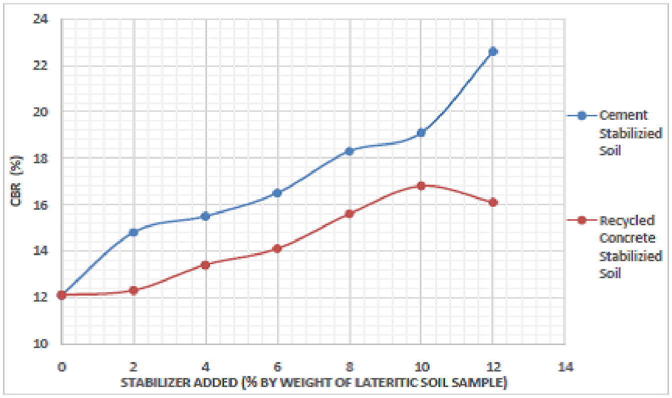

Figure 8. Soaked California Bearing ratio values of lateritic soil stabilized with recycled concrete and cement

There was a percentage increase of 86.8% in the soaked CBR value for sample stabilized with cement as the cement quantity was increased to 12% by weight of the soil sample. For recycled concrete, as the recycled concrete quantity was increased to 10% by weight of the soil sample there was a percentage increase of 38.8% in soaked CBR value which subsequently reduced to 33% as the quantity of the recycled concrete was increased to 12% by weight of the soil sample. The addition of 10% (by weight of the soil sample) recycled concrete produced the highest Soaked California Bearing Ratio (CBR) value in the lateritic soil samples from the varying quantities of recycled concrete tested.

The effects of addition of varying quantities of cement and recycled concrete by weight of the soil sample on the unsoaked CBR of the lateritic soil sample are illustrated in Figure 9.

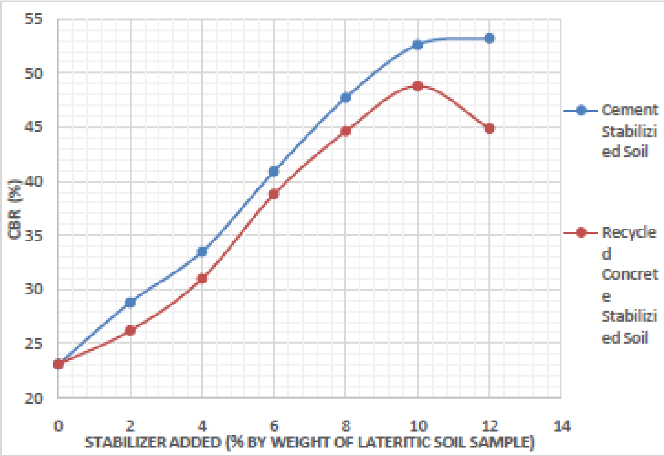

Figure 9. Unsoaked California Bearing ratio values of lateritic soil stabilized with recycled concrete and cement

There was a percentage increase of 130.3% in the unsoaked CBR value for sample stabilized with cement as the cement quantity was increased to 12% by weight of the soil sample. For recycled concrete, as the recycled concrete quantity was increased to 10% by weight of the soil sample there was a percentage increase of 111.2% in Unsoaked CBR value which subsequently reduced to 94.4% as the quantity of the recycled concrete was increased to 12% by weight of the soil sample. The addition of 10% (by weight of the soil sample) recycled concrete produced the highest Unsoaked California Bearing Ratio (CBR) value in the lateritic soil samples on addition of varying quantities of recycled concrete.

C. Unconfined compressive strength (UCS) test results

The effects of addition of varying quantities of cement and recycled concrete by weight of the soil sample on UCS of the lateritic soil sample are as illustrated in Figure 10.

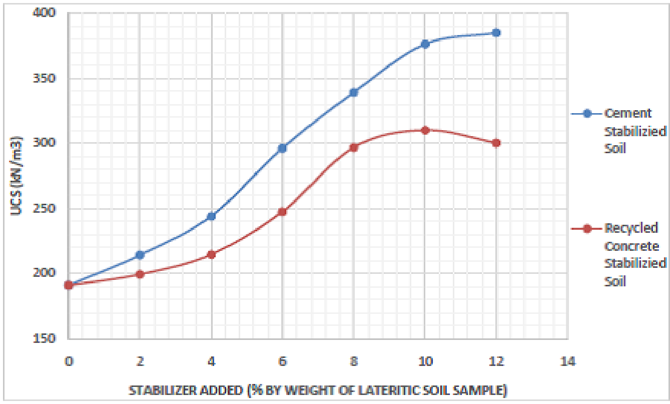

Figure 10. Unconfined compressive strength values of lateritic soil stabilized with recycled concrete and cement

There was a percentage increase of 101.8% in the compressive strength value for samples stabilized with cement as the quantity of cement was increased to 12% by weight of the soil sample. For recycled concrete, as the quantity of recycled concrete was increased to 10% by weight of the soil sample there was a percentage increase of 62.5% in the compressive strength value which subsequently reduced to 57.4% as the quantity of the recycled concrete was increased to 12% by weight of the soil sample. The addition of 10% (by weight of the soil sample) recycled concrete produced the highest compressive strength value in the lateritic soil samples from the varying quantities of recycled concrete tested.

V. CONCLUSION AND RECOMMENDATIONS

The study was conducted to determine the characteristics of lateritic soil stabilized with recycled concrete. The strength tests of the recycled concrete stabilized soil were also compared with the cement stabilized soil to evaluate the effectiveness of the stabilization process since cement is considered to be the best soil stabilizer. Based on the laboratory tests, the following conclusions were drawn:

- The suitability of recycled concrete to stabilize a soil sample depends on the type of the soil sample and the quantity of recycled concrete (stabilizer).
- The compaction test on the recycled concrete stabilized lateritic soil shows that the Maximum Dry Density (MDD) had a percentage increase of 5.07% from the initial MDD value of 1732.18 kg/m3, when the soil sample was stabilized with recycled concrete of 10% by weight of the soil sample. Increase in the recycled concrete to 12% by weight of the soil sample had a percentage increase of 4% from the initial MDD value. The Optimum Moisture Content (OMC) had a percentage increase of 24.63% from the initial OMC value of 19.41%, when the soil sample was stabilized with recycled concrete of 10% by weight of the soil sample. Increase in the recycled concrete to 12% by weight of the soil sample had a percentage decrease of 19.53% from the initial OMC value.
- The strength of the recycled concrete stabilized lateritic soil shows that the unsoaked California Bearing Ratio (CBR) value had a percentage increase of 111.2% from the initial CBR value of 23.1%, when the soil sample was stabilized with 10% recycled concrete by weight of the soil sample. Increase in the recycled concrete to 12% by weight of the soil sample had a percentage increase of 94.4% from the initial CBR value. The Unconfined Compressive Strength (UCS) had an increase of 62.5% from the initial UCS value of 190.77 kN/m2, when the soil sample was stabilized with 10% recycled concrete by weight of the soil sample. Increase in the recycled concrete to 12% by weight of the soil sample had a percentage increase of 57.4% from the initial UCS value.
- Finally, the 10% recycled concrete content by weight of the lateritic soil is the most suitable (of the varied percentages of recycled concrete tested) to stabilize the lateritic soil because it gives the peak values for the strength tests conducted with a compressive strength of 310.08 kN/m2 and a California bearing ratio of 48.8%. The Nigerian general specification for road and bridge work recommends a minimum CBR value of 80% for base course in pavement design, hence, the peak CBR values of 48.8% for the 10% recycled concrete stabilized lateritic soil sample did not satisfy the condition to be used as base course. However, it met the minimum conventional CBR value of 40% for sub-base soils for lightly trafficked road, since the CBR value for sub-base for the tropics are CBR≥ 45% (minor roads) and CBR≥ 65% (major or urban roads) [20].

As a result of the outcome of this study, the following recommendations were made:

- The use of Recycled Concrete Aggregate (RCA) as a lateritic soil stabilizer is recommended as this reduces the waste in the environment while also providing an alternative for soil stabilization.
- The use of RCA and Cement mixtures as soil stabilizer should be investigated.

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