EVALUATION OF STRENGTH CHARACTERISTICS OF LOW PLASTIC CLAY SOIL TREATED WITH CERAMIC DUST

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ABSTRACT

The effect of ceramic dust addition on the geotechnical characteristics of tropical clay was investigated. In the study, moisture content, particle size distribution, Atterberg limits, specific gravity, compaction tests, Califonia Bearing Ratio (CBR) and Unconfined Compressive Strenght (UCS) were carried out on samples of tropical clay with ceramic dust concentrations of 0 - 40% by dry weight of soil. Result obtained shows the average moisture content of the tropical clay in its natural state was 14.27 %, the tropical clay contain high proportions of clay-silt fractions (71.76%) and classified as A-6, having Liquid Limit of 37.8%, Plastic Limit of 22.64% and Plasticity Index of 15.16%. The plastic limit of the tropical clay decreases from 22.64 to 16.8%, the liquid limit decreases from 37.8 to 20.8% and the plasticity index decreases from 15.6 to 3.0% when ceramic dust is increased from 0 to 40% respectively. The liquid limit with 28.4 – 20.8% value range when stabilized with ceramic dust content variation of 20 - 40% respectively is in line as specified by the Nigeria general specification interms of Pavement Design (30%) but the Plasticity Index values (10.3 -3.0%) is below those specified by the Nigeria general specification interms of Pavement Design (13%). The tropical Clay sample had improved the MDD from its natural value using 0 - 20% ceramic dust, but beyound 20% ceramic dust, with further increase of OMC, the amount of voids in soil gots increased and dry density decreased under loading condition. The CBR increased from 14.23, 20.49 at 0% Ceramic Dust content to 20.49, 35.95 at 40% ceramic dust content respectively for 3 and 28 days unsoaked bearing test, but the bearing strength of the soaked tropical clay soil decreased significantly, with the addition of ceramic dust up to 40% content, the CBR decreased from 5.31, 1.52 at 0% to 11.38, 2.56 at 40% Ceramic Dust content respectively for 3 and 28 days soaked bearing test. however, both results indicate that a better CBR was achieved without soaking. therefore, the mechanical strength was improved. The UCS value of the soil sample increased from 18.11, 20.92, 19.62, 28.75 and 24.65 kN/m^2 to 18.54, 23.65, 29.64, 50.4 and 41.80 kN/m^2 for 0 - 28 days curing when ceramic dust is increased from 0 to 40%.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Expansive soils also known as problematic soils, have a tendency to swell and shrink due to variation of its moisture content. These soils are found in arid and semi-arid regions of Nigeria marked with dry and wet seasonal weather. Expansive soils deposits in the north-eastern part of Nigeria often referred to as tropical clay soil are usually dark grey to black in nature with high content of clay mineral (Morin, 1971). Adesunloye (1987) reported that they are found in arid and semi-arid regions of the tropical zones marked with dry and wet seasons as expansive clay deposits, lying within the upper Benue and the Chad basin trough. Due to the unfavourable characteristics and problematic nature of clay, their use in Civil Engineering construction has thus been limited (Nigerian Building and Road Research Institute, 1983). The soil has high potential for shrinking or swelling due to variation of its moisture content. Ola (1983) described tropical clays as being highly plastic silty clays formed by the weathering of basalt rock, shale and clay sediments. in north-eastern Nigeria where tropical clays are predominant, and wherever they exist in the world, they cannot meet the strength and compressibility requirements imposed for their use in sub-grades as they can cause extensive damage to structures if not stabilized or treated. it is important either to remove the existing expansive soil and replace it with non-expansive soil or to improve the engineering properties by mean of stabilization.

Poor base, subbase and subgrade soil condition can result in inadequate pavement support and reduced pavement life or a potential natural hazard which can cause extensive damage to foundations and structures. In Civil Engineering, soils that are expansive and collapsible such as clay, are extremely difficult to work with due to their high plasticity and low strenght. Such clays attract and absorb water, thereby making it highly susceptible to swelling and shrinkage with properties that cannot be safely and economically used for the construction of civil engineering structures without adopting some stabilization measures. Tropical clay shrink considerably when they dry out during hot weather, resulting in formation of extensive cracks and experiences high swelling when soaked in water, and also possesses low compressive strength at higher water content. To the highway and geotechnical engineers, a problem soil is one that poses problem to construction. Such problems may be as a result of unstable nature of the native soil which makes it unsuitable as a construction material in highways, foundations, water retaining structures etc., These problems can cause extensive damages not only to the structures built upon them, but also can cause loss of human life. Tropical clay containing the clay minerals montmorillonite generally exhibit these properties (Ola, 1987). However, there has been increasing need for research into sustainable development of roads, which has encouraged research into the use of alternative contruction materials, to complement the Conventional ones. Soils may be improved through the addition of chemical or cementitious additives, the methods of soil stabilization apply different principles and can be categorized into mechanical and chemical ones.

Mechanical methods of soil stabilization are changing just physical properties of soils, i.e. density, while chemical methods are changing chemical content of soils and thus influence chemical and physical properties. These stabilizers range from waste by-products to manufactured materials, this includes Portland cement, lime, chemical stabilizers, ceramic dust, etc. the common appropriate approach is to stabilize the soil with suitable stabilizers. Various types of soil stabilizers such as bitumen lime, cement, fly ash, kiln dust and locally available materials like rice husk ash, slate dust, ceramic dust etc. These stabilizers can be used with a variety of soil samples to help improve their engineering properties. The effectiveness of these stabilizers depends on the soil or clay material treated and the type and amount in percentage of additives used as stabilizer. Globally and nationally, Initiatives have been instigated to control and regulate waste management, regulations or waste management laws have become increasingly rigorous and consequently, options which are still rarely used at present, such as minimizing or recycling waste, are becoming economically attractive. Recycling and reuse of waste products involve research aimed at acquiring a full understanding of such products in order to determine suitable and specific applications (Sanchez *et al*., 2007).

The problem associated with quantity of waste being generated are becoming increasingly acute due to the growing quantity of industrial, construction and demolition waste generated. (Chen and Idusuyi, 2015) It has been estimated that about 30% of daily industrial production in the ceramic industry goes to waste and this waste is not fully recycled (Binici, 2007). Ceramic Dust (CD) is a waste by product of ceramic products. Manufactured ceramics include wall and floor tiles, sanitary ware, household ceramics and technical ceramics. According to Binnici (2007) use of ceramic waste has increased because it has various advantages over other industrial by products or waste materials.

1.2 Statement of the Research Problem

Although the country possesses various types of soil suitable for highway construction, the Nigerian North-Eastern part soils lying within the upper Benue and the Chad basin trough has a large presence of the problematic expansive Tropical clay . These expansive soils are usually dark grey to black in nature with high content of clay constituent are the most troublesome clay minerals when encountered in construction. The shrink-swell is usually in an uneven pattern with consequential causes of damage to structures and pavements resting on them (Nelson and Miller, 1992). It has been estimated that about 30% of daily production in the ceramic industry goes to waste and this waste is not fully recycled at present (Binici, 2007). Hence, putting industrial materials such as ceramic waste, locally and readily available materials from Indigenous locally sourced materials and local industrial by-products uniquely abundant in certain localities can be used in engineering construction to solve several environmental problems.

1.3 Aim and Objectives of Study

The aim of this research is to evaluate the strength characteristics of low plastic clay soil treated with ceramic dust.

The objectives of the research are to ;

(i) Determine the index and physio-chemical properties of the Tropical clay and the Ceramic Dust.

(ii) Acertain the moisture-density relationship using the three compactive efforts viz: West African Standard (WAS), British Standard Light (BSL), and British Standard Heavy (BSH) compactions.

(iii) Examine the strenght properties of the soil using California Bearing Ratio (CBR), and Unconfined Compressive Strength (UCS) with view to determine their maximum acceptable blends.

1.4 Justification of the Study

A lot of researches have been carried out on Tropical clay using using stabilizing agents such as Lime, Soya Beans, Chloride, Sodium Silicate, Saw Dust Ash, Ferric Chloride, Locust Bean Waste, Cement ,Bitumen etc. to strengthen the properties of the soil in the past (Ola, 1983), stabilizing expansive clay soil with ceramic dust has received very little attention. However, many attempts have been made to stabilize lateritic and clay soils with ceramic dust. So the stabilization of expansive tropical clay with the ceramic dust if found suitable economically would make available an abundant road improvement material.

1.5 Scope of the Study

The study is restricted to evaluation of laboratory experimental tests on the physical and strength properties of tropical clay soil treated with ceramic dust using of 0 - 40% content.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Geological Formation of Nigerian Expansive Soil

Two typical parent rock materials have been associated with the formation of unstable expansive soils. The first comprises sedimentary rock of volcanic origin, found in South Africa and North America (Ola, 1978), while the second group are basic igneous rocks found in Nigeria and India (Plait, 1953). Nigerian Tropical clays are formed from the weathering of shaly and clayey sediments and basaltic rocks. According to Ola (1983), the Nigerian Tropical clays contain more of the montmorillonite with subsequent manifestation of swelling properties and expansive tendencies.

Some of the major roads that link Nigeria with the neighboring republics of Cameroon and Chad pass through these problematic soils. These roads carry Nigeria's exports of fuel and other produce which approached some 250,000 tonnes annually from the main Nigerian ports through Kano and Maiduguri to these neighboring countries (Ibrahim, 1977). The problem of road construction on these soils is further complicated by the fact that about 75% of the commercial vehicles travelling out of Nigeria are overloaded. Also, most of the vehicles transporting fuel to the neighboring countries often have axle loads in excess of 14 tonnes and some axle loads are heavier than 20 tonnes (Ola,1983). According to Abdulfatai *et al,* (2014), some of these problematic soils have been classified, they include the unstable residual lateritic soils, the tropical clays which occur mostly in the North-Eastern part of Nigeria region of Adamawa and of the lake chad region, also, the Sokoto soft clay shale in the North-Western part of Nigeria (Ola,1987). Adesunloye (1987), classified problem soils in the Lagos area as peaty clays, in Port-Harcourt area, they occur naturally as clayey peat over the mud plains. Adesunloye (1987) noted this problematic soils tend to fall beyound the Casagrande's Plasticity Chart (Chukweze, 1991). The geological formation of the area considered to have expansive residual soils is shown in Figure 2.1.

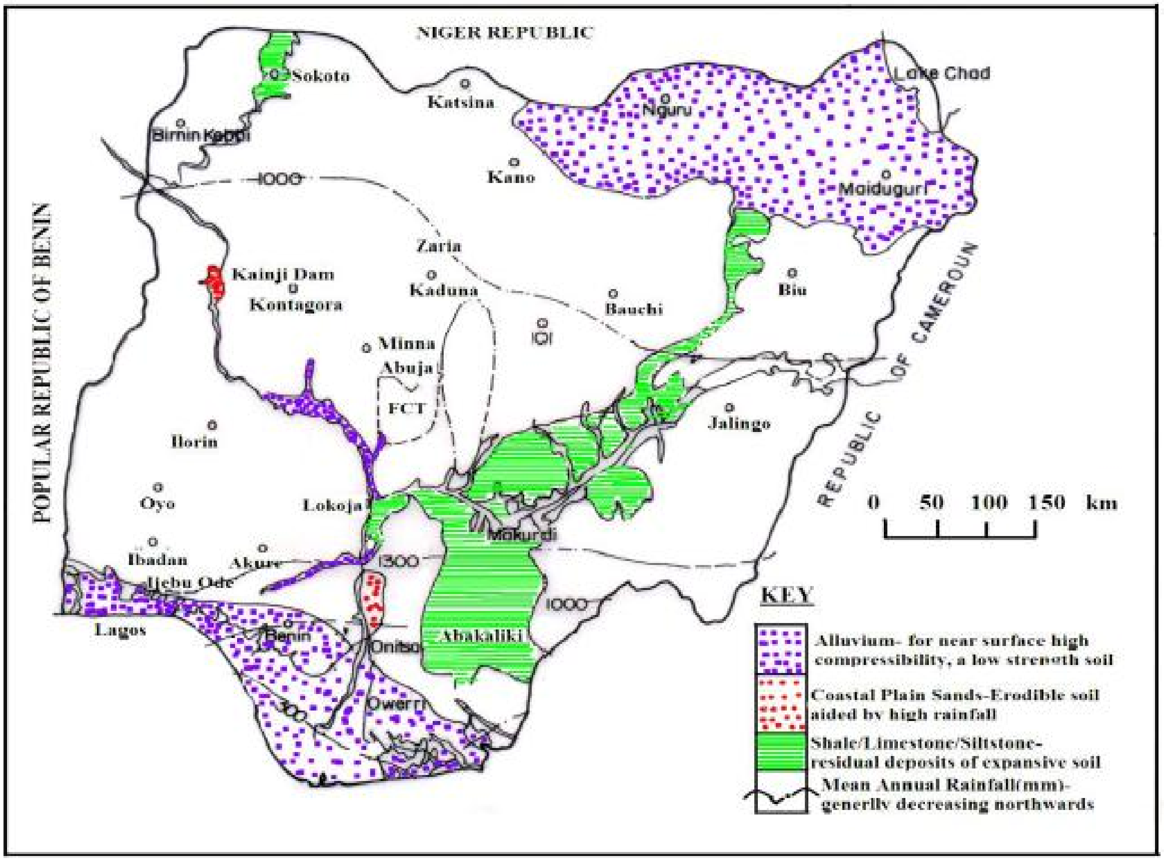


Figure 2.1: Geologic formations considered to have expansive residual soils (Adesunloye, 1987)

2.2 Origin of Tropical Clay

Tropical clays are expansive clay soil deposits found in arid and semi-arid regions of the tropical zones which are usually dark grey to black in nature with high plasticity usually, with over 50%, with montmorillonite as the principal clay mineral (Morin, 1971). They otherwise known as Canada's swelling clays, India's tropical clay and Kenya Tropical clays and can be found in Australia, India, South Africa, Tanzania, Asia and some other Africa countries especially Ethiopia, and in North Eastern Nigeria. According to Ola (1978, 1987), expansive tropical clays have a black upper (20cm) horizon due to the presence of a black colored humus-clay complex with relatively low organic content and free calcium carbonate concretions with heavy texture. Warren (2004) refer to tropical clays as "swelling soils" and "volume change" soils. Saleh (1993), described expansive clay formations as being favored by the geology, climatic condition and the environment of extreme disintegration, strong hydration and restrained leaching. Ola (1978, 1983 and 1987) in his work described tropical clays as being plastic silt clays formed by the weathering of basalt rock, shale and clay sediments.

They usually show high shrink-swell characteristics with surface cracks opening during the dry seasons, which are 50 mm or more wide. The cracks close during the wet season and uneven soil surface is produced by irregular swelling. Such soils are especially troublesome as pavement sub-grades or under shallow foundations. The amount of volume change or swelling is dependent on its clay mineral types and the mineralogical composition. This means that the soils with more montmorillonite content have higher potential volume change than those that have less (Ola, 1983). They are believed to contain active clay minerals of the Montmorillonite, with kaolinite and quartz making up the remainder, which are sensitive to changes in humidity (Adesunloye, 1985). Montmorillonite are group of clay minerals with large surface area, their chemical characteristics that swell in water possesses high cation-exchange capacities. Quartz is the most common mineral, It is found in every geological environment as least component of every rock type. Three problems have been identified where this material occurs; this includes sink-hole, collapsing sand and caverns in the limestone deposits, swelling of the clay shales (Ola 1983, 1987). The high volumetric shrinkage and swelling of these problematic soils has caused a lot of problems interms of their use for engineering construction purposes due to excessive cracking (Nigerian Building and Road research Institute, 1983). The Massive expansion and contraction of the clay minerals takes place leading to the formation of wide and deep cracks. Babalola (2008), summarized and compared the extensive research by Morin (1971), on the properties of African tropical black or tropical clay soil, and summarize results of studies carried out by Osinubi (1995, 1999) on samples of tropical clays taken from the new marte areas of Borno State, Nigeria and that of Indian tropical clay (Plait, 1953).

2.3 Origin of Ceramic Dust

Ceramic products are produced from materials containing a high proportion of clay substances. Following a process of material dehydration and controlled firing at temperatures ranging between 700ºC and 1000ºC, these minerals acquire or achieved the characteristic properties of fired clay. Ceramic factory waste is not sorted according to the reason for rejection, which may include: breakage or deformation and firing defects (Sánchez, 2007).

According to Ogwueleka (2009), after carrying out a municipal solid waste characteristics and management in Nigeria, eight cities in Nigeria which are Maiduguri, Kano, Abuja, Onitsha, Nsukka, Makurdi, Ibadan and Lagos. The result shows that 35.6, 32, 38.6, 33.8, 20.2, 25.8, 13.5 and 36% respectively of solid waste were glass and ceramics. According to Binici (2007), in stabilization, the use of ceramic waste has increased due to its various advantages and availability over other cementitious materials. Ceramic dust is a general term used to refer to as waste by product of ceramic products. Manufactured ceramics include wall and floor tiles, sanitary ware, household ceramics and technical ceramics. Ceramics products are usually hard, but brittle, and are in the form of non-crystalline or glassy solids. Ceramic by-products are durable, hard and highly resistant to chemical, biological and physical degradation. Ceramic Dust is available as a waste product and as a good additive, which will be a recommended additive if it gives desirable strength at economical rates. So the stabilization of expansive tropical clay with the ceramic dust if found suitable economically would a sustainably abundant road construction. The advantages of using ceramic waste dust in road construction as mineral filler includes; the ceramic dust is available at zero economic cost, the road construction activity encourages green environmental initiatives, an economical option in the design of green structures, it's durable, hard and highly resistant to biological, chemical and physical degradation forces. Ceramic dust gets fill in between the relatively fine grains, reducing the room available for water and consequently the water demand

2.3.1 Sources of ceramic waste

Ceramic waste may come from two main sources. The first source is from the ceramics industry, this waste is usually classified as Non-Hazardous Industrial Waste (NHIW). This is waste generated by industrial activity which is not classified as hazardous in accordance with the European List of Waste (ELW 2013). The second source of ceramic waste is usually associated with site construction and demolition activity. This constitutes a significant fraction of Construction and Demolition Waste (CDW), this includes waste from Concrete, bricks, roof tiles and ceramic materials. Stabilization using ceramic dust is one such waste material which can be used for improving the properties of poor expansive soil. Ceramic waste can be used for soil stabilization hence, problem of its disposal can be overcome in environmentally friendly way. Ceramic dust materials are easily available at various manufacturing units and at construction sites. In developing countries like Nigeria, waste management is a matter of serious environmental concern because waste materials are generated. The wastes from ceramic industry had been deemed unfit for sale or recycling due to a variety of reasons, including mechanical and firing process related defects (European List of Waste ,2013).

2.3.2 Types of ceramics

(i) Fire clays and shales

These products include ordinary bricks, clay roof tiles, flooring quarries and pavers.

(ii) Terracotta

This is literally 'burnt earth'. It is made from yellow to brownish-red clays with a uniformity and fineness between brick and vitrified wall tiles. Terracotta is often used for unglazed chimney pots, air bricks, copings and planters.

(iii) Faience

This is a glazed form of terra-cotta or stoneware. The base material may be fired to the 'biscuit' stage before glazing and re-firing, or a 'once-fired' process may be used. The latter improves resistance of the glaze to crazing (the spread of lines or cracks on the glazed surface), but reduces the range of colours available.

(iv) Fireclay

This contains a high proportion of clay resistant to high temperatures (kaolin). It is used for chimney flue linings and firebacks.

(v) Stoneware

This is similar in composition to fireclay, but is fired at a higher temperature than fireclay and contains a higher proportion of glass. As a result it is harder and less absorbent. Modern manufacturing processes mean that stoneware no longer has to be glazed for use in drainage pipes.

(vi) Earthenware

The raw materials are blended and may contain a considerable proportion of limestone. It is a finer product than stoneware and is used as the body for glazed wall tiles and table 'china'. Water absorption may be up to 15%, however, making it less suitable for sanitaryware than vitreous china.

(vii) Vitreous china

This has a higher glass content than earthenware, and its water absorption is only about 0.5%, which makes it suitable for sanitary fittings. It is stronger than earthenware.

(viii) Porcelain

Porcelain is very similar to vitreous china, but is often made from purer materials under more strictly controlled conditions. It is used for special uses, such as electrical insulators.

(ix) New ceramics

These are also called 'technical' or 'engineering' ceramics. Their purity is far higher than traditional ceramics, not using raw clay mined directly from the ground. Powders are formed which are then cast, pressed, extruded or moulded into shape. The powders may be set in organic binders. The combination of pure materials and exacting production techniques ensures the very high strength of these materials.

2.4 Soil Stabilization

In soil stabilization, unbound materials can be stabilized with cementitious or filler materials i.e cement, lime, fly ash, bitumen, ceramic dust, aggregates etc. or combination of these. Soil stabilization process involves the improvement of the engineering properties of soil to make it stable. This can be done by the use of controlled compaction, and by the addition of suitable different types of admixtures or stabilizers (Bairwa, 2013). Stabilized soil materials do have higher strength, lower permeability and lower compressibility than unstabilized soil material. Soil stabilization is aimed at the enhancement of the engineering properties of deficient soils to enable them perform and sustain their intended engineering use (Osinubi, 1995). Objectives of soil stabilization are to improvement of the strength of the soil and bearing capacity, decreasing permeability and water absorption, and to increasing the durability under varying moisture content. The simplest stabilization processes is compaction. The other process is by improving gradation of particle size, addition of binders or fillers to the weak soils (Rogers and Glendinning, 1996).

For a positive stabilization results, both laboratory and field tests may be required in order to determine the engineering and environmental properties. Although laboratory tests may produce higher strength results than corresponding material from the field, but will help to assess the effectiveness of stabilized materials in the field. Results from the laboratory tests, will enhance the knowledge on the choice of binders and amount needed.

2.4.1 Benefits of soil stabilization

The Benefits of soil stabilization include the reduction in moisture-holding capacity (drying), Swell reduction, Plasticity reduction, improved stability and substantial improvements in shear strength and strength gain with time, even after periods of environmental or load damage.

2.4.2 Types of soil stabilization

2.4.2.1 *Mechanical stabilization*

Mechanical stabilization is the densification or compaction of the soil sample by the application of mechanical energy. Mechanical soil stabilization is achieved through physical process by altering the physical nature of the soil particles by either induced vibration or compaction with or without incorporating other materials such as filler material or soil, this involves the modification of the water content as well as the gradation of the soil sample. The objective of mechanical compaction is the improvement of the engineering properties of the soil sample. Advantages which are obtained through compaction include reduction in settlement due to reduced void ratio, Increase in soil strength, Reduction in shrinkage (Habiba, 2017).

2.4.2.2 *Chemical stabilization*

Chemical soil stabilization depends mainly on chemical reactions between stabilizer (cementitious material) and soil minerals to achieve the desired effect, This involves increase in particle strength by cementation, internal friction among the particles, increase shear strength, reduction in the plasticity index, and reduced shrink-swell potential, Absorption and chemical bonding of moisture which will facilitate compaction. The addition of organic (bitumen) or inorganic (cement, lime etc) chemical compounds, to an expansive soils increase its strength, bearing capacity and durability of the expansive soil. These organic or inorganic chemical compounds perform cementations and bonding agents or water proofers or repellents (Slate and Johnson, 1953). bituminous and Resinous materials act as water proofing agent sometimes behave similar to glue. These water-proofing agents reduce the capacity for water intake and help the soil to retain its dry strength, even under wet condition (Bowles, 1979; O'Flaherty, 1988) Inorganic agents employed for soil stabilization, include lime, Portland cement,sodium silicate, slag, etc. Their functions are to reduce soils plasticity and facilitate its densification (Balogun, 1991). The transformation of soil properties by adding chemicals such as cement, lime, dust, fly ash, or a combination of these, often alters the physical and chemical properties of the soil including the cementation of the soil particles (Gregory, 2012).

2.5 Review on Stabilization of Clay soil with Ceramic dust

Rakhil and Devi (2016) researched on the improvement of geotechnical properties of an expansive soil stabilized with waste ceramic dust, the expansive soils alternatively swells and shrinks depending upon the presence of moisture in it. This behavior causes the volume change of the soil and it results in the cracking and failure of structures built on that soil. To improve the geotechnical properties of this expansive soils as to make them suitable for construction purposes, various methods are in available. The paper review the results of the experimental programme which is already carried out by stabilizing the expansive soil using ceramic dust made from locally available waste ceramic tiles. Also it reviews the economic feasibility of utilizing the ceramic dust for improving the properties of expansive soil used for construction. From the research, the liquid limit, plastic limit and plasticity index go on decreasing irrespective of the percentage of addition of ceramic dust, the addition of 30% ceramic dust changes the soil from CH group to CL group. The MDD goes on increasing and OMC goes on decreasing with increase in percentage of addition of ceramic dust. The UCS goes on increasing with increase in percentage of addition of ceramic dust. The soaked CBR goes on increasing with increase in percentage of addition of ceramic dust. There is 150% increase in soaked CBR value as compared to untreated soil, when 30% ceramic dust was added. The cohesion value goes on decreasing and angle of internal friction goes on increasing with increase in percentage of addition of ceramic dust. The swelling pressure goes on decreasing with addition of ceramic dust. There is 81.5% decrease in swelling pressure of soil as compared to untreated soil, when 30% ceramic dust was added. From the economic analysis it is found that ceramic dust up to 30% can be utilized for strengthening the subgrade of flexible pavement with a substantial save in cost of construction. The interaction behavior of waste ceramic dust with soils can lead to viable solution for its large scale utilization and disposal. Further experimental investigations are required to quantify this to use waste ceramic dust as a substitute for sand to improve the geotechnical properties of soil.

Akshaya (2012) presents the result of the effects of waste ceramic dust on, liquid limit, plastic limit, plasticity index, compaction characteristics, unconfined compressive strength, California bearing ratio, shear strength parameters and swelling pressure of an expansive soil. The expansive soil collected locally was mixed with ceramic dust from 0 to 30% at an increment of 5%. From the analysis of test results it was found that, liquid limit, plastic limit, plasticity index, optimum moisture content, cohesion and swelling pressure decreased, maximum dry density, unconfined compressive strength, California bearing ratio and angle of internal friction increased with an increase in ceramic dust content. Series of laboratory tests conducted reveals that the liquid limit, plastic limit and plasticity index go on decreasing irrespective of the percentage of addition of ceramic dust, the addition of 30%

ceramic dust changes the soil from CH group to CL group, the MDD goes on increasing and OMC goes on decreasing with increase in percentage of addition of ceramic dust, the UCS goes on increasing with increase in percentage of addition of ceramic dust, the soaked CBR goes on increasing with increase in percentage of addition of ceramic dust, there is 150% increase in soaked CBR value as compared to untreated soil, when 30% ceramic dust was added, the cohesion value goes on decreasing and angle of internal friction goes on increasing with increase in percentage of addition of ceramic dust, the swelling pressure goes on decreasing with addition of ceramic dust, there is 81.5% decrease in swelling pressure of soil as compared to untreated soil, when 30% ceramic dust was added, from the economic analysis, he concluded that ceramic dust up to 30% can be utilized for strengthening the subgrade of flexible pavement with a substantial save in cost of construction.

Iravanian and Saber (2020) conducted a review study to define the use of ceramic wastes as a raw material in soil structures and the construction of road pavement subgrades. According to the review, the global output of ceramic waste powder (CWP) produced during the final polishing phase of ceramic tiles exceeds 22 billion tones. The application of (CWP) in landfill sites could create major environmental issues for soil, water and climate. It has been calculated that about 30% of the daily growth in the ceramic industry goes to waste. By trying to reduce this material, we can provide a big benefit of minimizing the use of natural products, decreasing the amount of money used and enhancing land conditions, based on the quantities we can use. Such wastes cannot be processed in any manner and thus create issues with the disposal and loss to the industry. Ceramic waste is strong, durable and resistant to all kind of declining powers, and these properties allow it to be substitute for replacements. Using various quantities of ceramic waste, we will obtain different results and characteristics of soil structures in different California bearing ratios, dry unit weight, unconfined soil density and optimum water content. Ceramic waste can be used for soil stabilization, particularly in expansive soil. the Studies show that ceramic waste up to 30% is useful for replace pavement subgrades, with major reduction in building costs. With using addition ceramic waste liquid limit, plastic limit and plasticity index of soil reduces, California bearing ratio (CBR) of clay soil increase with more amount of ceramic waste. There is 150% rise in soaked CBR performance of treated soil compared to untreated soil by increasing 30% in ceramic dust, Swelling pressure decrease if addition ceramic dust used, when 30% ceramic dust is added to the soil mix, 81.5% of swelling pressure reduction can be seen compared to untreated soil. With improvement amount of ceramic dust, MDD will continue to rise. The unconfined compressive strength of clay soil samples increase as ceramic waste dust increases, Stability factor begin to decline while angle of internal friction continues to rise with sufficient amount of ceramic dust applies, 30% addition in ceramic dust will change the soil from CH group to CL group, mineralogy analysis of stabilized soil samples showed less quartz and montmorillonite peak in stabilization with lime and ceramic dust, it result in improved intensity due to the application of ceramic dust to saturated soil lime. Ceramic dust impacts more at lower lime content relative to higher lime content.

Olumuyiwa *et al.* (2019) examined the geotechnical properties of lateritic soil stabilized with ceramic waste dust (CWD) additive. Specific tests conducted on the modified soil samples include grain-size distribution, Atterberg Limits, Proctor Compaction tests, and California Bearing Ratio tests. Lateritic soil obtained from Agbara, South-West Nigeria and pulverized ceramic materials gathered from construction site rubbles were used for the experiment. The Lateritic soil samples were mixed with ceramic dust from 0 to 30% at an incremental rate of 5%. From the analyses of test results, it was found that the Liquid Limit, Plastic Limit, Plasticity Index, and Optimum Moisture Content decreased consistently with the incremental addition of ceramic dust from 0% up to 30%, whereas, Maximum Dry Density and California Bearing Ratio (Soaked and Un-soaked) increased with ceramic waste dust additive. Liquid Limit decreased from 59.62% (unmixed laterite) to 35.61% (30% CWD addition). The Plastic Limit decreased linearly from 40.11% (unmixed laterite) to 23.31% (when mixed with 30% CWD). The percentages for both unsoaked and soaked California Bearing Ratio increased from 6.82% to 21.97% and 4.55% to 14.39% respectively for 5% incremental addition of CWD up to 30%. The study concluded that the use of CWD in the stabilization of lateritic soil is recommended for economic, durability, and environmental advantages.

El-Alfi and Radwan (2014) examined the influence of sand as a substitute for clay on the physico-mechanical as well as ceramic properties of clay bricks. Sand was substituted for clay up to 20%. Briquettes were moulded, dried and then fired at different temperatures up to 1000°C, with a soaking time of 2h. The results revealed that the substitution of sand for clay allows controlled drying with shorter times required for complete dryness, and also improves dry and firing shrinkage, bulk density, apparent porosity, and crushing strength. The batch containing 10% sand exhibited the best results and was therefore selected as the optimum batch for making sand clay bricks.

Arya and Soorya (2020) concluded that the ceramic industry, which comprises of wall tiles, bricks and roof tiles, floor tiles, sanitary accessories, refractory materials and ceramic materials for domestic and other uses is generating a huge amount of ceramic wastes. Therefore, their problem of disposal is also a great concern. The research delineates the effects of waste ceramic dust on strength characteristics of clayey soil. Soil samples were prepared with the inclusion of various proportion of ceramic dust with clayey soil. The test results indicate that Atterberg limits showed significant variation with inclusion of different percentages of ceramic dust with the studied clayey soil, the Atterberg limits go on decreasing with the percentages of addition of ceramic dust, the liquid limit, plastic limit and plasticity index decreases with increase in the percentage of ceramic dust. The unconfined compressive strength goes on increasing with increase in percentage of ceramic dust. On the other hand, unconfined compressive strength value increase with the increase of inclusion of ceramic dust up to 20%. It is recommended that ceramic dust up to 20% may be used for improving the geotechnical properties of clayey soil thereby having maximum stabilization and economic considerations for soil.

Sabat (2012) researched stabilizing clayey soil mixed with ceramic dust. The locally available clayey soil was mixed with 0 to 30% ceramic dust content with an increment of 5%. Effect of ceramic dust on compaction characteristics, shear strength parameters and swelling pressure, unconfined compressive strength, California bearing ratio of clayey soil were evaluated in the laboratory. From the results of tests it was found that liquid limit decreases from 62 to 35%, plastic limit decreases from 30 to 20%, PI decreases from 32 to 15%. The compaction characteristics were also improved. The MDD value increases from 15.6 to 18.1 kN/m3, OMC decreased from 20.4 to 17.6%. The UCS increases from 55 KN/m2. There was 150% increase in soaked CBR value. The economic analysis for stabilized sample was conducted, it was revealed that ceramic dust up to 30% can be utilized for strengthening the sub grade of flexible pavement with a substantial save in construction cost.

Ameta and Wayal (2013) had treated the dune sand using ceramic tile waste as admixture. From results it was found with increment of particle size of admixture, the C.B.R. value of the mix composition increases. Also as the mix percentage of a stabilizer increases, the C.B.R. value increases. Increase in CBR values was observed at unsoaked condition than that compared with soaked sample. From the results obtained it was concluded that angle of internal friction varies with increase in size of ceramic tiles particles in the mix composition. aklternatively for the same size of ceramic tiles waste, the angle of internal friction was observed to increases with increase in percentage or quantity of ceramic tiles waste.

Koteswara (2013) studied the effect of Vitrified Polished Waste (VWP) on marine clay, when 0-35% added VWP content, with an increment rate of 5% was used. The optimum content of Vitrified Polished Waste (VWP) was found to be 15%, and the liquid limit decreased by 35.6%. The C.B.R. value of the marine clay had been increased by 187.3%, Specific Gravity value of the marine clay increased by 15.02%, the soaked CBR of the soil on stabilizing was found to be 4.5, the california bearing ratio value should be in between 5-6, according to IRC 2001.

Ajay and Suneet (2016) concluded that the Use of solid waste material in soil stabilization improves the geotechnical properties of soil. Ceramic dust materials can be used for soil stabilization in place of conventional stabilizer like lime. On the basis of the test conducted by different , the following conclusions were deduced; with the addition of ceramic waste liquid limit, plastic limit and plasticity index of the clayey soil decreased, Optimum moisture content of the clayey soil decreased as the percentage of ceramic waste content increased and maximum dry density obtained at certain optimum content of ceramic waste and decreased beyond the optimum content of ceramic waste product. California bearing ratio of the clayey soil increased, the unconfined compressive strength of the clayey soil increased as percentage of ceramic waste dust increased, the differential free swell (DFS) of the expansive soil decreased with increase in the percentage of ceramic waste.

Amrendra Kumar (2014) Based on his experimental investigations concerning the compressive strength of concrete, the following observations are made: The Compressive Strength of M20 grade, Concrete increases when the replacement of Cement with Ceramic Powder up to 30% replaces by weight of Cement and further, replacement of Cement with Ceramic Powder decreases the Compressive Strength. the cost of the cement is reduced for M20 grade and hence it becomes more economical without compromising concrete strength than the standard concrete. It becomes technically and economically feasible and viable, It is a possible alternative solution of safe disposal of Ceramic waste.

Chen and Idusuyi (2015) concluded that Based on the observations and discussions from the study of Effect of Waste Ceramic Dust (WCD) on Index and Engineering Properties of Shrink-Swell Soils it can be concluded that waste ceramic dust is suitable for improving the index and engineering properties of Shrink-Swell Soils. The index properties (liquid limit, plastic limit and plasticity index) of the shrink –swell soil decreased irrespective of the percentage of addition of ceramic dust. The MDD increased and OMC decreased with increase in percentage of addition of ceramic dust. The soaked CBR increased with increase in percentage of addition of ceramic dust. The soaked CBR value was increased by 150% as compared to the untreated soil, when 30% ceramic dust was added. The Free swell and swelling pressure of the soil also decreased with increase in waste ceramic dust. it is recommended that up to 30% of waste ceramic dust can be utilized for strengthening the sub grade of flexible pavement with a substantial saving in cost of construction.

2.6 Review on Stabilized Expansive Clay Soil

Oluyemi-Ayibiowu and Ola (2015) researched on stabilization of tropical clays from North-Eastern Nigeria with sodium silicate. Sodium silicate was mixed with the soils in varied percentages of 0 - 10% and their responses monitored by testing in the laboratory. The three soil samples tested were classified as A-7-6 with California Bearing Ratio (CBR) values ranging from 28.7 to 32.5%, thereby giving weak subgrade to fair sub-base materials. On stabilization, the plasticity values of the soils were reduced and the CBR values increased to between 88 to 95% . With these stabilizers, some of the unsuitable expansive soil materials could be improved and used in road construction works. This will definitely help in the provision of good road networks in the geographical areas where they exist.

Akinmade (2008) researched on expansive tropical clay taken from a borrow pit located along Numan –Ngurore road in the North Eastern part of Nigeria and treated with an agricultural waste ash produced from the the African Locust Bean tree by burning of the husks of ripe fruits that are abundantly available in Nigeria. In accordance with the AASHTO Soil Classification and Unified Soil Classification System (USCS), the soil was classified as A-7-6 and CH respectively. The study focused on the effect of up to 15% Locust Bean Waste Ash (LBWA) by weight of dry soil on the geotechnical properties of expansive tropical clay. The maximum dry density with values of 1.68, 1.59 and 1.8 Mg/m3 were obtained for the natural soil when compacted at the three different energy levels of the, BSH, BSL and WAS. These increased to 1.8, 1.72 and 1.7 Mg/m3, respectively with addition of 7.5% locust bean waste ash. The optimum moisture contents of 18.53, 16.83 and 14% for the natural soil when compacted at the three energy levels of the BSL WAS and BSH respectively, decreased when treated with 5 to 7.5% locust bean waste ash content to minimum values of 17.7, 16.6 and 13.7%, respectively. The CBR values of 3, 6 and 8% for the natural soil compacted at the energy levels of the BSL, BSH and WAS slightly increased to 6, 12 and 8%, respectively when stabilized with 7.5% locust bean waste ash. The highest CBR value of 12% was recorded using the BSH compactive effort and does not meet the minimum Specificationt of 15% prescribed by the Nigerian General Specification (1997) for subgrade materials. The UCS values for BSL, WAS and BSH compactive efforts obtained for the natural soil sample at 7 days curing period were 114.65, 299.96 and 401.50 kN/m2, respectively. For the same 7 days curing period the UCS values of the treated soil obtained increased to 321, 325.15 and 384.5 kN/m2 for the three compaction efforts, respectively, at 7.5% locust bean waste ash content. Considering the strength values recorded at an optimal 7.5% locust bean waste ash treatment of deficient Tropical clay, the LBWA cannot be used as a 'stand-alone' stabilizer.

Ikeagwuani (2013) concluded that tropical clay is highly notorious for its negative effect on engineering construction either as a sub grade material or material under the foundation of buildings. The geotechnical properties of the native soil are adversely affected by the extreme poor nature of the soil. One of such characteristics is the compressibility of the soil. To attempt to proffer solution to this problem, the research investigated the use of sawdust ash and lime on the compressibility characteristics of the tropical clay. This was done by subjecting the soil to one dimensional consolidation test, other studies such as the Atterberg's limits, specific gravity and particle size distribution test were carried out on the soil sample. Sawdust ash was used as additive in varying proportion of 0 - 20% by weight of tropical clay at increment of 4%. The results obtained from the laboratory tests conducted on expansive soil samples and various mix proportions showed that there were significant improvements in the compressibility characteristics of the tropical clay soil when a combination of 16% SDA and 4% lime were added.

Roland (2015) researched expansive tropical clay which is greyish black in colour with liquid limit of 56.8 %, plastic limit of 27.2 %, plasticity index of 29.6 %, free swell of 52.5 %, linear shrinkage of 18.1 %, specific and gravity of 2.48 with about 80.7 % passing the BS. No. 200 sieve (0.075 mm aperture) 0- 8% lime and Iron Ore Tailing Blend (IOT) 0-10 %) by dry weight of tropical clay was used. Research findings revealed that the liquid limit of the natural tropical clay decreased from 56.8 % to a minimum value of 43.8 % when treated with 8 % lime 6 % IOT blend. The Plastic limits decreased from of 29.2 to 18% for 8% lime / 8 % IOT treatment, while the plasticity index decreased from a value of 27.6 to 24.3 % for 6 % lime / 10 % IOT treatment. The OMCs decreased from 24.0, 19.8 and 19.5 to 19.0, 16.7 and 15Mg/m^3 with higher compactive efforts and IOT content. The UCS values for natural soil compacted with BSL, WAS and BSH energies at 7 days curing period are 107.24, 326.25 and 408.35 kN/m2, respectively; increased to 1074.54, 1569.02 and 1688.76 kN/m2 at 8 % lime/8 % IOT treatment respectively. The UCS values compacted using BSL, WAS and BSH energy all met the 7 day 1034.25 kN/m2 normally utilized/specified as criterion for adequate stabilization using lime. The unsoaked CBR values increased from 3, 4 and 8 % for the natural soil compacted with BSL, WAS and BSH energies efforts, respectively, increased to 55, 80 and 90 % at 8 % lime /8 % IOT treatment.

Madhusudan (2008) concluded that when an expansive tropical clay could be modified with fly ash and rice husk ash using 5 - 25% by weight of the clay. The CBR increased by 24.17, 37.09, 45.69, 39.40 and 26.15%. The maximum increase in CBR was due to the addition of 15% fly ash and rice husk ash resulting in increase in the density of the modified soil mix. The value obtained for liquid limit, plastic limit and plasticity index of modified soil reduced due to the use of non-plastic material for modification. The maximum dry density of modified soil increased as result of improvement of the binding capacity and proper rearrangement of modified soil mixture. The optimum moisture content of soil reduced due to proper rearrangement of soil particles, which have reduced the voids. The value of unconfined compressive strength of soil with addition of 15% fly ash was increased. The reason for this may be as a result of increase in the density of modified soil mixture, and the value of California bearing ratio of soil also increased due to increase in density of modified soil mix and binding capacity of rice husk ash.

Alemu (2017) noted that the industrial waste materials have a potential to modify the characteristics of expansive clay soils like tropical clay soil and to make it suitable for many engineering applications. He researched that the industrial wastes used in the soil stabilization can help in improving the strength and CBR value. The review concluded that Fly ash can be used to stabilize soil in different civil works such as in road construction in development of low permeability etc. The agricultural waste i.e. Rise Husk ash can be used in soil stabilization along with cement or lime as an additive. The use of industrial wastes or by-products in soil stabilization or modifications has proved to be effective in enhancing the strength of clayey soil. The use of stabilized soil has the dual benefits of removal of harmful materials from the environment and the usage of cheap construction material.

2.7 Review on Application of Ceramic waste in Concrete

Daniyal and Shakeel (2015) observed that in recent constructions, the consumption of ceramic materials is increasing day by day in the form of tiles, sanitary fittings, electrical insulators etc. But a large quantity of ceramic materials changes into wastage during processing, transporting and fixing due to its brittle nature. Therefore, using these wastes in concrete production could be an effective measure in maintaining the environment and improving the properties of concrete. Hence, the crushed waste ceramic tiles were used in concrete as a replacement for natural coarse aggregates with 10%, 20%, 30%, 40% and 50% of substitution. After analyzing results, the optimum value of waste ceramic tile to be used within the concrete mix with a water cement ratio of 0.5 was determined as about 30%. The compressive and flexural strength of optimal concrete was found 5.43% and 32.2% higher than reference concrete respectively. The findings revealed that using waste ceramic tile lead to enhancing the properties of concrete. The process of substituting 0 to 50 percent waste ceramic tile as coarse aggregate was studied and then parameters of Slump, compressive strength, unit weight and flexural strength were measured. The following conclusions was highlighted from the output of this research and summarized, The output results revealed that using coarse waste ceramic tile within the concrete mix lead to a considerable reduction in the workability for all the mixtures. Also, it was noticed that the workability of concrete gradually decreased with the increase of quantity of waste ceramic tile content.

As a general outcome, it was noticed that the concrete mass density was decreased by the increase of water cement ratio. Also, it was noticed that the density of concrete gradually decreased with the increase of quantity of waste ceramic tile content. Compressive strength of concrete gradually increased with the increase of quantity of coarse waste ceramic tile aggregate up to certain limits i.e 20% for w/c ratio of 0.4, 30% for w/c ratio of 0.5 and 40%

for w/c ratio of 0.6. The greatest compressive strength was observed for C5-10 concrete. It was noticed that the flexural strength of Optimal Waste Ceramic Concrete was 32.2% higher than flexural strength of Reference Concrete. Therefore, it can be concluded that the use of coarse waste ceramic tile content in the concrete enhanced the flexural strength considerably. Also, it can be seen that using waste ceramic tiles in concrete production causes no remarkable negative effect in the properties of concrete. The optimal case of using waste ceramic tiles as coarse aggregates is found to be 10 to 30 percent. In these measures, not only an increase happens in compressive strength, but also a decrease in unit weight is reported. Finally, using waste ceramic tiles in concrete is an effective measure with regard to reducing the costs of concrete and keeping the environment clean along with wastage management and decreasing the use of natural raw materials.

Amr, Mahmoud and Samir, (2018) researched on the use of Ceramic Waste Powder (CWP) in making Eco-Friendly Concretes. The global production of Ceramic Waste Powder (CWP), which is produced during the final polishing process of ceramic tiles, exceeds 22 billion tons. They observed that the disposal of CWP in landfills will cause significant environmental problems (such as soil, air, and groundwater pollution). CWP is characterized by its chemical composition that is mainly composed of silica (SiO_2) and alumina (Al_2O_3). Both minerals represent more than 80% of the CWP composition.

CWP has potentials to be used as an ingredient to partially or entirely replacing Portland cement to make eco-friendly concretes. The research summarizes the effect of using CWP in making eco-friendly concretes, with a particular focus on using CWP as a partial cement replacement in conventional-vibrated concrete (CVC) and self-compacting concrete (SCC), and the production of zero-cement alkali-activated concrete (AAC). According to the research, using CWP as an ingredient in making CVC is viable. High-performance concrete can be produced by including CWP as partial cement replacement. CWP improves the workability retention of the CVC mixtures. The inclusion of CWP will reduce the early-age strength and slowed the strength development. Significant improvement of CVC durability can be achieved by including high content of CWP. The CVC performance varies according to the CWP content. CWP can be used in the range of 10–20% to improve workability retention and late strength development. A CWP content ranging from 30 to 40% is needed to improve durability. If the performance of mixture requires the combination of workability retention, strength and durability, a CWP content ranging from 20 to 30% can be used to optimize all required characteristics. CWP can be used as a partial cement replacement to produce SCC that meets international requirements. All fresh concrete properties, except for slump flow, are significantly improved by the incorporation of CWP. The improvement is proportional to the CWP content. Similar to CVC, the inclusion of CWP affected the strength development and enhanced the durability. SCC with improved fresh performance and optimized strength can be produced using 40% CWP as partial cement replacement. The concluded that the concrete industry can and will play a vital role in the sustainable development through the utilization of industrial waste materials.

Krishna and Manthena (2013), observed that owing to globalization, privatization and liberalization, the construction of important infrastructure projects are increasing in developing countries and such development activities require large quantities of natural resources. This leads to faster depletion of natural resources on one side and manifold increase in cost of construction of structures on the other side, which is a major problem in construction sector today. In view of this people have started searching for suitable alternate materials which can be used either as an additive or as a partial replacement to conventional ingredients of concrete. Use of tile dust as partial replacement for cement in concrete is one such economical method. In the laboratory tests conducted by partially replacing cement in concrete by tile dust as 0%, 10%, 20%, 30%, 40% & 50%. The development of compressive strength, split tensile strength and flexural strength of concrete at the age of 7, 28, 56 days are investigated. These strengths are compared with conventional concrete of the same mix proportions. The following are the conclusions obtained on performing the experiments, using ceramic wastes in concrete can solve several environmental problems, concrete with tile dust as partial replacement for cement has minor strength loss which can be negligible, Tile dust concrete increased durability performance, There is not much remarkable decrease in strength of concrete up to 30% replacement, further replacement of cement with tile dust decreases the compressive strength, up to 30% replacement of cement with tile dust in concrete is technically and economically feasible and viable, It is the possible alternative solution of safe disposal of Ceramic waste, by adopting such methods we can overcome problems such as waste disposal crisis, for 20% cement replacement with tile dust indicates saving of around 17% in the cost of Portland cement in concrete. The cost of cement represents almost 45% of the concrete cost, therefore, overall cost of the concrete will be reduced by more than 7.5%, hence, the use of tile dust as partial replacement for cement in concrete is economical.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

3.1.1 Tropical clay soil

The clay soil used in this study was collected from Ngurore (Latitude 9^0 36N and Longitude 12^0 19E) along Numan - Yola road in Adamawa state, Nigeria.

3.1.2 Ceramic dust

The grey in colour Ceramic dust used in this research was sourced from BN ceramic plant, Ajaokuta Kogi state, Nigeria, directly from the processing facility.

3.2 Methods

The following laboratory experiments were performed to generate data on the resulting mixtures of tropical clay stabilized with various percentages of 0 - 40% Ceramic Dust by weight of dry soil. Moisture Content test in accordance with BS. 1377: 2003, part 2:3, Particle Size Distribution in accordance with B.S 1377:2003 Part 2:9, Atterbergs Limits test in accordance with BS. 1377, part 2:4,2:5 and 2:6, Specific Gravity test in accordance with B.S. 1377, part 2:8, Compaction test; West African Standard (WAS) following Nigerian General Specifications, (1997) British Standard Light (BSL), and British Standard Heavy (BSH) in accordance with B.S. 1377, part 4:4. California Bearing Ratio (CBR) in conformity with British Standard Institute, Methods of testing soils for Civil Engineering purposes, BS 1377, (1924) (1990), and the Nigerian General Specification (1997**),** the Unconfined Compressive Strength (UCS) in accordance with BS 1377.

3.2.1 Natural moisture content

Three empty moisture content cans were weighed (W_1) and then filled with representative specimen of the soil sample (W_2). The cans with the sample were weighed and then kept inside an oven for 24 hours at a temperature of 105°C. The weight of the samples was then obtained from difference in weight (W_3). Moisture content was then calculated using equation 3.1

$$\mathrm{M} = \frac{\mathrm{W2} - \mathrm{W1}}{\mathrm{W3} - \mathrm{W1}} X\ 100 \qquad (3.1)$$

The moisture content test is present in Table 3.1.

3.2.2 Specific gravity

A clean and dry density bottle of 250ml was weighed and then filled with distilled water. The density bottle with the water was weighed again, after which the content was discharge off and the bottle was then weighed again. Oven dried sample of soil was then introduced into the bottle after which distilled water was introduced and stirred with a glass rod to allow release of trapped air. Finally, the bottle was filled to 100m level with water after which the outside was dried and then weight. Same procedure was repeated for ceramic dust sample. The specific gravity (Gs) was calculated using equation 3.2

$$\mathrm{Gs} = \frac{W3-W1}{(W4-W1)(W4-W1)} \qquad (3.2)$$

where W_1 = Weight of Cylinder
W_2 = Weight of Cylinder+Dry Soil
W_3 = Weight of Cylinder+Soil+Water
W_4 = Weight of Cylinder+Water

The specific gravity test is present in Table 3.2.

3.2.3 Particle size distribution

About 3000g of tropical clay sample was used for this test. This involves washing out the clay content from the soil then placing the remaining soil sample in the oven for 24 hours and then weighed. The sample was placed in the top sieve of the sieve set-up (5.00mm, 3.350mm, 2.36mm, 2.00mm. 1.7mm, 1.18mm. 850μm, 600μm, 425μm 300μm, l50μm, 75μm and the base pan) and vibrated for 5 minutes. Each sieve content was then weighed. The weight of empty sieves and pan which had earlier been weighed was then subtracted from the combined weights of soils retained on the sieve and the pan. The result obtained in the Particle-Size Distribution is present in Table 3.2.3 under Appendix A.

3.2.4 Atterberg limits tests

(a) Liquid limit test: (cone penetrometer method)

About 200g of air dried soil mixture passing through 425μm sieve was mixed with distilled water to a putty-like consistency into a cup like cone and leveled with spank. The height of the penetrometer cone was adjusted to 0.00mm reading, the penetrometer brass cup well compacted with the soil sample was placed under the cone. The knob was adjusted until there was a slight contact between the tips of the penetrometer cone and the surface of the soil sample in the brass cup. The knob is pressed to `releases the penetrometer to penetrate into the soil sample. The penetrometer reading was noted. Soil sample from the brass cup was then placed in a numbered moisture can for identification. The weight of the can and the wet sample was also noted and recorded. It was then placed in an oven for moisture content determination. The test was repeated four times, but with increasing water content.

(b) Plastic limit test

About 150g of the soil sample passing through sieve 425μm prepared in the manner as in liquid limit test as used. The ball of the soil was then rolled between the hand and glass plate. The rolling continues until a thread of about 3mm in diameter was obtained, the thread crumbled at this stage. The portion of the crumbled soil were then gathered and placed in a moisture can for moisture content determination. The result of the Atterberg limit test are shown in Table 3.2.4b.

3.2.5 Compaction test

Properly mixed clay–ceramic dust mixture with varyig content of 0 -40% were compacted using British Standard Light (BSL), West African Standard (WAS) and British Standard Heavy (BSH). After compaction, the collar was removed and trimmed to the top of the mould and weighed to determine bulk density. Samples from top and bottom of the compacted soil sample were taken for moisture content determination. The procedure was repeated at increased moisture content. The test was carried out on the tropical clayand soil – ceramic dust mixtures at various percentages of ceramic dust. The result of the test is shown in Table 3.2.5

3.2.6 California bearing ratio test

The California bearing ratio (CBR) test enables a measure of strength of the natural tropical clay soil and the stabilized sample. The CBR is expressed by the force exerted by the plunger against the depth of penetration into soil specimen. The tests were carried out in conformity with British Standard Institute, Methods of testing soils for civil engineering purposes, BS 1377 (1924) (1990), and the Nigerian General Specification (1997). The soaked and unsoaked California bearing ratio test were conducted, Soil samples were prepared by dynamic compaction method and placed on the bottom plate of the loading device. Predetermined weights of the soil sample were placed into the 2360 cm^3 mould and compacted at the optimum moisture content and at the three compactive efforts. Since the weights of the soil samples was predetermined using the density – volume relationship, the soils will be completely compacted into the CBR moulds. After the compaction, the base plates was removed and then the compacted specimens were placed into sealed plastic bags for curing. Plastic bags were used to avoid loss of moisture due to evaporation. The specimens were cured for three (3), fourteen (14) and twenty-one days before testing in accordance with the specification by the Nigerian General Specification (1997). The specimens were removed from the plastic bags and the base plates replaced, they were then transferred to the CBR testing machine. The plunger was then made to penetrate the prepared specimen at a uniform rate. The procedure were be repeated for every successive increment in the concentration of the Ceramic Dust (CD) with variation percentage of 0%, 10%, 20%, 30% and 40% by dry weight of the soil to determine the effect of Ceramic Dust

(CD) on the natural tropical clay soil sample. The CBR curves were plotted (i.e. force versus penetration of plunger) using the values obtained from the tests. The greatest value calculated for penetrations at 2.5mm and 5.0mm were recorded as the CBR using equation 3.3

$$\text{California Bearing Ratio} = \frac{\text{Measured force}}{\text{Standard force}} X\ 100 \tag{3.3}$$

The average of the two values will be recorded as the CBR where they were within 10 % of each other, otherwise the higher value will be used as the CBR. The CBR values for the different concentrations of the stabilizer compacted at the three energy levels was recorded. Tropical Clayand soil – Ceramic Dust mixtures at various percentages of Ceramic dust. The result of the test is shown in Table 3.2.5

3.2.7 Unconfined compressive strength test

The Unconfined Compressive Strength (UCS) will be determined in accordance with BS 1377 (1990) tropical clay soil sample was compacted at their optimum moisture content, The procedure was also repeated for every successive increment in the concentration of the Ceramic dust with variation percentage of 0, 10, 20, 30 and 40 by dry weight of the soil to determine the effect of Ceramic dust on the natural tropical clay soil sample. After compaction, the samples was extruded from the mould and sealed by double wrapping in polythene bags and kept in the humidity room for a period of and cured for 3, 14, 21 and 28 days to allow for extended curing period, at a constant temperature of 24 ± 2oc. After curing, the samples was trimmed into a cylindrical apparatus and then placed in a load frame machine driven strain controlled at 0.10/ min until failure occurred. Three specimens of soil sample were used for each of the test and the average results taken. The result of the test is shown in Table 3.5.

The compressive strength for each sample was deduced from equation 3.4 :

$$\text{Compressive strength (KN/m2)} = \frac{\text{Failure load}}{\text{Cross}-\text{sectional area of sample}} \tag{3.4}$$

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

The tropical clay soil in its natural state was observed to have a moisture content of 14.27 %, liquid and plastic limits of 37.8 and 22.6% respectively, with an average specific gravity of 2.9% which is an indicative of clayey and silty clay (2.69 – 2.9) as reported in the Appendix A. The liquid limits of 37.8 and plastic limits of 22.64% is an indicative of low plasticity clay.

4.1 Particle Size Distribution

The result of the particle size distribution analysis is shown in Figure 4.1

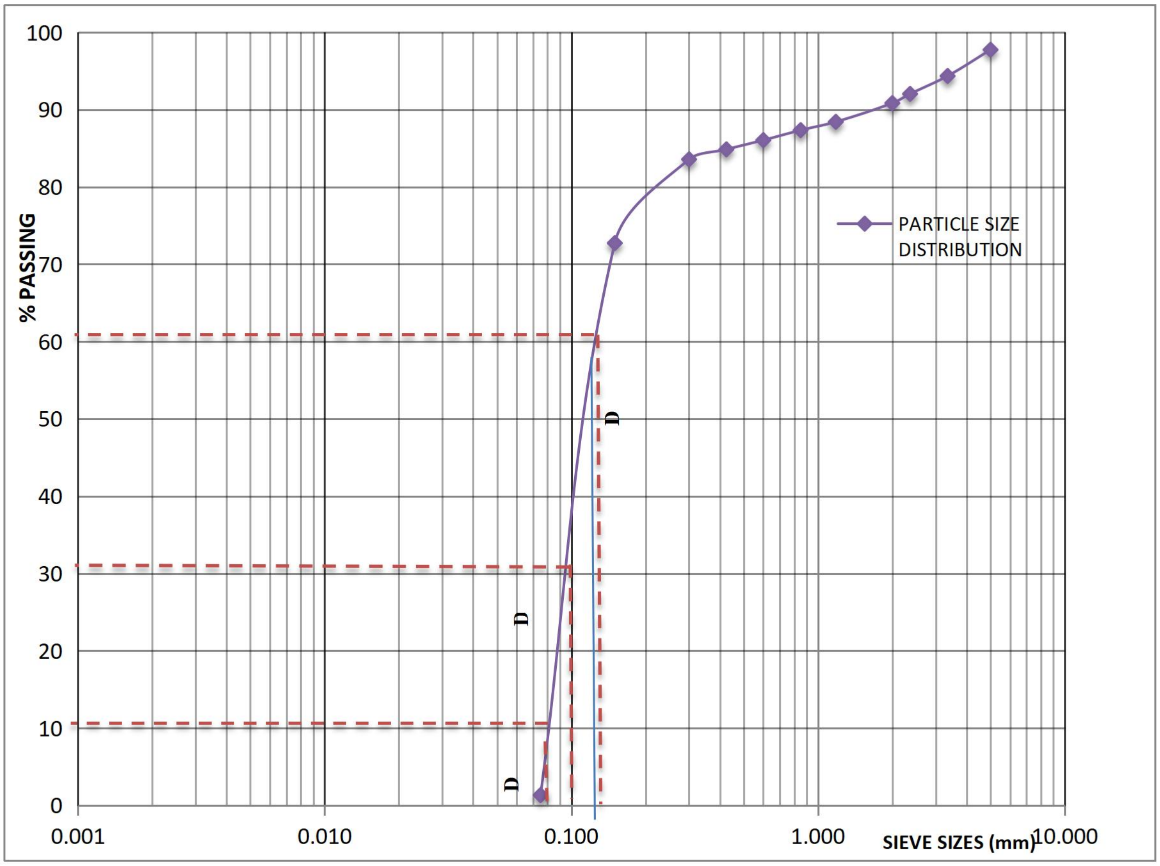


Figure. 4.1 : Particle-size curve of the tropical clay soil

The particle size analysis of the clay soil from this location is indicative of silty clay sand with 0.42 % gravel fraction, 27.82% sand fraction, with 71.76.% of silt-clay fractions (that is, passing through sieve 200 during sieve washing) . The particle size distribution curve is shown in Figure 4.1. Summary of the index and physical properties of the tropical clay is presented in Table 4.1

Table 4.1: Summary of physical properties of the tropical clay

Property	**Quantity**
Percentage Passing BS No. 200 Sieve	71.76
Natural Moisture Content, %	14.27

Specific gravity	2.79
Color	Dark grey
AASHTO Classification	A-6
UCS Classification	CL
Liquid limit %	37.8
Plastic limit %	22.64
Plasticity index %	15.6
(MDD) BSH (g/cm3)	1.99
(MDD) BSL (g/cm3)	1.72
(MDD) WAS (g/cm3)	1.87
(OMC) BSH (%)	13.42
(OMC) BSL (%)	20.1
(OMC) WAS (%)	16

Tropical clay mineral is generally refers to a natural material with plastic properties, very fine mineral fragments or particles composed mostly of oxide of silicates, though occasionally containing aluminum, magnesium and iron. The development of X-ray diffraction techniques in the 1920s and the subsequent improvement of microscopic and thermal procedures enabled researchers to establish that clays are composed of a few groups of crystalline minerals. This methods proved very useful in determining the oxides characteristic and size of clay minerals and have helped advance scientific knowledge of the crystal chemistry of these minerals. The oxide composition of the Tropical clay under consideration as determined by X-ray Diffraction (XRD) compound analyser is shown in Table 4.2, it composed mostly of oxide of silicates, aluminum and iron.

Table 4.2 Oxide composition of tropical clay determined by XRD compound analyser

Property	Concentration (%)
SiO_2	59.78
Al_2O_3	11.36
Fe_2O_3	4.18
CaO	2.09
MgO	0.90
MnO	0.14
P_2O_5	-8341.8
K_2O	1.37
Na_2O	0.03
SO_3	0.18

4.2 Variation of Atterberg Limits

The addition of 0 – 40% ceramic dust tend to reduced the plasticity, swelling and shrinkage characteristics of the tropical clay soil at all the mix ratios. The low values of the Liquid and Plastic limits and Plasticity Indices are consistent with the values obtained by Oluyemi-Ayibiowu (2015), when he carried out research on the samples obtained from Numan – Yola road in Adamawa state. The liquid limit with 28.4 - 20.8% value range when stabilized with ceramic dust content variation of 20 - 40% respectively is in line as specified by the Federal Government (30%) but the Plasticity Index values (10.3 -3.0%) is below those specified by the Federal Government (13%). The Plastic limit of the tropical clay soil decreased from 22.64 to 16.8%, when ceramic dust was increased from 0 to 40%

respectively.The Liquid limit decreases from 37.8 to 20.8% when ceramic dust is increased from 0 to 40%, the plasticity index decreases from 15.6 to 3.0% when ceramic dust is increased from 0 to 40%. The trend of the decrease showed a steady or gradual slope. This scenario is depicted in Figure 4.2

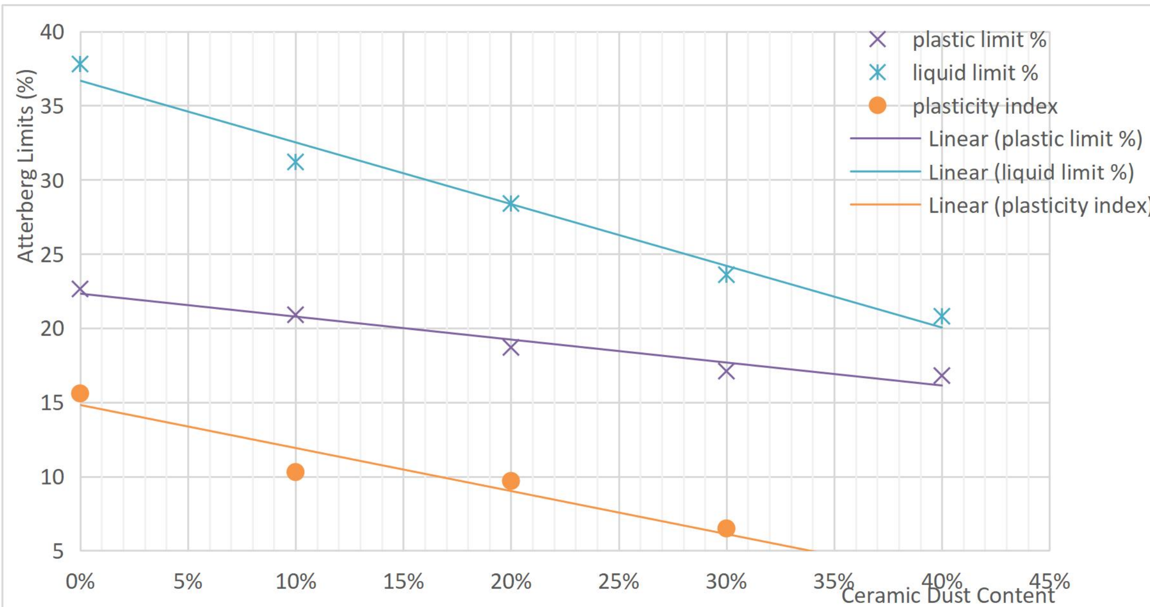
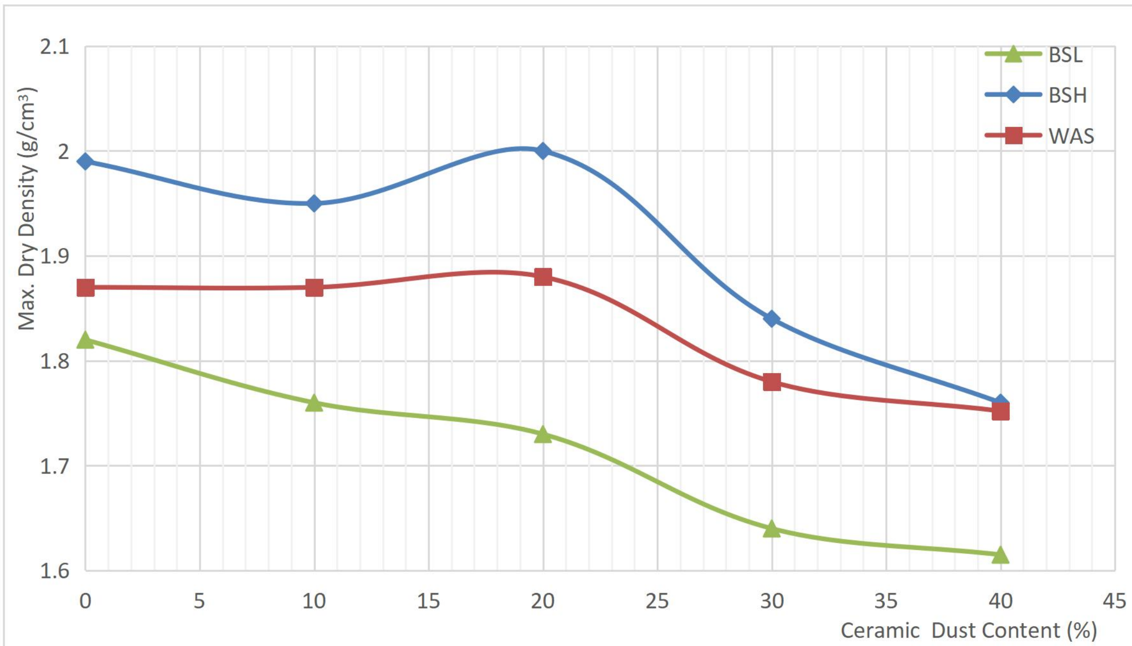


Figure. 4.2: Variation of plastic limit, liquid limit and plasticity index with percentage of ceramic dust content

4.3 Compaction Characteristics

The MDD for the BSH effort increased from 1.99 - 2.1 g/cm^3 when mixed with 20% ceramic dust, for the BSL compactive effort, the MDD increases from 1.72 - 1.77 g/cm3 when mixed with 20% ceramic dust. Similarly, the WAS compactive effort, the MDD increases from 1.87 - 1.92 g/cm^3 when mixed with 20% ceramic dust. The OMC for the BSH effort decreased from 13.42 - 9.09 g/cm^3 when mixed with 40% ceramic dust, for the BSL effort OMC decreases from 20.1 - 18.0% when mixed with 40% ceramic dust, for the WAS compactive effort, the WAS effort MDD decreases from 1.87 - of 1.92% when mixed with 40% ceramic dust. The tropical Clay sample had improved the MDD from its natural value using 0 - 20% ceramic dust, but beyound 20% ceramic dust, with further increase of

OMC, the amount of voids in soil gots increased and dry density decreased under loading condition. The variation of the ceramic dust on the Maximum Dry Density (MDD) and the Optimum Moisture Content (OMC) of the Tropical Clay Soil treated is presented in Figures 4.3a and 4.3b respectively.



Fi

gure 4.3a : Variation of MDD with ceramic dust content

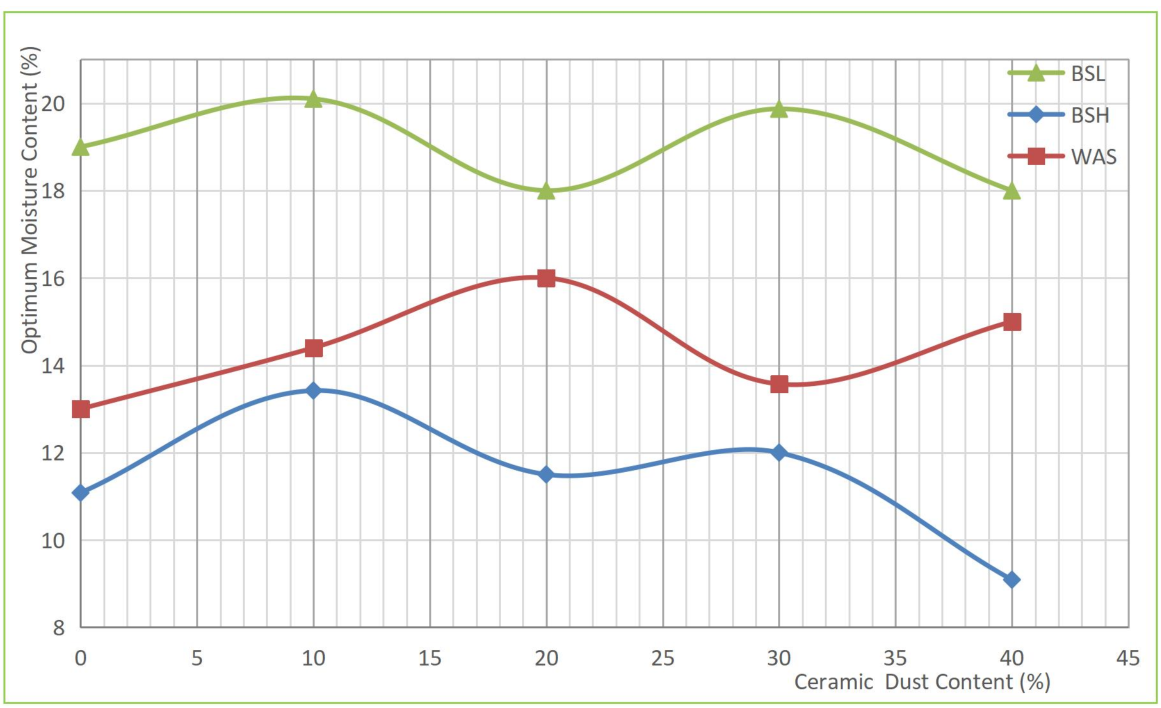


Figure 4.3b **:** Variation of OMC with ceramic dust content

4.4 California Bearing Ratio

The values of the California Bearing Ratio of the tropical clay soil increased significantly from 14.23, 20.49 to 20.49, 35.95 with the addition 0 - 40% ceramic dust content respectively for 3 to 28 days unsoaked bearing test, but the bearing strength of the soaked tropical clay soil decreased significantly from 5.31, 1.52 to 11.38, 2.56 with the addition 0 - 40% ceramic dust content respectively for 3 to 28 days soaked bearing test. However, it could be indicated that a better CBR value was achieved with unsoaked yield CBR between 0 and 20%. Only the CBR values of the soaked samples conformed to the Nigeria general specification interms of Pavement Design with CBR values of 5-11%, samples soaked for 3 days yielded 4.87 – 5.69%. The trend of the unsoaked and soaked CBR values are shown in Figures 4.4a and 4.4b respectively

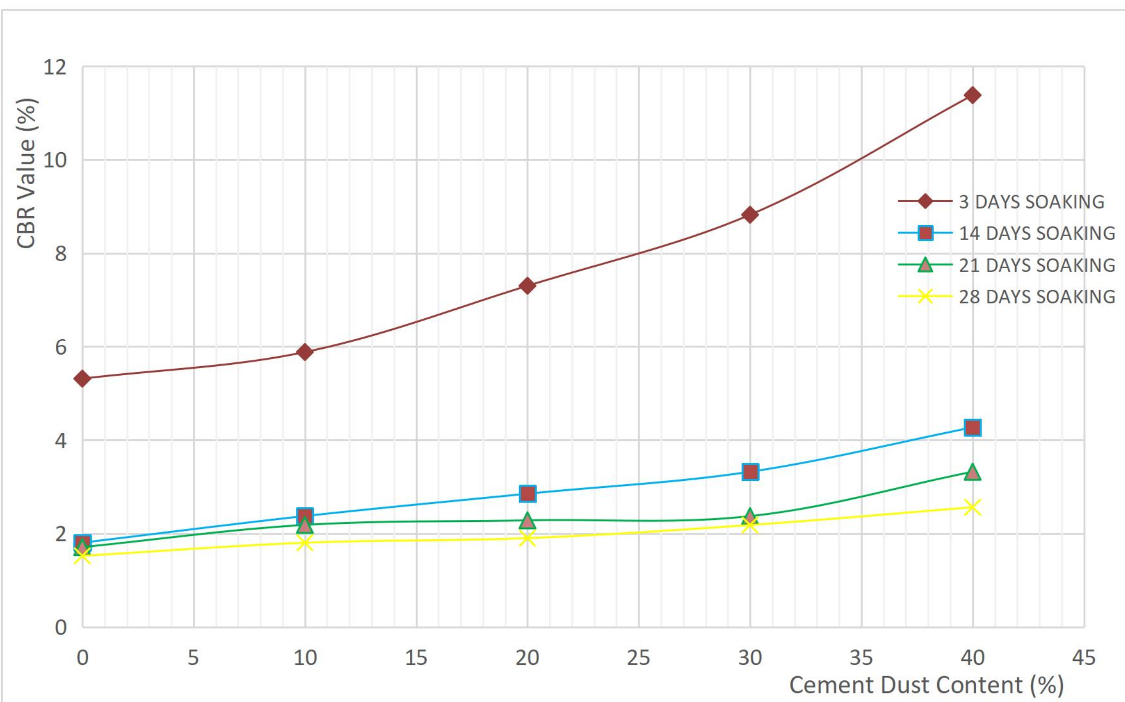


Figure 4.4a: Variation in CBR value for unsoaked clay soil with ceramic dust content

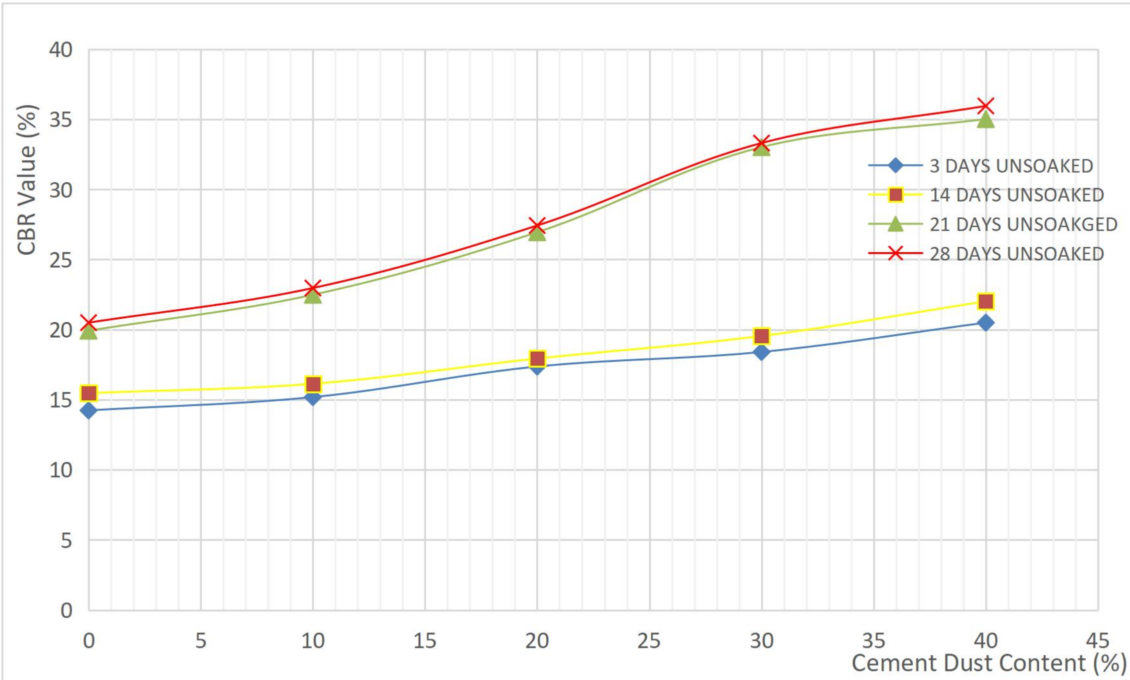


Figure 4.4b: Variation in CBR value for soaked clay soil with ceramic dust content

4.5 Unconfined Compressive Strength (UCS)

The values of the uncured UCS for the naturl soil samples increased from 13.79 to 24.64 kN/m^2, then for the 28days cured stabilized samples, the UCS value increased from 18.34 to 41.80 kN/m^2 when ceramic dust is increased from 0 to 40% respectively. The low value for the untreated tropical clay soil is consistent with the classification as a very soft clay soil. (< = 25kN/m^2). The variation of UCS with percentage of ceramic dust is shown in Figure 4.5

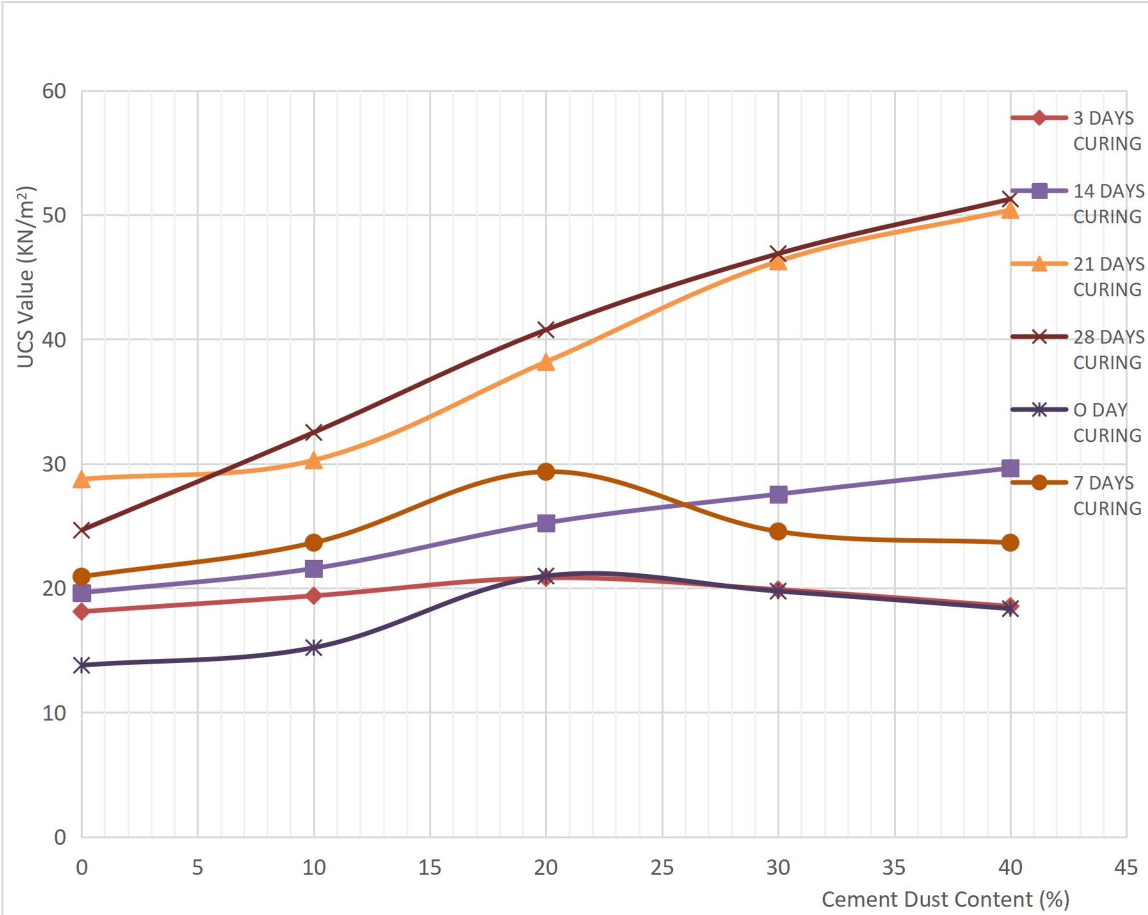


Figure 4.5: Variation of UCS with percentage of ceramic dust

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Based on the observations and discussions, following conclusions are drawn from this study;

It was observed that the tropical clay soil shows the soil sample is a low plasticity clay and classified as A-6.

Based on the laboratory tests observations, The liquid limit, plastic limit and plasticity index decreased with addition of ceramic dust.

The MDD increased and OMC decreased with increase in percentage of addition of ceramic dust. The Tropical Clay sample had improvement on the MDD from its natural value at 0% ceramic dust content to 20% mix of ceramic dust, but beyound the 20% mix of ceramic dust, it is clear that with further increase of OMC, the amount of voids in soil gets increase and dry density gets decrease under loading condition expulsion of the pore water.

With percentage increase of Ceramic dust , CBR of the tropical soil increased. The reason of such type of behavior of the stabilized soil is the reduction in clay content of soil by replacement of soil by ceramic dust mix. According to Simon *et al* (1973), a high reduction in CBR values after soaking indicates that the soil is very sensitive to changes in the moisture content.

The Unconfined Compressive Strength (UCS) of the tropical clay soil increased significantly, with the addition of ceramic dust up to 40%.the 28days cured UCS value increases from 24.65 kN/m^2 to 51.28 kN/m^2 when ceramic dust is increased from 0 to 40% respectively. The low value for the untreated tropical clay soil is consistent with the classification as a very soft or low plasticity clay soil. ($< = 25kN/m^2$).

5.2 Recommendations

1 It is found that ceramic dust up to 40% can be utilized for stabilizing the subgrade of flexible pavement with a substantial save in cost of construction and extend pavements life span.

2 The stabilization method prescribed in this study will require futher research works by increasing the curing period, further addition of ceramic dust or other stabilizers considered appropriate.

5.3 Contribution to knowledge

This research established that putting industrial waste materials such as ceramic dust, locally and readily available into use in construction can solve enviromenmetal pollution and construction problems. From the economic analysis it was found that waste ceramic dust up to 40% can be used in strengthening the sub grade of flexible pavements, to save the cost of construction and extending pavements life span.

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APPENDIX A

Tables for Natural Moisture Content and Specific Gravity Results

Table 3.2.1: Natural Moisture Content table of tropical clay soil

Can Number	**2B**	**Y15**	**A30**
Can Weight (g)	24.40	23.60	25.30
Can Weight + wet soil (g)	39.80	38.80	34.80
Can Weight + Dry soil (g)	37.90	36.90	33.60
Weight Moisture (g)	1.90	1.90	1.20
Weight of Dry soil (g)	13.50	13.30	8.30
Moisture content (%)	14.07	14.29	14.46
Average Moisture Content	14.27 %		

Table 3.2.2a: Specific Gravity table of tropical clay soil

No. of Trail	**1**	**2**	**3**
Weight of Empty bottle (M1)	116.6	69	116.6
Weight of Empty bottle + Sample (M2)	155.5	95.9	145.2
Weight of Empty bottle + Sample + Water (M3)	376.9	183.8	375.3
Weight of Empty bottle + Water (M4)	354.5	168.3	354.5
Specific Gravity	2.36	2.36	3.67
Average Specific Gravity	2.79		

The specific gravity indicates the soil is Clay / Silty clay (i.e. 2.67-2.9)

Table 3.2.2b: Specific gravity table of ceramic dust (CD)

No. of Trail	**1**	**2**	**3**
Weight of Empty bottle (M1)	69	69	69

Weight of Empty bottle + Sample (M2)	88.7	104.7	88.3
Weight of Empty bottle + Sample + Water (M3)	179.6	189.8	180.2
Weight of Empty bottle + Water (M4)	168.3	168.3	168.3
Specific Gravity	2.35	2.51	2.61
Average Specific Gravity	2.49		

APPENDIX B

Tables for Particle-Size distribution, Atterberg Limits and Compaction Results

Table 3.2.3: Particle-Size distribution table of the black cotton soil

S/N	SIEVE SIZE (mm)	MASS RETAINED (g)	% RETAINED	MASS PASSING (g)	% PASSING (g)	Cum. % retained (g)
1	5.000	4.20	2.26	295.8	97.74	2.26
2	3.350	6.30	3.39	289.5	94.35	5.65
3	2.360	4.30	2.32	285.2	92.03	7.97
4	2.000	2.20	1.19	278.5	90.84	9.16
5	1.180	4.50	2.42	274	88.42	11.58
6	0.850	2.00	1.08	272	87.34	12.66
7	0.600	2.40	1.29	269.6	86.05	13.95
8	0.425	2.20	1.19	267.4	84.86	15.14
9	0.300	2.40	1.29	265	83.57	16.43
10	0.150	20.10	10.83	244.9	72.74	27.26
11	0.075	132.50	71.39	112.4	1.35	98.65
12	PAN	2.5	1.35		0.00	100
			100			

Table 3.2.4: Summary Result for Atterberg Limits of the tropical clay soil and ceramic dust mixtures

Ceramic Dust Content (%)	0	10	20	30	40	FGN Specification 1997
Plastic Limit, %	22.64	20.9	18.7	17.1	16.8	-
Liquid Limit, %	37.8	31.2	28.4	23.6	20.8	30
Plasticity Index, %	15.6	10.3	9.7	6.5	3.0	13

Table 3.2.5 Summary Result for Compaction of the tropical clay soil ceramic dust mixtures

CERAMIC DUST CONTENT (%)	0	10	20	30	40
(MDD) BSH (g/cm^3)	1.99	2.0	2.1	1.84	1.76
(MDD) BSL (g/cm^3)	1.72	1.76	1.77	1.64	1.22
(MDD) WAS (g/cm^3)	1.87	1.88	1.92	1.78	1.75
(OMC) BSH (%)	13.42	11.8	11.5	11	9.09
(OMC) BSL (%)	20.1	19	18.4	18.1	18.0
(OMC) WAS (%)	16	14.4	13.8	13.57	13.1

APPENDIX C

Table for California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) Results

DETERMINATION OF THE C.B.R. VALUE OF THE TROPICAL SOIL USING STANDAED/HEAVY COMPACTION AND C.B.R. METHOD

Rammer	=	4.5kg
No. of Blow	=	62
No. of layer	=	5
Total weight of sample	=	6000g
Standard specemen load for 2.5mm penetration	=	13.44 kN
Standard specemen load for 5.0mm penetration	=	20.16 kN
Prooving ring factor	=	0.0255
Wieght of the mould + base plate	=	4500g
Volume of mould used	=	2305 cm3

Table 3.2.6: Result for the C.B.R. value of the Tropical Soil ceramic dust mixtures

UNSOAKED SAMPLES

Three (3) days CBR value for unsoaked Tropical Clay Soil ceramic Dust mixtures

CERAMIC DUST CONTENT	0%		10%		20%		30%		40%	
PENETRATION (mm)	LOAD ON PUNGER		LOAD ON PUNGER		LOAD ON PUNGER		LOAD ON PUNGER		LOAD ON PUNGER	
	TOP	BOT	TOP	BOT	TOP	BOT	TOP	BOT	TOP	BOT
2.5	69	81	78	82	87	96	92	102	98	118
5.0	140	97	151	112	158	118	169	138	185	179
Average penetration of 2.5mm	75		80		91.5		97		108	
Average penetration of 5.0mm	118.5		131.5		138		153.5		182	
C.B.R. VALUE (%) for 2.5mm	14.23		15.18		17.36		18.40		20.49	
C.B.R. VALUE (%) for 5.0mm	14.99		16.63		17.46		19.42		23.02	

Fourteen days (14) days CBR value for unsoaked Tropical Clay Soil Ceramic Dust mixtures

CERAMIC DUST CONTENT	0%		10%		20%		30%		40%	
PENETRATION (mm)	LOAD ON PUNGER		LOAD ON PUNGER		LOAD ON PUNGER		LOAD ON PUNGER		LOAD ON PUNGER	
	TOP	BOT	TOP	BOT	TOP	BOT	TOP	BOT	TOP	BOT
2.5	77	86	81	89	88	101	95	111	111	121
5.0	145	109	157	118	162	124	175	145	187	199
Average penetration of 2.5mm	81.5		85		94.5		103		116	
Average penetration of 5.0mm	127		137.5		143		160		193	
C.B.R. VALUE (%) for 2.5mm	15.46		16.13		17.93		19.54		22.01	
C.B.R. VALUE (%) for 5.0mm	16.06		17.39		18.09		20.24		24.41	

Twenty-one days (21) days CBR value for unsoaked Tropical Clay Soil Ceramic Dust mixtures

CERAMIC DUST CONTENT	0%		10%		20%		30%		40%	
PENETRATION (mm)	LOAD ON PUNGER		LOAD ON PUNGER		LOAD ON PUNGER		LOAD ON PUNGER		LOAD ON PUNGER	
	TOP	BOT	TOP	BOT	TOP	BOT	TOP	BOT	TOP	BOT
2.5	112	98	124	113	156	128	171	177	188	181
5.0	151	122	165	147	187	165	198	188	212	205
Average penetration of 2.5mm	105		118.5		142		174		184.5	
Average penetration of 5.0mm	136.5		156		176		193		208.5	
C.B.R. VALUE (%) for 2.5mm	19.92		22.48		26.94		33.01		35.01	
C.B.R. VALUE (%) for 5.0mm	17.27		19.73		22.26		24.41		26.37	

Twenty-eight days (28) days CBR value for unsoaked Tropical Clay Soil Ceramic Dust mixtures

CERAMIC DUST CONTENT	0%		10%		20%		30%		40%	
PENETRATION (mm)	LOAD ON PUNGER		LOAD ON PUNGER		LOAD ON PUNGER		LOAD ON PUNGER		LOAD ON PUNGER	
	TOP	BOT	TOP	BOT	TOP	BOT	TOP	BOT	TOP	BOT
2.5	115	101	126	116	159	130	169	182	192	187
5.0	163	131	172	151	191	168	201	191	215	209
Average penetration of 2.5mm	108		121		144.5		175.5		189.5	
Average penetration of 5.0mm	147		161.5		179.5		196		212	
C.B.R. VALUE (%) for 2.5mm	20.49		22.96		27.42		33.30		35.95	
C.B.R. VALUE (%) for 5.0mm	18.59		20.43		22.70		24.79		26.82	

SOAKED SAMPLES

Three (3) days CBR value for soaked Tropical Clay Soil Ceramic Dust mixtures

CERAMIC DUST CONTENT	0%		10%		20%		30%		40%	
PENETRATION (mm)	LOAD ON PUNGER		LOAD ON PUNGER		LOAD ON PUNGER		LOAD ON PUNGER		LOAD ON PUNGER	
	TOP	BOT	TOP	BOT	TOP	BOT	TOP	BOT	TOP	BOT
2.5	46	10	52	10	70	7	76	12	82	19
5.0	30	15	31	16	45	32	41	34	47	33
Average penetration of 2.5mm	28		31		38.5		44		50.5	
Average penetration of 5.0mm	22.5		23.5		38.5		37.5		40	
C.B.R. VALUE (%) for 2.5mm	5.31		5.88		7.30		8.82		11.38	
C.B.R. VALUE (%) for 5.0mm	2.85		2.97		4.87		5.06		5.69	

Fourteen days (14) days CBR value for soaked Tropical Clay Soil Ceramic Dust mixtures

CERAMIC DUST CONTENT	0%		10%		20%		30%		40%	
PENETRATION (mm)	LOAD ON PUNGER		LOAD ON PUNGER		LOAD ON PUNGER		LOAD ON PUNGER		LOAD ON PUNGER	
	TOP	BOT	TOP	BOT	TOP	BOT	TOP	BOT	TOP	BOT
2.5	12	7	20	9	21	9	25	10	31	14
5.0	17	8	19	8	22	10	23	13	28	16
Average penetration of 2.5mm	9.5		14.5		15		17.5		22.5	
Average penetration of 5.0mm	12.5		13.5		16		18		22	
C.B.R. VALUE (%) for 2.5mm	1.80		2.75		2.85		3.32		4.27	
C.B.R. VALUE (%) for 5.0mm	1.58		1.71		2.02		2.28		2.78	

Twenty-one days (21) days CBR value for soaked Tropical Clay Soil Ceramic Dust mixtures

CERAMIC DUST CONTENT	0%		10%		20%		30%		40%	
PENETRATION (mm)	LOAD ON PUNGER		LOAD ON PUNGER		LOAD ON PUNGER		LOAD ON PUNGER		LOAD ON PUNGER	
	TOP	BOT	TOP	BOT	TOP	BOT	TOP	BOT	TOP	BOT
2.5	11	7	15	8	15	9	16	9	17	18
5.0	16	8	17	8	18	11	19	12	20	17
Average penetration of 2.5mm	9		11.5		12		12.5		17.5	
Average penetration of 5.0mm	12		12.5		14.5		15.5		18.5	
C.B.R. VALUE (%) for 2.5mm	1.71		2.18		2.28		2.37		3.32	
C.B.R. VALUE (%) for 5.0mm	1.52		1.58		1.83		1.96		2.34	

Twenty-eight days (28) days CBR value for soaked Tropical Clay Soil Ceramic Dust mixtures

CERAMIC DUST CONTENT	0%		10%		20%		30%		40%	
PENETRATION (mm)	LOAD ON PUNGER		LOAD ON PUNGER		LOAD ON PUNGER		LOAD ON PUNGER		LOAD ON PUNGER	
	TOP	BOT	TOP	BOT	TOP	BOT	TOP	BOT	TOP	BOT
2.5	10	6	13	6	14	6	15	8	16	11
5.0	14	7	15	7	15	8	16	9	19	14
Average penetration of 2.5mm	8		9.5		10		11.5		13.5	
Average penetration of 5.0mm	10.5		11		11.5		12.5		16.5	
C.B.R. VALUE (%) for 2.5mm	1.52		1.80		1.90		2.18		2.56	
C.B.R. VALUE (%) for 5.0mm	1.33		1.39		1.45		1.58		2.09	

DETERMINATION OF UCS VALUE OF THE TROPICAL SOIL

A_o	:	0.01257
Proving ring constant	:	55
Deformation rate	:	0.01
Length of the sample	:	76cm
Diameter	:	38cm

Table 3.2.7 Summary Result for the UCS value of the Tropical Clay Soil Ceramic Dust mixtures

CERAMIC DUST CONTENT (%)	**0**	**10**	**20**	**30**	**40**
O DAY CURING (kN/m^2)	13.79	15.21	20.97	19.75	18.34
3 DAYS CURING (kN/m^2)	18.11	19.38	20.82	19.88	18.54
7 DAYS CURING (kN/m^2)	20.92	23.65	29.35	24.55	23.65
14 DAYS CURING (kN/m^2)	19.62	21.58	25.24	27.55	29.64
21 DAYS CURING (kN/m^2)	28.75	30.28	38.18	46.27	50.4
28 DAYS CURING (kN/m^2)	24.65	32.51	40.76	51.28	41.80