ASSESSMENT OF LATERIZED QUARRY DUST AND CRUSHED BRICKS AS ALTERNATIVE CONCRETE MAKING MATERIALS

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Assessment of Laterized Quarry Dust and Crushed Bricks as Alternative Concrete Making Materials

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

Signature: …………………................................... Date: ……………………......

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This thesis has been submitted for examination with our approval as University supervisors

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DEDICATION

This work is dedicated to my wife Stella, son Leshan and daughter Daisy and other family members for giving me easy moment during my studies.

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LIST OF SYMBOLS AND ABBREVIATIONS

P.C.C. -	Portland cement concrete
LECA -	Lightweight Expanded Clay Aggregate
ASTM-	American society for testing and materials
KS-	Kenya Standard
BS-	British Standard
ACV -	Aggregate Crushing Value
LVDT-	Linear Variable Displacement Transducer
UTM -	Universal Testing Machine
RBMA-	Recycled Brick Masonry Aggregate
ECSI -	Expanded Clay, Shale and Slate Institute
QdLB –	Quarry dust Latrite Brick

ABSTRACT

The research was conducted to study the suitability of using laterite soil, quarry dust and the crushed brick as alternative aggregates for concrete production for low cost housing since it is clear that the rising cost of concrete materials coupled with environmental degradation has impaired the construction industry. The following tests were carried out to determine the physical properties of these materials; density tests, silt content, water absorption, sieve analysis, specific gravity, flakiness index and aggregate crushing value. The research was conducted by testing concrete cylinder and cubes specimens at ages of 7, 14 and 28days concrete with concrete mix ratios 1:1.5:3 with a target strength of 25N/mm^2 and 1:2:4 with a target strength of 20N/mm^2. Samples of concrete specimens were made using varying contents of quarry dust and laterite as fine aggregate. The quantity of quarry dust was varied from 0 to 100% against laterite at intervals of 25%. The samples were cured for specified periods, i.e., 7, 14 and 28 days and tested in the laboratory for compressive strength and split tensile strength. Compressive strength at 28 days ranged from 17.5-19.9N/mm^2 for mix ratio 1:1.5:3 and 14.7-17.6N/mm^2 for mix ratio 1:2:4. Split tensile strength at 28 days ranged from 1.9-2.5N/mm^2, 1.4-2.5N/mm^2 respectively. These results are slightly lower as compare to those of conventional concrete. The results revealed that a combination of 50% quarry dust against 50% laterite and 75% quarry dust against 25% laterite attained higher compressive strength and that these materials are ideal for making concrete to be used where high strength of concrete, i.e., strength exceeding 20N/mm^2 is not required.

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Concrete is a versatile engineering material consisting of cementing substance, aggregates, water and often controlled amount of entrained air. It is initially a plastic, workable mixture which can be moulded into a wide variety of shapes when wet. The strength is developed from hydration due to the reaction between cement and water. The products, mainly calcium silicate, calcium silicate hydrate, calcium aluminates and calcium hydroxide are relatively insoluble which bind the aggregate in a hardened matrix. Concrete is considerably stronger in compression than in tension; for structures required to carry only compressive loads such as massive gravity dams and heavy foundations, reinforcement is not required and the concrete is consequently called plain concrete. When the structure is to be subjected to tensile stresses, steel bars are embedded in the concrete. Since 70-80% of concrete is made up of aggregates, its types, quality and general properties determine the quality of concrete (Khatita et al., 2009).

According to Arai (1986) good quality concrete in Kenya is manufactured from natural river sand and natural crushed aggregates satisfying the grading requirements of British Standards or Kenya Standards. The availability of these aggregates for concrete manufacture has become scarce in some areas due to high demand leading to over-exploitation during harvesting, excessive cost of the material on the market, reduced supply due to increasing construction activities and transportation difficulties due to the poor state of roads (Mustafa, 1990).

These materials are fast becoming rare and expensive commodities. Uncontrolled sand mining from river beds leads to problems like bank erosion lowering of water Table and other adverse effects to the environment. Likewise, quarrying of granite which is the main source of coarse aggregate has also led to similar problems.

It is high time the use of alternative aggregates in concrete production should be encouraged. The necessity of using locally available materials and recycled materials for the production of concrete is the need of the hour, particularly in fast developing countries like Kenya.

1.2 Problem Statement

Concrete is one of the most important building materials used in the construction industry globally. Concrete production has become expensive over the years due to increased demand for construction. This has led to an increase in the prices of the materials used to make concrete, i.e., aggregates and cement.

One of the development goals of Kenya's vision 2030 is to provide affordable housing to all citizens especially those in the slums and shanties. This may be accomplished by provision of quality alternative building materials such as clay aggregates, utilizing different types of soils available locally, recycling industrial waste products and using the agricultural by products. Thus, from an economical point of view, a research on alternative production of cost effective concrete to meet demand is one of the most important step in the right direction in concrete technology. Therefore, the provision of locally available aggregates from the utilization of clay products, waste chips and lateritic sand to be used in concrete production will help in lowering the cost of construction of housing units (low cost housing) for human dwelling.

Furthermore, production of common granitic aggregates and building stones by quarrying is very expensive economically. Quarrying creates an unfriendly environment by leaving land excavated and rocks blasted which can lead to subsidence and in some cases earth tremors due to disturbance of the rock strata**.**

1.3 Research Justification

As we know river sand and crashed granitic stone ballast are among the most common fine and coarse aggregates used in the production of concrete. But today, in many areas we are facing an acute shortage of these materials because of excessive use resulting to serious problems such as shortage in availability, cost and impact on environment.

It is clear that the rising cost of these concrete materials, depletion of natural sources of aggregates materials coupled with environmental degradation has impaired the construction industry, research on alternative materials to conventional aggregates justifies this research work.

1.4 Objectives of the Study

1.4.1 Main Objective

The main objective of this study was to investigate the suitability of using laterized quarry dust and crushed bricks as total replacement of conventional aggregates.

1.4.2 Specific Objectives

i. To determine the properties of laterized quarry dust as fine aggregates and crushed bricks as coarse aggregates.
ii. To assess the effect of replacing fine and coarse aggregates with laterized quarry dust and crushed bricks.

1.5 Research Hypothesis

Laterized quarry dust as fine aggregates and crushed bricks as coarse aggregates may be suitably used as alternative total replacement for river sand and normal granitic aggregates in concrete.

1.6 Scope and limitation

1.6.1 Scope

In order to achieve the above stated objectives, the scope of the research was limited to the following.

i. Determining the physical and mechanical properties alternative aggregates
ii. Determining the effects of curing methods on strength properties of concrete made of laterized quarry dust and crushed bricks as fine and coarse aggregates respectively

1.6.2 Limitations

The test materials, i.e., laterite, quarry dust and crushed bricks were all sourced from single sites, but it is expected that the same materials from other sites would have similar properties.

However, before they are used they need to be tested to check if they have same properties as the test materials in this research.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

An aggregate is a product having specific physical and gradational properties and is created by manipulation of material through a processing operation. The material may be from natural sand and/or gravel deposits, quarried bedrock, slag from steel mills or copper refineries, debris from mining operations, or crushed Portland cement concrete.

In concrete technology, aggregates have been depicted as hard, inert material incorporated in concrete mixes to serve as reinforcement to add strength to the overall composite material. In a typical medium-strength concrete mix, aggregates account for up to 75% of the total volume of concrete. Aggregates are incorporated into concrete mixes to serve the following functions;

They reduce the heat of hydration of concrete since they are normally chemically inert and act as a heat sink for hydrating cement.

They reduce the shrinkage of concrete since they do not swell and they restrain shrinkage of the hydrating cement.

They also reduce the cost of concrete since they are mostly derived from natural materials and they occupy a greater percentage in concrete.

2.2 Classifications of Aggregates

Aggregates may be broadly classified as natural or artificial, both with respect to source and method of preparation. Natural sands and gravels are the product of weathering and the action of wind or water, while stone sands and crushed stone are produced by crushing natural stone. Screening and washing may be used to process aggregates from either of these categories. Aggregates may be produced from igneous, sedimentary, or metamorphic rocks, but the presence or absence of any geological type does not, by itself, make an aggregate suitable or unsuitable for use in concrete. The acceptance of an aggregate for use in concrete on a particular job should be based upon specific information obtained from tests used to measure the aggregate quality, or upon its service record, or both. A typical consensus specification for concrete aggregate, both fine and coarse aggregate, is ASTM Standard C33, (2003).

Synthetic aggregates may be either by products of an industrial process, such as blast-furnace slag, or products of processes developed to manufacture aggregates with special properties, such as expanded clay, shale or slate that are used for lightweight aggregates. Some lightweight aggregates such as pumice or scoria also occur naturally.

2.3 Concrete Production in Kenya

Cement and aggregates, i.e., crushed rock as coarse aggregate and river sand or pit sand as fine aggregate are the most important constituents used in concrete production in the world and particularly in Kenya today.

This has resulted into degradation of the environment, therefore there is need to explore alternative construction materials from industrial as well as household waste and recyclable materials.

Research work has been generally carried out on most proposed alternative materials with a view of utilizing them in construction industry. Studies on the alternative materials have however been done in different parts of the world.

Udoeyo et al. (2006) studied the strength performance of laterized concrete, Oyawa (2004) studied eco-materials for sustainable development in developing countries, Nagaraj and Zahida (1996) studied the efficient utilization of rock dust and pebbles as aggregates in Portland cement concrete.

Use of waste as aggregates in new concrete has also gained increased interest in recent years for reasons related to both economics and environmental sustainability. Demolition waste materials used for production of recycled aggregates can include crushed concrete, crushed brick and crushed mixed rubble from various sources including demolished buildings and roadways. Concrete that contains recycled aggregates is called recycled aggregate concrete (RAC).

Use of recycled/waste materials as aggregates in concrete can provide a number of advantages to stakeholders including owners, contractors, and the ready-mixed concrete and precast concrete industries. From an economic standpoint, these aggregates can be cheaper than conventional (natural and manufactured lightweight) aggregates. Use of aggregates made from crushed construction and demolition debris may become an increasingly attractive alternative due to rising landfill tipping fees, diminishing landfill space, and rising cost of virgin natural aggregate material. From the standpoint of sustainability, use of recycled materials as aggregates provides several advantages. Landfill space used for disposal is decreased, and existing natural aggregate sources are not as quickly depleted.

2.4 Use of Laterite in Construction

According to Makasa (1998), the soil name "laterite" was given by Buchanan (1807), in India, from a Latin word "later" meaning brick. Laterite is used extensively in the construction of embankments for roads and earth dams. Lateritic soils, according to Osadebe and Nwakonobi (2007), are widely used as construction material in Nigeria and other under-developed and developing countries of the world. However, they argue that laterites have not been extensively used in constructing medium to large-size building structures, probably because of lack of adequate data needed in the analysis and design of structures built of lateritic soils. This underscores the need for more research efforts in this area.

According to Adoga (2008), laterite is a highly weathered material rich in secondary oxides of iron, aluminum or both. It is nearly devoid of base and primary silicates but may contain large amount of quarts, and kaolinite. Laterite has been used for wall construction around the world. It is cheap, environmentally friendly and abundantly available building material in the tropical region (Olugbenga et al., 2007).

Ayangade et al. (2009) reported that approximately 30% of the world's present population still lives in lateritic structures. They observed that the restriction of laterite building to rural areas is due to lack of accepted standard design parameters for the effective structural applications of laterized concrete. They described Terracrete as a mixture of laterite (as fine aggregate), granite or gravel (coarse aggregate), cement and water in a chosen weight proportion, mixed by means that are available and equally allowed to undergo curing processes. In this research laterite was used together with quarry dust and a detailed analysis of the two materials combination was done in order to provide standard design parameters for structural concrete.

2.5 Genesis of Laterite

Laterite is a product of intense sub aerial weathering; laterization process involves leaching of alkalis, basis and silica with complimentary enrichment of alumina, iron and some trace elements. Further concentration and dehydration and subsequent cementation forms hard concretionary nodules or the coalescence of particles into a hard vesicular mass of honeycomb structure where cavities may contain the host soil (Aleva, 1994), and (Bardosy et al., 1990).

The first global synthesis of the distribution of laterite was done by Prescott and Pendleton in 1952. Laterite and associated soils are widely distributed in the tropics and subtropics of Africa, Australia, India, South-East, Asia and South America.

Laterite is being extensively used as building block from the early civilization. Some of the structures constructed during Khmer civilization in Cambodia (802AD to 1431AD) still stand virtually untouched by time (Varghese & Byju, 1993). The fort at Bekal and Thalassery, Kerala constructed with laterate block ways back in 15th century is still a standing monument (Swami, 2001).

2.6 Laterised Concrete

According to Salau (2008) laterized concrete is defined as concrete in which sTable laterite fine replace aggregate (i.e. sand)**.** According to Osunade (2002a), laterized concrete is concrete in which the fine aggregates are lateritic soils. Laterite is a mixture of clayey iron and aluminum oxides and hydroxides formed as a result of the weathering of basalt under humid, tropical conditions.

The first published work on laterised concrete appears to have been done by Adepegba in 1975; he considered the possibility of replacing sand in concrete with laterite. He studied the effect of using laterite fines instead of sand in relation to the density, compressive strength, tensile strength, modulus of elasticity and resistance to high temperature. He observed that the plain laterite concrete is inferior to plain normal concrete as far as density and compressive strength is concerned, the impact resistance decreases with increases in percentage of laterite content in the concrete mix. Further he noted that the modes of failure in the laterised concrete specimens are essentially the same as those in the plain concrete and they are brittle and occurred through the granite aggregate particles. He also observed that the flexural strength and workability of a laterised concrete mix of 2:3:6 with water/cement ratio of 0.65 by weight compared favorably with those of a normal concrete mix of 1:2:4 with water/cement ratio of 0.65 by weight**.** He concluded that their properties fared well in comparison with those of normal concrete, thereby offering that laterite fines can be used in place of sand in structural concrete.

Balogun and Adepegba (1982) studied the effect of varying sand content in laterized concrete and observed that when sand is partially replaced with laterized fines, the most suitable mix for structural application is 1:1.5:3 with water cement ratio of 0.65

provided that the laterite content is kept below 30% of the total fine aggregate. The water cement ratio used confirms to the recommendation of Lasisi and Ogunjide (1984) who obtained a linear relationship between the laterite cement ratio and the optimum w/c ratio. The linear relationship was obtained using equation (2.1):

$$Y=0.9+3.85X \quad (2.1)$$

Where:

Y=*laterite cement ratio*

X=*optimum water cement ratio*

Chandrakaran et al. (1996) also reported that for fully laterized concrete, the compressive strength is 50% of that of normal concrete. The difference in strength is due to different chemical composition, method of compaction and difference in maximum size of aggregates used.

It has also been established from another study on effect of grain size on the strength characteristics of cement stabilized lateritic soils by Lasisi and Ogunjide (1984) that the higher the laterite/cement ratio the lesser the compressive strength and that the finer the grain size range the higher the comprehensive strength of cubes made from such soils. They have also reported that 10% cement by weight is needed to stabilize laterite soils to produce blocks of the same order of compressive strength as standard concrete blocks 450x225x150mm.

Osunade and Babalola (1991) conducted studies on the effect of mix proportion and reinforcement size on the anchorage bond stress of laterised concrete and established that both mix proportion and the size of reinforcement have significant effect on the anchorage bond stress of concrete made with fine aggregate. The richer in terms of cement content in the mix proportion, the higher the anchorage bond strength of laterised concrete, also the anchorage bond stress between plain round steel reinforcement and laterised concrete increases with the increase in size of reinforcement.

Lanre et al. (2007) studied the influence of weather on the performance of laterized concrete. This was achieved by conditioning laterized concrete cubes to varying temperatures and alternate wetting and drying. After curing for 28 days the specimens were tested to determine the compressive strength. The results showed that the comprehensive strength of the finalized laterized concrete decreased when subjected to alternate wetting and drying. The reason for this could be due to some other inherent salts present in the laterite which may experience a breakdown in their internal structure when subjected to alternating temperatures, thus leading to a reduction in the compressive strength of the laterized concrete.

This implies that laterized concrete depreciates with time under the prevailing conditions (rainy and dry season) in the tropics, therefore laterized concrete should not be exposed to constant rainy and dry season as it could result in reduction of its compressive strength.

2.7 Concrete Produced with Brick Aggregate

Fine and coarse aggregate make up the bulk of concrete mixture. Sand, natural gravel and crushed stone are mainly used for this purpose. Recycled aggregates (from construction, demolition and excavation waste) are increasingly used as partial replacements of natural aggregates. Concrete can be successfully produced using recycled materials. The use of recycled aggregate concrete (RAC) has steadily increased during the last two decades and its current field of applications includes: lightweight concrete, lightweight aggregate, asphalt concrete, concrete exposure to high temperatures and road construction. The use of crushed waste as aggregate in concrete began in Europe after the Second World War (Swamy, 1983).

In Japan, after the Second World War, many buildings have been constructed from crushed waste because of the need for low-cost and rapidly constructed buildings. These buildings remain functionally good up to date. The development of recycling technology in Germany dates back to about 1900 (Schulz, 1988).

Crushed bricks are extensively used in parts of India and Bangladesh for concrete making and the performance of this concrete is found to be quite satisfactory (Akhtaruzzaman et al., 1983) The same investigation has shown that the modulus of elasticity of brick-aggregate concrete is about 30% lower and the tensile strength about 11% higher for the same grade of the normal concrete, this characteristic is attributed to the higher water absorption of brick-aggregate as compared to natural aggregate.

Husain (1995) studied the use of coarse aggregate of crushed bricks untreated or treated with cement syrups of various consistencies, he found that the compressive strengths of crushed brick concrete are 75-80% of that of normal concrete at 28 days while the splitting tensile strength are higher than that of normal concrete and the modulus of elasticity is lower than that of normal concrete.

Extensive work on RAC has established that using of various types of recycled aggregate such as contaminated crushed brick, light weight crushed bricks, light weight expanded clay, low-strength bricks, granulated plastic, glass and fiber glass waste materials in concrete produces concrete with light weight, light density and low costs (Fouad & Devenny, 2005).Their works present the results of a testing programme to examine the possibility of using crushed clay bricks as aggregate in bituminous mixtures and established the physical and mechanical properties of new and recycled crushed clay brick aggregates for use in Portland cement concrete (PCC).

The results derived from these investigations showed that asphalt concrete specimens prepared using aggregates crushed from unused clay and recycled bricks outperformed specimens made with granite aggregate and most of the crushed clay-brick aggregates tested can be used in producing PCC for low-level civil engineering applications and that some kinds of brick aggregate possess good physical and mechanical properties that qualify them for producing high-quality concrete.

Furthermore, with increase in population and construction activities, the quantity of demolition wastes generated from various types of construction will increase in the coming years.

These construction wastes can effectively be used for making lightweight low cost RAC after exploring their suitability. In this research crushed bricks a construction waste were used as coarse aggregates to produce sustainable concrete that is environmentally friendly and economical.

2.8 Concrete Produced with Waste Ceramic Aggregate

Concrete as a primary building construction material is the most consumed man-made material in the world. In 2007 the world concrete consumption was 11 billion tons or approximately 1.7 ton for each living human being **(**Mehta, 2008; Naik, 2005; Naik, 2008). One of most important part of concrete is the aggregate; fine and coarse aggregates constitute approximately 80% of concrete volume. According to Mehta (2006), the global concrete industry consumes about 10 billion tons of sand and rocks and taking into account of today's industry development this number is ever higher. Therefore doing research about using modern technologies in production of concrete is of great importance. Furthermore one of the most critical problems of the world has been related to removal of the waste and reusing it.

In most countries particularly the third world countries, large amounts of waste is produced annually, most of these waste is not reusable or if it is, its recycling leads to wasting energy and pollution .

Tile and construction ceramic are among the most commonly used materials in the construction industry. The global production of ceramic tiles is about 8500 million square meters (Tavakoli et al., 2011). This huge amount of production has caused them to be among the most commonly consumed materials in the world. Usually, the wastage related to ceramic and sanitary ware are created in different forms some of which are produced in companies during and after production process due to errors in either construction, human activities and also inappropriate raw materials, but the most bulk of the wastage are created as a result of destruction during construction; for instance it is predicted that almost 3 to 7% of daily production of ceramic in Europe change into wastage and this amount reaches to millions of tons annually (Meyer, 2009).

The state of these materials are in a way that they are unusable in other cycles of construction, therefore they are treated as useless and are disposed to the environment. The hard physical structure of these materials and also their chemical structure make them good and suitable choice for concrete production (Khaloo, 1995).

2.9 Classification of Ceramic Wastes

Ceramic wastes are categorized into two categories in relation to the source of the raw materials. The first being fired wastes generated by the structural ceramic factories that use only red pastes to manufacture their products such as blocks, bricks and roof tiles. The second category is all fired waste produced in stoneware ceramic such as wall, floor tiles and sanitary ware.

This classification is shown in the following diagram;

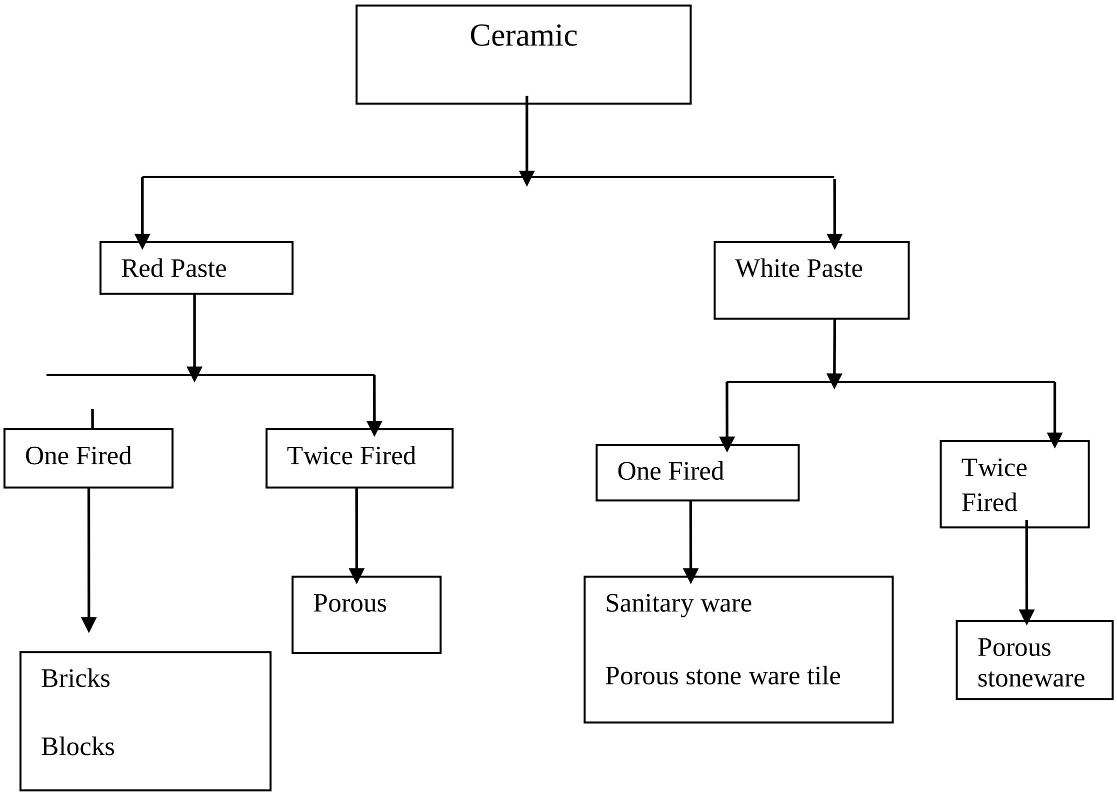

Figure 2.1: Classification of Ceramic wastes by type and production process.

Source: (Torgal & Jalali, 2010)

2.10 Clay-Based Aggregates

Clean broken brick of good quality can provide satisfactory aggregates, the strength and density of concrete depending on the type of brick; engineering and allied bricks when crushed make quite good concrete of medium strength (Murdock, 1991). In using second hand bricks, it is essential to remove all plaster otherwise calcium sulphate present is liable to prevent or delay setting and cause disintegration in a short time. Bricks containing soluble sulphates in excess of 0.5% should be avoided. Brick aggregates should be saturated before use because of its relatively high absorbency. Porous type of brick should not be used as aggregates in reinforced concrete work owing to the danger of penetration of moisture which may lead to corrosion of steel reinforcement (Murdock, 1991). Further the pores make a weaker matrix resulting in lower compressive strength.

In this research engineering properties of the bricks were determined in order to avoid use of bricks that do not meet the required standards.

2.11 Early History on use of Crushed Brick

The earliest use of crushed brick in cementitious materials using Portland cement occurred in Germany in 1860 (DeVenny & Khalaf, 1999). In Europe, many of the buildings damaged or destroyed by bombs during World War II included brick masonry. As part of rebuilding the damaged cities in Germany, rubble recycling plants were created, producing crushed recycled brick masonry aggregate (RBMA) that was used in new concrete construction. Crushed brick masonry was also used as aggregates in concrete in Great Britain after World War II.

Economic conditions and lack of suitable natural aggregates seems to have resulted in brick being used as aggregate in developing nations before being used in developed ones. Khan and Choudhry (1978) discussed how in Bangladesh, brick chips have been used as aggregate. They described the manufacturing processes used for making brick in Bangladesh and discussed the large variation in quality and mechanical properties of bricks made from these methods. General batching processes were described, and data for several brick aggregate concrete mixtures (compressive strengths ranging from 3,950 to 6,260 psi, or 27.2 to 43.2 MPa) was presented.

2.12 China Clay Products as Aggregates

China clay (kaolin) is formed by the hydrothermal alteration and decomposition of the feldspars within the parent rock. The material insitu takes the form of a weakened rock structure consisting predominantly of kaolin, quartz sand and mica. The `rock` is broken out by high pressure water jetting and the kaolin is separated from the resulting slurry.

The by-products resulting from the process are;

Stent – largely unaltered rock material often appearing as overburden or in isolated locations within the rock mass.

Sand – material consisting predominantly of quartz having a particle size grading from fine sand to coarse gravel.

Mica – sub-sand sized material.

China clay is largely produced in the southwest of England and in particular in Cornwall. Approximately nine tones of by-product results for every one ton of kaolin produced.

The crushed and graded stent has been used as a substitute for primary aggregate in highway construction. Using crushing and grading techniques it is possible to meet the majority of the required engineering properties. These include drainage filter media, pipe bedding and Type 1 sub-base. It is also possible to use the material as special fill and as an aggregate for concrete in accordance with BS 882(1995). Adjustments are necessary in some specifications, particularly for structural fill due to the wide range of 10% fines values (http//.clay waste products aggregates).

Crushed stent was used as Type 1 sub-base in the A30/A39 Indian Queens and Fraddon Bypass in Cornwall, England. This was a major trunk road scheme comprising of 7 km of new dual carriageway which was constructed in 1993-1994. China Clay by-products have properties similar to primary aggregates. In particular the better quality stent has properties not dissimilar to crushed granite. These materials are abundant in the south west of England and are available for exploitation. High road transport costs coupled with limitations in the existing rail link renders their transport to other parts of the UK uneconomic at present (http//.clay waste products aggregates).

Approximately 150 thousand tons of crushed stent was provided from the Indian Queens Quarry. This material was tested both by the contractor and Cornwall County Council and was found to be generally compliant to the specification with only occasional oversized material being present. China clay sand was also used as the fine aggregate in concrete for the by-pass. Testing again demonstrated high compliance rates with occasional instances of marginally high silt content. The concrete mixes incorporated both OPC and ground granulated blast furnace slag with a plasticizer admixture (http//.clay waste products aggregates).

2.13 Expanded Clay Aggregates

LECA (Lightweight Expanded Clay Aggregate) is a special type of clay that has been palletized and fired in a rotary kiln at a very high temperature. As it is fired, the organic compounds in the clay burn off forcing the pellets to expand and become honeycombed while the outside surface of each granule melts and is sintered. The resulting ceramic pellets are lightweight, porous and have a high crushing resistance. It is a natural product containing no harmful substances. It is inert with a neutral pH value, resistant to frost and chemicals, will not break down in water, is non-biodegradable, non-combustible and has excellent sound and thermal insulation properties.

LECA is an incredibly versatile material, and is utilized in an ever-increasing number of applications. In the construction industry, it is used extensively in the production of lightweight concrete blocks as well as both a sound and thermal insulation material, flue and chimney lining material. It is used in structural backfill against foundations, retaining walls, bridge abutments etc.

Two methods have been adopted in the preparation of the raw materials before burning; the wet process and the dry process. The wet process has been widely used in the manufacture of LECA. The clay minerals from the clay quarry are homogenized and crushed into very fine powder by passing through grinding mills. Water and expanding agents are then added. The fine and plastic paste of clay is then forced through perforated plates in extrusion press. The holes' diameters are chosen according to aggregate diameter required. The extruded clay paste is then cut into pieces of required length. The pellets obtained are first dried in a rotary kiln giving them rounded shapes. The burning process is mainly done in rotary kilns at 1150 degrees Celsius to 1200 degrees Celsius. The resulting products are cooled, crushed if necessary for fines and screened in different particle sizes fractions (The Concrete Society Ci80, 1980). The aggregates are brownish to reddish in colour, light, hard, rounded with honeycomb interior. Since LECA are porous, they absorb considerable quantities of water. The amount of water absorbed by LECA or Lytag (Pulverized Fly Ash, PFA) can exceed 20% by volume and the ultimate water absorption is of the order of 30% by volume. There is therefore, a considerable amount of water present within these aggregates and this can have a considerable influence on the thermal insulation, shrinkage and creep of concrete which is made with them (Murdock, 1991).

The bulk densities of LECA according to size fractions are as follows (The Concrete Society Ci80, 1980);

Less than 3mm: 600-750 kg/m3

3-10 mm: 400-500 kg/m3

10-20mm: 350-450 kg/m3

Lightweight chip seal and other uses with Asphalt on road surfaces when bonded to asphalt, structural lightweight aggregate chip seal creates a significantly improved asphalt bituminous surface treatment that is safer, more economical and longer lasting than conventional aggregates. Wet or dry, road surfaces of lightweight chip seal provide superior skid resistance that is maintained throughout the surface life. Lightweight aggregate does not polish as it wears. Because it is light in weight there are trucking and handling cost advantages to the contractor.

Also, windshield damage and damage to headlights, and paint caused by "flying" stones is virtually eliminated with structural lightweight aggregate, thus avoiding costly insurance claims and motorist complaints. (Expanded clay, shale and slate institute (ECSI 1953), East Ohio.

2.14 Quarry Dust as a Construction Material

Quarry dust is defined as a residue, tailing or other non-voluble waste material after the extraction and processing of rock to form fine particles less than 4.75mm (Ilangovan & Nagamani, 2007).

The demand for natural sand in the construction industry has consecutively increased which has resulted in the reduction of extraction sources, environmental degradation, social problems and increase in price making construction using concrete expensive. In such situation quarry dust which in most cases is considered as waste material can be an economical alternative.

According to Mamta and Rabbani (2017) the concept of replacement of natural fine aggregate (river sand) by quarry dust may help in many ways such as it is helpful to control environment pollution, erosion of river bank might stop and also the waste quarry material can be utilize.

According to Mulu et al. (1998) crushed rock quarry dust has physical properties comparable to natural sand and hence the desirable properties needed for this research work, Mulu et al. (1998) studied the characteristics of quarry dust as a low cost construction material in Kenya, The physical properties and grading characteristics of typical quarry dust were investigated and compared with those of natural river sand. The engineering properties of hardened concrete samples were also determined. The results indicated that, an increase in quarry dust content in concrete lead to decrease in compressive strength. However, Krishnamoorthi and Kumar (2010) reported that the third and seventh days cube compressive strength for concrete with 20% and 40% quarry dust is same as conventional concrete. The split tensile strength and flexural strength of concrete made with 40% of replacement of sand with quarry dust is more than that made with other percentage of replacement. The compressive strength of concrete made with 40% of quarry dust is more than that made with 0%, 20%, 50%, and 60% of quarry dust. Tensile strength of concrete made with 40% of quarry dust is more than that made with 0%, 20%, 50%, and 60% of quarry dust.

Tensile strength of concrete made with 60% of quarry dust is greater than that made with 0% of quarry dust. Compared to the control specimen the corresponding increase in 56 days compressive strength of specimens with 10 and 40% of partial replacement of fine aggregate by quarry dust was 11% to 5% respectively. Nadgir and Bhavikatti (2007), have argued that partial replacement of sand by stone quarry dust will not affect the strength of concrete. Sahu et al. (2003) and Krishnamoorthi et al. (2010), reported that the compressive strength, split tensile strength and flexural strength of concrete made with 40% or 50% replacement of sand with quarry dust was more than that made with other percentages of replacement. Natural river sand if replaced by 100% quarry dust from quarries may sometimes give equal or better than the reference concrete made with natural sand, in terms of compressive and flexural strength studies (Ilangovana et al., 2006).

According to Prakash and Rao (2016) the concept of replacement of natural fine aggregate by quarry dust could boost the consumption of quarry dust generated from quarries. By replacement of quarry dust, the requirement of land fill area can be reduced and can also solve the problem of natural sand scarcity.

Quarry dust satisfies the reason behind the alternative material as a substitute for sand at very low cost. It even causes burden to dump the crusher dust at one place which causes environmental pollution. From the results of experimental investigations conducted, it is concluded that the quarry dust can be used as a replacement for fine aggregate. It is found that 40% replacement of fine aggregate by quarry dust gives maximum result in strength than normal concrete and then decreases from 50%. The compressive strength is quantified for varying percentage and grades of concrete by replacement of sand with quarry dust.

From previous work as outlined, it can be deduced that quarry dust can be used to replace river sand in concrete without adversely affecting the mechanical properties; however there is generally lack of adequate information on optimum proportions of quarry dust to be used in concrete production. In this research the engineering properties of quarry dust and the optimum proportions required to produce concrete with comparable properties to conventional materials were investigated.

2.15 Summary of the Literature Review

From the review of available literature it can be concluded that research work has been generally carried out on most proposed alternative materials with a view of utilizing them in construction industry. Udoeyo et al. (2006) studied the strength performance of laterized concrete, Oyawa (2004) studied eco-materials for sustainable development in developing countries, Nagaraj and Zahida (1996) studied the efficient utilization of rock dust and pebbles as aggregates in Portland cement concrete. It can also be noted that lateritic soils have been widely used as construction material in under-developed and developing countries of the world (Osadebe & Nwakonobi, 2007).

From the literature review structures made of laterites can be long lasting. For instance, some of the structures constructed during Khmer civilization in Cambodia (802AD to 1431AD) still stand virtually untouched by time (Varghese & Byju, 1993). The fort at Bekal and Thalassery, Kerala constructed with laterate block way back in 15th century is still a standing monument **(**Swami, 2001). Also from previous research laterite has been found to be cheap, environmentally friendly and abundantly available building material in the tropical regions (Olugbenga et al., 2007). However, from the review, laterites have not been extensively used in construction of medium to large-size building structures because of lack of adequate data (Ayangade et al., 2009).

It is evident that there is need for more research in the use of laterite in concrete, conflicting out comes have been reported by various researchers for instance Adepegba (1975) studied replacing sand in concrete with laterite. He studied the effect of using laterite fines instead of sand in relation to the density, compressive strength, tensile strength, modulus of elasticity and resistance to high temperature. He observed that the plain laterite concrete is inferior to plain normal concrete as far as density and compressive strength is concerned.

Chandrakaran et al. (1996) reported that for fully laterized concrete, the comprehensive strength is 50% of that of normal concrete, the difference being due to different chemical composition, method of compaction and difference in maximum size of aggregates used. It has also been established from another study on effect of grain size on the strength characteristics of cement stabilized lateritic soils by Lasisi and Ogunjide (1984) that the higher the laterite/cement ratio the lesser the compressive strength and that the finer the grain size range the higher the comprehensive strength of cubes made from such soils.

From the review it can also be noted that the use of crushed waste as aggregate in concrete began in Europe since the Second World War (Swamy, 1983) crushed bricks have been extensively used in parts of India and Bangladesh for concrete making and the performance of this concrete have been found to be quite satisfactory (Akhtaruzzaman et al., 1983).

From the review it can be seen that quarry dust can be used to replace natural sand in concrete. According to Mulu et al. (1998) crushed rock quarry dust has physical properties comparable to natural sand; they studied the characteristics of quarry dust as a low cost construction material in Kenya. Nadgir and Bhavikatti (2007), reported that partial replacement of sand by stone quarry dust will not affect the strength.

From previous work as outlined, it can be deduced that quarry dust can be used to replace river sand in concrete without adversely affecting the mechanical properties; however there is generally lack of adequate information on optimum proportions of quarry dust to be used in concrete production.

2.16 Research Gaps

Based on the literature survey the following gap areas were identified:

Even though use of laterite as building blocks dates back to the early civilization, it is under-utilized in the construction of large building structures. This is because of lack of adequate data needed in the analysis and design.

The past researchers confined their study replacing sand with either laterite fine aggregate or quarry dust in concrete. To the best of the author’s knowledge, no attempt has been reported about the blending of laterite, quarry dust and crushed bricks as all-in aggregate in concrete.

To the best of the author’s knowledge, no attempt has been made to study the behaviour of concrete made with laterized quarry dust and crushed bricks at high temperatures for the purpose of using it as a fire protection material.

Therefore this research attempts to promote blending of laterite, quarry dust and crushed bricks as all-in aggregates in the production of sustainable concrete for construction works in Kenya.

2.17 Conceptual Framework

The conceptual framework helps to show the relationship that exist between the concrete constituent materials and the end results. It provides an overview of the different aggregates and how the relationship of these aggregates affects the strength and cost of concrete production. In this study the conceptual framework presented in Figure 2.2 was used.

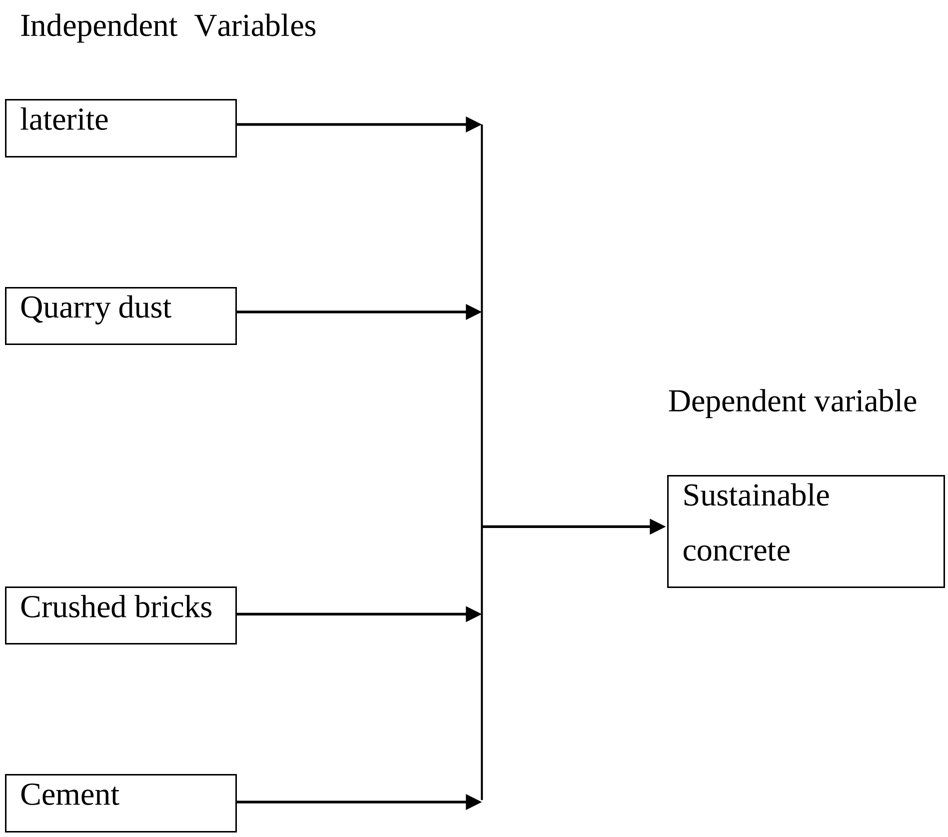

Figure 2.2: Conceptual framework

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

In order to achieve the objectives of the study, all the materials were investigated to establish their key properties, following which the optimum proportions of each ingredient material, were determined for concrete production. All the research was conducted in the field and in a laboratory.

The materials that were used for this research were cement, laterite, quarry dust and crushed bricks as coarse aggregate and potable water for mixing the materials. Laterite, one of the two fine aggregates used for this research work was obtained from Thika, the second fine aggregate used in this study was also obtained from Mlolongo crushing plant in Athi River. The laterite and quarry dust used in these tests were those passing sieve (2mm) and retained on sieve (150µm). All tests were conducted according to the relevant British standard.

Waste Clay bricks used in this investigation were obtained from Clay Works (K) Ltd

The waste bricks were crushed down into a coarse aggregate; their uniaxial compressive strength was recorded for comparison with the aggregate produced by crushing them down to coarse aggregate. The coarse aggregate was passed through sets of sieves, the portion passing through sieve (20mm) and retained on sieve (5mm) was used. The cement that was used was Portland pozzolana cement of normal strength of 32.5N/mm^2 as per the Kenya standards (Ks-18-1:2001).

Cement was purchased and taken to the laboratory in sealed 50kg bags, while the fine aggregates i.e. laterite and quarry dust were transported to the laboratory.

Water was obtained directly from the tap in the materials laboratory at JKUAT.

3.2 Determining the Properties of Laterized Quarry Dust as Fine Aggregates and Crushed Bricks as Coarse Aggregates

3.2.1 Experimental Set-Up

a) Sieve analysis test for laterite, quarry dust and crushed bricks aggregates

Sieve analysis is the process of screening a sample of aggregate into size fractions each consisting of particles of the same range size i.e. particle size distribution. This test was carried out according to the requirements of BS812: Part 1; 1975. The entire fine aggregates i.e. laterite, quarry dust and coarse aggregates used in this study were subjected to this test.

b). Determination of silt content in fine aggregates

Silt content in fine aggregates was determined according to the standard procedures required by BS812: Part 2 of 1996 and KS-02-95 of 1984.

Silt content information is important in determining the suitability of a particular material in concrete production and the water requirement of the concrete mix.

c). Density tests

Bulk density is used for proportioning material mix design; this test was carried out according to the standard procedures required by BS812: Part 2 of 1996. The bulk density measurements were done in two states of the aggregates: loose and compacted state. In both cases, the aggregates were oven dried.

Apparent specific gravity test was carried out according to the standard procedures required by BS812: Part 2 of 1996.

Apparent specific density, oven dry specific density and saturated specific density were carried out according to BS 812 Part 2 1996, in the civil engineering lab at room temperature (20-27) ˚C, using an oven capacity 350˚C, electronic weighing balance accuracy 0.5g.

Tests for both saturated and oven dry quarry dust and laterite samples for the test of oven dry density and saturated dry density were performed using a standard pycnometer, the original sample of 500g was poured in the filled pycnometer and water filled stirring to remove entrapped air the cover was screwed to seal tightly finally water refilled with a wash bottle and swirled carefully to remove bubbles the weight was recorded. The sample was carefully poured in a calibrated metal tray and dried in the oven at 105˚C, After emptying the contents the pycnometer was filled screwed to seal tightly and refilled to the brim and the weight taken, after the drying each oven dry sample was recorded and the oven dry density and saturated dry density computed.

d). Water absorption test

Water absorption tests were conducted on all the fine and coarse aggregates. The water absorption is defined as the ratio of the increase in weight to the weight of the dry sample, expressed as a percentage. The test was carried out according to BS 812: Part 2 of 1975 requirements.

3.2.2 Data Collection Procedure

a). Sieve analysis test

The results of sieve analysis were represented graphically in grading curves/charts. By using these charts, it is possible to see at a glance if the grading of a given sample conforms to that specified or it is too fine or coarse or deficient on a particular size. In the curves, the ordinates represent cumulative percentages passing and the abscissa the sieve sizes plotted in a logarithmic scale.

b). Silt content

The silt content data was obtained as per the procedure outlined in BS812: Part 2 of 1996.

c). Density tests

The crushed broken clay bricks sample for test was originally 2.0kgs and was oven dried to 1.78kgs. On the saturated surface dry condition the laterite sample for test was originally 500g and was oven dried to 491g. On the saturated surface dry condition the quarry dusts sample was originally 500.5 g and oven dried sample was 480g. On the oven dry condition the laterite sample for test was originally 500.5 g the mass of pycnometer water and sample was 1716.5 g oven dried sample was 491 g. On the oven dry condition the quarry dust sample for test was originally 500.5 g the mass of pycnometer water and sample was 1686.5 g and oven dried sample was 480 g.

d). Water absorption test

The crushed broken clay bricks sample for test was originally 2.0kgs and oven dried sample was 1.78kgs. On the saturated surface dry condition the laterite sample for test was originally 500 g and oven dried sample was 491 g. On the saturated surface dry condition the quarry dusts sample was originally 500.5 g and oven dried sample was 480 g.

3.2.3 Data Analysis

a). Sieve analysis test for fine and coarse aggregates

In all the samples analysis for percentage of particles passing was obtained and a plot of graphical curves done and presented. *(See Appendix A).* The crushed broken clay bricks graph was obtained as a curve on a semi-logarithimic scale and lies between specified boundaries in the overall limits as per the BS 812;105.2:1990.

The laterite and quarry dust were graded and a curve on a semi-logarithimic scale obtained for zones 1, 2, 3 and 4.

b). Silt content

Silt content in this study applied to only quarry dust and laterite and was calculated as a percentage, the values for quarry dust and laterite being 10% and 32% respectively.

c). Density tests

The relative density value for crushed broken clay bricks sample on oven dry basis was 2.04

The relative density value for crushed broken clay bricks sample on the saturated surface dry condition dry was 2.29. The relative density value for quarry dust sample on oven dry basis was 2.5. The relative density value for quarry dust sample on the saturated surface dry condition dry was 2.3. The relative density value for laterite sample on oven dry basis was 2.6. The relative density value for laterite sample on the saturated surface dry condition dry was 2.6

3.3 Assessing the effect of Replacing Fine and Coarse Aggregates with Laterized Quarry Dust and Crushed Bricks

3.3.1 Experimental Set-Up

a) Material combination

The optimum quarry dust test was aimed at determining the fine aggregate combination of laterite and quarry dust to give concrete with the best performance. In the conventional concrete of nominal mix 1:1.5:3 for cement, laterite, and crushed clay brick aggregates, respectively, laterite was partially replaced with 0,25,50,75 and 100% of quarry dust. Test cubes were then prepared and tested for compressive strength at the age of 7, 14 and 28 days using standard procedures as per BS1881.

b) Concrete mix proportioning

The batching of concrete was done by weighing the different constituent materials based on the adopted mix ratios of 1:1½:3 with target strength of 25N/mm^2; and 1:2:4 with target strength of 20N/mm^2, respectively. The fine aggregate portion of the mix was achieved by combining quarry dust and laterite in ratios of 25% steps starting with 0% quarry dust against 100% laterite (i.e., 0-100%; 25-75%; 50-50%; 75-25%; and 100-0%).

This was repeated for different mix ratios stated above. The materials were then mixed thoroughly before adding the prescribed quantity of water and then mixed further with crushed bricks to produce fresh concrete. Water/Cement ratio of 0.5 was adopted.

The freshly mixed concrete was then filled into moulds in approximately 50mm layers with each layer given 25 strokes of the tamping rod. The concrete was then toweled off level with the top of the mould and the specimen stored under damp sacking for 24 hours in the laboratory before de-moulding and storing in water for the required curing age. Several concrete cubes and cylinders in sets of threes were made.

Testing of the hardened cubes and cylinders was carried out after 7days, 14 days, and 28 days, respectively using a compression testing machine. The cube sample was placed between hardened steel bearing plates on a compression machine and load applied at the rate of 15N/mm^2 per minutes as specified in BS1881. The sample was wiped off from grit and placed centrally with load applied steadily to destruction and the highest load reached was determined. This was used to compute the compressive strength which is the ratio of the highest load to the cross sectional area of the sample expressed in N/mm^2. Three samples were used for each test and the average results were adopted as the compressive strength. Standard moulds of size 150x150x150mm and cylinders of 300mm x 100mm were used in casting the cubes and cylinders. A set of the samples was kept on the floor for air curing which was done after 7, 14 and

28 days. A second set was immersed in a water curing tank outside the civil engineering laboratory for the 7, 14 and 28 days cube test.

3.3.2 Data Collection Procedures

a) Casting and Mixing

Concrete mixes utilizing various combinations of materials were evaluated. The main aim was to determine the optimum combination of materials to be used in making of concrete. The batching of concrete was done by weighing the different constituent materials based on the adopted mix ratios of 1:1½:3 with target strength of 25N/mm^2; and 1:2:4 with target strength of 20N/mm^2, respectively. The fine aggregate portion of the mix was achieved by combining quarry dust and laterite in ratios with 25% steps starting with 0% quarry dust against 100% laterite (i.e., 0%-100%; 25%-75%; 50%-50%; 75%-25%; and 100%-0%).

This was repeated for different mix ratios stated above. The materials were then mixed thoroughly before adding the prescribed quantity of water and then mixed further with crushed bricks to produce fresh concrete. Water/Cement ratio of 0.5 was adopted. The freshly mixed concrete was then filled into (150×150×150mm cube and 150mm diameter and 300mm depth cylinder) moulds in approximately 50mm layers with each layer fully compacted. The concrete was then troweled off level with the top of the mould and the specimen stored under damp sacking for 24 hours in the laboratory before de-moulding and storing in water for the required curing age. Several concrete cubes and cylinders in sets of threes were made.

b) Testing of hardened concrete specimens

Testing of the hardened cubes of size 150x150x150mm and cylinders of size 300mm x 100mm diameter was carried out after 7days, 14 days, and 28 days, respectively using a compression testing machine. The cube sample was placed between hardened steel bearing plates on a compression machine and load applied at the rate of 15N/mm^2 per minute as specified in BS1881. The sample was wiped off from grit and placed centrally with load applied steadily to destruction and the highest load reached was determined. This was used to compute the compressive strength which is the ratio of the highest load to the cross sectional area of the sample expressed in N/mm^2. Three samples were used for each test and the average results were adopted as the compressive strength. Standard moulds of size 150x150x150mm and cylinders of 300mm x 150mm diameter were used in casting the cubes and cylinders. A set of the samples was kept on the floor for air curing which was done after 7, 14 and 28 days. Second set was immersed in water curing tank outside the civil engineering laboratory for the 7, 14 and 28 days cube test.

Table 3.1: Batching proportions mix 1:2:4, W/c 0.5

Replacement %	Water Kg	Cement Kg	Quarry dust Kg	Laterite Kg	Clay Bricks Kg
0	30	30	0	60	120
25	30	30	14	45	120
50	27	30	30	30	120
75	27	30	45	15	120
100	27	30	60	0	120

Table 3.2: Batching proportions mix 1:1.5:3, W/c 0.5

Replacement	Water	Cement	Quarry dust	Laterite	Clay Bricks
0	38	40	0	60	120
25	38	40	15	45	120
50	36	40	30	30	120
75	36	40	45	15	120
100	36	40	60	0	120

3.3.3 Data Analysis

a). Workability tests

Slump test was carried out on samples of fresh concrete as per the requirements of BS 1881: part 102 of 1983.Compacting factor test was also carried out on samples of fresh concrete as per the requirements of BS 1881: part 103 of 1983.Both tests were carried out immediately after mixing the concrete.

The freshly mixed concrete was sampled and filled into a slump cone 100mm and 200mm top and bottom diameters respectively and 300mm height, in three layers each layer tamped 25 times Simultaneously Compacting factor and Vee-Bee times were obtained and the results recorded.

The freshly mixed concrete was then filled into moulds in approximately 50mm layers with each layer given 25 strokes of the tamping rod. The concrete was then troweled off level with the top of the mould and the specimen stored under damp sacking for 24 hours in the laboratory before de-molding and storing in water for the required curing age. Several concrete cubes and cylinders in sets of threes were made.

Concrete specimens for cube, cylinders and beams were cast into the steel moulds which had been tightened and lightly oiled on the inside surface. The fresh concrete was poured in three layers each layer compacted with a 16mm diameter internal vibrator. The surface was trowelled and levelled with a steel float, the cast concrete remained in the steel moulds to set for 24hrs and then the steel moulds carefully removed. The samples were immersed in water to cure for 7 days, 14 days, and 28 days.

Plate 3.1: Material preparation ready for mixing

Plate 3.2: Wet concrete ready for testing

Plate 3.3: Vee-Bee consistometer test

Plate 3.4: Compacting Factor Test

Plate 3.5: Slump Test

Plate 3.6: Concrete Specimens for Testing

b). Hardened concrete tests

Testing of the first and second set of hardened cubes and cylinders was carried out after 7days, 14 days, and 28 days, respectively using a compression testing machine, the cubes were weighed before crushing to facilitate the determination of densities. The sample was wiped off from grit and was placed between hardened steel bearing plates on a servo universal testing machine and load applied at the rate of 0.25N/mm^2 per second as specified in BS1881. This was used to compute the compressive strength which is the ratio of the highest load to the cross sectional area of the sample expressed in N/mm^2.

Table 3.3: Compressive strength class 25 results

Compressive Strength For 1:1.5:3- 0%,25%,50%,75%,100% Qd/Lat					
Age (days)	Percentage replacement of Qd/Lat				
	0%	25%	50%	75%	100%
7.0	9.9	10.8	10.6	11.2	15.0
14	14.3	14.3	15.1	14.5	16.6
28	17.5	17.5	17.6	16.7	19.9

Table 3.4: Split cylinder test class 20 Table of results

Table For Split Cylinder Tensile Strength,C20-Cyl.- 0%,25%,50%,75%,100%Qd/Lat					
Age-days		Split Cylinder Tensile Strength (N/mm^2)			
0	0%	25%	50%	75%	100%
7	0.9	1.1	1.0	1.1	1.3
14	1.2	1.5	1.6	1.2	1.9
28	1.4	2.0	1.9	1.5	2.5

Table 3.5: Compressive Strength Class 20 results

Compressive Strength mix 1:2:4 -0%,25%,50%,75%,100% Qd/Lat					
Age(Days)	Compressive Strength (N/mm^2)				
	0%	25%	50%	75%	100%
0	-	-	-	-	-
7	9.9	9.9	10.1	9.9	11.4
14	12.8	12.8	13.5	12.6	14.8
28	14.7	15.2	16.5	15.8	17.6

Table 3.6: Split Cylinder Test results Class 25 Table of Results

Split Cylinder Test results Cyl.25- 0%,25%, 50%, 75%, 100% replacement (N/mm^2)					
Age Days	0%	25%	50%	75%	100%
0	-	-	-	-	-
7	1.1	1.3	1.4	1.2	1.1
14	1.6	1.8	1.8	1.5	2.1
28	1.9	2.3	1.9	2.2	2.5

c). Density measurement of hardened concrete specimens

For each compressive strength test of the cubes weights were measured and the concrete density calculated

d). Splitting tensile (indirect) strength of cylindrical concrete specimens (ASTM C496-85 or BS 1881: Part 117: 1983)

Three cylinders which were already caped properly with strong mix of mortar and cured for 28 days were removed from curing tank and dried off the surface moisture. The specimen was placed in horizontal position and centered carefully on the base plate of the compressive testing machine. A load was applied uniformly and without shock at the rate of 15 MPa per minute. The splitting cylinder strength and maximum load sustained by each specimen was recorded.

Plate 3.7: Experimental set-up for split tensile test

Plate 3.8: Crack pattern at failure

Table 3.7: Split cylinder test class 20 Table of results

Table For Split Cylinder Tensile Strength,C20-Cyl.-0%,25%,50%,75%,100%Qd/Lat					
Age-days		Split Cylinder Tensile Strength (N/mm^2)			
0	0%	25%	50%	75%	100%
7	0.9	1.1	1.0	1.1	1.3
14	1.2	1.5	1.6	1.2	1.9
28	1.4	2.0	1.9	1.5	2.5

Table 3.8: Split Cylinder Test results Class 25 Table of Results

Split Cylinder Test results Cyl.25- 0%,25%, 50%, 75%, 100% Qd/Lat replacement (N/mm^2)					
Age Days	0%	25%	50%	75%	100%
0	-	-	-	-	-
7	1.1	1.3	1.4	1.2	1.1
14	1.6	1.8	1.8	1.5	2.1
28	1.9	2.3	1.9	2.2	2.5

e). Compressive strength of cubic specimens (BS 1881: Part 108: 1983)

Cubes specimen to be tested were removed from the curing tank and wiped with a damp cloth to remove surface water. Test cube was placed centrally on the lower platen of the test machine.

The top platen was lowered onto the cube ensuring that a uniform seating by gently rotating the top platen as it is brought to bear on the cube. A load without shock was applied at a rate of 15 MPa per minute.

Table 3.9: Compressive strength class 25 results

Compressive Strength For 1:1.5:3- 0%,25%,50%,75%,100% Qd/Lat					
	Percentage replacement of Qd/Lat				
Age (days)	0%	25%	50%	75%	100%
7.0	9.9	10.8	10.6	11.2	15.0
14	14.3	14.3	15.1	14.5	16.6
28	17.5	17.5	17.6	16.7	19.9

Table 3.10: Compressive Strength Class 20 results

Compressive Strength mix 1:2:4 -0%,25%,50%,75%,100% Qd/Lat					
Age(Days)	Compressive Strength (N/mm^2)				
	0%	25%	50%	75%	100%
7	9.9	9.9	10.1	9.9	11.4
14	12.8	12.8	13.5	12.6	14.8
28	14.7	15.2	16.5	15.8	17.6

f). Flexural strength test (BS 1881: Part 118: 1983)

Beam specimen to be tested were removed from the curing tank and wiped with a damp cloth to remove surface water. The beam was placed in the testing machine in a manner that the top and bottom surfaces of the beam are parallel this is to ensure that loading is uniform across the width. Load was applied through 2 rollers, each at a distance of L/3 from the supports on either side. The loading without shock was applied and increased at a constant stroke rate (0. 25N/mm^2/). The maximum load sustained by the specimen was recorded.

Plate 3.9: Experimental set-up for flexural strength test

Plate 3.10: Crack pattern at failure

g). Effects of curing methods on strength properties of concrete

Two sets of concrete specimens of the same mix proportions (mix 1:1.5:3) were cast and de-moulded after 24hrs; one set was continuously cured in water while the second set stored on the laboratory floor ,the compressive strength was determined at the age of 7, 14 and 28 days.

The compressive strength of the cubes and split tensile strength of the cylinders was determined using ServoPlus matest 1500KN digital compression machine. The compressive strength of the concrete cubes was determined at a specified loading rate using BS 1881: Part 4 (1970) standard procedures; the split tensile strength of the cylinders was also determined at specified loading rate, in compliance with BS 1881: Part 117(1983) standard procedures. Three samples were tested for each parameter investigated and the results represent the average of three test specimen results.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Properties of Laterized Quarry Dust as Fine Aggregates and Crushed Bricks as Coarse Aggregates

The results of material physical properties for all the aggregates have been presented in this chapter. In evaluating the main material property both the British and American Standards were used. Samples were obtained and preparation of materials carried out in the laboratory. The materials (i.e. coarse aggregates, fine aggregates), for this study was investigated for the properties of concrete materials. The coarse aggregate in this study was recycled crushed brick aggregates and the fine aggregates were laterite and quarry dust. Both fine aggregates contained high silt content, the coarse aggregates has high water absorption as presented in Table 4.1.

Table 4.1: Summary of material physical properties tests

Property	Crushed brick	Laterite	Quarry dust
Maximum aggregate size (mm)	20mm	5mm	5mm
Specific density, oven dried (Kg/m^3)	2.029	2.306	2.571
Specific gravity, saturated (Kg/m^3)	2.273	2.392	2.62
Bulk density oven dried (Kg/m^3)	1010	1070	1210
Water absorption	12	3.6	1.8
Silt Content %	N/A	32	10
Fineness modulus	2.76	5.85	5.38
Aggregate crushing value	54	N/A	N/A
Flakiness index	30	N/A	N/A

The gradation of crushed recycled brick aggregates indicated a tendency of increasing fines which slightly reduced workability.

4.1.1 Properties of aggregates

a) Sieve analysis for aggregates

Sieve analysis was done to BS 812 part1 1975 and BS 882 Part1 1992. The sieve analysis test data for crushed broken clay bricks is presented in appendices Table A1 and the sieve analysis test data for quarry dust is presented in appendix Table A2, A4, A5 & A6, the sieve analysis for laterite is presented in appendix A3, A7, A8 & A9.

The grading was performed using standard test sieve 50, 37.5,20,14,10,5 and 2.36 mm for coarse aggregates. In this test the coarse aggregates were graded for a range between 20mm-5mm. Aggregate occupies two thirds of the total volume of concrete and its strength is important in the final concrete strength which is dependent of selection of the original brick strength from a construction waste site. The fine aggregates used was a combination of laterite and quarry dust in varying proportions which was graded using BS test sieves 10, 5, 2.36, 1.2, 600, 300, 150 and 75mm.

It has been reported that compressive strength of fully compacted concrete with a given water /cement ration is dependent of the grading of aggregates, hence the grading is important only as far as it affects workability (Neville, 1981). In all the samples analysis for percentage of particles passing was obtained and a plot of graphical curves done and presented. *(See Appendix A).*

Figure 4.1 presents the gradation curve for crushed bricks plotted with the British Standard specification for coarse aggregates.

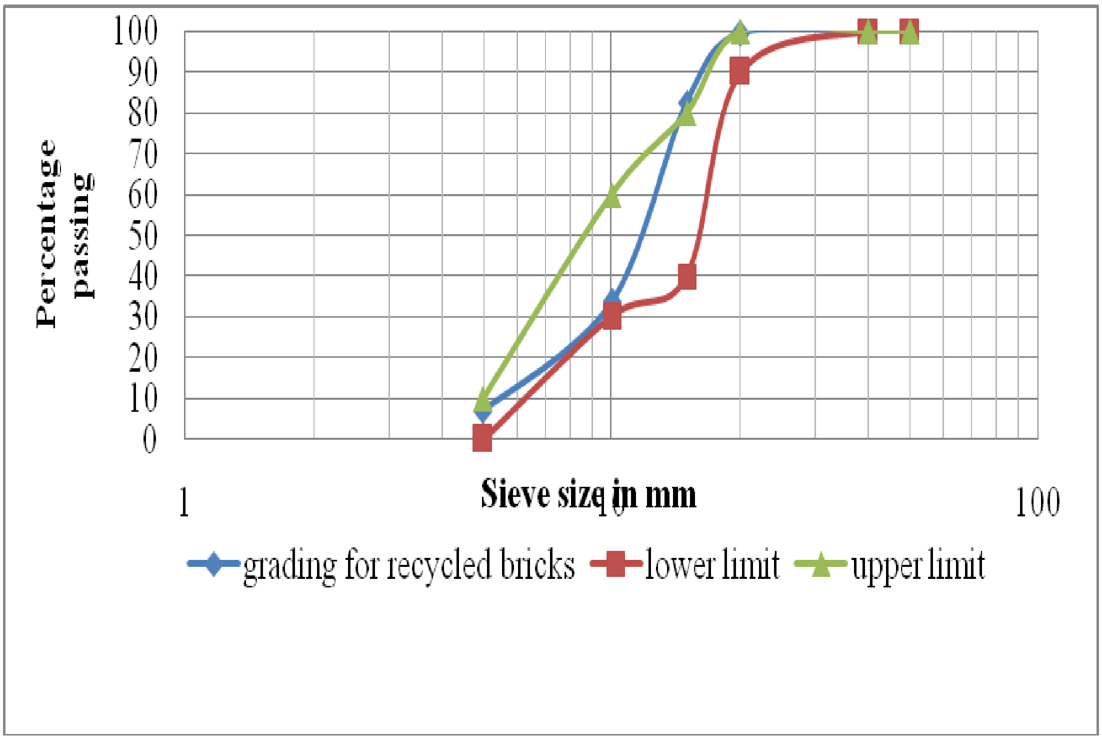

Figure 4.1: Grading curve for recycled bricks (BS 882 Part1 1992)

As seen the gradation curve produced a trend of a fairly graded sample to the requirements of BS 882:1992 for coarse aggregates. It was observed that there was a tendency of increase in fines along this gradation curve for crushed bricks. During the preparation of the concrete a difficulty with the workability was experienced. This contributed to a slight reduction in the concrete compressive strength as presented in this research. In this analysis the gradation for bricks was fairly graded within overall limits envelope, and thus showed the material is sized as coarse aggregates. It would be preferred as it takes a bigger volume in the production of concrete mix proportions.

Quarry dust and laterite were each air dried and a sample of 1kg sieved through BS test

Sieve analysis, for quarry dust and laterite aggregates was done to BS 812 Part 2 1996 and BS 882 Part1 1992. The selected samples for fine aggregates are represented in Figures 4.2 to 4.9 and analyzed across the four zones and their graphical representation report was given for all the zones. The quarry dust sample used for this study was analyzed for percentage of particles passing and a curve plotted. The curves show a well gradation in grading zones 1, 2 and 3 and this increased the confidence for approval to its use.

The laterite sample used for this research was analyzed for percentage of particles passing and a curve plotted. The curve showed a well gradation in grading zones 1,2 and 3 a very important property in selection of aggregate materials.

Fineness modulus is a single parameter used to give an indication of particle size distribution in fine aggregates. In Table 4.1, laterite has the highest fineness modulus of 5.85, and then quarry dust fineness modulus is 5.38. Therefore, the fineness modulus and the gradation curves show that literate contains the largest amount of coarse material after the quarry dust in that order.

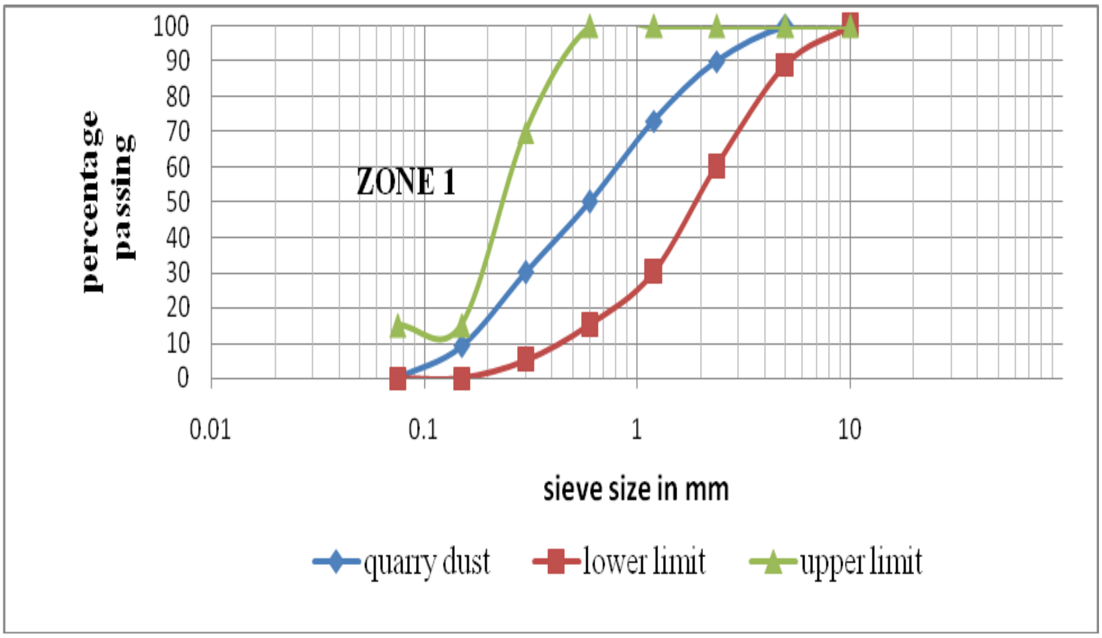

Figure 4.2: Grading curve for quarry dust (BS 882 Part1 1992)

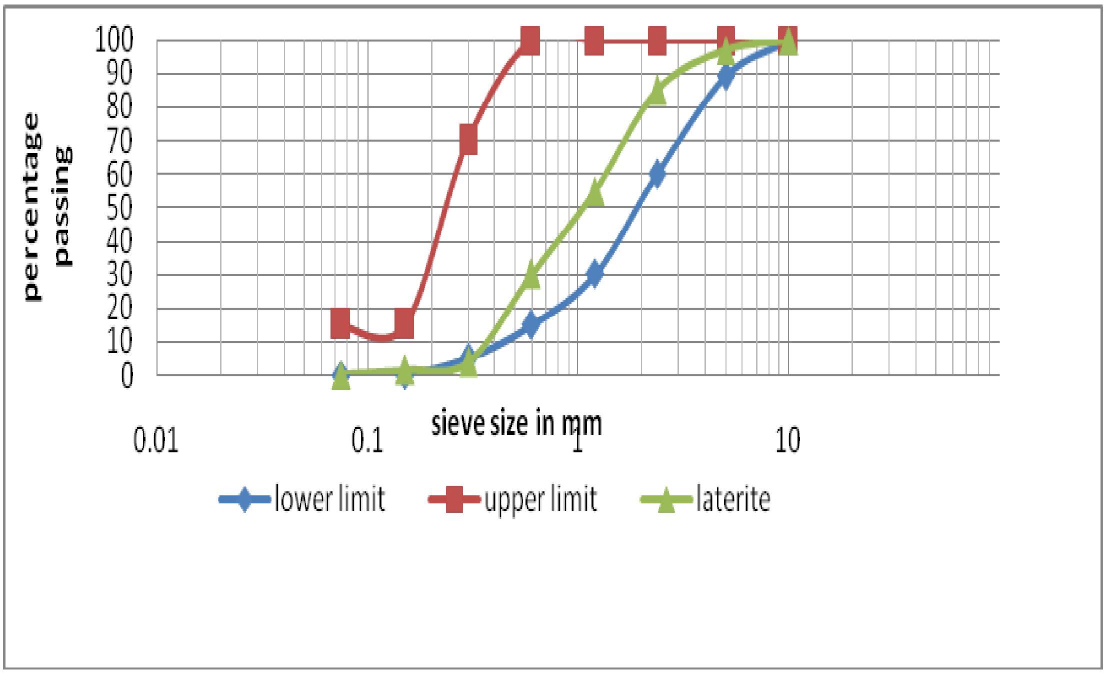

Figure 4.3: Grading curve for laterite (BS 882 Part1 1992)

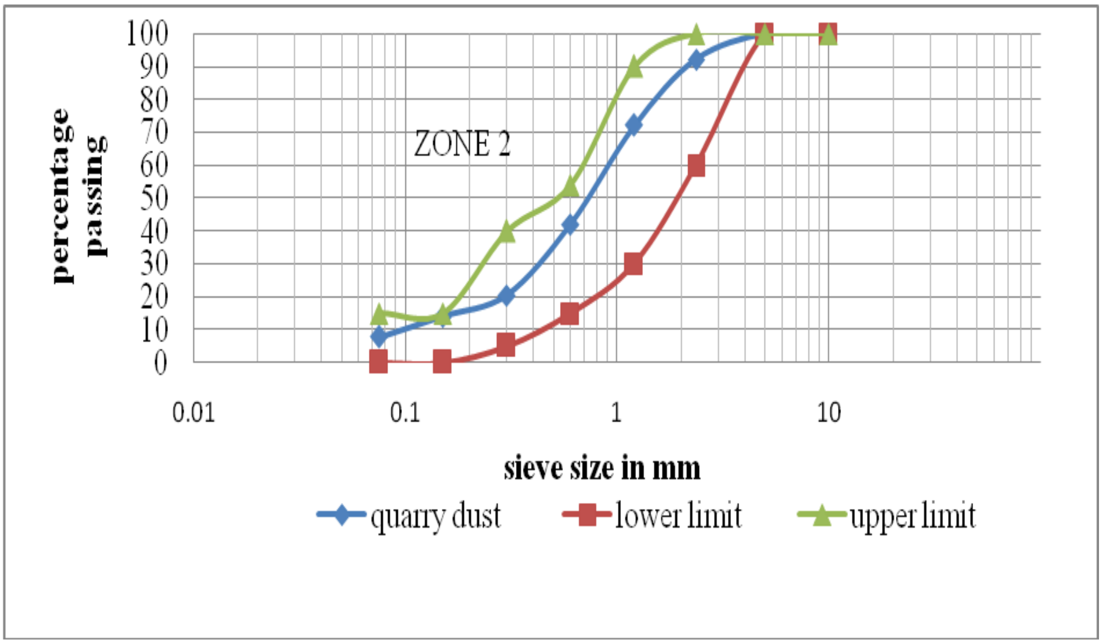

Figure 4.4: Grading curve for quarry dust (BS 882 Part1 1992)

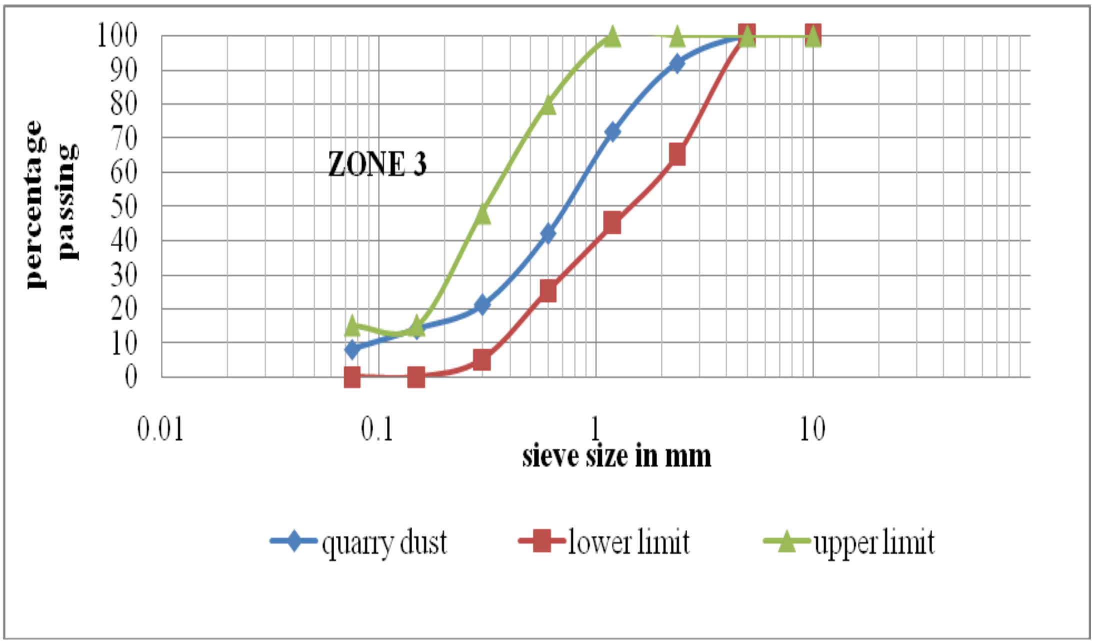

Figure 4.5: Grading curve for quarry dust (BS 882 Part1 1992)

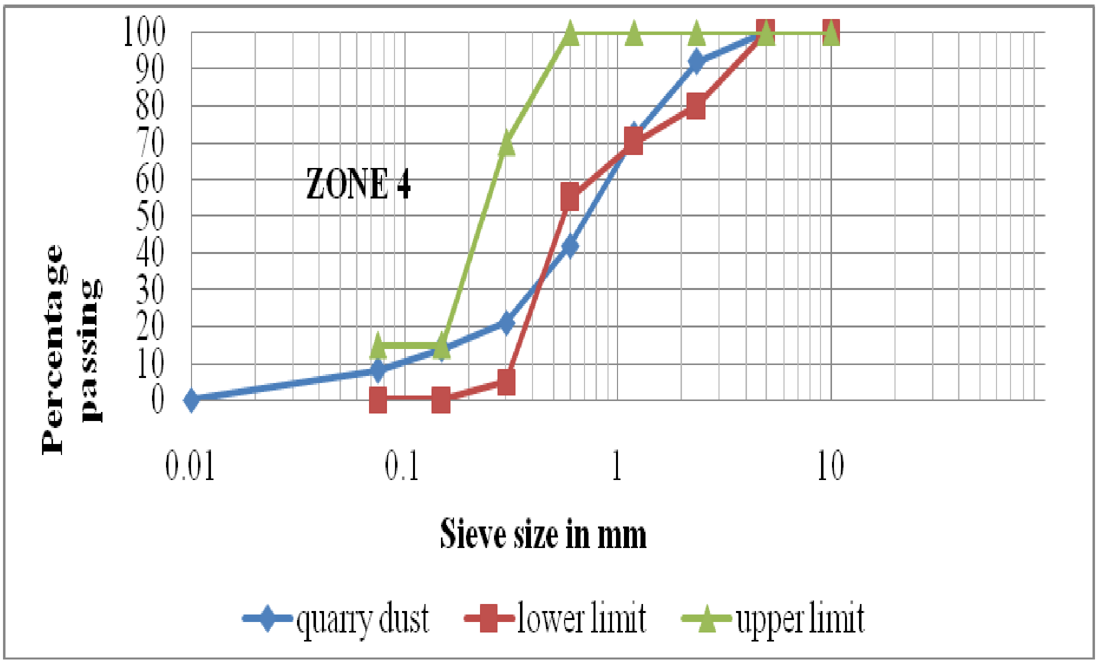

Figure 4.6: Grading curve for quarry dust fine limits (BS 882 Part1 1992)

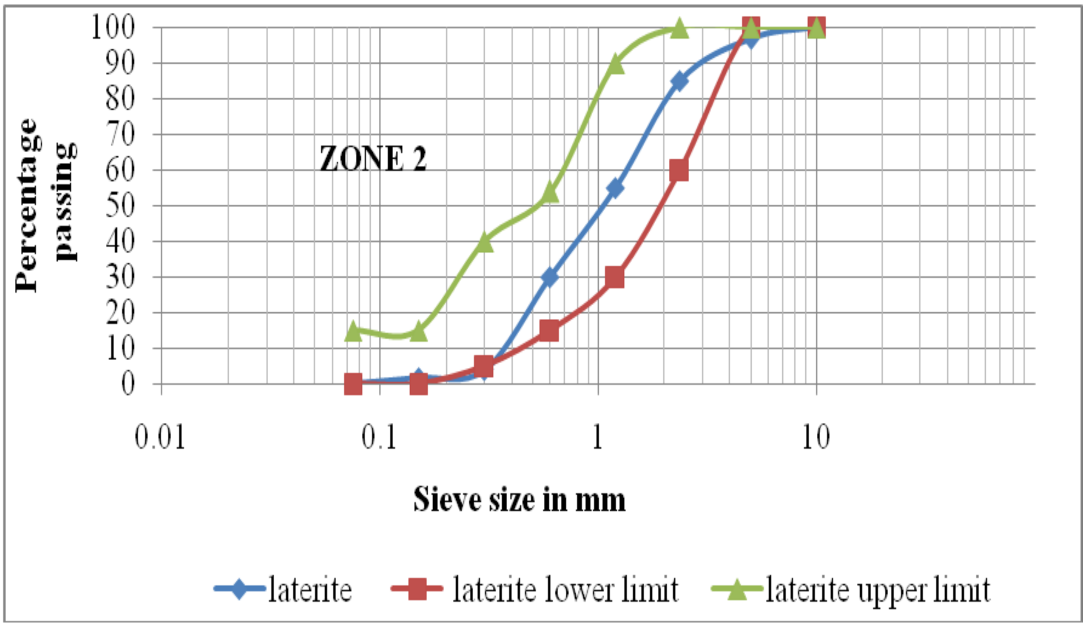

Figure 4.7: Grading curve for laterite coarse limits (BS 882 Part1 1992)

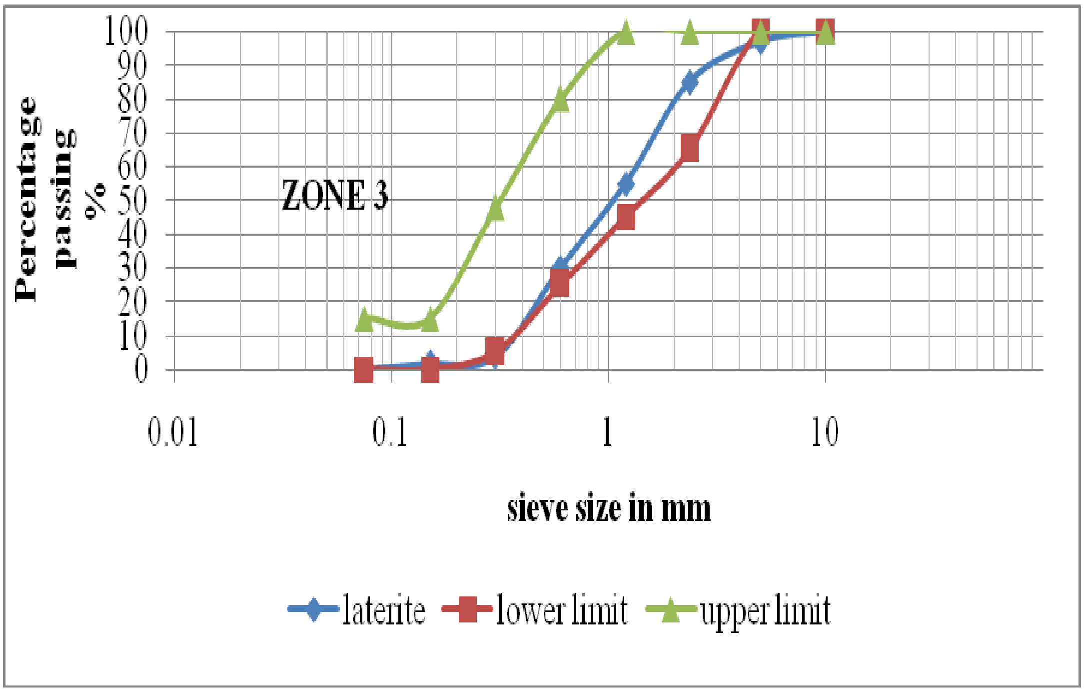

Figure 4.8: Grading curve for laterite medium limits (BS 882 Part1 1992)

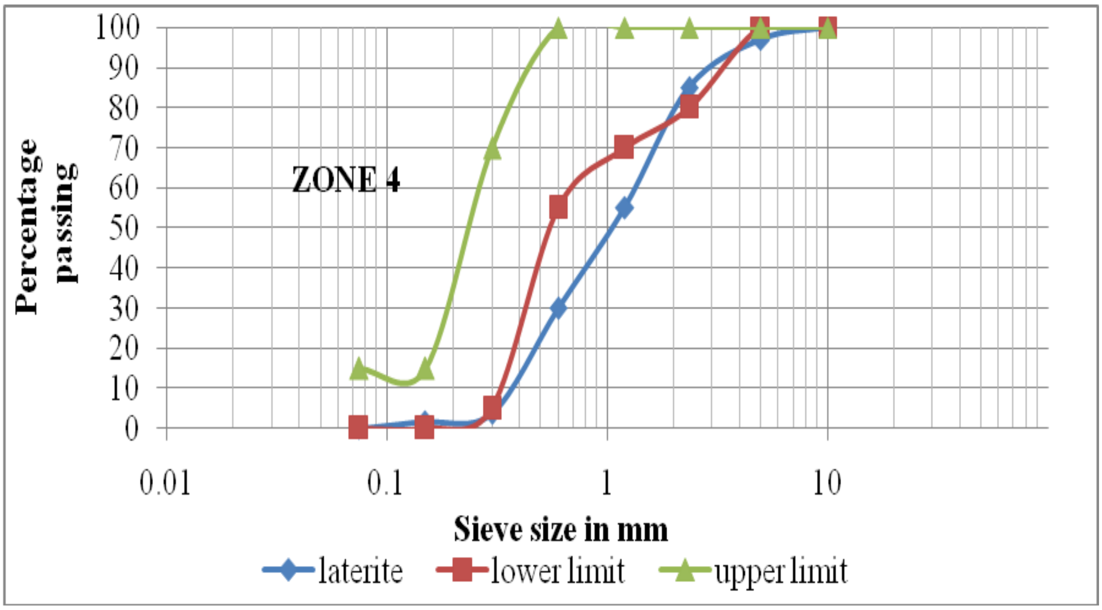

Figure 4.9: Grading curve for laterite fine limits (BS 882 Part1 1992)

b) Density tests

The results for crushed clay bricks were as follows:- relative density on an oven dry density basis was of 2.571 Kg/m^3 , relative density on saturated and surface dry density basis was 2.620 Kg/m^3; apparent relative density was 2.705 Kg/m^3.

The results for laterite were as follows: - relative density value on an oven dry density basis was 2.039Kg/m^3, relative density on saturated and surface dry density basis was 2.292 Kg/m^3, and apparent relative density was 2.726 Kg/m^3.

Another fine material used was quarry dust and relative density on an oven dry basis was 2.571Kg/m^3, and the relative density on saturated and surface dry density basis obtained was 2.620Kg/m^3, the apparent relative density obtained was 2.705Kg/m^3. (*See Appendix E)*

c) Water Absorption

The saturated surface dry samples for the three aggregates were measured and oven dried for 24 hours and measured too, the result obtained was used to compute the water absorption in percentage. Table 4.1 shows water absorption of all the fine aggregates and crushed clay bricks, laterite recorded higher value of 3.6% and quarry dust 1.8%. The water absorption value of crushed clay brick aggregates was 12% in relation to the material in its dry state. This absorption is considered high and can be a major problem to the concrete in regard to corrosion of embedded steel, as it can carry chlorides and sulphates as well as other ions. The presence of water can also cause freeze thaw damage to concrete, thus durability of concrete with recycled brick aggregate turning to be a major insufficiency, since the water absorption increase with the proportion of recycled crushed brick aggregates. The high water absorption problem may be solved by using a pre-saturation method of the aggregates (Correia, & de Britto et al., 2006).

d) Silt content test

Silt content in fine aggregates was determined according to the standard procedure required in BS812 part2 1996. The silt content of the fine aggregates is shown in Table 4.1. The result obtained was computed as 32% for laterite and 10% for quarry dust. BS 882:1973 specifies maximum silt content of 15% in crushed stone sand and 3% in natural and crushed gravel sand. Laterite and quarry dust with silt content of 10 and 32% is beyond the minimum specified in BS 882:1973. High silt content in construction material has the effect of increasing the water requirement of concrete to achieve a specified level of workability.

e) Aggregate Crushing Value (ACV)

Aggregate crushing value was carried out to BS 812 Part 1 1975. The test result value for crushed bricks was 54%. The value lies within maximum prescribed value for ordinary concrete used for non-wearing surfaces by BS882. Although there is no direct relationship between aggregate crushing value and the compressive strength of concrete, the test is a guide to the expected strength of a concrete. The objective of the test was to determine the relative measure of the resistance of an aggregate to crushing under gradually applied compressive load.

f) Flakiness Index for crushed bricks (coarse aggregates)

Flakiness index was done to BS 812 part 1 1975. The flakiness test in this study was used as a guide to obtain particles that were angular in shape which is achieved by the mechanical crushing technique. Flaky and elongated particles were screened and discarded throughout the sample preparation.

The results have established that the fine aggregates have varying properties. They both have high silt content and water absorption. Therefore, based on this study the materials require special consideration in design of concrete mixes for structural use.

4.2 Effect of Replacing Fine and Coarse Aggregates with Laterized Quarry Dust and Crushed Bricks

4.2.1 Workability Tests Results

Concrete made of crushed clay brick as coarse aggregate, laterite and quarry dust as fine aggregates exhibited three basic forms of slump depending on the water/cement ratio just like normal concrete, this can be seen in the slump results shown in Plate 4.1. The slump is between 0 and 30mm

Plate 4.1: Slump Test

The workability of quarry dust laterite crushed clay brick concrete are shown in the Figure 4.10 to Figure 4.12 for varying percentage replacements, i.e., 0,25,50,75 and 100% for two mix proportions; 1:2:4 and 1:1.5:3, It can be seen that workability increases to a small extend from 15 to 30mm and from 15 to 50mm respectively. Studies on laterite show there is reduction in workability as laterite constitute much finer materials and has higher water absorption. On the basis of the findings of properties of the fine aggregates it's practically understood as the water absorption for the laterite is 3.6% and for quarry dust is 1.8% for the same crushed clay bricks as coarse aggregate with absorption of 12%.and a W/C ratio between 0.6-0.7.(*See Appendix C).*

These results agree with the findings of past researchers like Adepegba and Balogun, et al. who in their separate works recommended 0.65 water/cement ratio as most suitable for laterized concrete. This trend of results was confirmed by similar compacting factor test results on the two mix proportions 1:2:4 and 1:1.5:3 of quarry dust-laterite crushed clay bricks concrete in varying percentage replacements of 0,25,50,75 and 100%. For compacting factor test were performed on the same fresh quarry dust-laterite crushed clay bricks concrete results for both mix proportions 1:2:4 and 1:1.5:3 were 0.93-0.87 and 0.9-0.8, respectively, which is close to the range of 0.82-0.95 specified in BS 1881, Part 103 of 1993. It is experimentally true based on the values of Slump for similar mix proportions in this research finding.

The workability results of this study also compare favorably with those obtained by Adoga (2008) for laterite rock concrete (0.81-0.99).

The slump test showed results varying from 13-30mm, compaction factor 0.87-0.92 and Vee-Bee results ranged from 6-10secs for concrete C20 and slump ranging from 15-50mm, compaction factor 0.8-0.9 and Vee-Bee 5-9 secs for concrete C25 as shown in Appendix C.

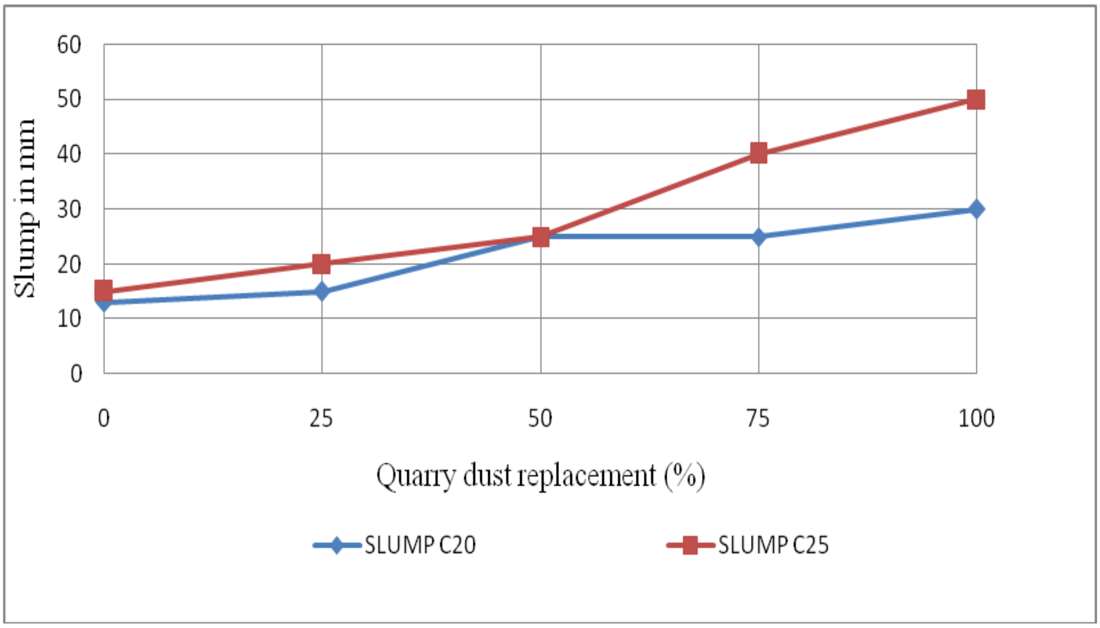

Figure 4.10: Slump values for 1:2:4 mix ratio (C20) and1:1.5:3 mix ratio (C25)

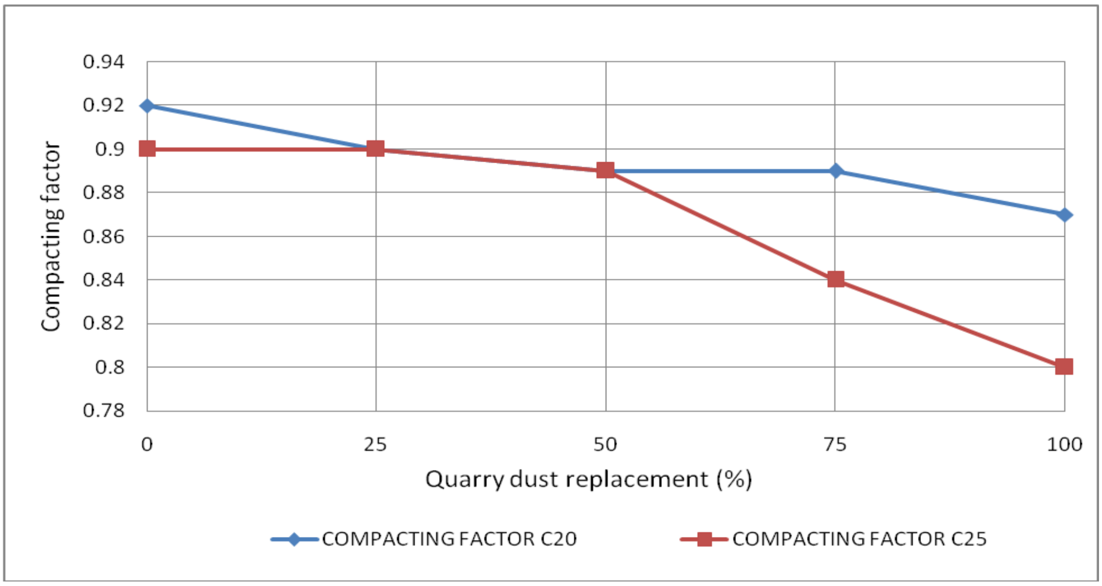

Figure 4.11: Mix 1:2:4 Compacting Factor results (C20) and1:1.5:3 mix ratio (C25)

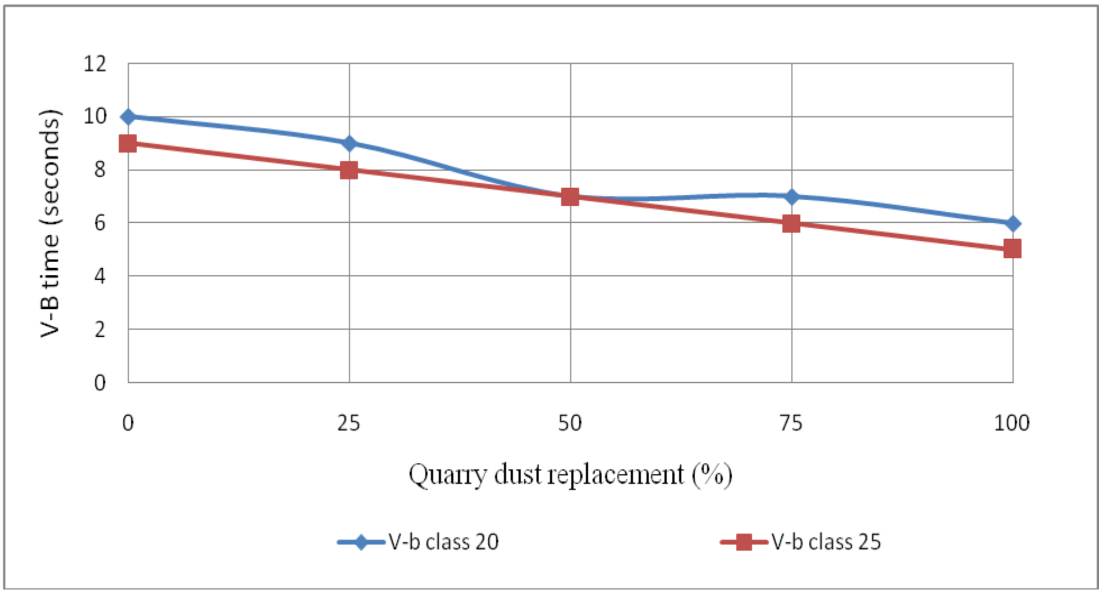

Figure 4.12: Mix ratio 1:2:4 (C20) and Mix 1:1.5:3(C25) results (V-B time in Secs)

4.2.2 Hardened Concrete Tests Results

Figures 4.13 to 4.15 show the compressive strength of different specimens after 7, 14 and 28 days of water curing. In target concrete compressive strength 20N/mm^2 i.e. mix ratio 1:2:4 with 100% quarry dust replacement exhibited a compressive strength of 17.6 N/mm^2 and split tensile strength of 1.1 N/mm^2 at 28 days which is the highest compressive strength and tensile strength gain in this category. From the results the strength gain is very slow as compared to conventional concrete made of conventional materials. In target concrete compressive strength 25N/mm^2 i.e. concrete mix ratio 1:1.5:3 concrete with 100% quarry dust replacement exhibited the highest tensile strength at 28 days as shown in Figure 4.18 and 4.19 and the highest compressive strength. (*See Appendix D*).

Researchers of high performance concrete have discovered that one of the method of achieving high strength in concrete is to ensure that the fine void in concrete are as filled as much as possible (Ilangovan *et al.,* 2007). Therefore the consequence of introducing quarry dust is to increase the compressive strength as the amount of quarry dust increases laterite material in general has a lot of fine material that demand for much water in order to achieve a specified level of workability. The results reveal that, compressive strength was reducing with increasing amount of laterite in the concrete mix. There is a clear distinction from the results of 100% replacement in both materials and it is justified that quarry dust disperses well filling all the voids in the concrete and thus a considerable strength of 19.9 N/mm^2 for mix ratio of 1:1.5:3 and 17.6 N/mm^2 for the mix ratio of 1:2:4.

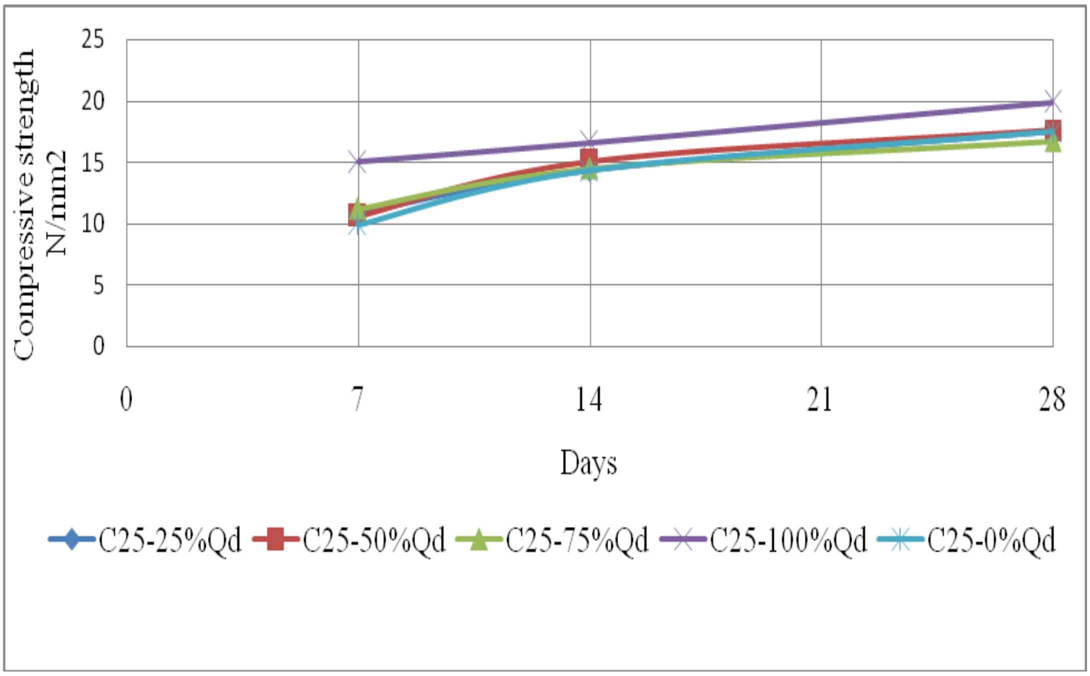

Figure 4.13: Mix ratio 1:1.5:3 (C25) Compressive Strength (N/mm^2) Results

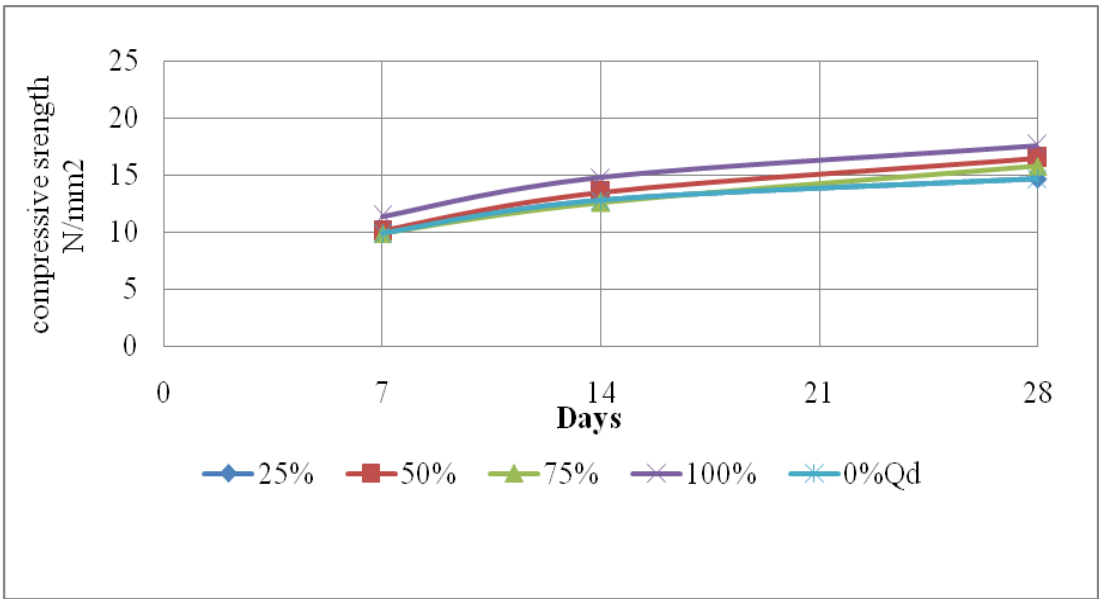

Figure 4.14: Mix ratio 1:1.5:3 (C20) Compressive Strength (N/mm^2) Results

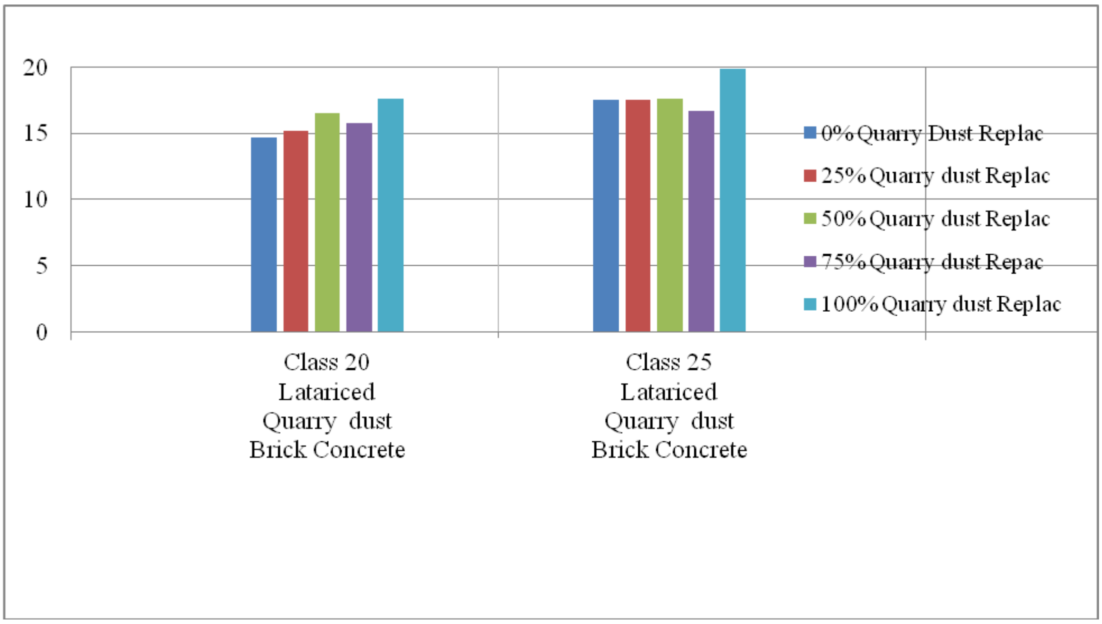

Figure 4.15: Classes 20 and 25 split cylinder tensile strength for laterized quarry dust brick concrete at 28days

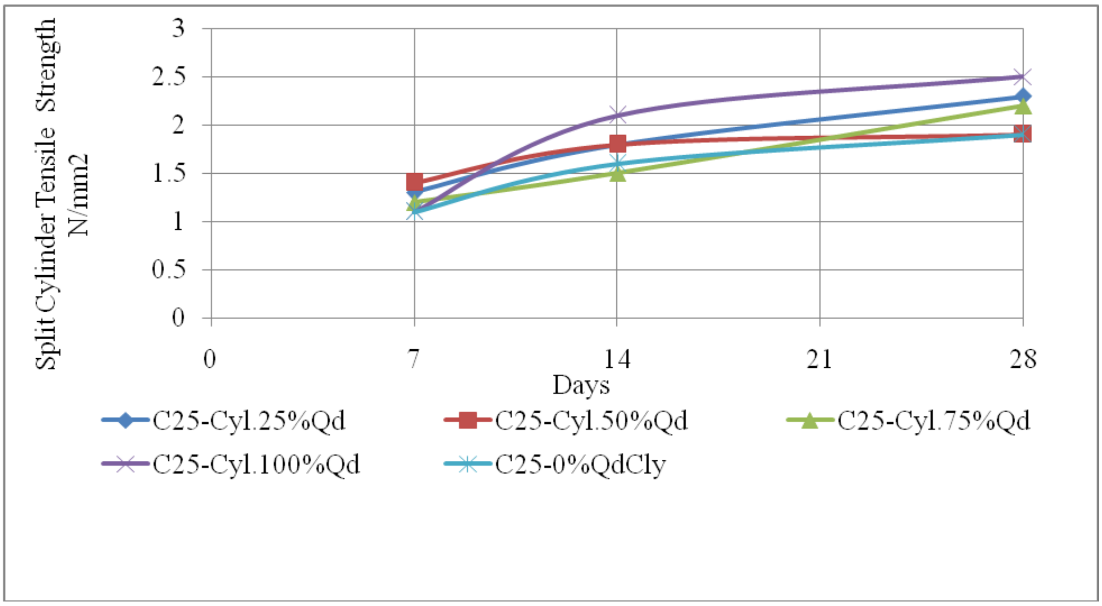

Figure 4.16: Mix Ratio 1:1.5:3 (C25) Split cylinder tensile test results

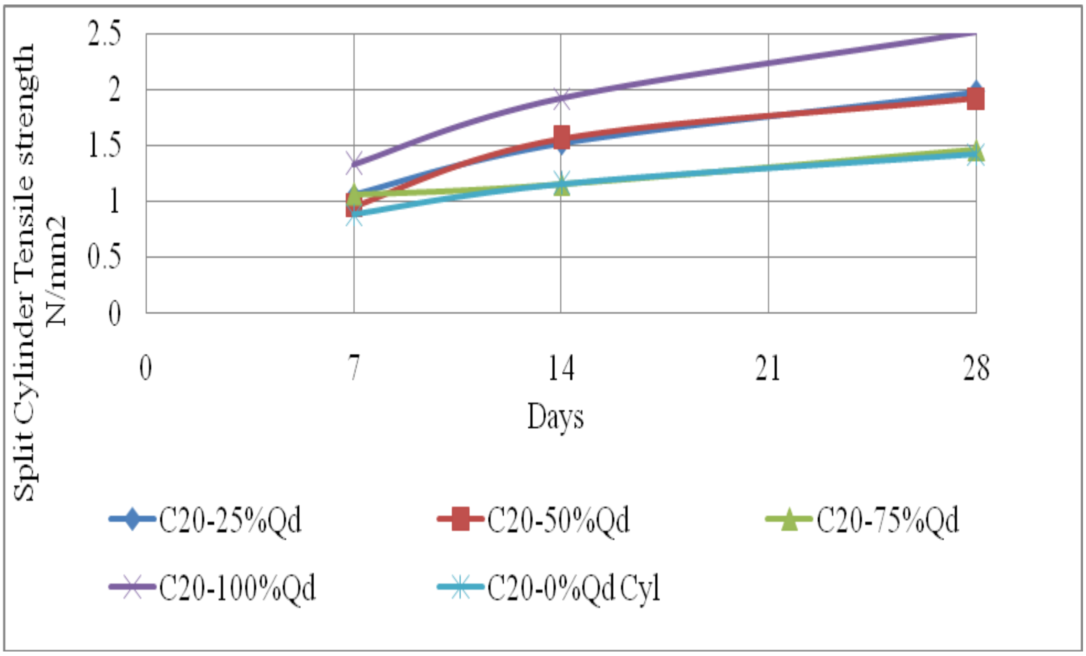

Figure 4.17: MIX Ratio 1:2:4 (C20) Split cylinder tensile test results

Generally concrete with crushed brick aggregate as an aggregate has a relatively lower strength than a normal aggregate concrete, this characteristic can be attributed to the higher water absorption of brick aggregate and the reduction in weight due to high amount of voids and also due to the lower intrinsic strength of the crushed brick aggregate compared to normal aggregate.

The reduction in density of the cubes as the percentage replacement of quarry dust increases because the percentage replacement of the laterite fine is reducing hence the water content is also reducing thus affecting the overall density of the cubes.

Recycled crushed clay bricks quarry dust laterized concrete generally produced results of compressive strength of good fire resistance. This was attributed with the total replacement of the recycled crushed brick aggregate which is thermally sTable when subjected to high temperatures. In this study wet recycled crushed brick quarry dust laterized was used and a slight variation in compressive strength was observed. In the elevated temperatures the wet concrete samples showed a spilling behavior and thus indicated that the best performance should be when it's at dry condition as shown by the results of tests on cubes dried at 50˚C, at the higher temperatures of 105˚C the results of compressive strength of recycled clay bricks quarry dust laterized concrete was decreased by a small margin this is an indication that there is minimal depreciation in strength under fire and this is an advantage to the structural integrity of structures.

4.2.3 Effects of Curing Methods on Strength Properties of Concrete as Required in BS 1881

In this study two sets of concrete specimens of the mix proportions 1:1.5:3 were cast and de-moulded after 24 hours. One set was continuously cured in water while the second set was air cured inside the laboratory floor. The compressive strength was determined at the age of 7, 14 and 28 days as shown in Figure 4.18. To a large extend the effect of elevated temperatures had a substantial significance in the densities of the recycled crushed clay quarry dust laterized concrete, the wet cured samples for between (0%-100%) quarry dust laterite replacement the density reduced from 2300kg/m3 to 2000kg/m3,similarly when the samples from 50˚C oven dried samples were checked their density was between 2000kg/m3 to 1700kg/m3,and it was shown that the densities for samples oven dried at 105˚C their densities was between 1600kg/m3 to 1400kg/m3.

The behaviours is a clear indication of presence of high pores thus water pockets which were expelled by the subsequent heat and steam process and the effect in reduced density and change in the weights and this implies that further test should be conducted to expound on the long term behaviour of this recycled crushed clay quarry dust laterized concrete. It was concluded that water immersion cured samples had highest compressive strength and density for the recycled crushed clay brick quarry dust laterized concrete.

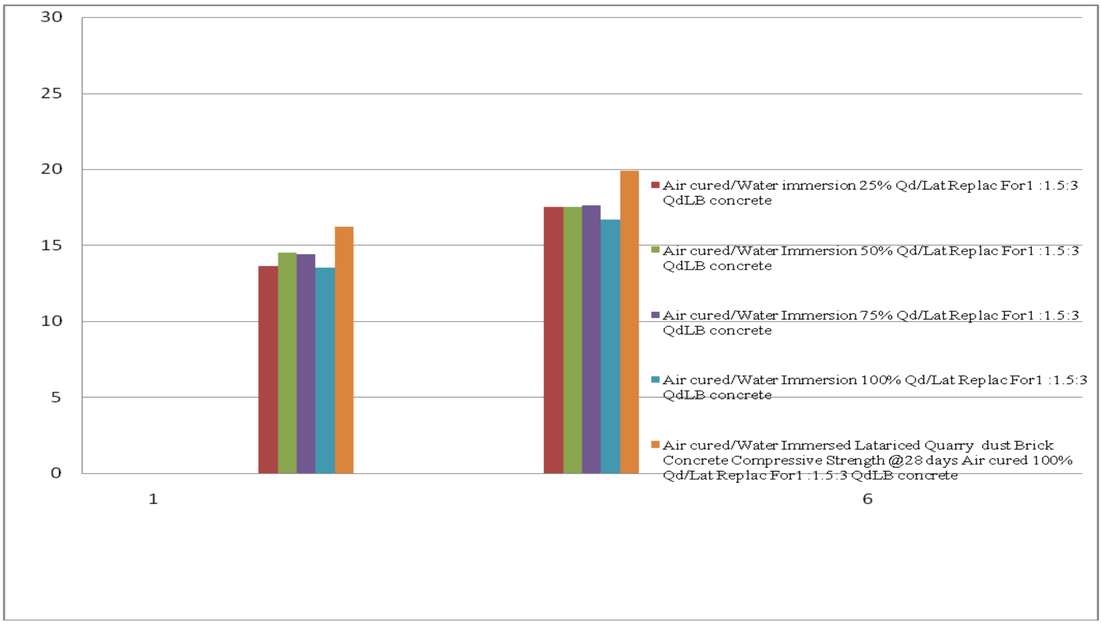

Figure 4.18: Compressive Strength for QdLB concrete mix 1:1.5:3 in air cured and Water Immersion condition @ 28 Days

The air cured concrete results show a slight reduction in strength as compared to water immersion cured concrete

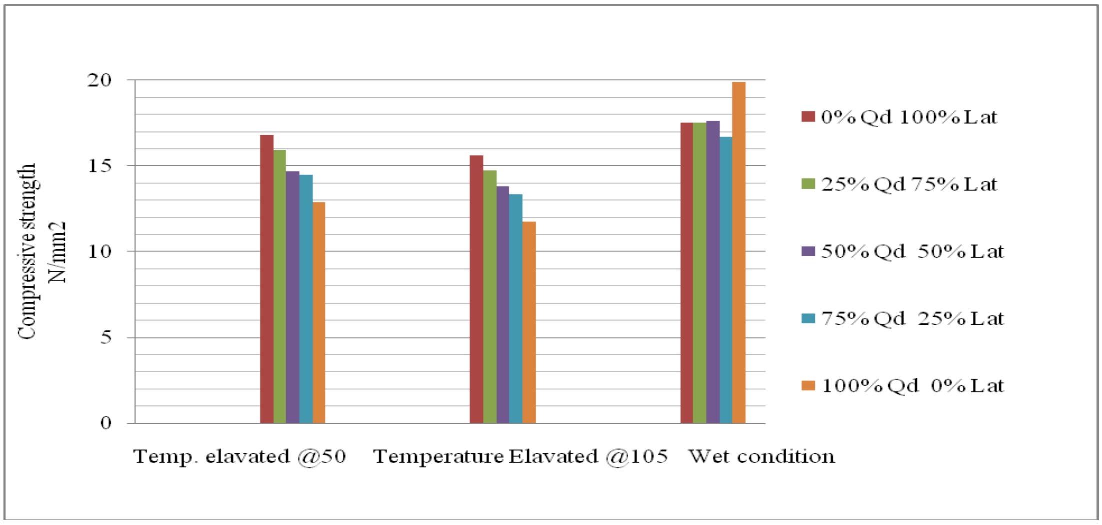

Figure 4.19: Compressive Strength for QdLB concrete mix 1:1.5:3 in elevated temperature @ 28 Days

4.2.4 Effects of Curing Methodo Compressive Strength of Crushed Bricks Quarry Dust Laterized Concrete

The results of samples tested after curing (i.e., after immersion in water and air curing in each of samples in oven drying at 50˚C and oven drying at 105˚C) are shown in Table 4.2 and Table 4.3.

Table 4.2: Cube results for oven dried @ 50˚c water immersion cured concrete

Compressive Strength for 1:1.5:3 mix at 28 days						
Replacement	Average weight	volume	Density	Crushing load(KN)	Effective Area	Compressive strength (N/mm^2)
0%	6742	0.15^3	2000	378.000	150^2	16.8
25%	6021	0.15^3	1780	357.750	150^2	15.9
50%	5891	0.15^3	1750	330.750	150^2	14.7
75%	5910	0.15^3	1750	326.250	150^2	14.5
100%	5699	0.15^3	1690	290.250	150^2	12.9

Table 4.3: Cube results for oven dried @ 105˚c water immersion cured concrete

Compressive strength for 1:1.5:3 mix at 28 days						
Replacement	Average weight	volume	Density	Crushing load(KN)	Effective Area	Compressive strength (N/mm^2)
0%	5482	0.15^3	1620	351.675	150^2	15.63
25%	4954	0.15^3	1470	331.200	150^2	14.72
50%	4790	0.15^3	1420	310.950	150^2	13.82
75%	4764	0.15^3	1410	300.600	150^2	13.36
100%	4776	0.15^3	1710	264.825	150^2	11.77

The compressive strength of concrete for air cured crushed brick quarry dust laterized concrete produced was in the range of 13 to 16N/mm^2, upon water immersion the result was in the range of 17.6 and 19.9 N/mm^2.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

From the results of this study it can be established that the combination of laterite, quarry dust and crushed clay bricks to replace the conventional aggregates in the production of concrete results in structures with reasonable structural characteristics should be encouraged where there is comparative cost advantage.

The following conclusions can be made from this study;

i. The physical properties of laterite, quarry dust and crushed clay bricks investigated were; specific gravity, density and particle size distribution. The specific gravities for laterite, quarry dust and crushed cay bricks were found to be 2.392, 2.62 and 2.273, respectively.
ii. The 28 - day compressive strength of laterized quarry dust and crushed brick concrete was found to range from 14.7 – 17.6N/mm^2 and 17.5-19.9 N/mm^2 for class 20 and class 25 concrete mixes, respectively, for different mixes. The above strength properties were found to compare closely with normal concrete. The concrete mix with a proportion of 0% laterite to 100% quarry dust produced higher values of compressive strength.

5.2 Recommendations

Laterized quarry dust and crushed bricks can be used for concrete production where structural strength not exceeding 20N/mm^2 is required. The combination with adequate strength characteristics that should be adopted for fine aggregates is 25% laterite to 75% quarry dust and 0% laterite to 100% quarry dust. Intense Curing should also be done to increase the strength properties of the concrete

5.3 Further work

Further work is required to get data for structural properties of reinforced concrete produced with laterized quarry dust as fine aggregates and crushed bricks as coarse aggregates. The knowledge of all properties concerning the use of alternative aggregates in production of concrete will greatly assist engineers, builders and designers when using these materials for construction works.

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APPENDICES

Appendix A: Grading of Aggregates

Table A1: Grading Table for crushed Bricks

Grading Table For Recycled Bricks							Limits	
sieve size	weight of Sieve	Wt. Of sieve & sample	Wt. Retained	CUMM Wt. Retained	CUMM Wt. Passing	Percentage Passing.	Lower Limits	Upper Limits
50	538	538	0	0	1994.5	100	100	100
40	520.5	520.5	0	0	1994.5	100	100	100
20	586	595.5	9.5	9.5	1985	100	90	100
15	569.5	909	339.5	349	1645.5	83	40	80
10	493	1468	975	1324	670.5	34	30	60
5	483	1012	529	1853	141.5	7	0	10
Pan	301.5	443	141.5	1994.5	0	0	0	0
				1994.5				

Table A2: Grading for quarry dust-overall limits

Grading for quarry dust-overall limits							Overall	
sieve size	weight of Sieve	Wt. Of sieve & laterite	Wt. Retained	Cumm. Wt. Retained	Cumm. Wt. Passing	Quarry Percentage Passing.	lower limit	upper limit
10	468	468	0	0	997	100	100	100
5	463	463	0	0	997	100	89	100
2.36	447	535	88	88	909	90	60	100
1.2	396.5	575	178.5	266.5	730.5	73	30	100
0.6	344.5	570	225.5	492	505	50	15	100
0.3	362.5	560	197.5	689.5	307.5	30	5	70
0.15	342.5	530	187.5	877	120	9	0	15
0.075	301.5	332.5	31	908	89	0	0	15
Pan								
				997				

Table A3: Grading for laterite - overall envelope

Grading for laterite /overall envelope							Overall	
sieve size	Wt.of Sieve	Wt. of sieve & laterite	Wt. Retained	Cumm Wt. Retained	Cumm Wt. Passing	Laterite Percentage Passing.	lower limit	upper limit
10	468	480	12	12	977.5	100	100	100
5	463	677.5	214.5	226.5	763	97	89	100
2.36	447	753	306	532.5	457	85	60	100
1.2	396.5	647.5	251	783.5	206	55	30	100
0.6	344.5	425.5	81	864.5	125	30	15	100
0.3	362.5	439	76.5	941	48.5	4	5	70
0.15	342.5	367.5	25	966	23.5	2	0	15
0.075	301.5	332.5	31	997	-7.5	0	0	15
Pan								
				989.5				

Table A4: Grading for Quarry dust- Coarse Limits

Table of results for Quarry dust-Coarse gradation							Coarse limits	
sieve size	weight of Sieve	Wt. Of sieve & laterite	Wt. Retained	CUMM Wt. Retained	CUMM Wt. Passing	Quarry dust Percentage Passing.	lower limit	upper limit
10	468	468	0	0	989.5	100	100	100
5	463	463	0	0	989.5	100	100	100
2.36	447	525	78	78	911.5	92	60	100
1.2	396.5	590	193.5	271.5	718	72	30	90
0.6	344.5	643	298.5	570	419.5	42	15	54
0.3	362.5	579	216.5	786.5	203	21	5	40
0.15	342.5	407.5	65	851.5	138	14	0	15
0.075	301.5	362.5	61	912.5	77	8	0	15
Pan								
				989.5				

Table A5: Grading for Quarry dust -Medium limits

Table for quarry dust/Medium gradation							Medium limits	
sieve size	weight of Sieve	Wt. Of sieve & laterite	Wt. Retained	CUMM Wt. Retained	CUMM Wt. Passing	Quarry dust Percentage Passing.	lower limit	upper limit
10	468	480	12	12	977.5	100	100	100
5	463	677.5	214.5	226.5	763	100	100	100
2.36	447	753	306	532.5	457	92	89	100
1.2	396.5	647.5	251	783.5	206	72	70	100
0.6	344.5	425.5	81	864.5	125	42	40	80
0.3	362.5	439	76.5	941	48.5	21	30	48
0.15	342.5	367.5	25	966	23.5	14	5	15
0.075	301.5	332.5	31	997	-7.5	8	4	15
Pan								
				989.5				

Table A6: Grading for Quarry dust-Fine Limits

Table of results for Quarry Dust/Fine gradation							Fine limits	
sieve size	weight of Sieve	Wt. Of sieve & laterite	Wt. Retained	CUMM Wt. Retained	CUMM Wt. Passing	Percentage Passing.	lower limit	upper limit
10	468	480	12	12	977.5	100	100	100
5	463	677.5	214.5	226.5	763	100	100	100
2.36	447	753	306	532.5	457	92	80	100
1.2	396.5	647.5	251	783.5	206	72	70	100
0.6	344.5	425.5	81	864.5	125	42	55	100
0.3	362.5	439	76.5	941	48.5	21	5	70
0.15	342.5	367.5	25	966	23.5	14	0	15
0.075	301.5	332.5	31	997	-7.5	8	0	15
Pan								
				989.5				

Table A7: Grading for Laterite-Coarse Limits

Table for results of laterite/coarse gradation							Coarse limits	
sieve size	weight of Sieve	Wt. Of sieve & laterite	Wt. Retained	CUMM Wt. Retained	CUMM Wt. Passing	laterite Percentage Passing.	lower limit	upper limit
10	468	480	12	12	977.5	100	100	100
5	463	677.5	214.5	226.5	763	97	100	100
2.36	447	753	306	532.5	457	85	60	100
1.2	396.5	647.5	251	783.5	206	55	30	90
0.6	344.5	425.5	81	864.5	125	30	15	54
0.3	362.5	439	76.5	941	48.5	4	5	40
0.15	342.5	367.5	25	966	23.5	2	0	15
0.075	301.5	332.5	31	997	-7.5	0	0	15
Pan								
				989.5				

Tasble A8: Grading for laterite - Medium Limits

Table for results of laterite/medium gradation							Medium limits	
sieve size	weight of Sieve	Wt. Of sieve & laterite	Wt. Retained	CUMM Wt. Retained	CUMM Wt. Passing	laterite Percentage Passing.	lower limit	upper limit
10	468	480	12	12	977.5	100	100	100
5	463	677.5	214.5	226.5	763	97	100	100
2.36	447	753	306	532.5	457	85	65	100
1.2	396.5	647.5	251	783.5	206	55	45	100
0.6	344.5	425.5	81	864.5	125	30	25	80
0.3	362.5	439	76.5	941	48.5	4	5	48
0.15	342.5	367.5	25	966	23.5	2	0	15
0.075	301.5	332.5	31	997	-7.5	0	0	15
pan								
				989.5				

Table A9: Grading for laterite-Fine limits

Table of results for laterite/fine gradation							Fine limits	
sieve size	weight of Sieve	Wt. Of sieve & laterite	Wt. Retained	CUMM Wt. Retained	CUMM Wt. Passing	laterite Percentage Passing.	lower limit	upper limit
10	468	480	12	12	977.5	100	100	100
5	463	677.5	214.5	226.5	763	97	100	100
2.36	447	753	306	532.5	457	85	80	100
1.2	396.5	647.5	251	783.5	206	55	70	100
0.6	344.5	425.5	81	864.5	125	30	55	100
0.3	362.5	439	76.5	941	48.5	4	5	70
0.15	342.5	367.5	25	966	23.5	2	0	15
0.075	301.5	332.5	31	997	-7.5	0	0	15
Pan								
				989.5				

Appendix B: Batching of Aggregates

Table B1: Batching proportions mix 1:2:4, W/c 0.5

Replacement %	Water Kg	Cement Kg	Quarry dust Kg	Laterite Kg	Clay Bricks Kg
0	30	30	0	60	120
25	30	30	14	45	120
50	27	30	30	30	120
75	27	30	45	15	120
100	27	30	60	0	120

Table B2: Batching proportions mix 1:1.5:3, W/c 0.5

Replacement %	Water Kg	Cement Kg	Quarry dust	Laterite Kg	Clay Bricks
0	38	40	0	60	120
25	38	40	15	45	120
50	36	40	30	30	120
75	36	40	45	15	120
100	36	40	60	0	120

Appendix C: Workability

Table C1: Workability test results C20

Concrete/Replacement	Replacement (%)	Slump (MM)	Compacting factor	V-B time
C20/0%Qd100%Lat	0	13	0.92	10
C20/25%Qd75% Lat	25	15	0.9	9
C20/50%Qd50% Lat	50	25	0.89	7
C20/75%Qd25% Lat	75	25	0.89	7
C20/100%Qd0% Lat	100	30	0.87	6

Table C2: Workability test results C25

Concrete/Replacement	Replacement (%)	slump (mm)	Compacting factor	V-B time (Sec)
C25/0%Qd100% Lat	0	15	0.9	9
C25/25%Qd75% Lat	25	20	0.9	8
C25/50%Qd50% Lat	50	25	0.89	7
C25/75%Qd25% Lat	75	40	0.84	6
C25/100%Qd0% Lat	100	50	0.8	5

Appendix D: Hardened Concrete Test Results

Table D1: Compressive strength class 25 results

Compressive Strength For 1:1.5:3- 0%,25%,50%,75%,100% Qd/Lat					
Age (days)	**Compressive Strength (N/mm^2)**				
	0%	25%	50%	75%	100%
0					
7.0	9.9	10.8	10.6	11.2	15.0
14	14.3	14.3	15.1	14.5	16.6
28	17.5	17.5	17.6	16.7	19.9

Table D2: Split cylinder test class 20 Table of results

Table For Split Cylinder Tensile Strength,C20-Cyl.-0%,25%,50%,75%,100%Qd/Lat					
Age-days		**Split Cylinder Tensile Strength (N/mm^2)**			
0	0%	25%	50%	75%	100%
7	0.9	1.1	1.0	1.1	1.3
14	1.2	1.5	1.6	1.2	1.9
28	1.4	2.0	1.9	1.5	2.5

Table D3: Compressive Strength Class 20 results

Compressive Strength mix 1:2:4 -0%,25%,50%,75%,100% Qd/Lat					
Age(Days)	**Compressive Strength (N/mm^2)**				
	0%	25%	50%	75%	100%
0	-	-	-	-	-
7	9.9	9.9	10.1	9.9	11.4
14	12.8	12.8	13.5	12.6	14.8
28	14.7	15.2	16.5	15.8	17.6

Table D4: Split Cylinder Test results Class 25 Table of Results

Split Cylinder Test results Cyl.25- 0%,25%, 50%, 75%, 100% replacement (N/mm^2)					
Age Days	0%	25%	50%	75%	100%
0					
7	1.1	1.3	1.4	1.2	1.1
14	1.6	1.8	1.8	1.5	2.1
28	1.9	2.3	1.9	2.2	2.5

Table D5: Cube results for air cured concrete

Replacement	0%	25%	50%	75%	100%
Age (Days)	**Compressive Strength (N/mm^2)**				
7	7.92	8.53	8.90	9.17	12.23
14	11.47	11.59	12.39	12.10	13.62
28	13.65	14.53	14.43	13.55	16.21

Table D6: Cube results for air cured concrete

Compressive strength for 1:1.5:3 mix at 28 days						
replacement	Average weight	volume	Density	Crushing load(KN)	Effective Area	Compressive strength (N/mm^2)
0%	6212	0.15^3	1840	393.750	150^2	13.65
25%	6149	0.15^3	1820	393.750	150^2	14.53
50%	5950	0.15^3	1760	396.000	150^2	14.43
75%	5930	0.15^3	1760	375.750	150^2	13.55
100%	5755	0.15^3	1705	447.750	150^2	16.21

Table D7: Cube results for water immersion cured concrete

Compressive strength for 1:1.5:3 mix ratio					
Age (days)	**Compressive Strength**				
	0%	25%	50%	75%	100%
0					
7.0	9.9	10.8	10.6	11.2	15.0
14	14.3	14.3	15.1	14.5	16.6
28	17.5	17.5	17.6	16.7	19.9

Table D8: Cube results for wet water immersion cured concrete

Compressive strength for 1:1.5:3 mix at 28 days						
replacement	Average weight	volume	Density	Crushing load(KN)	Effective Area	Compressive strength (N/mm^2)
0%	7994	0.15^3	2250	393.750	150^2	17.5
25%	7223	0.15^3	2140	393.750	150^2	17.5
50%	6986	0.15^3	2070	396.000	150^2	17.6
75%	6953	0.15^3	2060	375.750	150^2	16.7
100%	6848	0.15^3	2030	447.750	150^2	19.9

Table D9: Mix ratio 1:1.5:3 (C25) and 1:2:4 (C20) Split Cylinder Tensile Strength @28 days (N/mm^2) (N/mm2) Results

Class 20 & 25 Quarry Dust Laterite Crushed Clay Brick Aggregate Concrete Split Cylinder Tensile Strength @28 days (N/mm^2)					
	0% Quarry Dust Replaced	25% Quarry dust Replaced	50% Quarry dust Replaced	75% Quarry dust Repack	100% Quarry dust Replaced
Mix 1:2:4 Lat. Quarry dust Brick Concrete	1.4	2.0	1.9	1.5	2.5
Mix 1:1.5:3 Lat. Quarry dust Brick Concrete	1.9	2.3	1.9	2.2	2.5

Table D10: Class 20 & 25 Laterized Quarry dust Brick Concrete Compressive Strength @28 days (N/mm^2)

Class 20 & 25 Laterized Quarry dust Brick Concrete Compressive Strength @28 days (N/mm^2)					
	0% Quarry Dust Replaced	25% Quarry dust Replaced	50% Quarry dust Replaced	75% Quarry dust Repack	100% Quarry dust Replaced
Mix 1:2:4 Lat. Quarry dust Brick Concrete	14.7	15.2	16.5	15.8	17.6
Mix 1:1.5:3 Lat. Quarry dust Brick Concrete	17.5	17.5	17.6	16.7	19.9

Table D11: Cube results for water immersion cured concrete

Compressive strength for 1:1.5:3 mix ratio					
Age	**Compressive Strength**				
	0%	25%	50%	75%	100%
7.0	9.9	10.8	10.6	11.2	15.0
14	14.3	14.3	15.1	14.5	16.6
28	17.5	17.5	17.6	16.7	19.9

Table D12: Cube results for wet water immersion cured concrete

Compressive strength for 1:1.5:3 mix at 28 days						
Replacement	Average weight	Volume	Density	Crushing load (KN)	Effective Area	Compressive strength (N/mm^2)
0%	7994	0.15^3	2250	393.750	150^2	17.5
25%	7223	0.15^3	2140	393.750	150^2	17.5
50%	6986	0.15^3	2070	396.000	150^2	17.6
75%	6953	0.15^3	2060	375.750	150^2	16.7
100%	6848	0.15^3	2030	447.750	150^2	19.9

Table D13: Cube results for oven dried @ 50˚c water immersion cured concrete

Compressive Strength for 1:1.5:3 mix at 28 days						
Replacement	Average weight	Volume	Density	Crushing load(KN	Effective Area	Compressive strength
0%	6742	0.15^3	2000	378.000	150^2	16.8
25%	6021	0.15^3	1780	357.750	150^2	15.9
50%	5891	0.15^3	1750	330.750	150^2	14.7
75%	5910	0.15^3	1750	326.250	150^2	14.5
100%	5699	0.15^3	1690	290.250	150^2	

Table D14: Cube results for oven dried @ 105˚c water immersion cured concrete

Compressive strength for 1:1.5:3 mix at 28 days						
Replacement	Average weight	volume	Density	Crushing load(KN)	Effective Area	Compressive strength (N/mm^2)
0%	5482	0.15^3	1620	351.675	150^2	15.63
25%	4954	0.15^3	1470	331.200	150^2	14.72
50%	4790	0.15^3	1420	310.950	150^2	13.82
75%	4764	0.15^3	1410	300.600	150^2	13.36
100%	4776	0.15^3	1410	264.825	150^2	11.77

Appendix E: Apparent Specific Density

Table E1: Apparent specific density, Oven dry specific density and saturated specific density for laterite

Specimen reference			Sample
Mass of saturated surface dry aggregate in air	A	g	500.5
Mass of Pycnometer + sample filled with water	B	g	1716.5
Mass of pycnometer filled with water only	C	g	1407.0
Mass of oven dry aggregate in air	D	g	491
Relative density on an oven dry density basis	ρ_d=D/{A-(B-C)}	Kg/m^3	2.571
Relative density on saturated & surface dry density basis	ρ_s= A/{A-(B-C)}	Kg/m^3	2.620
Apparent Relative density	ρ_a= D/{D-(B-C)}	Kg/m^3	2.705
Water absorption	W_{abs} = {(A-D)/D}*100	%	2.0

Table E2: Apparent specific density, Oven dry specific density and saturated specific density crushed bricks.

Specimen reference			**Sample**
Mass of saturated surface dry aggregate in air	A	g	2000.0
Mass of basket + sample in water	B	g	1523.0
Mass of empty basket in water	C	g	396.0
Mass of oven dry aggregate in air	D	g	1780
Relative density on an oven dry density basis	ρ_d=D/{A-(B-C)}	Kg/m^3	2.039
Relative density on saturated & surface dry density basis	ρ_s= A/{A-(B-C)}	Kg/m^3	2.292
Apparent Relative density	ρ_a= D/{D-(B-C)}	Kg/m^3	2.726
Water absorption	W_{abs} = {(A-D)/D}*100	%	12

Table E3: Apparent specific density, Oven dry specific density and saturated specific density quarry dust

Specimen reference			sample
Mass of saturated surface dry aggregate in air	A	g	500.5
Mass of Pycnometer + sample filled with water	B	g	1686.5
Mass of pycnometer filled with water only	C	g	1407.0
Mass of oven dry aggregate in air	D	g	480
Relative density on an oven dry density basis	ρ_d=D/{A-(B-C)}	Kg/m^3	2.513
Relative density on saturated & surface dry density basis	ρ_s= A/{A-(B-C)}	Kg/m^3	2.265
Apparent Relative density	ρ_a= D/{D-(B-C)}	Kg/m^3	2.705
Water absorption	W_{abs} = {(A-D)/D}*100	%	1.8