

**STRENGTH PROPERTIES OF CONCRETE CONTAINING LATERITE AS PARTIAL
REPLACEMENT FOR FINE AGGREGATES.**

BY

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CERTIFICATION

This is to certify that this project topic titled “Strength Properties of Concrete Containing Laterite as Partial Replacement for Fine Aggregates” was done by Obioma Prince Chukwujigidem with registration number (NAU/2016224071) in the Department of Civil Engineering, Nnamdi Azikiwe University, Awka, Anambra State.

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APPROVAL PAGE

This research work “Strength Properties of Concrete Containing Laterite as Partial Replacement for Fine Aggregates” has been assessed and approved by department of Civil Engineering, Nnamdi Azikiwe University.

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DEDICATION

This work is dedicated to God Almighty.

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Special thanks go to Almighty God for giving me the strength to complete this work and also for His guidance and protection throughout my stay in Nnamdi Azikiwe University.

I want to thank in a very special way, my project supervisor in the person of Dr. Adinna for his time and guidance in the accomplishment of this project. May the good lord enlarge your coast and also protect your family.

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ABSTRACT

The need to reduce the high cost of concrete production resulting from increasing cost of fine aggregate formed the basis for the study. The study was undertaken to effect of partial replacement of sand with laterite on strength properties of concrete. Laterite sample was added to sand in an increasing order of 5%, 10%, 15%, 20% and 25% by weight of sand. Experimental testing was conducted so as to evaluate the effect of partial replacement of sand with laterite on strength properties of concrete. These tests are: sieve analysis test, specific gravity test, bulk density test, slump test and compressive strength test. Results obtained from sieve analysis test revealed that granite, sand and laterite were classified as A-1-b, A-2-4 and A-2-6 according to AASHTO Soil Classification System, GC, SM and SC according to Unified Soil Classification System, the specific gravity of granite, sand and laterite were 2.61, 2.55 and 2.66 respectively, the liquid limit, plastic limit and plasticity index of the laterite sample was 42.4%, 25.9% and 16.5%. The slump of the concrete increased from 0% addition of laterite to 15% addition of laterite to sand, the hardened density and compressive strength of the concrete increased from 0% addition of laterite to sand to 5% addition of laterite to sand beyond 5% laterite content, the hardened density and compressive strength was found to decrease. This study therefore discourage the use of laterite as partial substitute for sand in concrete beyond 5% addition of laterite to sand as the compressive strength of the concrete were found to decrease.

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LIST OF SYMBOL & ABBREVIATION

G_s – Specific Gravity

AASHTO – American Association of State Highway and Transportation Officials

USCS – Unified Soil Classification System

ASTM – American Society for Testing and Material

BSL – British Standard Light

BSH – British Standard Heavy

LL – Liquid Limit

PL – Plastic Limit

SL – Shrinkage Limit

PI – Plasticity Index

D_{10} – Particle Size such that 10% is finer than the Size

D_{30} – Particle Size such that 30% is finer than the Size

D_{60} – Particle Size such that 60% is finer than the Size

C_u – Coefficient of Uniformity

C_c – Coefficient of Curvature

SC – Clayey Sand

SM – Silty Sand

GM – Silty Gravel

GC—Clayey Gravel

GW—Well Graded Gravel

GP—Poorly Graded Gravel

SP—Poorly Graded Sand

SW—Well Graded Sand

CL – Inorganic Clay of Low Plasticity (lean clay)

CH—Inorganic Clay of High Plasticity (fat clay)

ML- Silt of low Plasticity

MH – Silt of High Plasticity

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CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Concrete is a material used for infrastructural development. The design of the concrete structure requires accuracy at the design and implementation stages by considering the price and strength aspects of the concrete structure which has a high strength but with a low cost (Tumingan and Alwi, 2019). Both of these can be achieved by optimizing the design and innovation of materials by adopting certain materials that have lower prices, but do not reduce quality or strength of the structures designed (Tumingan and Alwi, 2019).

High cost of building materials has been the bane of construction industry in the developing countries of the world as a result of importation of most of the building materials. As prices increase sharply, there is a growing awareness to relate research to local materials as alternatives for the construction of functional but low-cost dwellings both in the urban and rural areas of Nigeria (Joshua, et al., 2014). One of such local material that is being researched is lateritic soil. Lateritic soil has been one of the major building materials in Nigeria for a long time. The main reason lies on the fact that it is readily available and the cost of procuring it is relatively low.

Lateritic soil possesses other advantages which makes it potentially a very good and appropriate material for construction, especially for the construction of structures in the developing countries. These merits include little or no specialized skilled labour required for lateritized concrete production and for its use in other construction works; and lateritized concrete structures have potentially sufficient strength compared with that of normal concrete (Lasisi and Ogunjimi, 1984). Visual observation of the laterite material shows that the variation of sand is much sharper than those considered in previous works. This is confirmed by the preliminary assessment of its particle size distribution. There is therefore every reason to believe that this laterite can be used in structural concrete production. The particle sizes of aggregates are known to affect the strength properties of concrete greatly

The importance of fine aggregate (Natural river sand) in concrete production cannot be over emphasized. As a result of its relative importance in concrete production, the demand for it is very high among the construction industry. Also, Nigeria as one of the developing nations is

seriously experiencing excessive excavation and mining of natural river sand which has negative environmental consequences. Among these are erosion and failure of river banks, lowering of river beds and damage of structures situated closer to the rivers, saline water intrusion into the land and coastal erosion are the major adverse effects due to intensive river sand mining.

Udoeyo et al, (2006) carried out an experimental investigation on some characteristics of concrete containing laterite as partial or full replacement of fine aggregate. Test results showed that concrete with 40% replacement of sand with laterite could attain design strength of 20N/mm^2 . This fact is reinforced in the comparative study of strength properties of unreinforced and fiber reinforced normal and laterized concrete by Ikponmwoosa and Falade (2006). Test results showed that strength increases with age of the test specimens. Also, laterite replacing sharp sand in concrete up to 45% produced the highest compressive strength.

Ayangade et al (2009) took the study to a new dimension when they evaluated the effects of different curing methods on the compressive strength of terracrete (Granite and laterite). Sixty cubes of $100 \times 100 \times 100\text{mm}$ using a mix of $1:1\frac{1}{2}:3$, water/cement ratio of 0.62 were cast and cured using four different methods of curing for up to 35 days. Test results of the various compressive strengths of the cubes showed that out of the four curing methods, open method produced cubes with the highest compressive strength of 10.3N/mm^2 after 35 days of curing. Still, in the same vein to ascertain the strength properties of laterized concrete, Udoeyo et al, (2010) studied early prediction of laterized concrete strength by accelerated testing using the boiling water of accelerated strength testing to predict the 28 days compressive strength of laterized concrete, results showed that the accelerated strength of the concrete was between 72 and 84% of its twenty- eight days strength.

In other to reduce adverse environmental consequence resulting from excessive excavation and mining of river sand and reduce cost of concrete production, this study will therefore evaluate the effect of partial replacement of fine aggregate (sand) with laterite on strength properties of concrete.

1.2 Statement of Problem

Concrete is one of the most widely used composite materials Ajam, et al., (2020). It is a composite mixture of binding materials (cement), coarse aggregate (gravel), fine aggregate (sand) and water in their correct proportion. The importance of fine aggregate (Natural river

sand) in concrete production cannot be over emphasized. As a result of its relative importance in concrete production, the demand for it is very high among the construction industry. Also, Nigeria as one of the developing nations is seriously experiencing excessive excavation and mining of natural river sand which has negative environmental consequences. Among these are erosion and failure of river banks, lowering of river beds and damage of structures situated closer to the rivers, saline water intrusion into the land and coastal erosion are the major adverse effects due to intensive river sand mining.

High cost of building materials has been the bane of construction industry in the developing countries of the world as a result of importation of most of the building materials. As prices increase sharply, there is a growing awareness to relate research to local materials as alternatives for the construction of functional but low-cost dwellings both in the urban and rural areas of Nigeria Joshua, et al., (2014). One of such local material that is being researched is lateritic soil. Lateritic soil has been one of the major building materials in Nigeria for a long time. The main reason lies on the fact that it is readily available and the cost of procuring it is relatively low.

In order to effectively tackle issue associated with high cost of production and also ensure rational use of earth resources, this study will therefore investigate the effect of partial replacement of fine aggregate (sand) with laterite on strength properties of concrete.

1.3 Aim and Objectives

1.3.1 Aim

The aim of the study is to evaluate the strength properties of concrete containing laterite as partial replacement for fine aggregates.

1.3.2 Objectives

The objectives of the work are:

- 1 To partially replace the fine aggregate of concrete with laterite and compare the weight and strength with corresponding normal concrete.
- 2 To determine the Index properties of the laterite sample
- 3 Study the effect of partial replacement of sand with laterite on mechanical properties of concrete.
- 4 To test the finished concrete for dry density, workability and compressive strength.
- 5 Draw conclusion and make recommendation based on the findings.

1.4 Scope of Study

The scope of the study is entirely on concrete produced with partial replacement of sand with laterite. Concrete mix ratio to be used for the experimental study is 1:2:4. Fine aggregate (sand) will be partially replaced with laterite in a stepped increase of 5% starting from 0% to 25% by dry weight of sand. The laterite sample and laterized concrete will be subjected to various laboratory testing. The tests includes: Sieve analysis test, Specific gravity and Atterberg limit test of the laterite sample, Bulk density test of Fine aggregate (sand), Workability (slump) and compressive strength test of the laterized concrete. The weight of the conventional concrete will be determined and compared with that of laterized concrete. The curing of the concrete is entirely by outer immersion other method of curing will not be used. The laterized concrete will thereafter be analyzed for it compressive strength and recommendation based on findings will be made.

1.5 Significance of Study

This research will be carried out to assess the efficacy of using laterite as a partial substitute for fine aggregates (sand) and the findings obtained from the research will be useful in the following ways:

1. Mitigate environmental problems associated with excessive excavation of fine aggregate (Natural river sand).
2. Ensure rational utilization of earth resources.
3. Promote economy in concrete production
4. Facilitate high rate of construction works through low cost production of laterized concrete.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

Concrete is a composite material consisting of cement, aggregates and water with water and cement being one of the most active constituents. Production of cement has steadily increased to 3.7 billion tons in 2012 (USGS, 2015), thereby releasing a significant amount of carbon dioxide (CO₂) in the atmosphere. Aggregates serve as inert filler materials while at the same time improving concrete workability, volume stability and durability. Recent studies Udoeyo et al, (2006) carried out an experimental investigation on some characteristics of concrete containing laterite as partial or full replacement of fine aggregate. Test results showed that concrete with 40% replacement of sand with laterite could attain design strength of 20N/mm². This fact is reinforced in the comparative study of strength properties of unreinforced and fibre reinforced normal and laterized concrete by Ikponmwosa and Falade (2006). Test results showed that strength increases with age of the test specimens. Also, laterite replacing sharp sand in concrete up to 45% produced the highest compressive strength.

This study is part of the continuing effort to investigate the strength characteristics of concrete produced with partial replacement of fine aggregate with laterite.

2.2 Concrete

Concrete may be defined as a composite material consisting of a binding material, water, fine and coarse aggregates, and in some instances, the incorporation of admixtures all in definite proportions to achieve a desired property. The binding material in most instances is the Ordinary Portland Cement (OPC) although other binding materials are also in used. Concrete is an artificial material comparable in appearance and properties to some natural lime stone rock. It is a man-made composite, the major constituent being natural aggregate such as gravel, or crushed rock, sand and fine particles of cement powder all mixed with water. The concrete as time goes on through a process of hydration of the cement paste, producing a required strength to endure the load (Maninder and Manpreet, 2012).

Concrete is defined in student Encarta as a mixture of sand, cement, aggregate and water in specific proportions that hardens to a strong stony consistency over varying length of time. The aggregate in this context refers to rock particles of size above 5mm². American concrete institute

also sees concrete as an engineering material made from a mixture of Portland cement, water, fine and coarse aggregate and small amount of air. Olanipekun (2006) defines concrete as a composite material consisting of a binding medium within which the particles are embedded. Other scholars also define concrete as a combination of aggregates and a paste composed of a Portland cement and water. The aggregate refer to sand and gravels or crushed stones (Mannan and Ganapathy, 2002).

Concrete is a widely used construction material in civil engineering projects throughout the world for the following reasons: It has great resistance to water, structural concrete elements can be formed into a variety of shapes and sizes and it is usually the cheapest and most readily available material for the job (Olanipekun, 2006). Light Weight Concrete (LWC) can be defined as a concrete with a density of 1840 kg/m^3 (115 lb/ft^3). According to BS 5328 (1997), it is a hardened concrete having an oven dried density greater than 2000 kg/m^3 but not exceeding 2600 kg/m^3 . It has a setting time of 30 - 90 minutes depending upon the moisture in the atmosphere and fineness of cement among others.

According to Stanley and Bond (1999), the oldest concrete discovered dates from around 7000 BC, and was found in 1985 when a bulldozer uncovered a concrete floor during the construction of a road at Yiftah El in southern Galilee, Israel. It was also reported that the Romans also developed the concept of light weight concrete by casting jars into wall arches as well as the use of pumice aggregates. However, though concrete might have existed as early as 7000 BC, the massive use of it might have started around the 19th century.

2.2.1 History of Concrete

The first major concrete users were the Egyptians in around 2,500BC and the Romans from 300BC the Romans found that by mixing pink sand like material which they obtained from Pozzuoli with their normal lime-based concretes they obtained a stronger material. The pink sand turned out to be fine volcanic ash and they had unintentionally produced the first pozzolanic cement. Pozzolanic is any siliceous and aluminous material which possesses little or no cementitious value in itself but will, if finely divided and mixed with water, chemically react with calcium hydroxide to form compounds with cementitious properties (<http://www.bushywood.com/concrete.htm>).

2.2.2 Structural Benefits of Concrete.

Concrete provides so many benefits among which include its low cost when compared to steel. By incorporating waste materials for its production, the cost can significantly reduce hence leading to a significant reduction in the total construction cost. Also, repairing work for concrete is easier and more economical than other construction materials. It is durable and can also be recycled for use in other areas such as a filler material for road construction. Unlike wood, for example, which can rot and decay and is susceptible to natural disaster, concrete requires little or no maintenance and can stand up to the toughest winds, the harshest of weather conditions and resist fire with ease. Concrete can also have a decorative function. Concrete does not burn and therefore provides comprehensive fire protection including life safety, protection of properties and of the environment. Concrete is one of the more sustainable building materials when both the energy consumed during its manufacture and its inherent properties in-use are considered. Concrete's thermal mass can be used to avoid or reduce temperature swings in the building and to eradicate the need for energy guzzling air conditioning systems. Dense, heavyweight concrete provides the highest amount of thermal mass (European Concrete Platform ASBL, 2009).

Another important feature of concrete is that it is environmentally friendly. Concrete is one of the best, most natural building materials to use when considering the environmental impact of construction. The use of waste in the production of concrete helps to reduce environmental pollution and also addresses the problem of waste management. Concrete walls and floors are effective storage heaters, absorbing free heat from the sun during the daytime and releasing heat at night. Concrete stores heat in the winter and cools buildings in the summer, creating optimum comfort conditions for the occupants (European Concrete Platform ASBL, 2009). Concrete in buildings provides exceptional levels of security and safety.

2.3 Component of Concrete

Concrete is a composite mixture of several materials and its performance during construction significantly depends on the properties of these materials, this material is highlighted below:

2.3.1 Cement

The most generally used cement is ordinary Portland cement (OPC), but other additional materials such as pozzolana, silica fume and fly ash can also be included as long as their

acceptance has been proven. Cement is a substance that is used in construction as a binder for bonding mineral fragments into a compact whole. According to the Energy Technology Systems Analysis Programme (ETSAP, 2010), global cement production has grown steadily from less than 200 million tonnes in 1950 to more than 2500 million tonnes in 2006. The manufacture of Portland cement consists of ingredients mainly lime, silica, alumina and iron oxide from limestone and clay/shale which react together on firing to form a series of more complex products.

The relative proportions of these oxide compositions are responsible for influencing the various properties of particular cements; in addition to the rate of cooling and fineness of grading which affects the strength of the cement. In many structural applications, the choice of cement has a lesser influence on the long-term performance of concrete than the practical aspects of mix control, cement content, water content, aggregate quality, and compaction, finishing and curing (Newman and Choo, 2003). There are different types of cements with different properties and performance. BS EN 197-1 (2000) stated that the choice of cement, especially the type and/or strength class, based on the requirements for durability largely depends on the exposure and type of construction in which it is incorporated. The most common type of cement used in construction is the Ordinary Portland Cement (OPC) other types of cement include: Portland composite cement, blast furnace cement, pozzolanic cement, composite cement.

2.3.1.1 Mechanism for Cement Production

The manufacture of OPC involves two stages, notably, clinker production and cement grinding. In the clinker production stage, raw materials are fed to the kiln system to produce clinker. These materials are crushed, grounded and mixed to obtain a homogenous blend. During this process, significant amount of carbon dioxide (CO₂) is released to the atmosphere. Shivaram (2014) stated that producing a tonne of cement will generate approximately a ton of CO₂. This stage ends with the cooling of the clinker in a cooler system. In the second stage, the clinker is grounded with the addition of other minerals to obtain cement with desired properties such as setting time and strength grade. According to Cement Sustainability Initiative/European Cement Research Academy (CSI/ECRA, 2009), the grinding of clinker with additives to produce cement requires only electricity (no heat) and accounts for about 38% of total electricity used. Table 2.0 shows the physical, chemical, and mechanical properties of Portland cement. As can be seen

from the Table, Portland cement contains over 60% of lime (calcium oxide) which makes cement sound and also provides strength to the cement. It is the excess of this lime that reacts with pozzolana in the presence of moisture to produce cementitious properties.

Table 2.0 Physical, Chemical and Mechanical Properties of Ordinary Portland Cement (Salas et al., 2009).

Chemical Composition	Percentage s (%)	Physical Properties	Magnitude or Value	Mineralogical Composition (%)	Percentage s (%)
SiO₂	21.27	Density (kg/m³)	3,050	C₃A	53.29
Al₂O₃	4.63	Blaine Fineness (m²/kg)	377	C₂S	20.79
Fe₂O₃	3.96	Mechanical Properties		C₄AF	12.05
CaO	63.05	Compressive Strength (Mpa)		C₃A	5.56
MgO	1.56	1 day	10.1	Free CaO	0.54
Na₂O	0.16	3 day	23.3		
K₂O	0.18	7 day	36.0		
SO₃	1.75	28 day	46.7		

It is seen that the major products of the hydration reactions, which primarily account for the strength of concrete, are the calcium silicate hydrates (C3S and C2S) that make up most of the hydrated cement (Nawy, 2008). These silicates are the most vital compounds responsible for the strength of hydrated cement paste and are formed from the reactions between the two calcium silicates and water.

2.3.2 Water

In general, potable water is safe for use in concrete. Water containing harmful substances such as salts, silts, suspended particles, organic matter, oil, or sugar cane unfavorably affect the strength

and setting properties of cement and disturb the affinity between aggregate and cement paste (Nawy, 2008). Therefore, the suitability of water should be examined before use. As a rule, any water with silt content below 2000 mg/L is suitable for use in concrete (Shetty, 2005). (Nakhil, et al. 2011), Also state that water plays a vital role in the strength of concrete as it helps in the following areas:

- a) It wets the surface of aggregate as it helps to develop cohesion thereby enabling the cement paste to adhere quickly and satisfactorily to the wet surface of aggregate than to the dry surface.
- b) To prepare a plastic mixture of the various ingredients and to impart workability to concrete so as to facilitate placing in the desired position.
- c) Water is also needed for hydration of the cementing material to set and harden during the period of curing.

2.3.3 Aggregate

Aggregate is a collective term for the mineral materials such as sand, gravel and crushed stone that are used with a binding medium to form concrete. Aggregate may be defined as an inert filler material in concrete. It is a granular material, such as sand, gravel, crushed stone, and iron blast-furnace slag, used with a cementing medium to form a hydraulic cement concrete or mortar (ACI 318, 1995). According to Gambhir (2013), the reasons of using aggregate in the construction of concrete are due to the economic reasons, volume stability and durability of concrete. Aggregates were originally viewed by Troxell et al. (1968) as being inert and dispersed all through the cement paste in concrete, largely due to economic reasons, that is, as a fill material.

Studies have shown that fine and coarse aggregates are very important in concrete because aggregates occupy 60% to 75% of the concrete volume and strongly influence the concrete's freshly mixed and hardened properties, mix proportions, and economy (Quiroga and Fowler, 2004). The vital requirement of an aggregate for concrete is that it remains constant within the concrete (both in the fresh and hardened states) and in any given environment, throughout the design life span of the concrete (Smith and Collis, 2001). Coarse aggregates are materials retained on 5mm (3/16 inches) test sieve and containing only so much finer material as allowed

from the various sizes. Table 2.1, classifies aggregate according to the production method, Petrological characteristics, unit weight, and according to the particle sizes. Depending on the mix design, aggregate may occupy about 70 – 80 percent of the total volume of concrete.

Table 2.1 General Classification of Aggregate (Gambhir, 2013)

No	Classification Type	Examples
1.	Natural Aggregates (no change in their natural state except for crushing, grading, or washing)	Sand, gravel, crushed stone, lime rock.
	By-product aggregates	Blast-furnace slags and cinders, fly ash
	Processed aggregates (heat treated) Colored Aggregate	Perlite, burnt clays, shales, processed fly ash Glass, ceramics, manufactured marble
2.	According to Petrological Characteristics	
	Igneous Rocks	Quartz, granite, basalt, obsidian, pumice, tuff
	Sedimentary Rocks	Sandstone, limestone, shale
	Metamorphic Rocks	Marble, slate, schist
3.	According to Unit Weight	
	Normal Weight Aggregates	Sand, gravel and crushed rock
	Light Weight Aggregates	Slag, slate

	Heavy Weight Aggregates	Hematite, barite magnetite, steel and iron punchings
4.	According to Particle Size	
	Fine Aggregate	Sand
	Coarse Aggregate	Gravel

Generally, fine aggregates include particles that pass through 4.75mm sieve and retain on a 0.075mm sieve such as river sand. Their functions include filling the voids between the coarse aggregate while holding them in suspension, producing workable and uniform concrete mixtures. On the other hand, coarse aggregate are those particles retain on a 4.75mm sieve and use as an inert filler material.

2.3.3.1 Properties of Aggregate

Aggregate possess certain properties, which directly influences the strength of concrete. Some of these properties cannot be measured qualitatively and some indirect measures are taken sometimes. The main properties of aggregates, which may influence the concrete properties, are:

- a) Shape
- b) Texture
- c) Size gradation
- d) Moisture content
- e) Specific gravity
- f) Bulk unit weight
- g) Strength of aggregate
- h) Soundness
- i) Wear resistance
- j) Alkali-aggregate reaction
- k) Impurities
- l) Unsound particles

2.4 Origin and Definition of Laterite

Lateritic soils are highly weathered and altered residual soils formed by the in-situ weathering and decomposition of parent rocks under tropical and subtropical climatic conditions (Aginam, et al 2015). This weathering process primarily involves the continuous chemical alteration of minerals, the release of iron and aluminum oxides and the removal of bases and silica in the rocks. Lateritic soils are void or nearly void of bases primarily silicates, but may contain substantial amount of quartz and kaolinite (Alexander & cady, 1962). They are formed in hot, wet tropical regions with an annual rainfall of at least 1200mm and a daily temperature in excess of 25°C and typically occur in humid tropical climate with 30°N and 30°S of the equator (Madu, 1975). They are also composed entirely of iron and aluminum oxide. They are reddish in colour and are the least soluble of rock weathering in tropical climate (Plummer, et al 2001). Laterite is also described as a product of in-situ weathering in igneous, sedimentary and metamorphic rocks commonly found under unsaturated conditions (Rhardjo, et al 2004). Lateritic soil is one of the most common and important material used in earth work engineering construction in the tropics and subtropics where it is in abundance.

The name laterite was coined by an English surgeon Francis Buchanan in 1807 in India from a Latin word “later” meaning brick. In the 19th century, He coined the term laterite when he wrote “What I have called indurate clay is one of the most valuable materials for building. It is diffused in immense masses without any appearance of stratification and is placed over the granite that forms the bases of Malayala. It is full of cavities and pores and contains a very large quantity of quartz in the form of yellow and red ochres In the masses, while excluded from the air It is so soft, that any iron instrument readily cut it, and it is dug up in square masses with a pick-axe, and immediately cut into shape wanted with a trowel or large knife. It very soon become as hard as brick, and resists the air and water much better than materials made from bricks. The most proper English name would be laterite, from lateritis, the appellation that may be given to it in sciences”. Since then lot of researches have been carried out on laterite and a lot of terms referring to many soil types have been produced. There is a tendency to apply the term to any red soil and rocks in the tropics (Abebaw, 2005). Nearly all kind of rock can be deeply decomposed by action of high rainfall and elevated temperature. The percolating rainwater causes dissolution of primary rock material and a decrease of soluble elements such as sodium, potassium, calcium

and magnesium. As a result, there remain a residual concentration of insoluble element predominantly iron and aluminum. In geosciences, only those weathered products that are most strongly altered geochemically and mineralogically are termed laterite.

2.5 Formation of Laterite

(Tuncer et al, 1987) described the genesis of laterite as the weathering process which involves leaching of silica, formation of colloidal oxide and precipitation of the oxide with increasing crystallinity and dehydration as the soil is weathered. The major processes of weathering are physical, chemical and biological process. The physical weathering is predominant in the dry climate while the extent and rate of chemical weathering is largely controlled by the availability of moisture and temperature (Abebaw, 2005). As the disintegration of underlying rock occurs, the primary element are broken down by the process of physical and chemical weathering to simple ionic form. The silica and bases in the weathered material such as sodium, potassium, calcium and magnesium are washed out by the percolated rain water (verdose water), boxides and hydroxides of sesquioxide are accumulated thereby enriching the soil and giving the soil it's characteristic red colour. This process is termed laterization and it depends on the nature and extent of chemical weathering.

Laterization is the weathering process by which the rock is transformed into laterite. It is a gradual process which must be active for centuries. In tropical countries the “verdose water” is at high temperature and as a result they may contain more carbonic acids, alkaline, carbonates and organic matter. This element explains why rocks that are leached by verdose water are commonly found in tropical countries than in temperate ones. After weathering, dehydration occurs. Dehydration (either partial or complete) alters the composition and distribution of the sesquioxide rich material in a manner which is generally not reversible over wetting (Abebaw, 2005). It leads to the formation of strongly cemented soil with a unique granular soil structure. The topography and drainage of an area also influences the rate of weathering because to some extent, it determines the amount of water available for laterization to occur and the rate at which it moves through the weathering zone. The rate at which weathered material is eroded is also controlled.

2.6 Properties of Laterite

2.6.1 Chemical Properties

(Mallet, 1883) was perhaps the first to introduce the chemical concept for establishing the ferruginous and aluminum nature of lateritic soils. (Fermor, 1990) defined various forms of lateritic soils on the basis of the relative contents of the so-called lateritic constituents (Iron, Aluminum, Titanium, and Manganese) in relation to silica. Also, (Lacroix 1998) divided laterite into: true laterite, silicate laterite, and lateritic clays depending on the relative content of the hydroxides. There are other several attempts by the researchers to classify laterite in terms of their chemical compositions, but (Fox, 1986) has demonstrated that such classification are inadequate, other than in relations to deposits that may be exploited for their mineral content, classification based on chemical composition cannot be used to distinguish between indurate and softer formations.

The high content of the sesquioxides of iron or aluminum relative to other components is a feature of laterite. These essential components are mixed in variable proportions. Some laterite may contain more than 80% of Fe_2O_3 and little of Al_2O_3 , While others may contain up to 60% of Al_2O_3 and a little of Fe_2O_3 . Although alkali and alkaline bases are almost entirely absent in most cases, this is not an absolute criterion. In particular, some ferruginous tropical soils may contain significant amounts of alkaline bases. Combined silica content is low in sesquioxides. This combined silica is predominantly in the form of Kaolinite, the characteristic clay mineral of most tropical formation.

2.6.2 Physical Properties

The physical properties of residual soils, commonly known as the index properties, vary from region to region due to their heterogeneous nature and highly variable degree of weathering controlled by regional climate and topographic conditions, and the nature of bedrock, (Nnadi, 1988). It also varies with the depth of the soil and can be determined by simple laboratory tests. Studies on the effect of weathering on the physical properties of lateritic soil by (Tuncer et al, 1977 and Rahardjo, 2004) have revealed the following;

- a) Pore-size distribution varies with the degree of weathering.
- b) Higher pore volume and larger range of pore-size distribution indicates advancement in the weathering stage.
- c) Soil classification and Atterberg limits do not show any correlation to weathering.
- d) High specific gravity is a good indication of advanced degree of weathering.
- e) Soil aggregation increases with increasing weathering.
- f) Position in the topographical site, and depth of soil in the profile.
- g) Genesis and pedological factors (parent material, climate, vegetation, period of time in which the process have operated).

2.6.3 Plasticity

Textural lateritic soils are very variable and may contain all fractions sizes; boulders, cobbles, gravel, sand, silt, and clay as well as concretionary rocks. The interaction of the soil particles at the micro scale is reflected in the atterberg limits of the soil at micro scale level. Knowledge of the atterberg limits may provide the following information:-

- a) A basis for identification and classification of a given soil texture.
- b) Strength and compressibility characteristics swell potential of the soil or the water holding capacity.

Atterberg limit depends on:

- a) The clay content: plasticity increases with increase in clay content (Piaskowski, 1963).

Nature of soil minerals: only minerals with sheet-like or plate-like structures exhibit plasticity. This is attributed to the high specific surface areas and hence the increased contact in the shaped particles.

b) Chemical composition of the soil environment: the absorptive capacity of the colloidal surface of the actions and water molecules decrease as the ratio of silica to sesquioxides decreases (Baver, 1980).

c) Nature of exchangeable actions: this has a considerable influence upon the soil plasticity (Hough, 19

Pre-test preparation, degree of molding and time of mixing, dry and re-wetting, and irreversible changes may affect the plasticity of soil. Drying drives off absorbed water, which is not

completely regained, on re-wetting (Fookes, 1997). Studies on the relationship between the natural moisture content, liquid limits and plastic limits of laterite have shown that generally the natural moisture contents is less than the plastic limit in normal lateritic soils (Vargas, 1953). However, the lateritic soil from high rain fall areas may have moisture contents as high as the liquid limit (Hirashima, 1979).

2.6.4 Particle Size Distribution

Consequently great importance has also been accorded to particle-size distribution in dealing with lateritic soils. Recent studies have revealed that lateritic soils are strikingly different from temperate zone soils in terms of genesis and structure. Their concretionary structure as compared to the dispersed temperate zone soils has necessitated modifications to mechanical or grading tests (Remillion, 1967; 1955). Consistent reports of variations in the particle-size distribution with methods of pretreatment and testing have been widely reported on laterite soils. Schofield (1957) found out that wet sieving increased the silt and clay fraction from 7 to 20% as compared to the dry sieving. It has been found that sodium hexametaphosphate generally gives better dispersion of the fine fractions. It was also found, for example, that using sodium oxalate on a halloysitic clay from Kenya gave between 20 and 30% clay fraction, while the sodium hexametaphosphate gave as high as between 40 to 50% clay fraction for the same soil (Quinones, 1963).

Another factor which has been found to affect the sedimentation test is the method of drying. Oven-dried lateritic soils were found to give the least amount of clay fraction, as compared to air-dried (Mohr and Mazhar, 1969). The decrease in the clay content was accompanied by an increase in silt and sand fraction contents as a result of the cementation and coagulation of the clay particles by free iron oxide into clusters (Terzaghi, 1958). The variation in the grading of lateritic gravels with the method of manipulation is also widely reported (Novais-Ferreira and Correia 1965 and Nascimento et al., 1959). In the study of the particle-size distribution of lateritic soils, three sources of confusion were noted. The first confusion arises from the belief by some authors, e.g. Bawa (1957), opined that lateritic soils represent a group of materials that can be defined within a specific range of particle-size distribution. The second source of confusion seems to arise out of attempts by some authors to confine the word laterite to concretionary lateritic gravels. The third source of confusion arises out of the attachment of unnecessary

importance to the soil colour. (Nascimento et al. 1959) have suggested an interesting lithological classification of lateritic soils as follows:

Lateritic clays <0.002 mm

Lateritic silts $=0.002 - 0.06$ mm

Lateritic sands $\sim 0.06 - 2$ mm

Lateritic gravel $=2 - 60$ mm

Laterite stones and cuirasse ≥ 60 mm

Studies on lateritic gravels by de Graft-Johnson et al. (1969) among others have shown that the grading, though important for identification purposes, cannot alone form the basis for grouping lateritic gravels in terms of mechanical properties. The strength of the aggregates was found to be an important factor. Studies of lateritic aggregates in Nigeria, has also established that the strength of the aggregates is mainly a function of the degree of maturity of the lateritic concretionary particles and the predominant sesquioxide in the aggregates (Novais-Ferreira et al).

2.6.5 Compaction Characteristics

The compaction characteristics of lateritic soils are determined by their grading characteristics and plasticity of fines. Most lateritic soils contain a mixture of quartz and concretionary coarse particles, which may vary from very hard to very soft. The strength of these particles has major implications in terms of field and laboratory compaction results and their subsequent performance in civil engineering construction projects. Placement variables (moisture content, amount of compaction, and type of compaction efforts) also influence the compaction characteristics. Varying each of these placement variables has an effect on permeability, compressibility, strength and stress-strain characteristics of the soil.

2.6.7 Shear Strength Characteristics

Shear strength is a term used in soil mechanics to describe the magnitude of the shear stress that a soil can sustain. The shear strength of a lateritic soil is a function of the friction and interlocking of particles (soil angle of internal friction) and possibly cementation or bonding at

particle contact relative to total and effective stress. Due to cohesion, particulate materials may expand or contract in volume as it is subject to shear strains. If soil expands in volume, the density of particles will decrease and the strength will decrease likewise the shear strength.

The cohesion is attributable to the resultant of inter particle forces which are mainly associated with the clay-size particle of soils and will vary with the particle size and the distance separating them. The angle of internal friction included the effect of interlocking. The interlocking effect is affected to some degree by the shape of particles and the grain-size distribution. The two parameters cohesion (c) and angle of friction (ϕ) depends on the grading, particle shape and void ratio factors of the soil. Cohesion also depends on degree of saturation, while angle of internal friction does not (Gidigasu, 1976).

The shear strength characteristics of lateritic soils have been found to depend significantly on the parent materials, and the degree of weathering which in turn depends on the position of the sample in the soil profile and compositional factors as well as the pretest preparation of the samples (Lohnes et al., 1971).

2.6.7 Specific Gravity

The available data indicate that specific gravities vary not only with the textural soil groups but also within different fractions. In the first place lateritic soils have been found to have very high specific gravities of between 2.6 to 3.4 (de Graft-Johnson and Bhatia, 1969). For the same soil, gravel fractions were found to have higher specific gravities than fine fractions due to the concentration of iron oxide in the gravel fraction. While alumina is concentrated in the silt and clay fractions (Nascimento et al., 1959; Novais-Ferreira and Correia, 1965). It is common to find specific gravities reported for the gravel and fines separately. The average of the two values can be assumed to be more representative of the specific gravity for the whole soil.

2.6.8 Compressibility and Consolidation

When a soil mass is subjected to a compressive force, its volume decreases. The property of the soil due to which it decrease in volume occurs under compressive force is known as the compressibility of soil. The compression of soil can occur due to;

- a) Compression of solid particles and water in the void

- b) Compression and expulsion of air in the void
- c) Expulsion of water in the voids

The compression of saturated soil under a steady static pressure is known as consolidation. It is entirely due to expulsion of water from the voids. The consolidation characteristics of lateritic soils is generally moderate with the modulus of compressibility ranging between 1×10^{-3} to 1×10^{-2} sq. ft./ton.

2.7 Laterized Concrete

Laterized concrete is defined as concrete in which stable laterite fine replaces fine aggregate (Sand) Salau, (2008). Adepegba was identified as the first to study the effect of using laterite as fine aggregate in concrete (Olugbenga, 2017). This was supported by Salau, (2008) when he asserted that “Adepegba (1975) recommended up to 40% laterite in clay for laterized concrete. In a further research by Adepegba, (1977) compared resistance to high temperature, modulus of elasticity and compressive and tensile strength of laterized concrete mixes (1:2:4; 1:1.5:3 and 1:1:2 by weight) with that of normal concrete. It was deduced that for high strength and workability, only 25% of sand in concrete should be substituted with lateritic fine, while the mix ratio should be 1:1.5:3 (cement: sand/laterite: granite) with a water/cement ratio of 0.65.

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. It is readily available in all parts of Nigeria.

Working on shrinkage deformations of laterized concrete, Salau and Balogun, (1998) recommended that laterized concrete with up to 25% laterite content of the aggregate could be used in load-bearing structural elements. It was also found out in another work by Balogun and Adepegba, (1982) that the most suitable mix for structural application of laterized concrete was 1:1.5:3 with about 0.65 water/cement ratio provided that the percentage of laterite content was kept below 50%. They asserted also that compressive strength of not less than 25N/mm^2 was obtained at 28days for the mix with laterite content of about 25-50%. A combination of crushed granite, sharp sand and fine laterite was used in their experiment.

The quest of having concrete which is cheaper has prompted many researchers to work on laterized concrete. Different properties of laterized concrete have been considered at different stages with far reaching recommendations in favour of laterite as suitable for use in the construction industry. This study will therefore investigate the recommendation of laterite as an effective stabilizer for partial replacement of fine aggregate in concrete.

2.7.1 Review of Past works on Laterized Concrete

Udoeyo et al, (2006) carried out an experimental investigation on some characteristics of concrete containing laterite as partial or full replacement of fine aggregate. Test results showed that concrete with 40% replacement of sand with laterite could attain design strength of 20N/mm². This fact is reinforced in the comparative study of strength properties of unreinforced and fibre reinforced normal and laterized concrete by Ikponmwoosa and Falade (2006). Test results showed that strength increases with age of the test specimens. Also, laterite replacing sharp sand in concrete up to 45% produced the highest compressive strength.

Ayangade et al (2009) took the study to a new dimension when they evaluated the effects of different curing methods on the compressive strength of terracrete (Granite and laterite). Sixty cubes of 100 x 100 x 100mm using a mix of 1:1½:3, water/cement ratio of 0.62 were cast and cured using four different methods of curing for up to 35 days. Test results of the various compressive strengths of the cubes showed that out of the four curing methods, open method produced cubes with the highest compressive strength of 10.3N/mm² at 35 days of curing. Still, in the same vein to ascertain the strength properties of laterized concrete, Udoeyo et al, (2010) studied early prediction of laterized concrete strength by accelerated testing using the boiling water of accelerated strength testing to predict the 28 day compressive strength of laterized concrete; results revealed that the accelerated strength of the concrete was between 72% and 84% of its 28 days strength.

Efe and Salau, (2010) showed that normal concrete cannot withstand appreciable load above 250°C while laterised concrete with 25% laterite in the fine aggregate being able to resist higher load with increase in age and at temperature up to 500°C. Compressive strength of up to 30.44N/mm² was achieved for laterized concrete with 25% laterite and 75% sand at 500°C.

According Efe and Salau, (2010) can be classified as normal weight concrete as the density of all test specimens of 28-day curing age exceeds 2000Kg/m³. They also observed that there is

economic saving if laterized concrete is used in areas of high temperature up to 500°C. This differs from the findings of Udoeyo et al., (2010) where the strengths of laterized concrete and normal concrete decreased in a similar manner when subjected to elevated temperatures of between 200°C and 600°C.

Lanre and Mnse (2007) advanced the investigation further when they 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 revealed that the compressive strength of the treated laterized concrete decreases when subjected to alternate wetting and drying. The specimens conditioned to a temperature range of 75 – 125°C attained compressive strength as high as 22.52N/mm². However, the study could not ascertain the critical failure temperatures.

In view of previous studies conducted on concrete produced with partial replacement of sand with laterite, this study will extensively investigate the strength characteristics of concrete produced with partial replacement of fine aggregate (sand) with laterite. The fine aggregate (sand) will be partially replaced with concrete in a stepped increase of 5% starting from 0% to 25% by dry weight of sand.

CHAPTER THREE

MATERIALS AND METHOD

This section will review the materials, process of collection, conveyance and preservation and also relevant laboratory testing to be performed on the materials. Some of the materials required for this research work are fine aggregate (river sand) designated as SD, Coarse aggregate (granite) designated as GT, additive (laterite) designated as LAT, ordinary Portland cement designated as OPC and water. The mode of collection and preparation of these materials are discussed below:

3.1 Materials

3.1.1 Cement

The ordinary Portland cement designated as OPC used for this experiment is Dangote cement. The cement was obtained from a local distributor at Awka in Anambra State. Upon purchase, the cement was conveyed to school laboratory where it was kept in a cool dry place preparatory for various laboratory testing. The cement sample satisfy the requirement for use as one of the major component of concrete in that, it was not caked or baked through visual inspection and quick setting time.



Plate 3.0: Portland cement used for the Experimental Study

3.1.2 Fine Aggregate (Sand)

Natural river sand used in producing the concrete was collected from a construction site at Nnamdi Azikiwe university campus in Awka, Anambra State. The sand sample was collected in two cement bags with the aid of shovel. The sand sample after collection was conveyed to the school laboratory for various testing. The sand was Sieved on a 5.0mm test sieve to remove larger particles and then air-dried to a saturated state of an aggregate. The sample passed the necessary requirement for use as ingredient of concrete based on the fact that it is gritty with particle sizes visible to the naked eyes. The fine aggregate used for the study will be partially replaced with laterite sample

3.1.3 Coarse Aggregate (Granite)

The granite samples designated as GT was procured from a building material vendor in Awka Anambra State. The granite sample passed all the necessary physical test in that, it has high crushing strength, it is relatively large in size (within range of 4.75mm to 20mm) and is a representative of granite (chippings) in color. The granite was collected in two cement bag and was conveyed to the school laboratory via public transport.



Plate 3.1: Coarse Aggregate used for the Study

3.1.4 Water

The water sample used for this experiment was collected from Civil Engineering Laboratory in Nnamdi Azikiwe University Awka Anambra State. The sample passed all the necessary requirement for use as ingredient of concrete based on the fact that it is colorless, devoid of suspended solid particles, contains infinitesimal trace of dissolved solid particles with no trace of turbidity after being subjected to laboratory testing. The water was collected in three gallons (25 litre each).

3.1.5 Laterite

The laterite samples designated as LAT was obtained from borrow pits at Garki-Ugwuoba in Enugu State. The choice of sites is justified by the fact that it is a borrow pits from where construction companies obtain their materials for road construction .The laterite sample was collected with the aid of a digger and a shovel at a depth of 300mm (1 foot) .The samples passed all the physical test that could classify them as lateritic soils in that, it is reddish-brown in colour, fine grained in texture and could become hard during the dry season. These samples were collected in four cement bags each and were conveyed via public transport to the school laboratory for various laboratory testing. The in-situ moisture content of the sample was determined using oven-dried method before air-drying for a period of two weeks in an open area using corrugated roofing sheets (commonly known as zinc) so as to ensure complete and even dissipation of moisture from the samples (i.e. zero moisture content).

The fine aggregate (sand) used for the experimental study will be partially replaced with laterite in a stepped increase of 5% starting from 0% to 25% by dry weight of sand.

3.2 Laboratory Investigation

3.2.1 Particle Size Distribution

Sieve analysis is a procedure used to assess the particle size distribution of a granular material (sand, gravel). The size distribution is often of critical importance to the behaviour of the material during use. Sieve analysis can performed on any type of non-organic or organic granular material including sand, crushed rock, clay, granite, feldspar and a wide range of manufactured powders, grains and seed down to minimum size depending on the exact method. The standard

grain size analysis test determines the relative proportion of different grain sizes as they are distributed among certain size ranges.

Soil posses a number of physical characteristics which can be used as aid to identify it sizes in the field. A handful of soil rubbed through the finger can yield the following:

1. Sand and other coarser particle are visible to the naked eye.
2. Silt particle becomes dusty and are easily brushed off.
3. Clay particle are greasy and sticky when wet and hard when dry and have to be scrapped or washed off hand and boot

For a soil to be well graded the value of coefficient of uniformity (C_u) has to be greater than 4 and 6 for gravel and sand respectively, while the Coefficient of Curvature (C_v) should be in the range of 1 to 3.

The apparatus needed for this experiment is listed below:

1. Stack of sieves including pan and cover.
2. Mechanical sieve shaker.
3. Weighing balance of 0.01g sensitivity.
4. Hand brush
5. Mortar and pestle (Used for crushing if the sample is conglomerated or lumped)
6. Thermostatically controlled Oven (With temperature of about 80°C-110°C).
7. Masking tape for identification of sample.
8. Exercise book and pen for recording of result.
9. The calculation for attaining Coefficient of uniformity and Coefficient of curvature are outlined below.

$$\text{Percentage retained (\%)} = \frac{\text{mass of soil retained \textit{e}t h e sieve (g)}}{\text{total mass of soil sample (g)}} \times 100$$

$$\text{Cumulative percentage retained} = \sum \text{Percentage retained (\%)}$$

$$\text{Cumulative Percentage Finer (\%)} = 100 - \text{Cummulative percentage retained.}$$

$$\text{Coefficient of Curvature} = \frac{D_{60}}{D_{10}^2}$$

$$\text{Coefficient of Uniformity} = \frac{(D_{30})^2}{D_{10} \times D_{60}}$$

Where

D₁₀= particle size such that 10% of the soil is finer than the size

D₃₀= particle size such that 30% of the soil is finer than the size.

D₆₀= particle size such that 60% of the soil is finer than the size.



Plate 3.2: Apparatus for Particle Size Distribution Test (Sieve Analysis).



Plate 3.3: Apparatus for Particle Size Distribution Test.

Test Procedure

1. Clean properly the stack of sieves to be used for the experiment using hand brush.
2. Weigh about 500g of air-dried soil sample on a weighing balance.
3. Pour the weighed soil sample into 75 μ m sieve and wash under a steady supply of water until clear water start coming out from the sieve after passing through the soil sample.
4. After washing pour the washed soil sample into a pre-weighed plate and dry it inside the thermostatically controlled oven at a controlled temperature of 80-110°C for 16-24hrs.
5. Remove the sample from the oven and determine its weight (net weight) by deducting the weight of plate from the weight of plate and soil.
6. Arrange the stacks of sieve in the ascending order, place in a mechanical sieve shaker, and thereafter pour the sample and connect the shaker for about 10-15 minute.
7. Disconnect the sieve shaker and determine the mass retained on each of the sieve sizes.
8. Determine the percentage retained, Cumulative percentage retained and Cumulative percentage finer.
9. Plot the graph of sieve Cumulative percentage finer against sieve sizes.
10. Determine D₁₀, D₃₀ and D₆₀ from the plotted graph.
11. Determine the Coefficient of Curvature and Coefficient of Uniformity and classify the soil using the American Association of State Highway and Transportation Official (AASHTO) and Unified Soil Classification System (USCS) respectively.



Plate 3.4: Weighing of Mass Retained on Different Sieve Sizes



Plate 3.5: Recording of Mass Retained on Different Sieve Sizes

3.2.2 Specific Gravity of Fine Aggregate (Sand) and Laterite

Specific gravity is the ratio of mass of unit volume of soil at a stated temperature to mass of equal volume of gas-free distilled water at the same temperature (Krishna, 2002). Also as defined

by (Braja, 2006), Specific gravity can be defined as the ratio of unit weight of a material to unit weight of water. The specific gravity of soil solids is often needed for various calculations in soil mechanics. It can be determined accurately in the soil laboratory.

The apparatus employed for this experiment includes:

1. Density bottle of 50ml capacity and a stopper.
2. Desiccator containing anhydrous silica gel.
3. Thermostatically controlled oven with temperature of about 80-110°C.
4. Weighing balance of 0.01g sensitivity.
5. Mantle heater.
6. Plastic wash bottle.
7. Distilled water.
8. Funnel
9. Thin glass rod for stirring.
10. 425um Sieve.
11. Dry piece of cloth for cleaning.
12. Masking tape for identification of sample.
13. Exercise book and pen for recording of result.

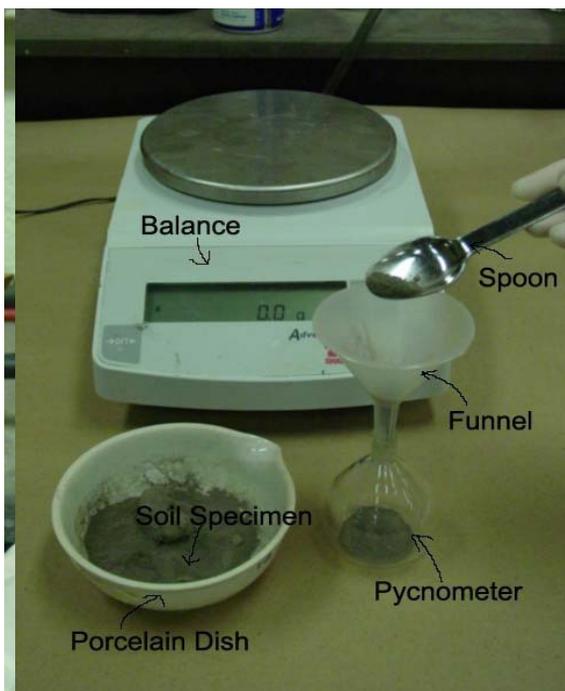


Plate 3.6: Apparatus used for Specific Gravity Test.

3.2.3 Specific Gravity Test for Coarse Aggregate (Granite).

The specific gravity of aggregate is defined as the ratio of aggregate to the weight of equal volume of water. The specific gravity of an aggregate is considered to be a measure of strength or quality of the material. Aggregate having low specific gravity is generally weaker than those with high specific gravity. This property helps in general identification of aggregate.

Apparatus Employed.

1. Wire mesh Bucket or perforated container of convenient sizes with thin wire hangers for suspending it from a balance.
2. Pycnometer of 1000ml.
3. Set up consisting of container for filling water and suspending the wire basket in it and airtight container of capacity similar to that of a bucket, a shallow tray, two dry absorbent clothes.

Test Procedure

1. About 2 kg of aggregate sample is taken, washed to remove fines and then placed in the wire basket. The wire basket is then immersed in water, which is at a temperature of 22°C to 32°C.
2. Immediately after immersion the entrapped air is removed from the sample by lifting the basket 2mm above the base of the tank and allowing it to drop, 25 times at a rate of about one drop per second.
3. The basket, with aggregate are kept completely immersed in water for a period of 24 ± 0.5 hour.
4. The basket and aggregate are weighed while suspended in water, which is at a temperature of 22°C to 32°C.
5. The basket and aggregates are removed from water and dried with dry absorbent cloth.
6. The surface dried aggregates are also weighed.

7. The aggregate is placed in a shallow tray and heated to about 110°C in the oven for 24 hours. Later, it is cooled in an airtight container and weighed.

3.2.4 Atterberg Limit Test

The behavior of soils especially fine grained soils differs considerably in the presence of water. Clay in the presence of water may almost take a liquid or can be quite hard. Consistency is the property of soil that offers resistance to deformation, it denote the degree of firmness of a soil and can be explained in terms of plasticity and stickiness of soil. Stickiness is the ability of soil especially fine grained soil to adhere to other materials while plasticity on the other hand is the ability of soils to undergo a change in shape under the action of an impressed force without a change in volume.

The atterberg limit is a limit characterized by visible transition of soil (especially fine grained soils) from liquid-plastic-semi-solid-solid state consequent upon the variation of moisture content. This test was developed by Albert Atterberg a Swedish agricultural scientist in 1911. This test is divided into three limits namely:

1. Liquid Limit (LL)
2. Plastic Limit (PL)

Shrinkage Limit

3.2.4.1 Liquid Limit

It is the water content at which the soil has a small shear strength that it flows to close a groove of standard width when jarred in a specified manner. It is the minimum water content at which the soil tends to flow like a liquid. When a soil is mixed with an excessive amount of water, it will be in a liquid state and flow like a viscous liquid. When the viscous liquid dries gradually due to loss of moisture it will pass into a plastic state. With further loss of moisture, the soil will pass into a semi-solid state. With even further reduction of moisture, the soil will pass into a solid state. The moisture content (%) at which a cohesive soil will pass from liquid state to plastic state is referred to as the liquid limit of the soil.

The apparatus used for liquid limit determination is outlined below:

1. Liquid limit device (Cassagrande type)
2. Grooving tool
3. Moisture content tins
4. Porcelain evaporating dish
5. Spatula or pellet knife
6. Thermostatically controlled oven
7. Weighing balance sensitive to 0.01g
8. Plastic wash bottle containing distilled water
9. Paper towels
10. Masking tape for identification of tin.
11. Exercise book and pen for recording of data
12. 425um Sieve
13. Airtight container

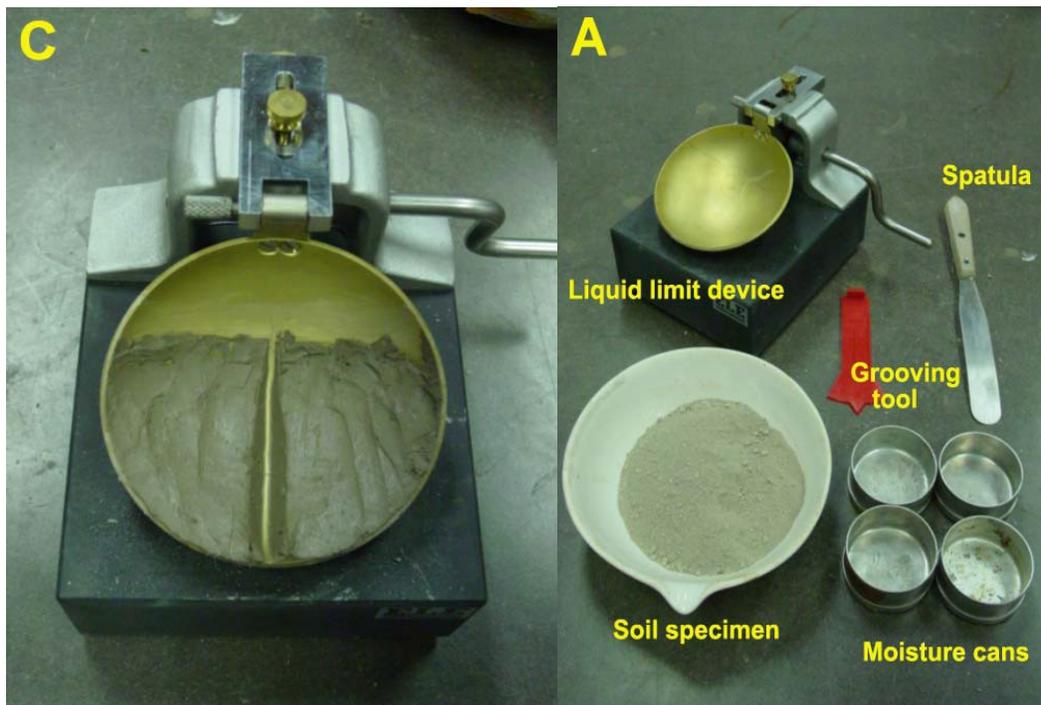


Plate 3.7: Apparatus for Liquid and Plastic Limit Test

Test Procedure

1. Prepare the sample by weighing about 150g of soil passing through 425um sieve, mix the sample with distilled water in a glass plate mixing with pellet knife, remove any coarse particle by hand and mix to form a thick homogenous paste, place the mixed soil in an airtight container and leave to mature for 24hrs.
2. Determine the mass of four moisture content tins say (W_1)
3. Place the matured sample on an evaporating dish and add little water using the plastic squeeze bottle, mix the soil properly to ensure uniform distribution of moisture.
4. Place a portion of the paste (mixed soil) on the liquid limit device and level the mixture so as to obtain a maximum depth of 1cm.
5. Using the grooving tool, cut a groove along the symmetrical axis of the cup holding the tool perpendicular to the cup.
6. Turn the crank or rotate the handle of the liquid limit device at the rate of 2 revolution per second and count the no of blows required to close the groove at a distance of 13mm. Closing of the groove should be as a result of plastic flow of the soil and not by sliding, if sliding occurs repeat the test.
7. Take about 10g of soil in the closed groove and put in the moisture content tins for moisture content determination, weigh the sample say (W_2)
8. Remove the rest of the soil in the cup and use paper towel to clean the cassagrande cup.
9. Alter the water content of the soil and the repeat the process to get the no of blows in the range of 15-40 blows.
10. Plot the graph of moisture content against the log of no of blows, the moisture content corresponding to 25 blows on the abscissa gives the value of the liquid limit.

The Procedure employed for the Computation of the Result obtained is as Follows:

$$\text{Moisture content} = \frac{\text{Weight of water}}{\text{weight of dry soil}} \times 100 = \frac{W_2 - W_3}{W_3 - W_1} \times 100$$

Where W_1 = Weight of empty tin.

W_2 = Weight of tin + wet soil.

W_3 = Weight of tin + oven-dried



Plate 3.8: Rotating of Casagrande Device Handle for Liquid Limit Determination



Plate 3.9: Adjustment of Casagrande Device for Liquid Limit Determination

3.2.4.2 Plastic Limit Test

The plastic limit of a soil is the moisture content expressed as a percentage of the weight of oven-dried soil at the boundary between the plastic and the semi-solid state of consistency. It is the moisture content at which a soil will just begin to crumble when rolled into a uniform 3mm

diameter thread using a glass plate or other recommended surface for rolling. Soil used for Atterberg limit test can be classified based on the plasticity index of the soil. The plasticity index is the amount of water required to change a soil from its plastic limit to liquid limit, in other word it is the numerical difference between the liquid limit and the plastic limit of soil. Table 3.2 is used to classify soil based on the ranges of it plasticity index.

Table: 3.1 Plasticity Ratings for Fine grained Soil (Braja, M.Das, 2002).

Plasticity Index	Plasticity
0	Non-Plasticity
<7	Low Plasticity
7-17	Medium Plasticity
17-35	High Plasticity
>35	Very High Plasticity

The apparatus used for this experiment includes:

1. A smooth glass plate about 300mm square and 10mm thick.
2. A palette knife or spatula
3. A short length of 3mm metal rod
4. Moisture content tins
5. Plastic squeeze bottle
6. Weighing balance with 0.01g sensitivity
7. Veneer caliper
8. Masking tape for tin identification
9. Exercise book and pen for recording of result.

Test Procedure

1. Prepare the sample by the method described in the liquid limit using the sample passing 425um sieve.
2. Identify and weigh the empty moisture content tins say (W1).

3. Take about 20g of the prepared soil paste on a porcelain evaporating dish, add water from the plastic squeeze bottle and mix thoroughly until the paste is plastic enough to be rolled into a ball.
4. Take a portion of the ball and roll it on a glass plate with the palm of the hand into a thread of uniform diameter throughout its length by rolling forward and backward.
5. Continue rolling and remolding until the thread just start to crack at a distance of 3mm.
6. Collect the small crumbed pieces, place in a moisture content tin and weigh say (W₂).
7. Place the tin in the oven at a constant temperature of 80-110°C for a period of 16-24hrs.
8. After 24hrs, remove the tin from the oven and determine the weight of the dry soil plus the tin say (W₃).
9. Repeat the test for at least two trials and take the average plastic limit value for all the trials.

The Computation for Plastic Limit is as follows:

$$\text{Plastic limit} = \frac{\text{Weight of water}}{\text{Weight of oven-dried soil}} \times 100 = \frac{W_2 - W_3}{W_3 - W_1} \times 100$$

Where W₁ = Weight of empty tins.

W₂ = Weight of tin plus wet soil

W₃ = Weight of tin plus oven-dried soil

3.2.5 Slump (Workability) Test

Slump test is used to determine the workability or consistency of concrete mix prepared at the laboratory or the construction site during the progress of the work.

The procedures are as follows:

1. Clean the internal surface of the mold and apply oil.
2. Place the mold on a smooth horizontal non-porous base plate.
3. Fill the mold with the prepared concrete mix in 4 approximately equal layers.

4. Tamp each layer with 25 strokes of the rounded end of the tamping rod in a uniform manner over the cross section of the mold. For the subsequent layers, the tamping should penetrate into the underlying layer.
5. Remove the excess concrete and level the surface with a trowel.
6. Clean away the mortar or water leaked out between the mold and the base plate.
7. Raise the mold from the concrete immediately and slowly in vertical direction.
8. Measure the slump as the difference between the height of the mold and that of height point of the specimen being tested.

Calculation

Slump = Height of the slump cone – Height of the unsupported concrete

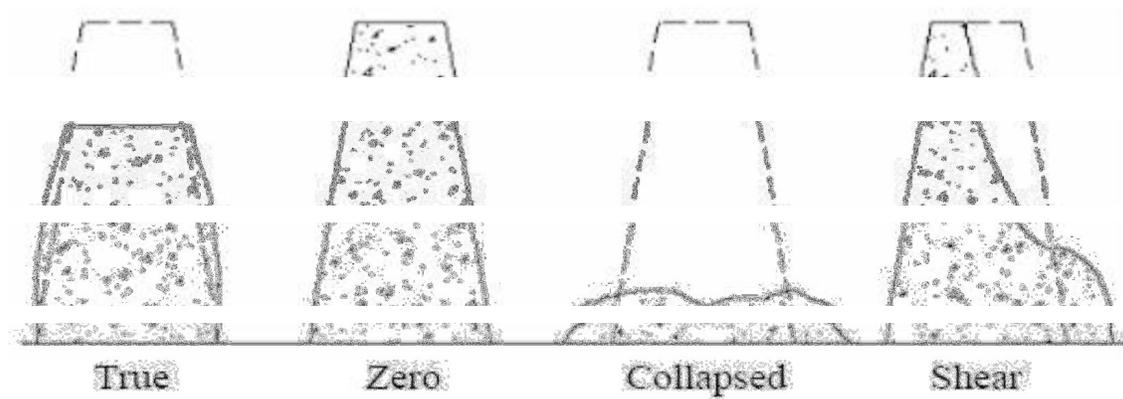


Figure 3.0: Types of Concrete Slump Test Results.

- a) **True Slump** – True slump is the only slump that can be measured in the test. The measurement is taken between the top of the cone and the top of the concrete after the cone has been removed as shown above. In a true concrete just subsides shortly and more or less maintain the mould shape. This type of slump is most desirable and represents the reliable condition to get an idea about the workability of concrete.

- b) **Zero Slump** – Zero slump is the indication of very low water-cement ratio, which results in dry mixes. This type of concrete is generally used for road construction. In this slump, the concrete maintains the actual shape of the mould as it is said to be stiff, consistent and almost non-workable.
- c) **Collapsed Slump** – In the case, fresh concrete collapses completely. This is an indication that the water-cement ratio is too high, i.e. concrete mix is too wet or it is a high workability mix, for which a slump test is not appropriate.
- d) **Shear Slump** – In this case, one-half of the cone slide down in an inclined plane, this slump indicates lack of cohesion in the concrete mix. Shear slump may occur in case of a harsh mix.



Plate 3.10: Apparatus used for Slump Test

3.2.6 Compressive Strength of Hardened Laterized Concrete

The test method covers determination of compressive strength of cubic concrete specimens. It consists of applying a compressive axial load to molded cubes at a rate which is within a prescribed range until failure occurs.

The Apparatus Used includes:

1. **Testing Machine** - The testing machine may be of any reliable type, of sufficient capacity for the tests and capable of applying the load at the rate specified in 5.5. The permissible error shall be not greater than ± 2 percent of the maximum load.
2. **Cube Moulds** - The mould shall be of 150 mm size conforming to IS: 10086-1982.
3. Weights and weighing device
4. Tools and containers for mixing,
5. Tamper (square in cross section)

Test Procedure

1. **Sampling of Materials** - Samples of aggregates for each batch of concrete shall be of the desired grading and shall be in an air-dried condition. The cement samples, on arrival at the laboratory, shall be thoroughly mixed dry either by hand or in a suitable mixer in such a manner as to ensure the greatest possible blending and uniformity in the material.
2. **Proportioning** - The proportions of the materials, including water, in concrete mixes used for determining the suitability of the materials available, shall be similar in all respects to those to be employed in the work.
3. **Weighing** - The quantities of cement, each size of aggregate, and water for each batch shall be determined by weight, to an accuracy of 0.1 percent of the total weight of the batch.
4. **Mixing Concrete** - The concrete shall be mixed by hand, or preferably, in a laboratory batch mixer, in such a manner as to avoid loss of water or other materials. Each batch of concrete shall be of such a size as to leave about 10 percent excess after moulding the desired number of test specimens.
5. **Mould** - Test specimens cubical in shape shall be $15 \times 15 \times 15$ cm. If the largest nominal size of the aggregate does not exceed 2 cm, 10 cm cubes may be used as an alternative. Cylindrical test specimens shall have a length equal to twice the diameter.

6. Compacting - The test specimens shall be made as soon as practicable after mixing, and in such a way as to produce full compaction of the concrete with neither segregation nor excessive laitance.

7. Curing - The test specimens shall be stored in a place, free from vibration, in moist air of at least 90 percent relative humidity and at a temperature of $27^{\circ} \pm 2^{\circ} \text{C}$ for 24 hours $\pm \frac{1}{2}$ hour from the time of addition of water to the dry ingredients.

8. Placing the Specimen in the Testing Machine - The bearing surfaces of the testing machine shall be wiped clean and any loose sand or other material removed from the surfaces of the specimen which are to be in contact with the compression plates.

9. In the case of cubes, the specimen shall be placed in the machine in such a manner that the load shall be applied to opposite sides of the cubes as cast, that is, not to the top and bottom

10. The axis of the specimen shall be carefully aligned with the centre of thrust of the spherically seated platen. No packing shall be used between the faces of the test specimen and the steel platen of the testing machine.

11. The load shall be applied without shock and increased continuously at a rate of approximately 140 kg/sq cm/min until the resistance of the specimen to the increasing load breaks down and no greater load can be sustained.

12. The maximum load applied to the specimen shall then be recorded and the appearance of the concrete and any unusual features in the type of failure shall be noted.

The compressive strength of concrete cube is computed as follows:

$$\text{Compressive Strength (N/mm}^2\text{)} = \frac{\text{Applied load (N)}}{\text{Area of Cube (mm} \times \text{mm)}}$$

Where applied load (N) = Force

Now conversion of applied load from Ton force to KN or N.

1 Ton force = 10kN or 10,000N.

For 220kN = $220 \times 1000 = 220,000\text{N}$

Area of cube = $150\text{mm} \times 150\text{mm} = 22,500\text{mm}^2$

$$\text{Compressive Strength} = \frac{220,000 \text{ N}}{22,500 \text{ mm}^2} = 9.78\text{N/mm}^2$$



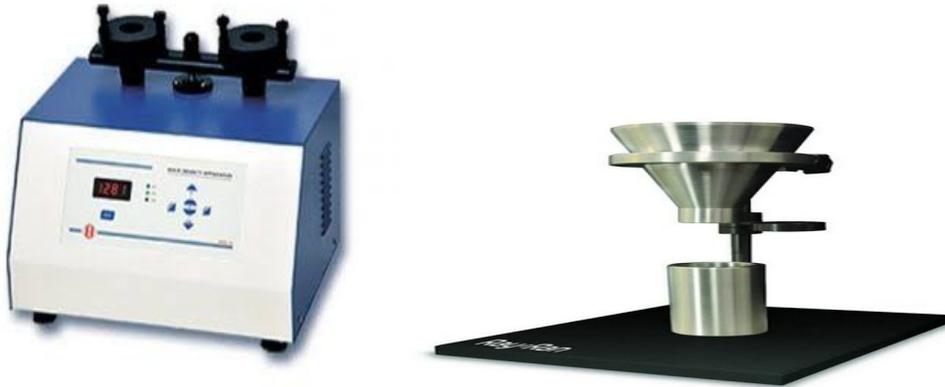
Plate 3.11: Compression Testing Machine.

3.2.7 Bulk Density of Aggregate

Bulk density is an indicator of soil compaction (USDA, 2019). It affects infiltration, rooting depth, water capacity and porosity of aggregate. Bulk density of aggregate is the loosed and compacted weight of aggregate per unit of volume at field moisture capacity or at specified moisture content (USDA, 2019). It typically is expressed as kilogram per cubic meter (kg/m^3). It is a composition of aggregate loosed and compacted density.

Apparatus Employed

- 1 Weighing balance sensitive to 0.5% by weight of material.
- 2 Metallic cylinder of 3 litre capacity for fine aggregate and 15 litre capacity for coarse aggregate up to 40mm in size.
- 3 Tamping rod of 16mm diameter and 60cm long.



■ |
Plate 3.12: Apparatus used for Bulk Density Test



Plate 3.13: Apparatus used for Bulk Density Test

Test Procedure for Compacted Bulk Density of Aggregate

- 1 The volume of the metallic cylinder was measured by pouring water into it and recording its volume (litres).
- 2 The metallic cylinder were filled with aggregate about one-third of its volume and tamped 25 times using a tamping rod.
- 3 Another layer of about one-third the volume of the cylinder was added and equally tamped for 25 times with adequate care exercised to ensure even distribution of blows at the top surface of the cylinder.
- 4 The metallic cylinder heaped with aggregate above the top surface and tamped evenly for another 25 times.
- 5 The surplus aggregate was removed using the tamping rod as a straight edge such that the top surface of the metallic cylinder flushes with the aggregate.
- 6 The weight of the compacted aggregate was determined and recorded in kg.

Computation of Aggregate Compacted Density

Compacted unit weight or bulk density = W/V

Where,

W = Weight of compacted aggregate in cylindrical metal measure, kg

V = Volume of cylindrical metal measure, litre

Test Procedure for Aggregate Loosed Density

- 1 The volume of the metallic cylinder was measured by pouring water into it and recording its volume (litres).
- 2 The metallic cylinder was filled with aggregate to overflowing by means of a shovel and the aggregate being discharged from a height not exceeding 5cm above the top of the cylinder.
- 3 The top surface of the metallic cylinder was leveled using a straight edge.
- 4 The weight of the aggregate was determined and recorded in kg.

Computation of Aggregate Loosed Density

Compacted unit weight or bulk density = W/V

Where,

W = Weight of loosed aggregate in cylindrical metal measure, kg

V = Volume of cylindrical metal measure, litre

CHAPTER FOUR
RESULTS AND DISCUSSION

During the course of the experimental study, certain results were obtained which was valuable in evaluating the strength properties of concrete containing laterite as partial replacement of fine aggregate. These results are presented in Table 4.1 below.

4.1 Results

Table 4.1: Physical Properties of Concrete Components Employed in the Research

Properties	GT	SD	LAT
Specific Gravity	2.61	2.55	2.66
Compacted Density (kg/m³)	-----	1523.33	1487
Loosed Density (kg/m³)		1133.33	1366.67
Liquid Limit (%)	-----	-----	42.4
Plastic Limit (%)	-----	-----	25.9
Plasticity Index (%)	-----	-----	16.5
Coefficient of Uniformity (Cu)	1.42	-----	-----
Coefficient of Curvature (Cc)	0.8	-----	-----
Percentage Passing Sieve Size 0.075mm	-----	22.36	43.56
Percentage Passing Sieve Size 4.75mm	1.63	-----	-----
AASHTO	A-1-b	A-2-4	A-2-6

Classification System			
Unified Soil Classification System	GC	SM	SC

Table 4.2: Slump Test Result for Concrete at varying percentages of Laterite

Percentage Replacement of Laterite (%)	Slump Value at 0.5w/c ratio (mm)	Slump Type
0	22	True Slump
5	24	True Slump
10	32	True Slump
15	30	True Slump
20	28	True Slump
25	24	True Slump

Table 4.3: Average Density Results for Concrete produced at varying percentages of Laterite

Percentages of Laterite (%)	Average Density (kg/m³)
0	2385
5	2389
10	2396
15	2404
20	2413
25	2325

Table 4.4: Average Density Results for Concrete produced at varying intervals of Curing Days

Curing Days (Age)	Average Density (kg/m³)
7	2238
14	2255
21	2288
28	2309

Table 4.5: Average Compressive Strength Results for Concrete produced at varying percentages of Laterite after 28days of curing.

Percentages of Laterite (%)	Average Compressive Strength (N/mm²)
0	22.06
5	21.39
10	21.68
15	22.11
20	22.39
25	20.88

Table 4.6: Average Compressive Strength Results for Concrete produced at varying intervals of Curing Days

Curing Days (Age)	Average Compressive Strength (N/mm²)
7	20.42
14	20.96
21	21.52
28	22.06

4.2 Analysis of Results

4.2.1 Specific Gravity

Figure 4.1 shows the specific gravity values obtained for granite, sand and laterite sample respectively. Comparative deduction revealed that laterite sample with a specific gravity of 2.66 recorded the highest specific gravity value. The specific gravity of the aggregate samples tested was greater than 2.4 and as a result, they are classified as normal weight aggregate. The classification was done in accordance with the specification given by Popovics, (2014) on weight classification of aggregate based on their respective specific gravity values. Popovics, (2014) stated that aggregate with specific gravity value less than 2.4 are classified as light weight aggregate while aggregate with specific gravity value exceeding 2.4 are classified as normal weight aggregate which correlate with the result obtained by the study. The range of specific gravity values (2.55 -2.61) obtained by the study for sand, laterite and granite satisfied ASTM D854-14 requirements which state that the specific gravity of aggregate used for concrete production should lie between 2.55 to 2.9 and therefore, the result obtained justifies the use of this aggregates for the study. This finding is consistent with the works of Apeh and Ogunbode, (2012).

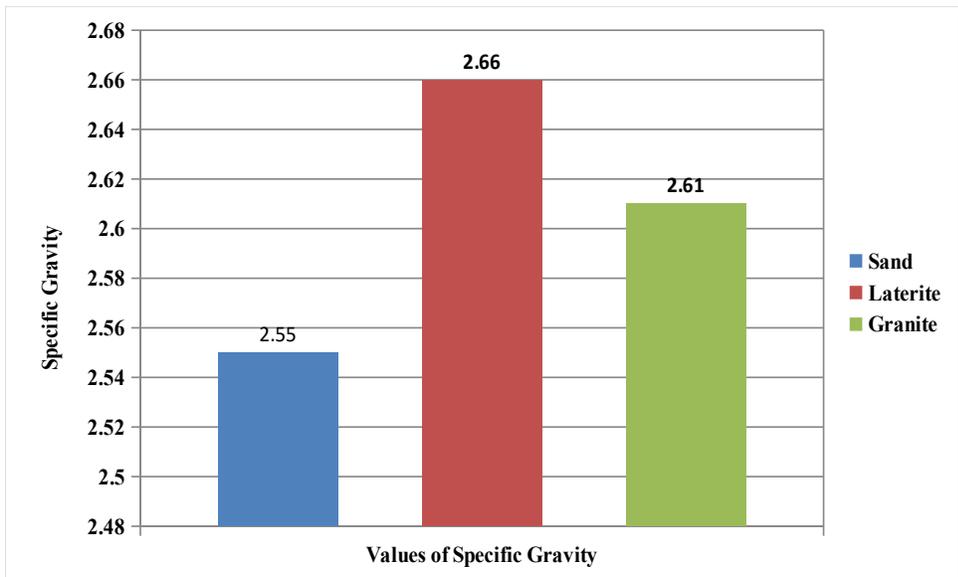


Figure 4.1: Specific Gravity Values of SD, LAT and GT.

4.2.2 Sieve Analysis

Figure 4.2 is a semi logarithmic plot of the particle size distribution of granite, sand and laterite samples respectively. Results obtained revealed that the percentage passing through sieve size 4.75mm for GT was 0.16, coefficient of uniformity and curvature were 1.42 and 0.82 and according to AASHTO classification system, the granite sample was classified as A-1-b and Clayey gravel (SC) according to unified soil classification system. The percentage passing through sieve size 0.075mm for sand and laterite were 22.36 and 43.56 and as a result, they are classified as A-2-4 and A-2-6 according to AASHTO Classification System, SM (sand mixed with silt) and SC (sand mixed with clay) according to unified soil Classification System. The shape parameters (coefficient of uniformity and coefficient of curvature) for laterite and sand samples cannot be obtained from the graph and as a result gradation of both samples cannot be ascertained.

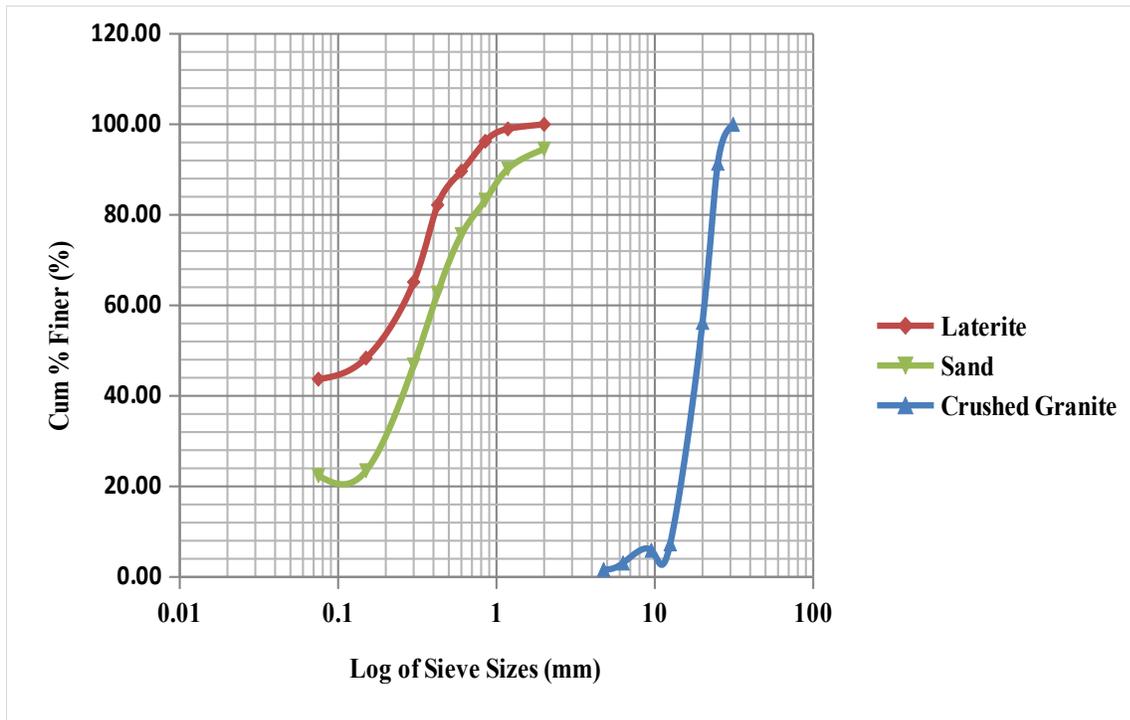


Figure 4.2: Particle Size Distribution Curve for LAT, SD and GT.

4.2.3 Atterberg Limit

The atterberg limit shows the state of transition of cohesive soils in the presence of water. It is the degree of firmness of the soil in the presence water. It is an index of the amount of fines present in the soil samples George, et al., (2019). Soil samples containing significant amount of fines are likely to exhibit high liquid and plastic limit than soils with lesser fine content George,

et al., (2019). The liquid, plastic and plasticity index of the laterite sample tested was 42.4, 25.9 and 16.5%. These results suggest that the laterite sample may exhibit high water absorption capacity due to larger surface area determined by the amount of finer fraction present in the sample. The laterite sample justifies the requirement for use as the liquid limit and plasticity index does not exceed 80 and 55% according to the specification given by federal ministry of works (1997). Similar results were obtained by Apeh and Ogunbode, (2012), Tumingam and Alwi, (2019) and Joshua, et al., (2014).

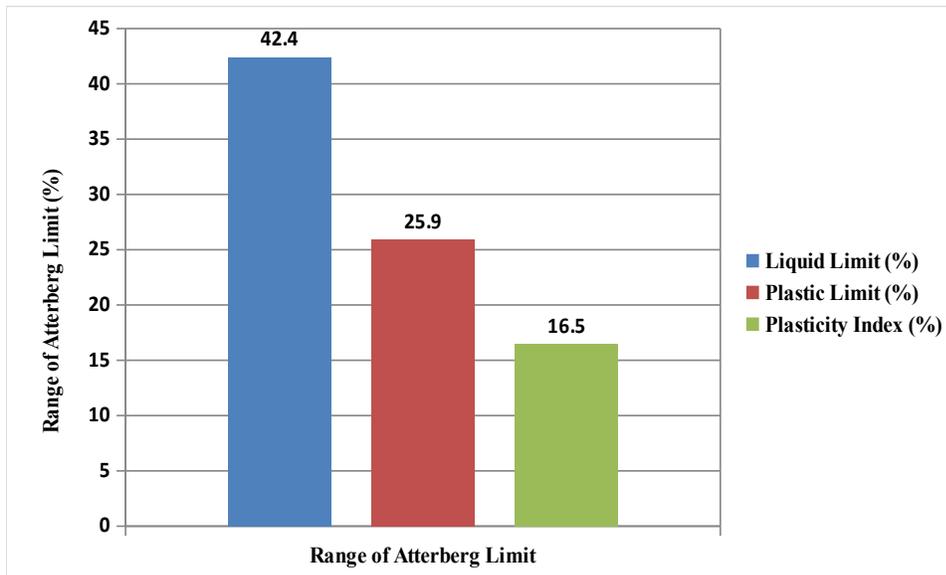


Figure 4.4: Liquid and Plastic Limit Value of Laterite Sample

4.2.4 Bulk Density

Table 4.1 shows the loosed and compacted density of laterite and sand respectively. Result obtained revealed that the density of sand in it compacted state was relatively higher than that of laterite. Conversely, the density of laterite in it loosed state was higher than that of sand. These results suggest that concrete produced with sand sample may have relatively higher density than that produced with laterite sample.

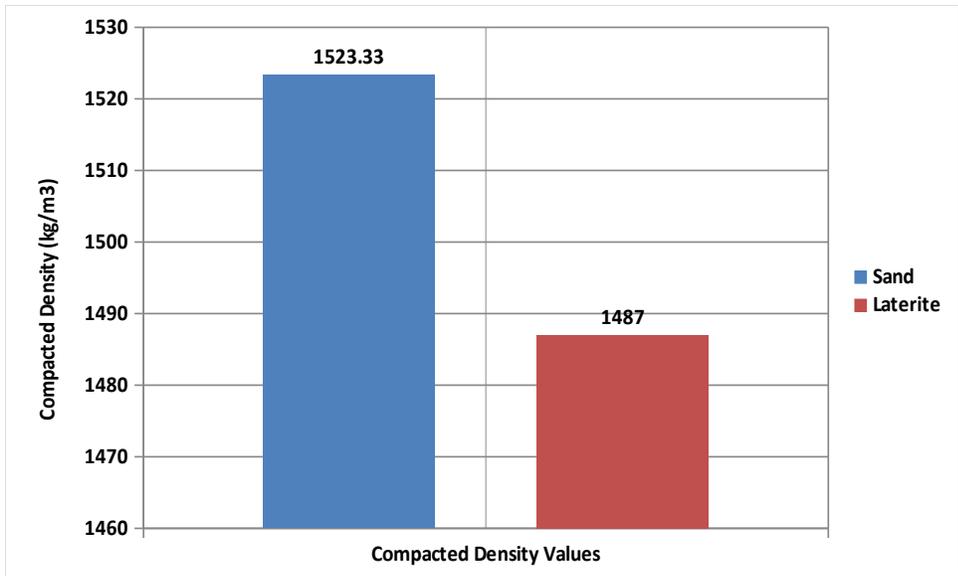


Figure 4.5: Compacted Density Values of Laterite and Sand.

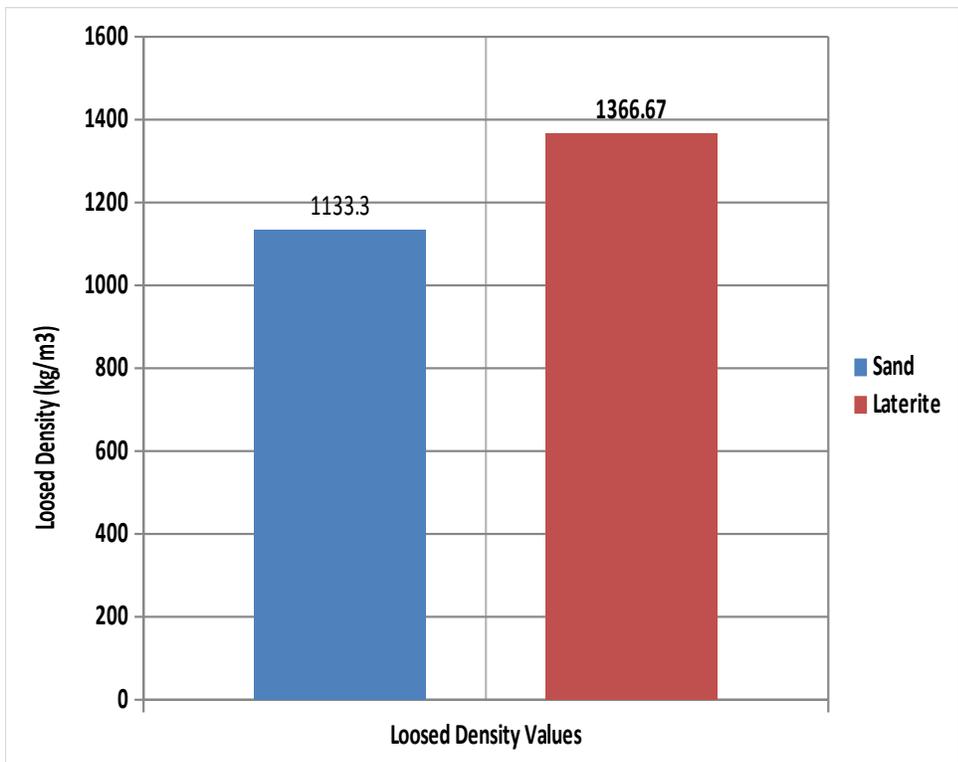


Figure 4.5.1: Loosed Density Value of Laterite and Sand.

4.5 Slump

The slump measures the workability of the concrete. It is the ability of the concrete to flow. Concrete used for construction must be a workable mix as workable mix is characterized by high void filling ability. Results of slump test obtained revealed that the workability of the concrete increased from 22mm to 32mm after 10% addition of laterite to sand but beyond 10% laterite content, the workability of the fresh laterized concrete decreased. The initial increase in workability could be attributed to the low surface area of the laterized concrete while the later decline could be attributed to the increasing content of laterite in the fresh concrete mix. Ultimately, the slump type formed by the samples was true slump as the slump value does not exceed 40mm.

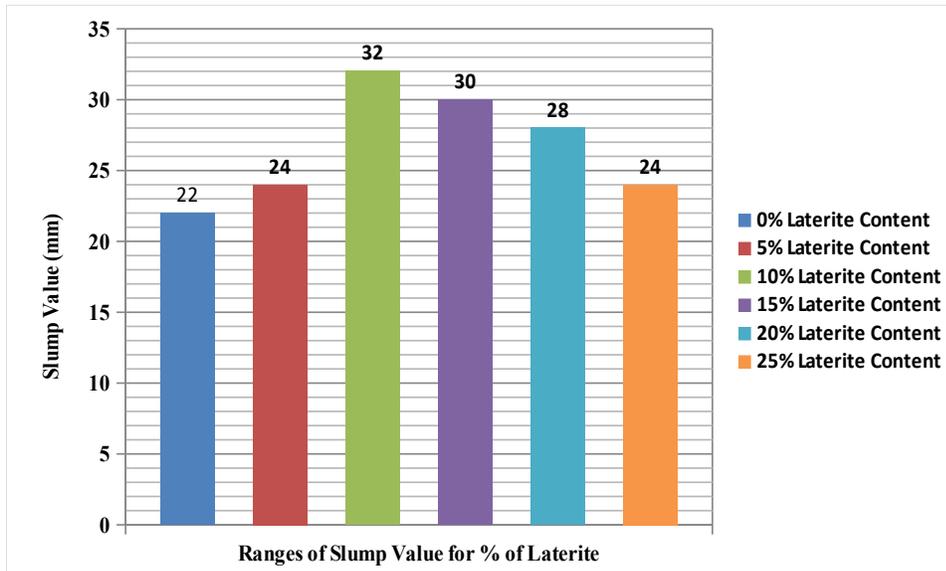


Figure 4.6: Slump Value of the Laterized Concrete

4.2.6 Compressive Strength

Figure 4.7 and 4.8 shows the results of compressive strength against curing days and percentage partial replacement of laterite content. It was observed that the compressive strength of the concrete increased with curing days which agrees with findings obtained by Nevile (2012) which stated that concrete gains over 60% of its compressive strength at 28 days of curing. On partial replacement of laterite with sand, an improvement in compressive strength of the hardened laterized concrete was recorded as the average compressive strength increased from 22.06N/mm² to 22.39N/mm² at 20% of laterite addition, beyond 20% laterite content, the compressive

strength of the hardened laterized concrete decreased. The initial improvement in compressive strength of the hardened laterized concrete could be attributable to the low content of laterite which makes it possible for the concrete to be compacted at high density while the later decrease could be due to high amount of fines associated with the laterite sample which makes it difficult for the concrete to be compacted so as to achieve improved compressive strength of the hardened laterized concrete. This finding is in agreement with works of Tumingam and Alwi, (2019) and Apah and Ogunbode, (2012).

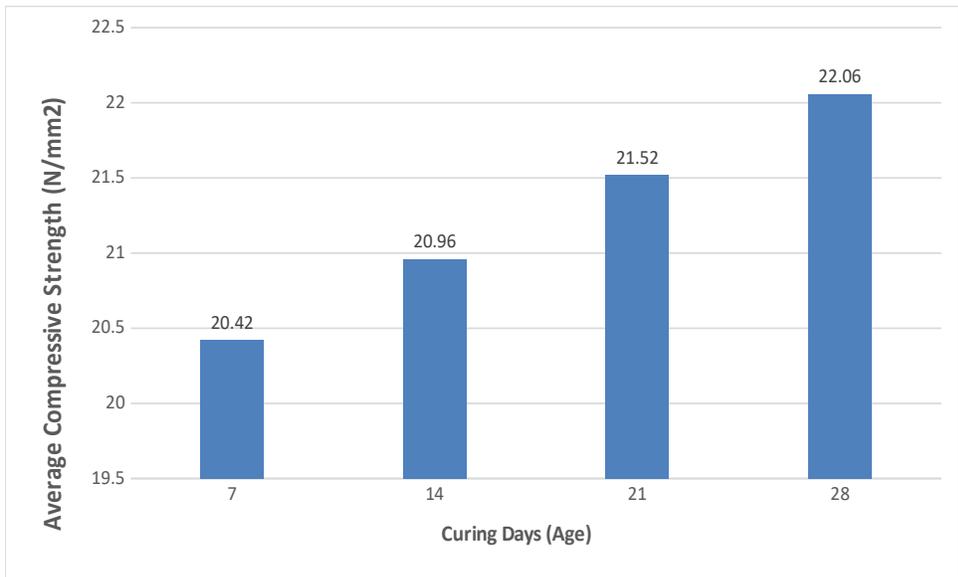


Figure 4.7: Compressive Strength of Concrete against Curing Days

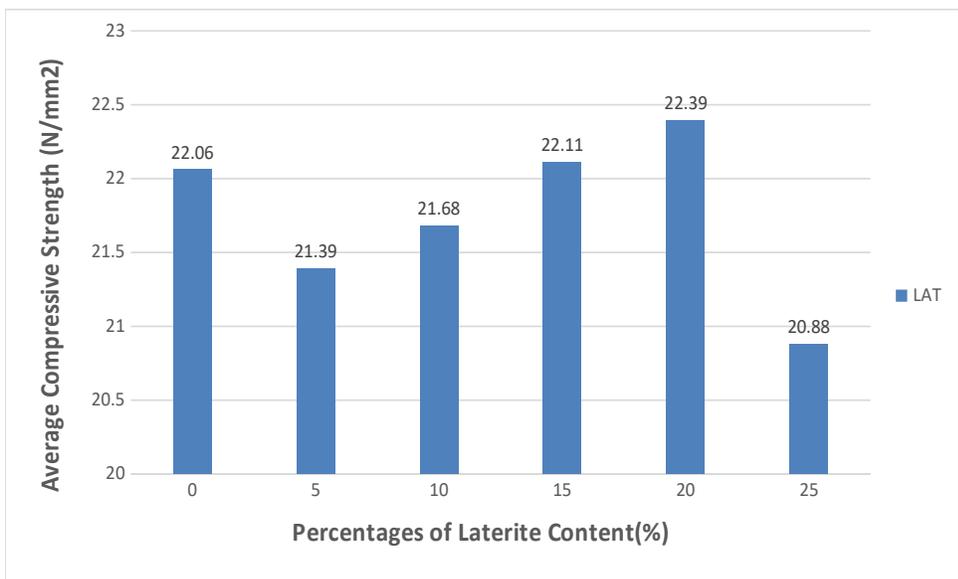


Figure 4.8: Compressive Strength of Concrete against Percentages of Laterite.

4.2.7 Density

The density result obtained for the laterized concrete was similar to that of compressive strength as the density of the concrete was found to increase from 2385 to 2413kg/m³ after 5% addition of laterite content to the concrete, beyond 5% laterite content, the density decreased. It was observed that density increased with curing days. The range of value for density obtained classified the laterized concrete as normal weight concrete.

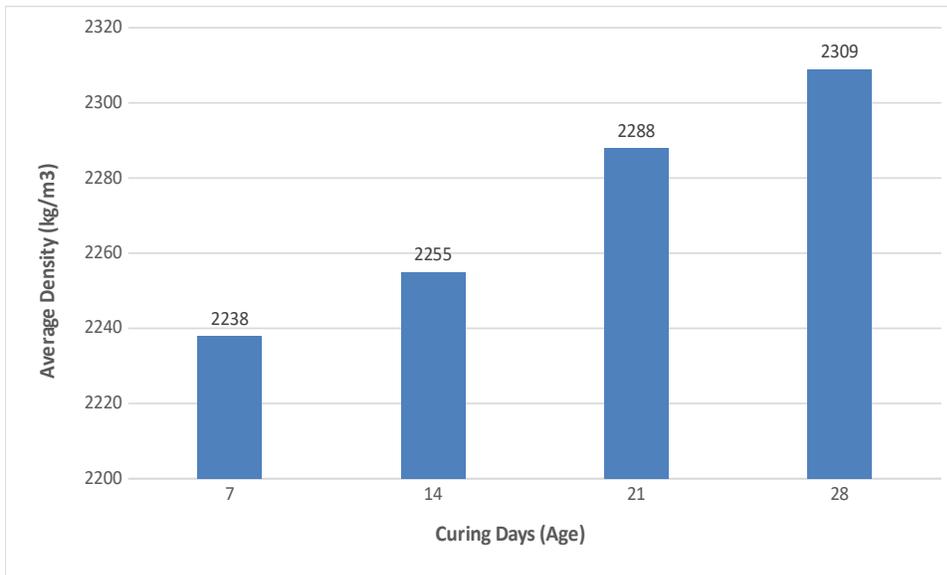


Figure 4.9: Graph of Average Density against Curing Days.

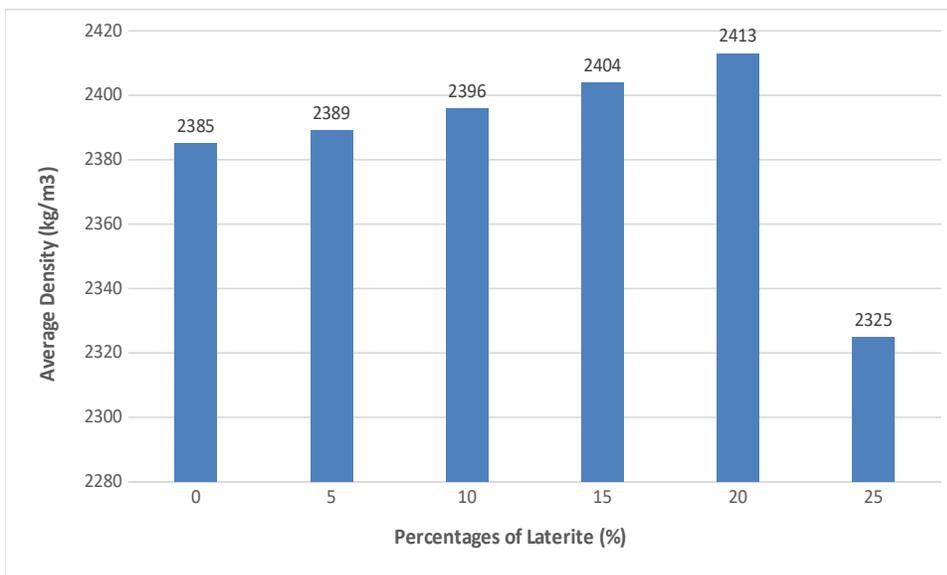


Figure 4.10: Graph of Average Density against Percentage Replacement of Laterite

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

From the findings obtained on effect of partial replacement of laterite with sand on strength properties of concrete, the following conclusion can be drawn:

1. The specific gravity of laterite, sand and granite are 2.66, 2.55 and 2.6 respectively and as a result, these samples are classified as normal weight aggregate.
2. The particle size distribution test of the aggregate classified laterite, sand and granite as Clayey sand, Silty sand and Clayey gravel according to Unified Soil Classification System and A-2-6, A-2-4 and A-1-b according to AASHTO Classification System.
3. The liquid limit, plastic limit and plasticity index of laterite are 42.4, 25.9 and 16.5% respectively.
4. The density of sand and laterite in its loosed state was 1133.3 and 1333.67kg/m³ while the density in its compacted state was 1523.33 and 1487kg/m³ respectively.
5. The workability of the fresh laterized concrete increased from 22mm to 32mm at 10% laterite content but beyond 10% laterite content, the workability decreased.
6. The compressive strength of the hardened concrete increased from 22.06N/mm² to 22.39N/mm² at 20% laterite content but beyond 20% laterite content, the compressive strength of the hardened laterized concrete decreased. It was also observed that compressive strength increased with curing days.
7. The average density of the concrete increased from its natural value of 23.85kg/m³ to 2413kg/m³ at 20% laterite content, beyond 20% laterite content, the average density of the hardened laterized concrete decreased. It was also observed that the density increased with curing days.
8. A direct relationship was established between the compressive strength and weight of the hardened laterized concrete as both properties of the hardened concrete undergo an improvement at similar percentages of laterite replacement.
9. The laterite sample employed in the study was adjudged as partly effective as slight improvement in density and strength properties of the hardened concrete was observed.

5.2 Recommendations

The recommendation on strength properties of concrete containing laterite as partial replacement of sand in concrete are as follows:

1. Concrete produced with partial replacement of sand with laterite can only be feasible and effective at 20% addition of laterite content to sharp sand.
2. The physical and chemical properties of laterite should be investigated prior to its incorporation into the concrete.
3. The recommendation 1 should be subjected to further investigation so as to ascertain whether the additional materials could be added which could result to an enhanced improvement in strength and density properties of the laterized concrete.

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APPENDICES

APPENDIX A

Specific Gravity Test

Table A1: Specific Gravity Result for Sand

Determinants	Trial 1	Trial 2	Trial 3
Wt of density bottle, W_1 (g).	24.50	25.32	25.12
Wt of bottle + dry soil, W_2 (g).	34.48	35.31	35.10
Wt of bottle + soil + water, W_3 (g).	84.43	86.39	85.03
Wt of bottle + water, W_4 (g).	78.35	80.32	78.93

The Specific gravity of the sample is calculated as follows:

Specific Gravity for Sand.

$$\text{Trial 1 } (G_{S1}) = \frac{(W_2 - W_1)}{(W_2 - W_1) - (W_3 - W_4)} = \frac{(34.48 - 24.50)}{(34.48 - 24.50) - (84.43 - 78.35)} = 2.56$$

$$\text{Trial 2 } (G_{S2}) = \frac{(W_2 - W_1)}{(W_2 - W_1) - (W_3 - W_4)} = \frac{(35.31 - 25.32)}{(35.31 - 25.32) - (86.39 - 80.32)} = 2.55$$

$$\text{Trial 3 } (G_{S3}) = \frac{(W_2 - W_1)}{(W_2 - W_1) - (W_3 - W_4)} = \frac{(35.10 - 25.12)}{(35.10 - 25.12) - (85.03 - 78.93)} = 2.53$$

$$\text{Specific Gravity} = \frac{(G_{S1} + G_{S2} + G_{S3})}{3} = \frac{(2.56 + 2.55 + 2.53)}{3} = 2.55$$

Table A2: Specific Gravity Result for Laterite

Determinants	Trial 1	Trial 2	Trial 3
Wt of density bottle, W₁ (g).	24.76	25.64	25.90
Wt of bottle + dry soil, W₂ (g).	34.74	35.63	35.90
Wt of bottle + soil + water, W₃ (g).	84.33	85.15	85.79
Wt of bottle + water, W₄ (g).	78.07	78.94	79.56

The Specific gravity of the sample is calculated as follows:

Specific Gravity for laterite

$$\text{Trial 1 } (G_{S1}) = \frac{(W_2 - W_1)}{(W_2 - W_1) - (W_3 - W_4)} = \frac{(34.74 - 24.76)}{(34.74 - 24.76) - (84.33 - 78.07)} = 2.68$$

$$\text{Trial 2 } (G_{S2}) = \frac{(W_2 - W_1)}{(W_2 - W_1) - (W_3 - W_4)} = \frac{(35.63 - 25.64)}{(35.63 - 25.64) - (85.15 - 78.94)} = 2.64$$

$$\text{Trial 3 } (G_{S3}) = \frac{(W_2 - W_1)}{(W_2 - W_1) - (W_3 - W_4)} = \frac{(35.90 - 25.90)}{(35.90 - 25.90) - (85.79 - 79.56)} = 2.65$$

$$\text{Specific Gravity} = \frac{(G_{S1} + G_{S2} + G_{S3})}{3} = \frac{(2.68 + 2.64 + 2.65)}{3} = 2.66$$

Table A3: Specific Gravity Result for Crushed Granite.

Determinants	Trial 1	Trial 2	Trial 3
Wt of Saturated aggregate and basket in water W ₁ (g).	458.72	460.68	462.46
Wt of basket in Water W ₂ (g).	190.48	192.84	192.88
Wt of Saturated aggregate in air W ₃ (g).	438.62	442.24	440.82
Wt of Oven-dried aggregate in air W ₄ (g).	432.80	434.28	434.86

The Specific gravity of the sample is calculated as follows:

Apparent Specific Gravity for Crushed Granite.

$$\text{Trial 1 } (G_{S1}) = \frac{W_4}{\cancel{\cancel{W_1}}} = \frac{432.80}{\cancel{\cancel{458.72}}} = 2.63$$

$$\text{Trial 2 } (G_{S2}) = \frac{W_4}{\cancel{\cancel{W_1}}} = \frac{434.28}{\cancel{\cancel{460.68}}} = 2.61$$

$$\text{Trial 3 } (G_{S3}) = \frac{W_4}{\cancel{\cancel{W_1}}} = \frac{434.86}{\cancel{\cancel{462.46}}} = 2.60$$

$$\text{Apparent Specific Gravity} = \frac{(G_{S1} + G_{S2} + G_{S3})}{3} = \frac{(7.84)}{3} = 2.61$$

Bulk Specific Gravity for Crushed Granite.

$$\text{Trial 1 } (G_{s1}) = \frac{W_4}{\rho_w} = \frac{432.80}{\rho_w} = 2.48$$

$$\text{Trial 2 } (G_{s2}) = \frac{W_4}{\rho_w} = \frac{434.28}{\rho_w} = 2.49$$

$$\text{Trial 3 } (G_{s3}) = \frac{W_4}{\rho_w} = \frac{434.86}{\rho_w} = 2.54$$

$$\text{Bulk Specific Gravity} = \frac{(G_{s1} + G_{s2} + G_{s3})}{3} = \frac{(2.48 + 2.49 + 2.54)}{3} = 2.50$$

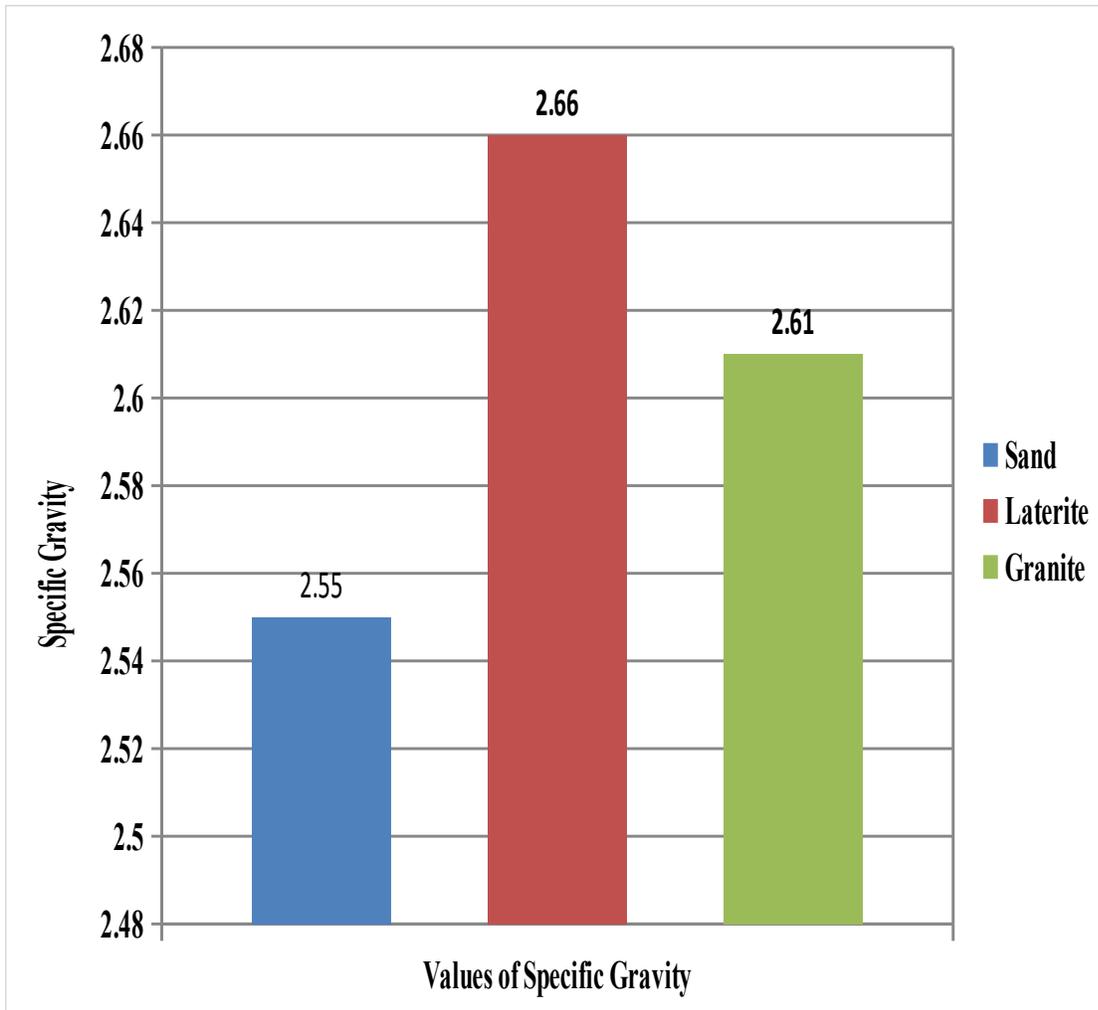


Figure A1: Graph Showing the Specific Gravity Values of Sand, Laterite and Granite

APPENDIX B

Sieve Analysis Test

Table B1: Sieve Analysis Result for Laterite

Sieve Sizes (mm)	Mass Retained (g)	% Mass Retained	Cum % Retained	Cum % Finer
2	0.03	0.006	0.006	99.994
1.18	5.04	1.008	1.014	98.986
0.85	13.78	2.756	3.77	96.23
0.6	32.95	6.59	10.36	89.64
0.425	37.26	7.452	17.812	82.188
0.3	85.14	17.028	34.84	65.16
0.15	84.09	16.818	51.658	48.342
0.075	23.21	4.642	56.3	43.7
Tray	0.68	0.136	56.436	43.564

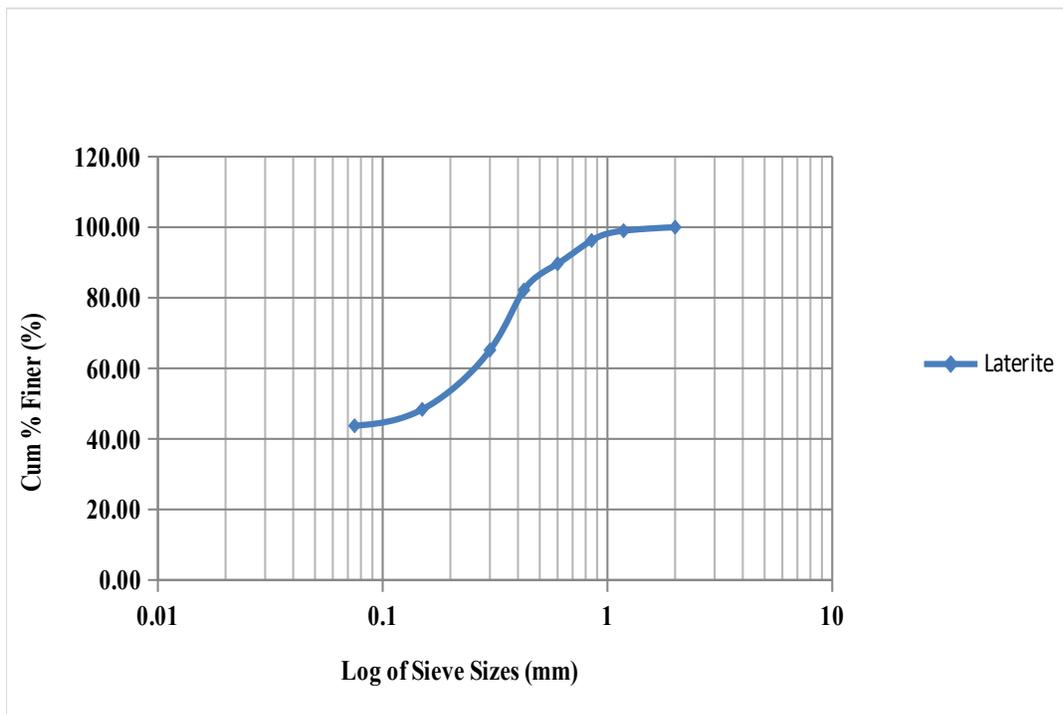


Figure B1: Particle Size Distribution Curve for Laterite

Table B2: Sieve Analysis Result for Sand

Sieve Sizes (mm)	Mass Retained (g)	% Mass Retained	Cum % Retained	Cum % Finer
2	16.42	5.47	5.47	94.53
1.18	13.07	4.36	9.83	90.17
0.85	20.89	6.96	16.79	83.21
0.6	22.74	7.58	24.37	75.63
0.425	38.75	12.92	37.29	62.71
0.3	47.76	15.92	53.21	46.79
0.15	70.04	23.35	76.55	23.45
0.075	3.27	1.09	77.64	22.36
Tray	0.68	0.23	77.87	22.13

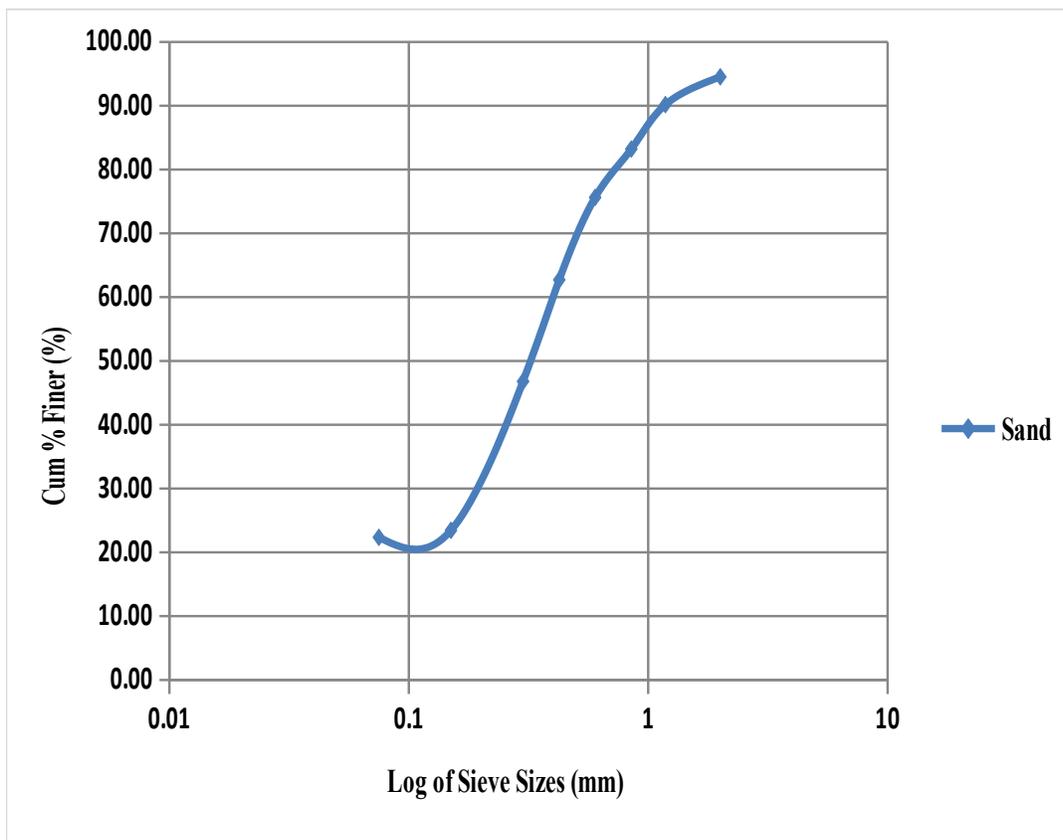


Figure B2: Particle Size Distribution Curve for Sand

Table B3: Sieve Analysis Result for Granite

Sieve Sizes (mm)	Mass Retained (g)	% Mass Retained	Cum % Retained	Cum % Finer
31.25	0.14	0.01	0.01	99.99
25	88.5	8.63	8.644146341	91.36
20	362.11	35.33	35.33780488	64.66
12.5	504	49.17	49.18073171	50.82
9.5	14.61	1.43	1.435365854	98.56
6.3	29.02	2.83	2.841219512	97.16
4.75	14.83	1.45	1.456829268	98.54
Tray	12.44	1.21	1.223658537	98.78

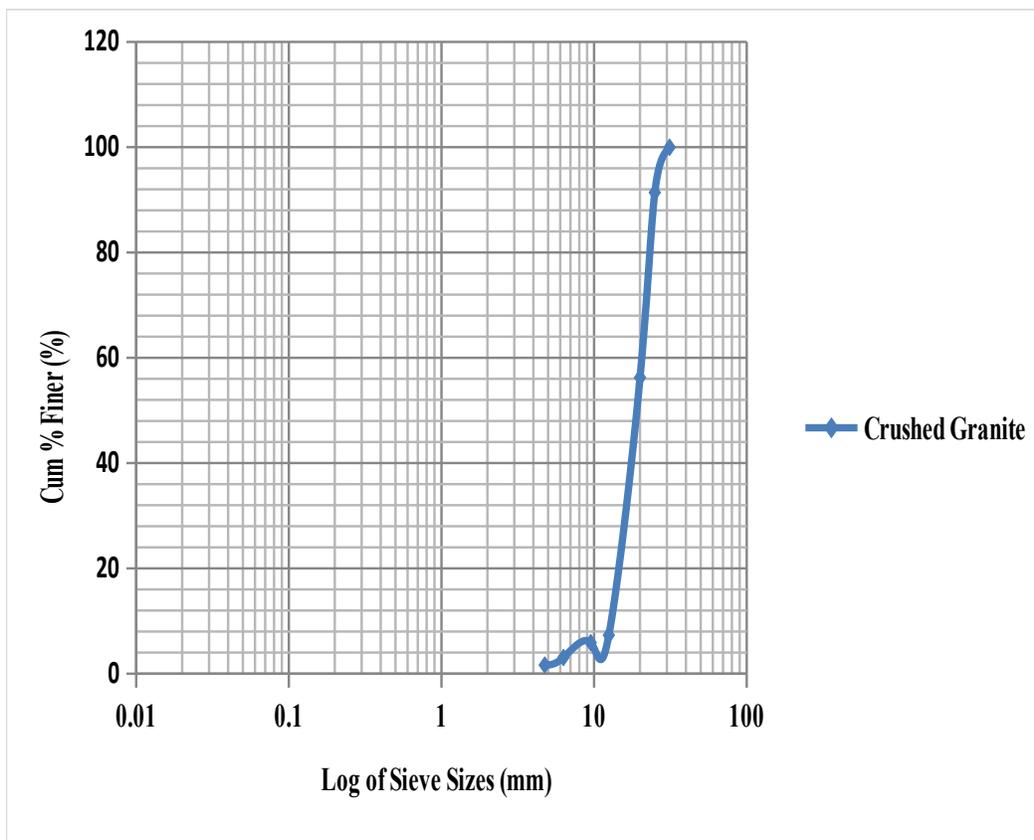


Figure B3: Graph Showing the Particle Size Distribution Curve for Granite

APPENDIX C

Table C1: Liquid Limit Result for Laterite

Blows	32	27	21	18	13
Wt of empty tin (g)	15.24	14.86	15.46	17.81	17.04
Wt of tin + wet soil (g)	35.04	40.44	56.18	60.4	45.66
Wt of wet soil	19.8	25.58	40.72	42.59	28.62
Wt of tin + oven dried soil (g)	29.96	33.18	43.02	46.08	35.22
Wt of oven dried soil (g)	14.72	18.32	27.56	28.27	18.18
Wt of water (g)	5.08	7.26	13.16	14.32	10.44
Moisture Content (%)	34.5108 7	39.6288 2	47.7503 6	50.6544	57.4257 4

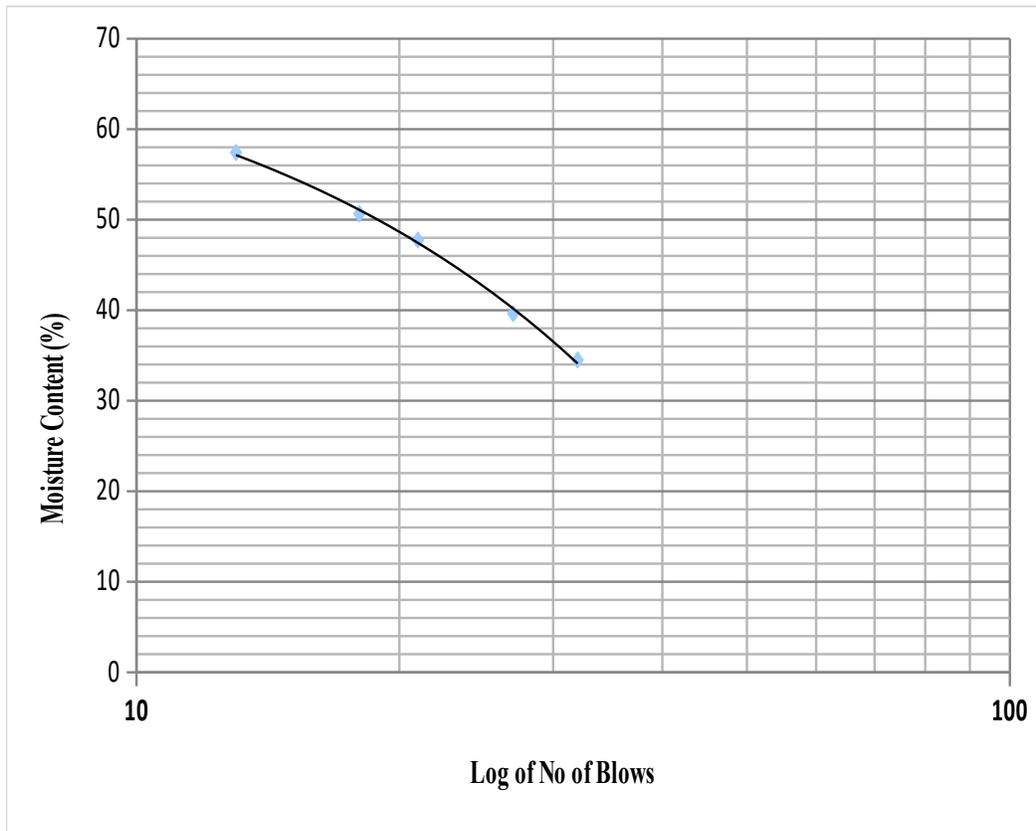


Figure C1: Liquid Limit Graph for Laterite

Table B2: Plastic Limit Result for Laterite

Laterite	Test 1	Test 2	Test 3
Wt of empty tin (g)	14.68	13.58	14.21
Wt of tin + wet soil	31.77	35.84	38.31
Wt of wet soil (g)	17.09	22.26	24.1
Wt of tin + dry soil (g)	28.41	31.14	33.28
Wt of oven dried soil (g)	13.73	17.56	19.07
Wt of water (g)	3.36	4.7	5.03
Plastic Limit (%)	24.47	26.77	26.38

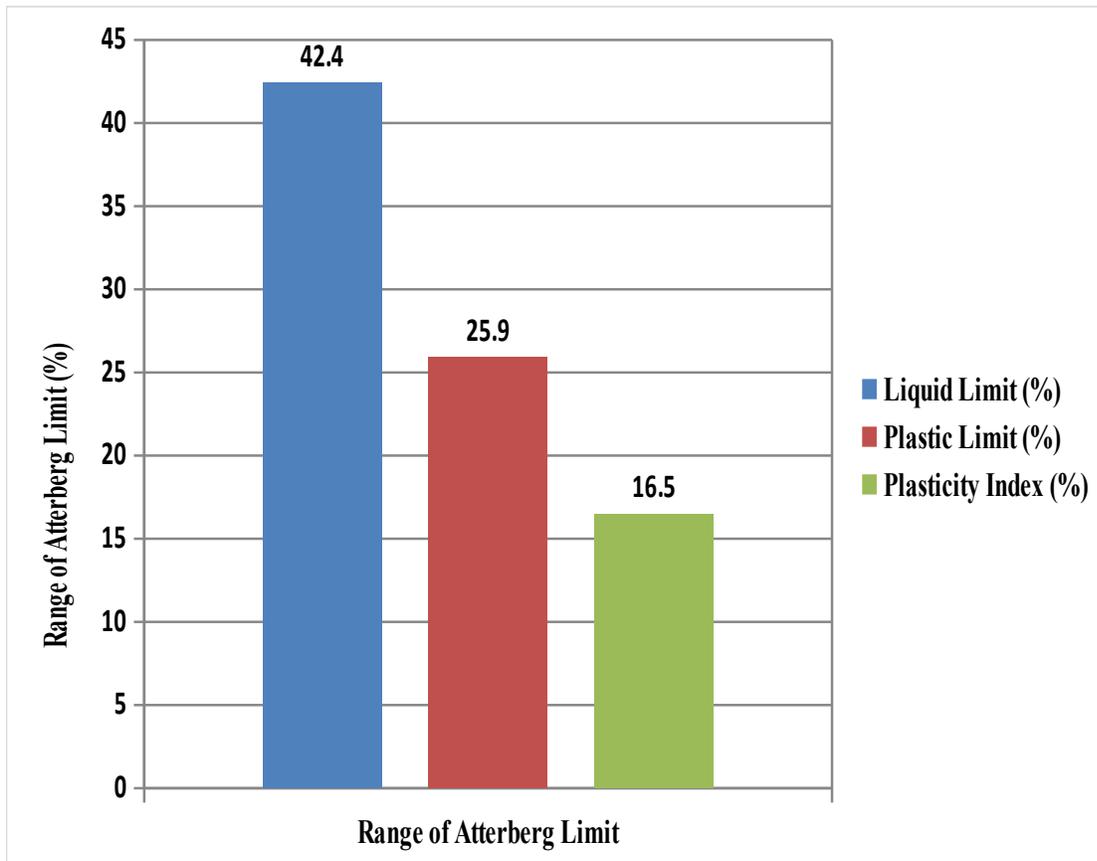


Figure C2: Graph Showing the Liquid, Plastic and Plasticity Index of Laterite

APPENDIX D

Bulk Density Test

Table D1: Loose and Compacted Density of Laterite

Sample	W (kg)	WL (kg)	Wc (kg)	Loose density (kg/m ³)	Density Compacted (kg/m ³)
1	4.0	5.5	5.68	1500.00	1680
2	4.0	5.4	5.38	1400.00	1380
3	4.0	5.2	5.4	1200.00	1400
Average				1366.67	1487

Table D2: Loose and Compacted Density of Sand

Sample	W (kg)	WL (kg)	Wc (kg)	Loose density (kg/m ³)	Density Compacted (kg/m ³)
1	4.0	5.4	5.67	1400.00	1670
2	4.0	5.1	5.35	1100.00	1350.00
3	4.0	4.9	5.5	900.00	1550.00
Average				1133.33	1523.33

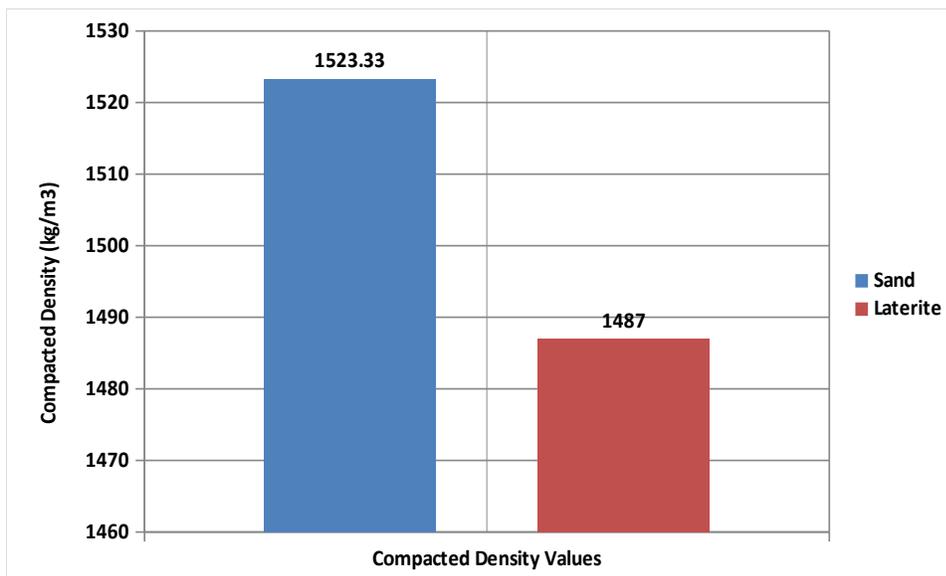


Figure D1: Chart Showing the Compacted Density of Sand and Laterite

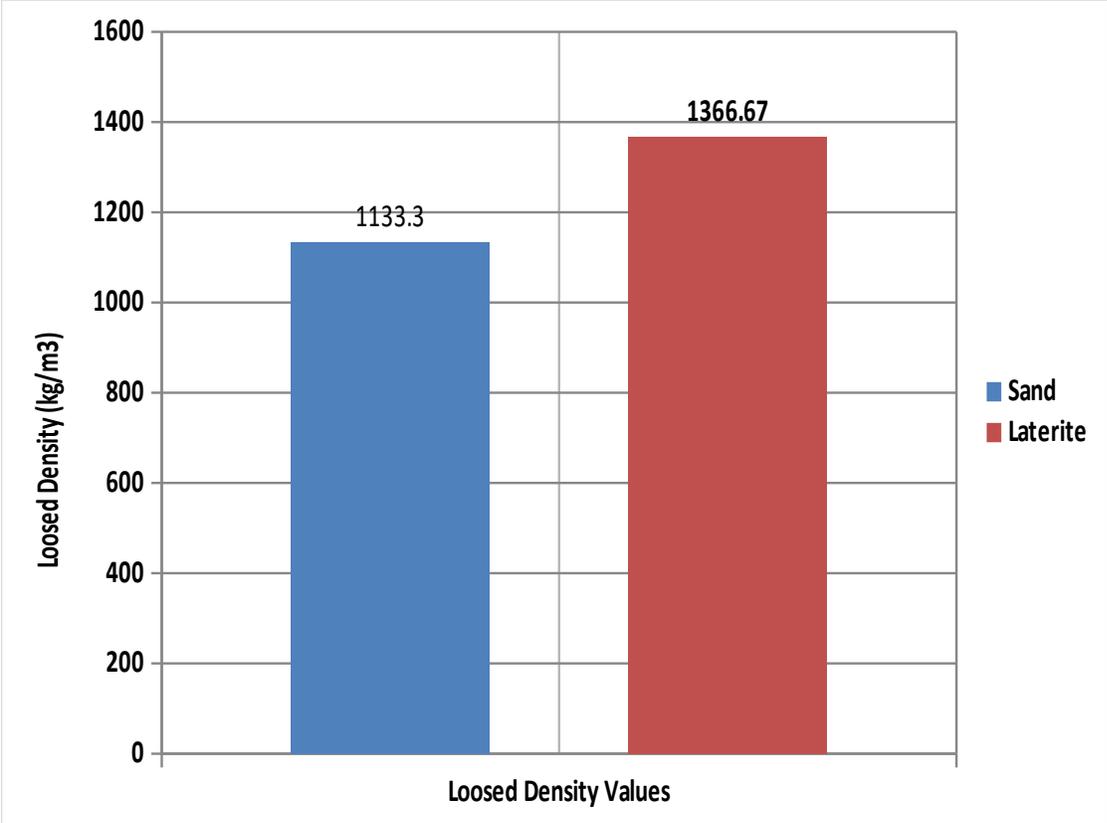


Figure D1: Chart Showing the Loosed Density of Sand and Laterite

APPENDIX E

Slump Test

Table E1: Slump Test Result for Laterized Concrete

Percentage Replacement of Laterite (%)	Slump Value at 0.6w/c ratio (mm)	Slump Type
0	22	True Slump
5	24	True Slump
10	32	True Slump
15	30	True Slump
20	28	True Slump
25	24	True Slump

APPENDIX F

Compressive Strength Test

Table F1: Compressive Strength Test Result for 0%Laterite + 100% Sand

Curing Days (Age)	Mix Ratio	Failure Load (kN)	Compressive Strength (N/mm²)	Average Compressive Strength (N/mm²)
7 days	1: 2: 4	483.5	21.49	21.41
		485.6	21.58	
		478.5	21.15	
14 days	1: 2: 4	490.3	21.79	21.84
		488.5	21.71	
		495.4	22.1	
21 days	1: 2:4	502.4	22.33	22.39
		508.6	22.60	
		500.5	22.24	
28 days	1: 2: 4	504.6	22.43	22.06
		511.3	22.72	
		508.4	22.60	

Table F2: Compressive Strength Test Result for 5%Laterite + 95% Sand

Curing Days (Age)	Mix by Volume	Failure Load (kN)	Compressive Strength (N/mm²)	Average Compressive Strength (N/mm²)
7 days	1: 2: 4	488.6	18.66	18.61
		492.5	18.45	
		494.4	18.72	
14 days	1: 2: 4	498.6	20.68	20.84
		500.3	20.88	
		504.4	20.97	
		506.8	21.33	

21 days	1: 2:4	509.4	21.16	21.31
		511.2	21.43	
28 days	1: 2: 4	512.5	21.33	21.39
		514.6	21.27	
		510.2	21.58	

Table F3: Compressive Strength Test Result for 10%Laterite + 90%Sand

Curing Days (Age)	Mix Ratio	Failure Load (kN)	Compressive Strength (N/mm ²)	Average Compressive Strength (N/mm ²)
7 days	1: 2: 4	486.4	18.62	18.59
		482.5	18.44	
		488.7	18.72	
14 days	1: 2: 4	487.5	20.67	20.84
		492.3	20.88	
		494.4	20.97	
21 days	1: 2:4	501.8	21.30	21.30
		498.6	21.16	
		504.7	21.43	
28 days	1: 2: 4	508.8	22.61	21.68
		505.3	22.46	
		506.7	22.52	

Table F4: Compressive Strength Test Result for 15%Laterite + 85% Sand

Curing Days (Age)	Mix Ratio	Failure Load (kN)	Compressive Strength (N/mm ²)	Average Compressive Strength (N/mm ²)
7 days	1: 2: 4	454.2	20.19	19.78
		448.3	19.92	
		432.8	19.24	
14 days	1: 2: 4	462.2	20.54	20.62
		468.5	20.82	
		461.3	20.50	
		480.4	21.35	

21 days	1: 2:4	478.8	21.28	21.24
		474.5	21.09	
28 days	1: 2: 4	492.6	21.89	21.86
		488.5	21.71	
		494.8	21.99	

Table F5: Compressive Strength Test Result for 20%Laterite + 80% Sand

Curing Days (Age)	Mix by Volume	Failure Load (kN)	Compressive Strength (N/mm ²)	Average Compressive Strength (N/mm ²)
7 days	1: 2: 4	440.5	19.58	19.43
		438.7	19.50	
		432.2	19.21	
14 days	1: 2: 4	448.5	19.93	20.02
		450.2	20.01	
		452.6	20.12	
21 days	1: 2:4	465.5	21.69	21.75
		470.7	21.92	
		464.2	21.63	
28 days	1: 2: 4	475.8	21.15	22.39
		472.4	21.10	
		477.3	21.21	

Table F6: Compressive Strength Test Result for 25%Laterite + 75% Sand

Curing Days (Age)	Mix by Volume	Failure Load (kN)	Compressive Strength (N/mm ²)	Average Compressive Strength (N/mm ²)
7 days	1: 2: 4	420.2	18.68	18.50
		418.3	18.59	
		410.5	18.24	
14 days	1: 2: 4	424.5	18.87	19.16
		430.6	19.14	
		438.3	19.48	
		440.7	19.59	

21 days	1: 2:4	442.5	19.67	19.76
		450.7	20.03	
28 days	1: 2: 4	464.8	20.86	20.88
		460.2	20.95	
		468.8	20.84	

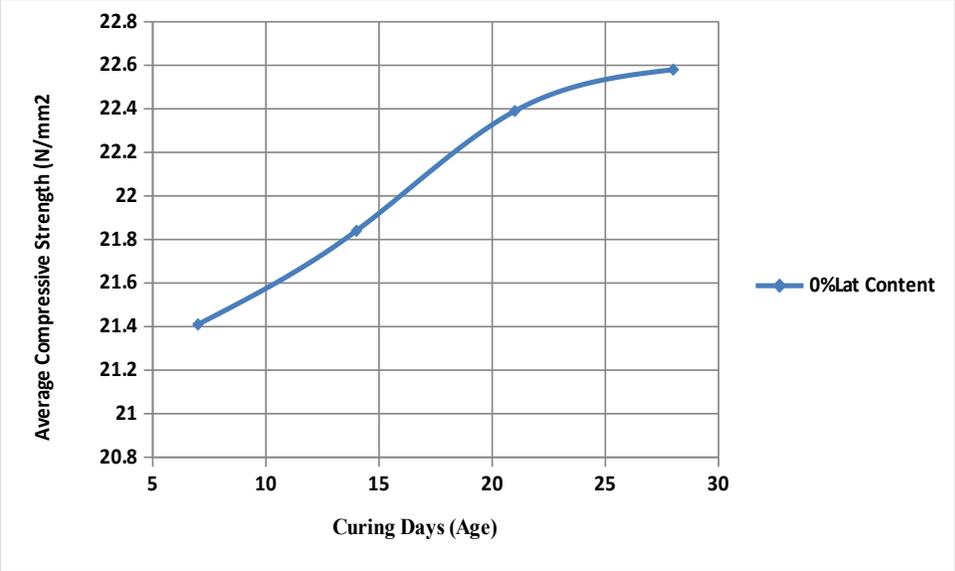


Figure F1: Graph of Compressive Strength against Curing Days for 0% Laterite Content

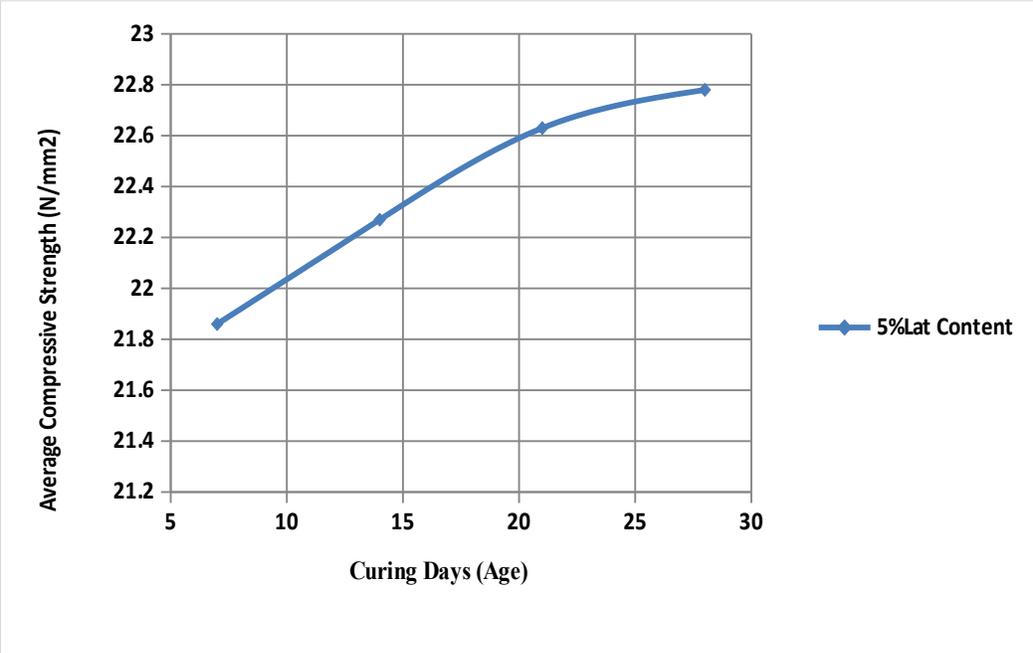


Figure F2: Graph of Compressive Strength against Curing Days for 5% Laterite Content

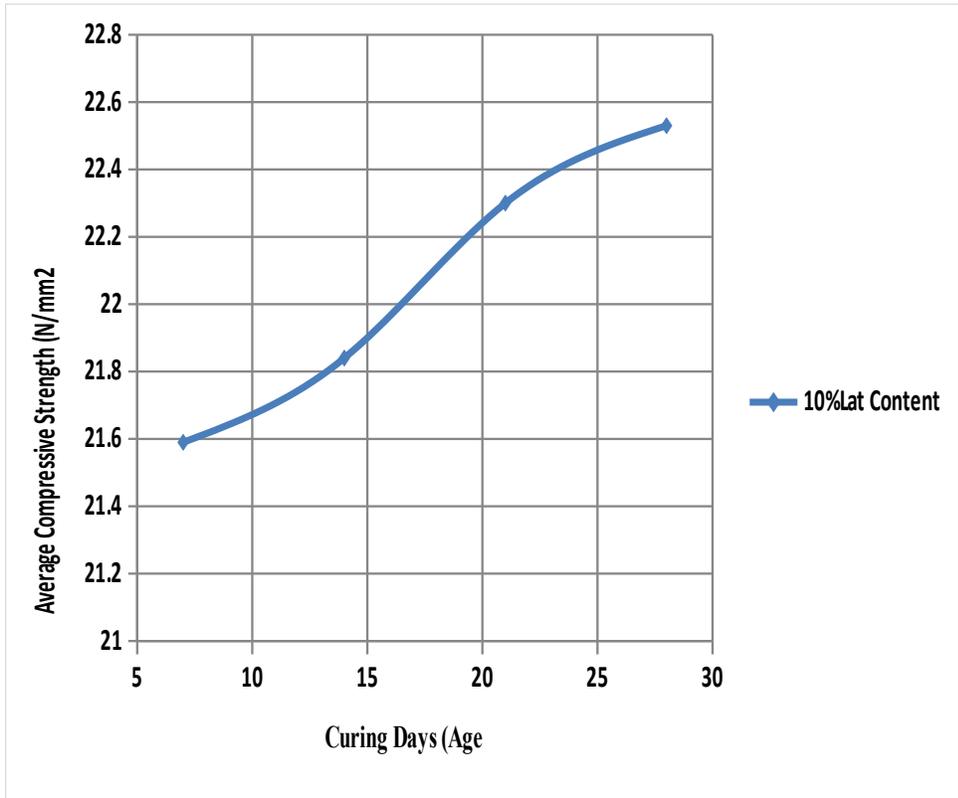


Figure F3: Graph of Compressive Strength against Curing Days for 10% Laterite Content

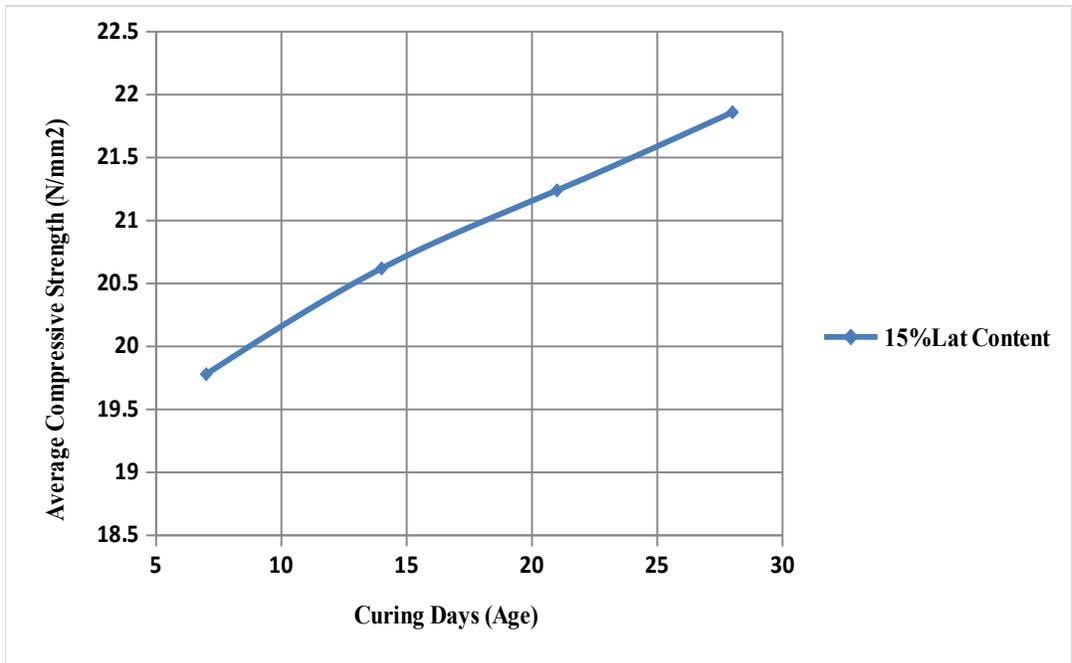


Figure F4: Graph of Compressive Strength against Curing Days for 15% Laterite Content

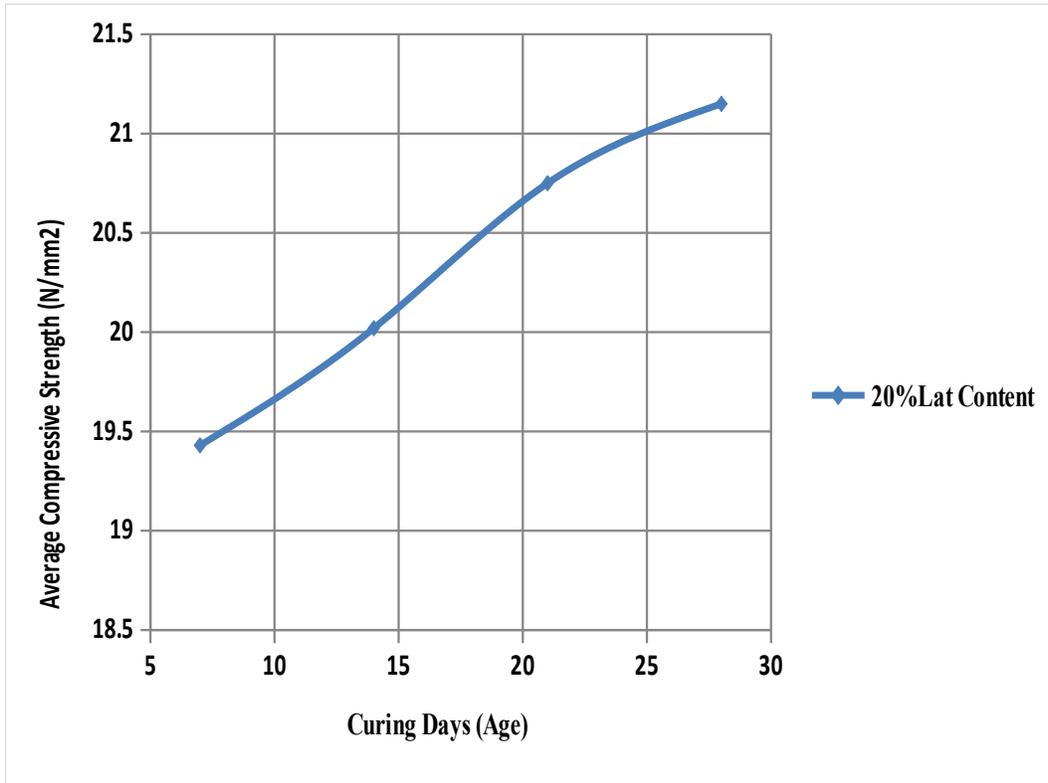


Figure F5: Graph of Compressive Strength against Curing Days for 20% Laterite Content

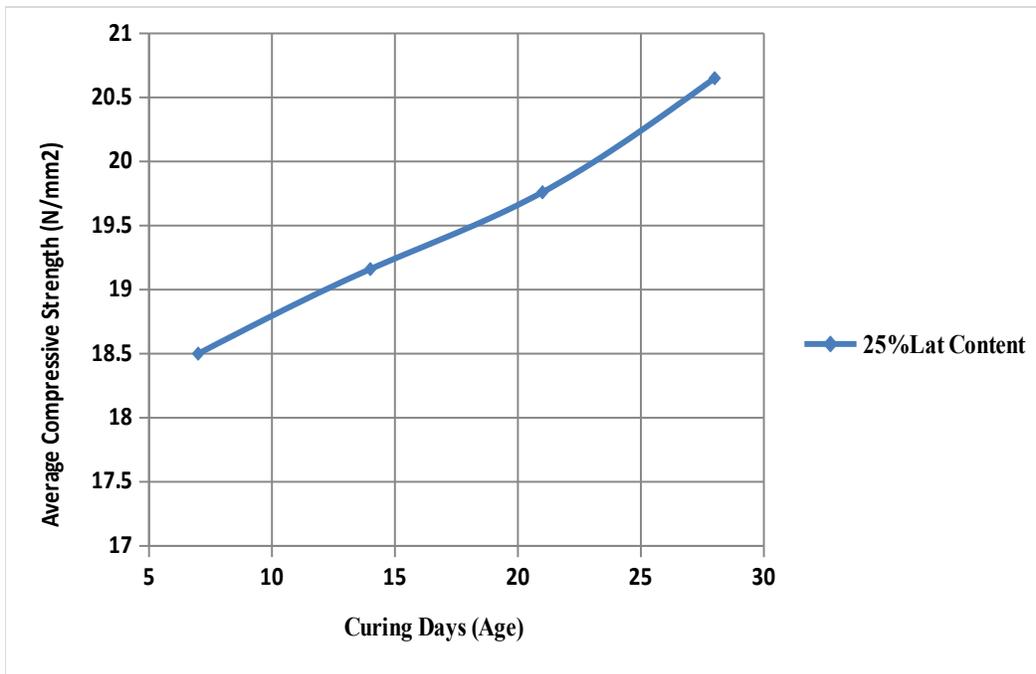


Figure F6: Graph of Compressive Strength against Curing Days for 25% Laterite Content

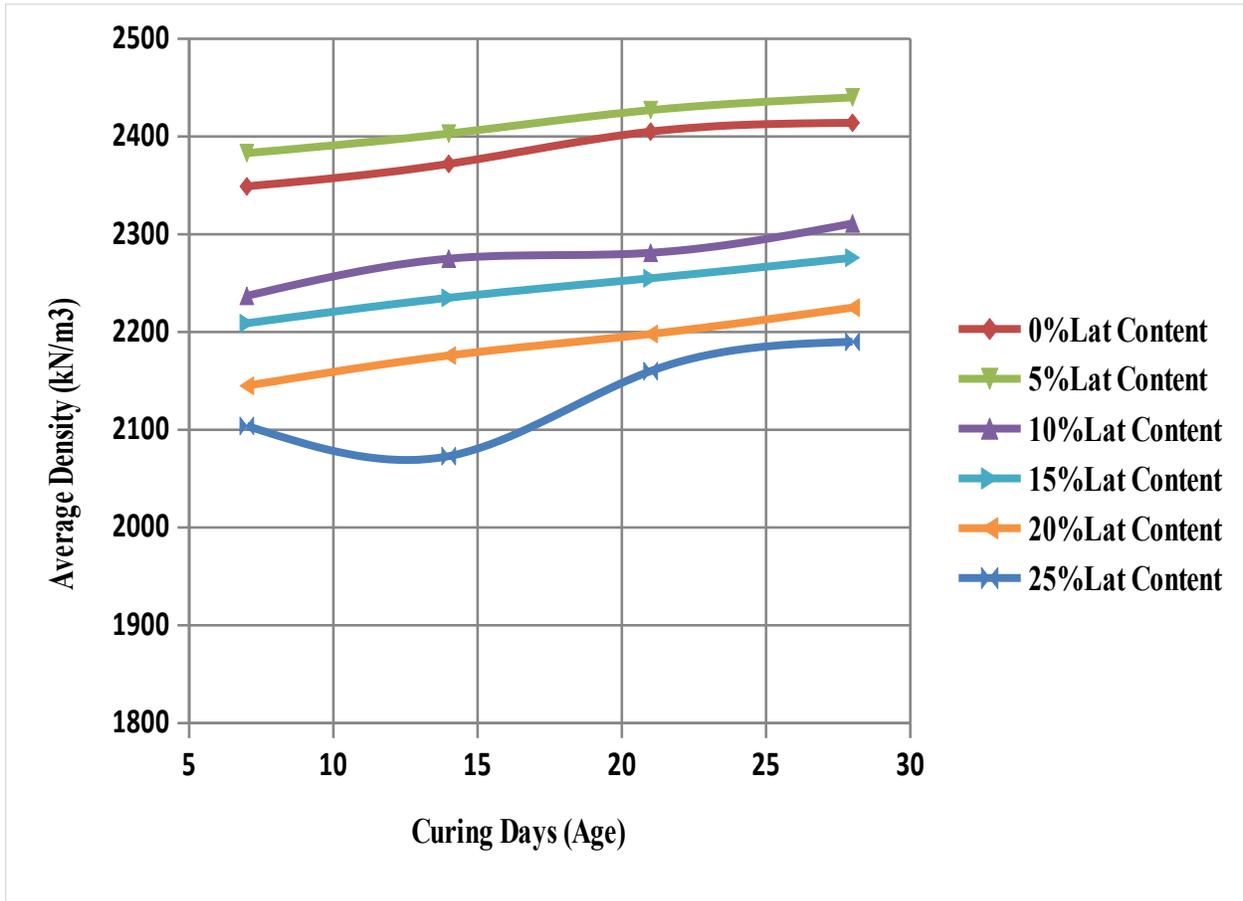


Figure F7: Combined Graph of Compressive Strength against Curing Days

APPENDIX G

Density Test

Density Test for 0%Laterite + 100% Sand

Curing days (Age)	Weight (kg)	Average Weight (kg)	Density (kg/m³)	Average Density (kg/m³)
7 days	7.84	7.93	2323	2349
	7.90		2341	
	8.04		2382	
14 days	7.92	8.01	2347	2372
	8.08		2394	
	8.02		2376	
21 days	8.12	8.12	2406	2405
	8.09		2397	
	8.14		2412	
28 days	8.14	8.15	2412	2414
	8.20		2430	
	8.11		2400	

Density Test for 5%Laterite + 95% Sand

Curing days (Age)	Weight (kg)	Average Weight (kg)	Density (kg/m³)	Average Density (kg/m³)
7 days	8.02	8.04	2376	2383
	7.99		2367	
	8.12		2406	
14 days	8.08	8.11	2394	2403
	8.16		2418	
	8.09		2397	
21 days	8.18	8.19	2424	2427
	8.24		2441	
	8.15		2415	
28 days	8.22	8.23	2436	2440
	8.20		2430	
	8.28		2453	

Density Test Result for 10% Laterite + 90% Sand

Curing days (Age)	Weight (kg)	Average Weight (kg)	Density (kg/m³)	Average Density (kg/m³)
7 days	7.45	7.55	2207	2237
	7.52		2228	
	7.68		2276	
14 days	7.58	7.68	2246	2275
	7.64		2264	
	7.81		2314	
21 days	7.65	7.70	2267	2281
	7.64		2264	
	7.80		2311	
28 days	7.68	7.8	2276	2311
	7.84		2323	
	7.88		2335	

Density Test Result for 15% Laterite + 85% Sand

Curing days (Age)	Weight (kg)	Average Weight (kg)	Density (kg/m³)	Average Density (kg/m³)
7 days	7.32	7.46	2169	2209
	7.48		2216	
	7.57		2243	
14 days	7.52	7.54	2228	2235
	7.58		2246	
	7.53		2231	
21 days	7.58	7.61	2246	2255
	7.61		2255	
	7.64		2264	
28 days	7.64	7.68	2264	2276
	7.68		2276	
	7.72		2287	

Density Test Result for 20%Laterite + 80% Sand

Curing days (Age)	Weight (kg)	Average Weight (kg)	Density (kg/m³)	Average Density (kg/m³)
7 days	7.24	7.20	2145	2145
	7.18		2127	
	7.30		2163	
14 days	7.38	7.34	2187	2176
	7.35		2178	
	7.3		2163	
21 days	7.42	7.42	2199	2198
	7.45		2207	
	7.38		2187	
28 days	7.55	7.51	2237	2225
	7.5		2222	
	7.48		2216	

Density Test Result for 25%Laterite + 75% Sand

Curing days (Age)	Weight (kg)	Average Weight (kg)	Density (kg/m³)	Average Density (kg/m³)
7 days	7.07	7.1	2095	2104
	7.12		2110	
	7.11		2107	
14 days	7.2	7.21	1946	2073
	7.24		2145	
	7.18		2127	
21 days	7.25	7.29	2148	2160
	7.34		2175	
	7.28		2157	
28 days	7.4	7.39	2193	2190
	7.36		2181	
	7.41		2196	

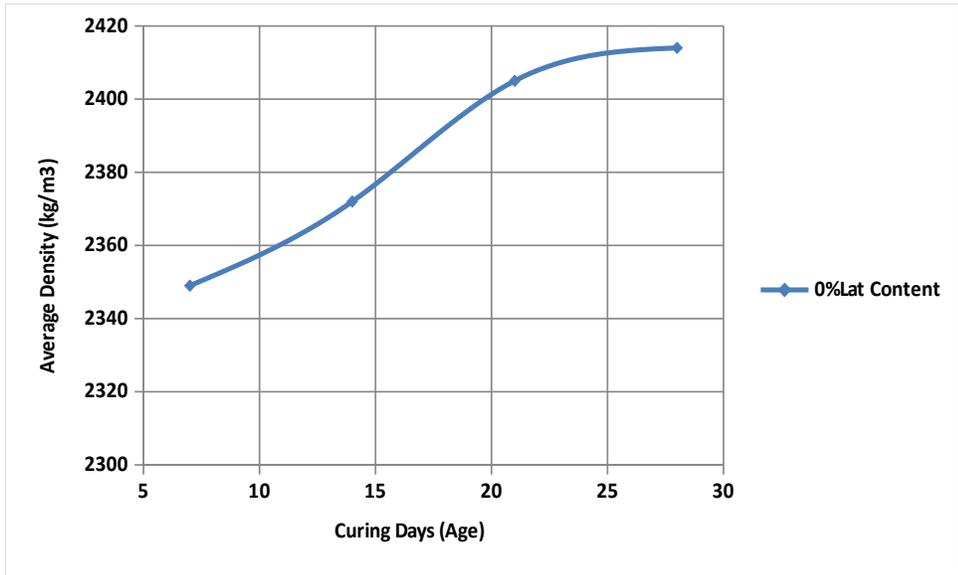


Figure G1: Chart Showing the Average Density of the Concrete against Curing Days at 0% Laterite Content.

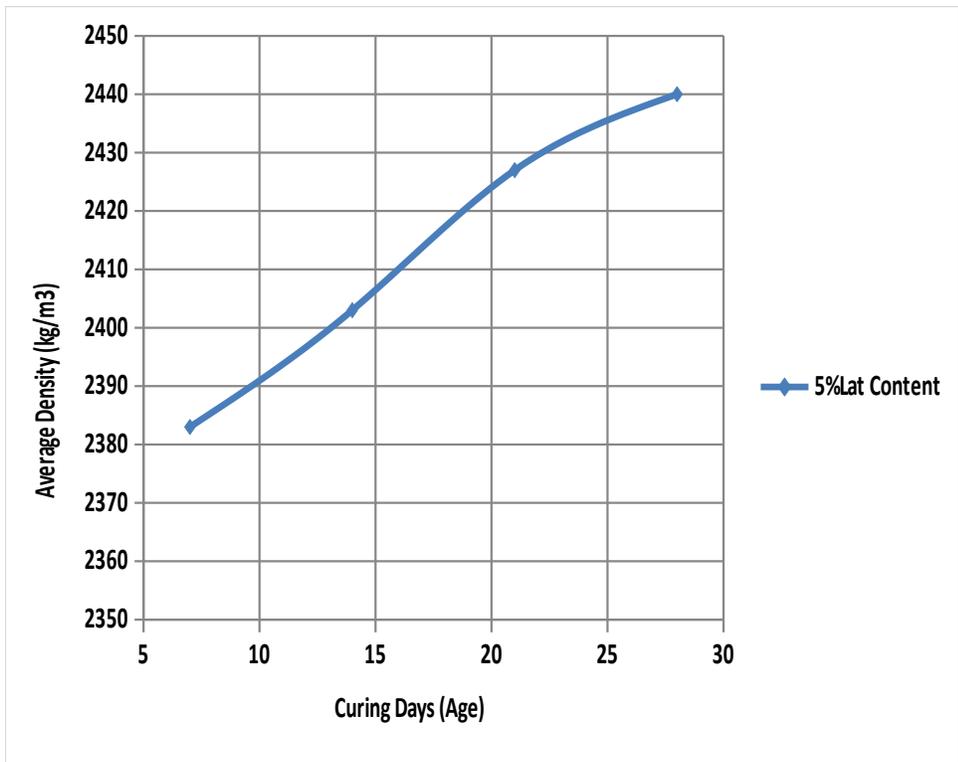


Figure G2: Chart Showing the Average Density of the Concrete against Curing Days at 5% Laterite Content.

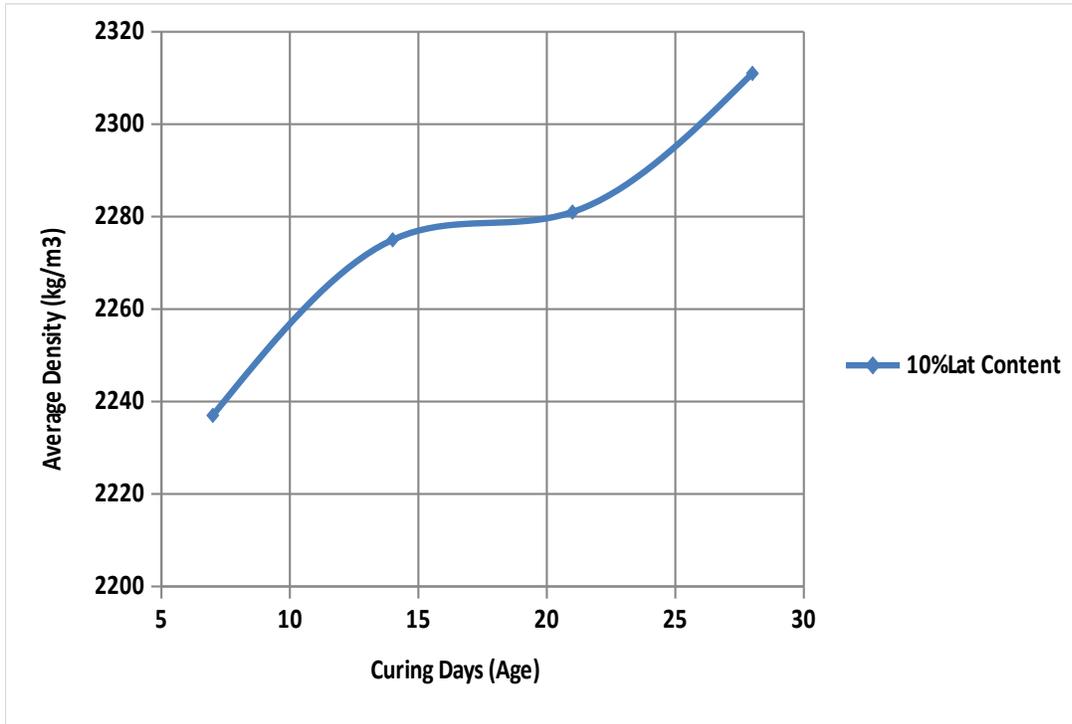


Figure G3: Chart Showing the Average Density of the Concrete against Curing Days at 10% Laterite Content.

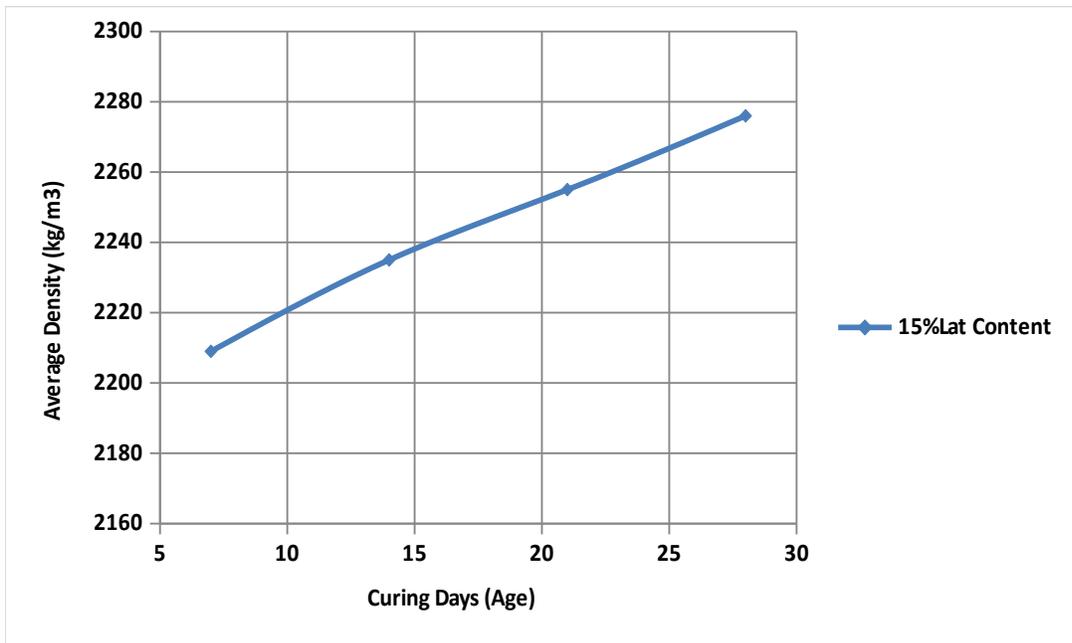


Figure G4: Chart Showing the Average Density of the Concrete against Curing Days at 15% Laterite Content.

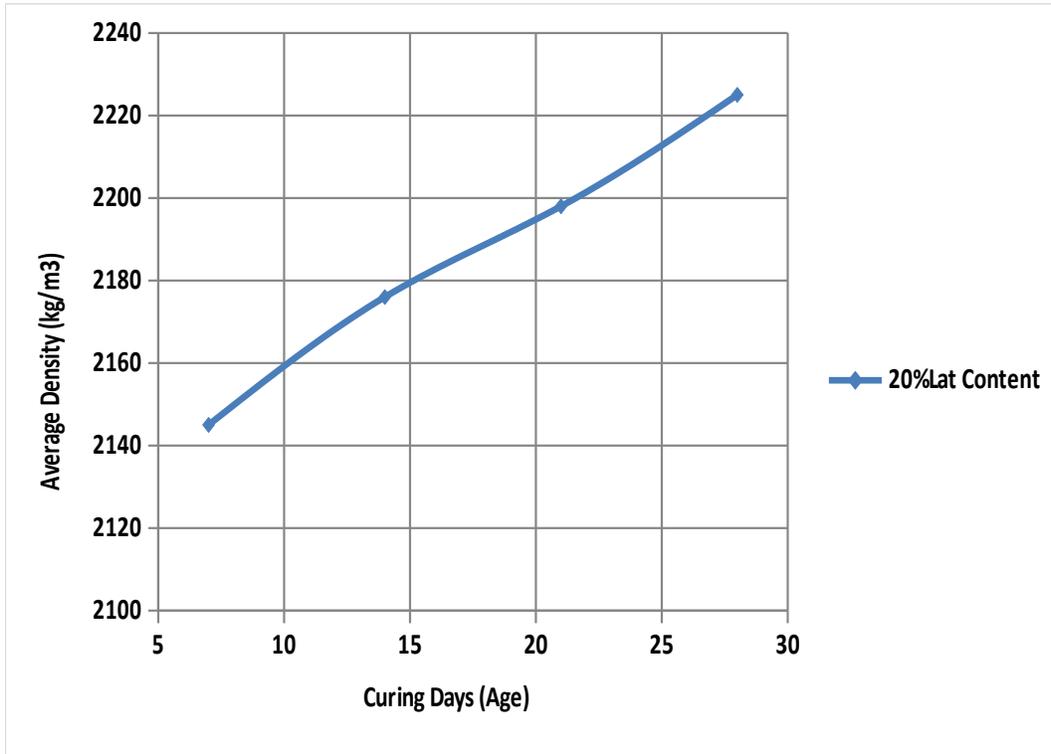


Figure G5: Chart Showing the Average Density of the Concrete against Curing Days at 20% Laterite Content.

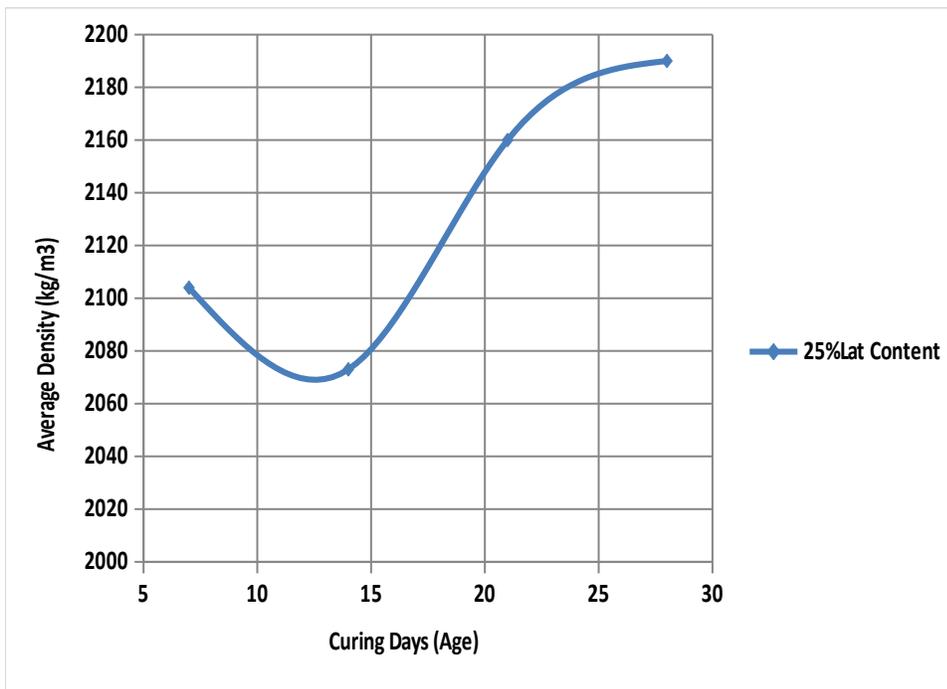


Figure G6: Chart Showing the Average Density of the Concrete against Curing Days at 25% Laterite Content.