



Effect on the Compressive Strength of Concrete Made with its Fine Aggregate Partially Replaced with Laterite Soil

Adeniseun Olaolu F ^{1*}, Akinwunmi Ayoola ², Taiwo Akintayo Joshua ³

¹⁻³ Department of Civil Engineering, Federal Polytechnic, Ile-oluji, Nigeria

* Corresponding Author: Adeniseun Olaolu F

Article Info

ISSN (online): 2582-7138

Volume: 06

Issue: 01

January-February 2025

Received: 06-11-2024

Accepted: 07-12-2024

Page No: 1962-1976

Abstract

In spite of the rise in the cost of river sand which has become quite challenging for low-income households to acquire, rapid increase in infrastructure projects in Nigeria has also led to indiscriminate mining of river sand. The adversely aggrandizement of river sand mining includes river bank erosion, river bed degradation, loss of biodiversity and deterioration of river water quality and ground water availability. Researchers have beamed their searchlight to find substitutes for river sand to be used as fine aggregate in concrete production to address these issues. One of the locally available resources is laterite. Laterite is an abundant soil material which is formed from topical or sub-tropical weathering. The tremendous increase led this study to investigate utilization of lateritic soil from a borrow pit within Ondo state, Nigeria. Area explored for the laterite was Ile-Oluji labelled (Lat. I) in replacement of river sand as fine aggregate and produced laterite-fine aggregate concrete. However, experiment were designed and conducted to study the performance of laterite as partial replacement for river sand to assess the durability performance of this concrete. A lateritic replacement levels of 0, 10, 20, and 30% were prepared in the form of cubes (150 × 150 × 150 mm). The selected laterite soil was subjected to laboratory tests to determine their physical, chemical and mineralogical contents and their results were obtained. The strength and durability assessment of Ile-Oluji lateritic concrete with their control concrete specimen were investigated through compressive strength, splitting tensile strength and sorptivity tests. After water curing for 28 days, the specimens were tested for the determination of compressive strength and durability against water absorption. It was found that concrete with low water absorption can be produced through the integration of 20% of lateritic sand. The result revealed that at 56 days of curing, concrete attained optimum compressive strengths of 11.45 N/mm², respectively for mixtures produced by partially replacing river sand with 10% Lat. I. The sorptivity was optimal at 5.66×10^{-4} mm/min^{0.5} with partial replacement of laterite at 10% Lat. I respectively. Thus, 10% Lat. I gives the optimum strength. The insight gained from this experimental research enables the development of optimized mix designs and predictive models for utilizing laterite as partial replacement for fine aggregate in concrete production.

Keywords: Concrete, Laterite, Fine aggregate and Compressive strength.

Introduction

Concrete as an essential material in civil engineering has remained a widely used ingredient in building construction in Nigeria and around the world. Concrete is used to finish many types of construction project to form various shapes in dams, skyscraper, building foundations, rigid pavements, and hydrostatic structures. Its appeal stems from several characteristics, including its availability, durability, ability to withstand water and adaptability to a range of forms and dimensions. Thus, concrete is often considered as the number one choice material when it comes to building construction. It is essentially appropriate to consider concrete where flexure, strength, adaptability, workability performance, durability, impermeability, fire resistance and abrasion

resistance are required (Garba *et al.*, 2024) ^[20]. Basically, compressive strength and the durability of concretes is important in any concrete works, whereby strengthened by the use of appropriate admixtures. Musonda (2023) ^[26] study concrete as its capacity to uphold axial loads, relate the compressive strength of the concrete to its ability to withstand load before failure, and the durability of concrete is its ability to resist weather action, chemical attack and abrasion. A solid matrix that fills the void between the aggregate particles enhances the binding power of the concrete.

In recent times, however, the upsurge in prices of materials for building construction has raised a lot of concerns due to more utilization of building materials such as fine and coarse aggregates for construction. Sabarish (2015) ^[30] noted that Sand and crushed stone are the major materials employed in concrete production, aside the Ordinary Portland Cement OPC, has been highly exploited in many years due to their importance. Dinh *et al.*, (2022) ^[18] explained that the river sand has a role on concrete's flowability, durability, strength, weight and shrinkage. The river sand closes the pores that present in the concrete, which add to the strength of the concrete. Additionally, river sand reduces volume change that leads to setting and hardening process in concrete, and provides a mass of particles appropriate for resisting the action of applied stresses, resulting in greater durability than that possessed by cement paste alone.

However, restraint caused on the use of river sand in some regions of the world for protecting riverbeds degradation, have resulted in a tremendous increase in the want for alternatives to river sand in building construction (Dinh *et al.*, 2022) ^[18]. Below 5% of the world's river sand supply is suitable for the production of concrete, as river sand may be sometimes too round to stick to the binders (Awoyera *et al.*, 2018) ^[9].

Arum *et al.* (2022) ^[3] posited that the rising cost of river sand is becoming quite a challenge for low-income households to acquire, and this consequently affects the availability of affordable housing for the country's growing populace. Thus, research efforts, in recent times, are being geared towards the revitalization and use of locally and readily available materials, such as laterite, in concrete for building construction. Any effort aimed at reducing the use of river sand will have direct impact in reducing the cost of construction especially housing. This is where laterite finds a significant role to play. Laterite is a product of intense sub-aerial weathering by laterization which involves leaching of alkalis, basis and silica with complimentary enrichment of alumina, iron and some trace elements. In Nigeria, we have abundant varieties of lateritic soils in every region ranging from the normal to conglomerate type of the soil which may be suitable in concrete works. Also, the strength of lateritic soil can be greatly improved upon when stabilized with low contents of cement. Hence, the lateritic soil stabilized with cement can be widely utilized in low-cost building construction, particularly in areas where lateritic soil is abundant. On this note, Awoyera *et al.* (2018) ^[9] encouraged the use of non-conventional aggregate based on the properties of concrete once there is evidence of experimental values made from them.

It is essential to have a thorough understanding of how the various concrete constituents interact with varied properties to achieve a desired properties. Hence, this study seeks to determine the effect of mechanical properties of concrete with fine aggregate partially replaced with Ile -Oluji laterite soil.

Statement of Problem

There has been incessant hike in the cost of fine aggregate used in concrete as a result of high demand and this has posed a challenge in construction of building in Nigeria. It is also evident that laterite soil exists in abundance in most parts of Nigeria which can be employed in concrete work and their incorporation in structural concrete element or system will reduce the cost of fine aggregate tremendously in building construction. According to Jaritngam *et al.* (2013) ^[23], the strength of lateritic soil in laterite-fine aggregate concrete will increase tremendously by stabilizing with low contents of cement. Thus, the lateritic soil stabilized with cement can be widely used as a low-cost concrete particularly in areas where laterite is dominantly present.

Furthermore, the excessive mining of river sand, has resulted in erosion which has led to the destruction of some buildings. Sankh *et al.* (2014) ^[32] noted that excessive river-sand mining for use as fine aggregate in concrete is responsible for riverbed degradation which causes a wide range of problems, including the loss of water-holding soil strata and the slippage of riverbanks. In some areas river sand and dune sand which are used as fine aggregate in concrete production have not been readily available for concrete production (Ukpata *et al.*, 2012) ^[35]. Hence, there is a need to discover and develop the body of knowledge on the application of alternative materials that will be environmentally conservative and economically viable to mitigate the aforementioned problems.

Aim of the Research

The aim of this research is to determine the effect on the mechanical properties of concrete with fine aggregate partially replaced with Ile-Oluji laterite soil.

Objective of the Study

The specific objectives are to:

- determine index and chemical properties of different laterite types;
- evaluate the compressive strength and durability properties of lateritic concrete produced from different laterite types; and
- develop statistical models for prediction of compressive strength and durability of concrete produced from different laterite.

Justification of the Study

The cost of building materials in construction varies from place to place and year to year. This dwindling scenario has unseemly placed some constraint in the execution of plans as regards building construction. Since laterite is a paramount material in the construction of structural buildings, its incorporation in concrete should be considered as recovery measures to reducing the cost of fine aggregate in building construction. It is also pertinent to note that, laterite absorb less heat and pollution which makes it suitable for most foundations and walls. Unnikrishnan (2013) ^[36] noted that, laterite soils are environmentally friendly materials and the incorporation of laterite in the construction projects can significantly reduce the cost. Buildings constructed of earth materials are indeed the most common affordable accommodation since earth materials are readily available almost anywhere on the planet. It has also been known that the use of laterite in concrete production generates lesser amount of heat in buildings compared to the conventional river sand (Joseph *et al.*, 2012) ^[24].

To justify the claims of this research work, theoretical analysis and experimental field approach will be employed to evaluate the suitability of lateritic soil as a partial replacement of river sand in concrete for building construction.

Scope of the Study

This research will focus primarily on the suitability of lateritic soil as a partial replacement of fine aggregate in concrete. It will involve a systematic approach to determining the properties of laterite soil in terms of its strength, elasticity, and workability when partially mixed with ordinary Portland cement, fine aggregate, coarse aggregate and water.

On the note that, laterite is readily available in Ile-Oluji, Ondo state, Nigeria with different properties, and detailed study of these properties will be subjected to laboratory tests to determine its strength and durability.

Limitation of the Study

The study assessed the limits or strengths of its application and specify measures to be taken for an improved performance of Ile-Oluji laterite.

Literature Review

Partial or total replacement of concrete component has been the direction of research on alternative building materials development. One of such is laterized concrete. Laterized concrete is defined by concrete in which the fine aggregate component is lateritic soil (Obioma, 2023) ^[28], and characteristics of laterized concrete have been widely investigated. The recommendations are in support of laterite as suitable for use in the construction industry. The need for a thorough knowledge on the characteristics and suitability of lateritic soil in concrete, including the laterized concrete strength and stiffness, cannot be underestimated if an economical and safe construction will be achieved. The behaviour of laterite soil is essentially frictional, compressible and largely inelastic (Gowda *et al.*, 2018) ^[21]. (Sivalingam *et al.*, 2024) ^[33] asserted that the replacement level of sand by laterite up to 40% for laterized concrete attained the strength of 20N/mm². This posed for their recommendation of concrete made up of laterite for the construction of buildings and rural infrastructures.

There is an abundance of lateritic soil all over the world, especially in tropical regions with high characteristic rainfall and persistently high temperatures. The typical regions of occurrence of laterite apart from Nigeria includes India, Burma, Indonesia, Malaysia, Australia, Africa and interior parts of South America (Muthusamy *et al.*, 2015) ^[27]. An extensive area of Nigeria is covered with laterite materials in various weathered states, ranging from clay laterite, sandy laterite to rock laterite. In local construction practice, these materials are variously used mainly in blocks production, road fills and as fine or coarse aggregates in concrete production. Lateritic soils according to Mengue *et al.* (2018) ^[25], are widely used as construction material in Nigeria and other under-developed and developing countries of the world. However, they argued that laterites have not been extensively used in constructing medium to large-size building structures, probably because of lack of adequate data needed in the analysis and design of structures built of lateritic soils. This underscores the need for more research efforts in this area. Udoeyo *et al.* (2010) ^[34] also proposed that in a concrete mix ratio of 1:2:4:0.56 (cement: sand: coarse aggregate: water/

cement ratio), sand can be replaced with laterite up to 40% replacement level with promising strength results. This indicates the possibility of using laterite as a partial replacement for sand up to 40%. Adebola and Aluko (2022) ^[1] also noticed from their research that the workability of laterite concrete increased with increase in the replacement level of sand by laterite, while the compressive, split tensile, and flexural strengths and the percentage water absorption of the concrete decreased with increase in the replacement level of sand. They recommended laterized concrete for the construction of buildings and rural infrastructures.

Origin of Laterite Soil

Laterite soil is rich in aluminum and iron that formed in wet and hot tropical regions. Almost all laterites are reddish due to the presence of iron oxides Muthusamy *et al.* (2015) ^[27], Laterite is often confused with lateritic soil; lateritic soils are fine-grained materials than the laterite. An important physical difference between laterite and lateritic soil is that laterite has a gravel component but a lateritic soil is free from gravel. According to Joseph *et al.* (2012) ^[24], the soil name "laterite" was given by Buchanan (1807) in India, from a Latin word "later" meaning brick. Laterite is used extensively in the construction of embankments for roads and earth dams.

Laterite is generally defined as a highly weathered material rich in secondary oxides of iron, aluminum or both. It is nearly devoid of bases and primary silicates but may contain large amounts of quartz and kaolinite. It is a group of mineral materials formed as the degradation products of certain igneous rocks and composed mainly of hydrated oxides of aluminum, iron and titanium $\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ (gibbsite), HF_6O_2 (geothite) $\text{FeO}(\text{OH})$ (Lepidocrocite) and Fe_2O_3 (hematite) (Gowda *et al.*, 2018) ^[21]. Laterites are formed from the leaching of parent sedimentary rocks, metamorphic rocks and igneous rocks which leaves the more insoluble ions of mainly iron and aluminum (Ilangovana *et al.*, 2008) ^[22]. Aliyu *et al.* (2023) ^[2] ascertained those lateritic soils are groups of soil riched in iron where they are formed in hot and wet tropical regions. Generally, all lateritic soils are developed by severe weathering of the parent rock, and they are mostly reddish-brown coloration due to the presence of intense iron oxides content. Laterite soils constitute about one-third of the earth's land sections. Geology of Nigeria by (Oluwatuyi *et al.*, 2019) ^[29] describes laterites Made up of three layers, a basal lateritic clay, a middle laterite gravel and a surface crust. He further explained types of laterites as laterite crust which has a cellular texture and that is difficult to break with a geologists' hammer otherwise, light explosives may be required to excavate this nature of laterite. It is usually found on top of flat-topped hills or as boulders on slope surfaces. Also, laterite gravel, is a type of laterite that may be found below a layer of laterite crust. At some locations, the gravel deposit is only covered by a thin layer of soil. Laterite gravel is usually plastic. Additionally, laterite Clay is also a kind of laterite often located below the gravel or the crust, and usually above the weathered basement. It has a very rich reddish-brown color, with patches of pinkish white material (Kaolinite). Flakes of micas are visible in hand specimens. It is usually employed in the earthen dam construction.

However, there are different variation of lateritic soils in terms of fineness, plasticity, rate of water absorption and air space. These proponents vary from region to region. This is shown in Figure 2.1.

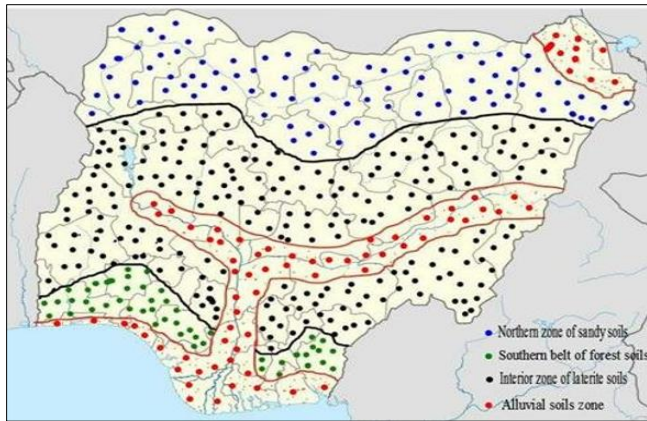


Fig 2.1: Distribution of Lateritic Soils in Nigeria

Composition of Laterite

Laterite is composed of both cohesionless and cohesive soils. This forms the basis of laterites being referred to as C- ϕ (C-Phi) soils. The cohesionless portion consist of gravel, sand and silts while the cohesive portion includes fine particles usually in silt and clay sizes. Lateritic soils behave in a unique way with some laterites changing volume when exposed to humidity variations while others are not affected. Mengue *et al.* (2018) ^[25] described the properties of each of these components of lateritic soil as follows:

Gravels

Gravels composed of fragments of rock of varying hardness, whose size fall between 2 -20 mm with stable mechanical properties when it comes in contact with water.

Sands: composed of mineral particles, with size ranging between 0.06 - 2 mm. Stable, though lacks cohesion when dry, it has an appreciable degree of internal friction, which means, it offers a great resistance (i.e. mechanical) to intra-particle movement. It is normally characterized by apparent cohesion when wet due to the surface tension of the water present in the void spaces.

Silts

Silt consists of grain particles ranging from 0.002 to 0.06 mm; cohesion is low when dry and it offers lower resistance to intra-particle movement than sands. Silts are characterized by cohesion in wet condition and susceptible to swell and shrinkage on exposure to varying levels of humidity, leading to appreciable change in volume. In the dry state, they have very poor cohesion and therefore cannot be used independently as main material for building.

Clay

Clay is the finest of the particle sizes in lateritic soil, generally smaller than 0.002mm. Their characteristics differ completely from the larger sized particles in that they consist mainly of microscopic clay minerals which include: kaolinite, illite and montmorillonite.

Formation of Lateritic Soil

Laterite is soil and rock rich in iron and aluminum that is considered to have formed in hot, humid tropical settings. Tropical weathering (laterization) is a prolonged process of chemical weathering which produces a wide variety in the thickness, grade, chemistry and ore mineralogy of the resulting soils. The initial products of weathering are essentially kaolinized rocks called saprolites. A period of active laterization extended from about the mid-Tertiary to

the mid-Quaternary periods (35 to 1.5 million years ago). Statistical analyses show that the transition in the mean and variance levels of ^{18}O during the middle of the Pleistocene was abrupt. It seems this abrupt change was global and mainly represents an increase in ice mass; at about the same time an abrupt decrease in sea surface temperatures occurred; these two changes indicate a sudden global cooling. The rate of laterization would have decreased with the abrupt cooling of the earth. Weathering in tropical climates continues to this day, at a reduced rate. Laterites are formed from the leaching of parent sedimentary rocks (sandstones limestone clays) metamorphic rocks (schists gneisses, migmatites) igneous rocks (granites basalts, gabbros, peridotites); and mineralized proto-ores which leaves the more insoluble ions, predominantly iron and aluminum. The mechanism of leaching involves acid dissolving the host mineral lattice, followed by hydrolysis and precipitation of insoluble oxides and sulfates of iron, aluminum and silica under the high temperature conditions of a humid sub-tropical monsoon climate. An essential feature for the formation of laterite is the repetition of wet and dry seasons. Rocks are leached by percolating rain water during the wet season; the resulting solution containing the leached ions is brought to the surface by capillary action during the dry season. These ions form soluble salt compounds which dry on the surface; these salts are washed away during the next wet season. Laterite formation is favored in low topographical reliefs of gentle crests and plateaus which prevents erosion of the surface cover. The reaction zone where rocks are in contact with water from the lowest to highest water table levels is progressively depleted of the easily leached ions of sodium, potassium, calcium and magnesium. A solution of these ions can have the correct pH to preferentially dissolve silicon oxide rather than the aluminum oxides and iron oxides. Silcrete has been suggested to form in zones in relatively dry "precipitating zones" of laterites. To the contrary, in the wetter parts of laterites subject to leaching ferricretes have been suggested to form. The mineralogical and chemical compositions of laterites are dependent on their parent rocks. Laterites consist mainly of quartz, zircon, and oxides of titanium, iron, tin, aluminum and manganese, which remain during the course of weathering. Quartz is the most abundant relic mineral from the parent rock. Laterites vary significantly according to their location, climate and depth. The main host minerals for nickel and cobalt can be either iron oxides, clay minerals or manganese oxides. Iron oxides are derived from mafic igneous rocks and other iron-rich rocks; bauxites are derived from granitic igneous rock and other iron-poor rocks. Nickel laterites occur in zones of the earth which experienced prolonged tropical weathering of ultramafic rocks containing the ferro-magnesian minerals olivine, pyroxene, and amphibole.

However, laterisation is a major crisis of the natural process and hence, generation of laterite soil is unavoidable and uncontrolled. The fine particulates of laterite soil cause air pollution to the surrounding locality. Meanwhile we currently exploit large amount of raw materials from limited natural resources that causing sustainability issues. As a result, the quantum of laterite soil increases year by year enormously. To overcome these issues, a feasible solution is to utilize laterite soil as an alternative source of sand aggregates raw material for construction applications. This review discusses the geotechnical, chemical and mineralogical characterization of laterite soil and its potential applications in the construction sector.

Characteristics of Laterite Soil

The significant features of the lateritic soils are their unique color, poor fertility, and high clay content and lower cation exchange capacity. In addition, lateritic soils possess a great amount of iron and aluminum oxides.

- Laterite soil is red or yellow in colour.
- Laterite soil is formed by rapid leaching action caused by tropical heavy rainfall.
- Laterite soil is rich in silica and salts.
- Lime, phosphorus and potash are found in small amounts in laterite soil.
- Laterite soil is suitable enough for bacteria.

Fine Aggregates and its Qualities

Fine aggregates are essentially any natural sand particles won from the land through the mining process. Fine aggregates consist of natural sand or any crushed stone particles that are $\frac{1}{4}$ " or smaller. This product is often referred to as $\frac{1}{4}$ ' minus as it refers to the size, or grading, of this particular aggregate. Fine aggregate (Sand) Fills voids between aggregates. It forms the bulk and makes mortar or concrete economical. It provides resistance against shrinking and cracking. It is naturally available.

Qualities of fine aggregates

- Fine aggregate should be clean i.e. it should be free from lumps, organic material, etc.
- It should be strong and durable.
- It should not react with cement after mixing.
- Also, it should have a tough floor.
- It should not absorb greater than 5% of water.

Type of Fine Aggregate and their Size

The classification of aggregate based on sizes is shown in Table 2.1

Table 2.1: Classification of aggregates and size

Fine Aggregate	Size (mm)
Coarse Sand	2.0-0.5
Medium sand	0.5-0.25
Fine sand	0.25-0.06
Silt	0.06-0.002
Clay	0.002

Properties of Fine Aggregates

- Fineness modulus:** The fineness modulus is the measure of the overall fineness of sand. It is calculated using the sieve analysis. The fineness of sand determines the proportion of sand in the concrete mix. It is an essential factor influencing the quality of concrete.
- Moisture content:** The moisture content of the sand determines the cement-water ratio for making concrete. All aggregates have their respective porosity and moisture content (based on their storage/procurement areas). Fine aggregates have four different moisture conditions: oven-dry, air-dry, saturated-surface dry, and wet. Fine aggregate in wet conditions can hold 5% moisture. It can cause bulking problems while forming concrete. Ideally, the moisture content of sand for construction works should not be more than 5%.
- Specific Gravity:** Specific gravity is calculated by dividing the solid density of sand particles by the density of water. Heavier sand particles have higher specific gravity. It creates higher-density concrete. At the same time, lower specific gravity sand particles create low-density concrete. Bulk-specific gravity helps determine the proportion of materials required in the concrete

mixture. It measures the volume of aggregate particles in concrete based on the solid aggregates and voids between them.

- Silt content:** is measured by wet-sieving of sand. The particles that pass through a 75- micron sieve are classified as silt. Ideally, the silt content of sand should not be more than 3% by weight. The silt demands a higher water/cement ratio. It results in low strength and poor workability of concrete.
- Grading zone of fine aggregates:** The grading zone measures the percentage of fine aggregate that can pass through the 600 microns sieve. It helps in assessing the quality of fine aggregates for different uses.
- Impurities:** There are two types of common impurities in the sand – organic and inorganic. Organic pollutants such as vegetative waste, hummus, animal decay, etc., are present in the sand extracted from riverbeds. Inorganic impurities commonly exist in the form of silt and clay. Both organic and inorganic pollutants require thorough washing of the sand before use in concrete.

Present Status of Research

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 building construction industry. Working on shrinkage deformations of laterized concrete, Salau and Balogun (2014) advise that laterized concrete that is enriched with 25% laterite content of the aggregate can be used in load-bearing structural elements. Materials of different source may vary in their properties to make concrete of stipulated qualities, an intimate knowledge of the interaction of such materials that will go into the making concrete is required to be known both in the fresh and hardened concrete. This knowledge is important for concrete technologists also for site engineers (Sajeev *et al.*, 2017) ^[31]. Mixture of laterite with conventional concrete components provides an inimitable material for construction that is profitable for use in construction industry (Arum *et al.*, 2022) ^[3]. Salau and Balogun (2014) also recommended that 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 that compressive strength of not less than 25 N/mm² was obtained at 28 days for the mix with laterite content of about 25-50%, through a combination of crushed granite, sharp sand and fine laterite with cement. Yuan *et al.* (2024) showed that normal concrete cannot withstand appreciable load above 250°C while laterized concrete with 25% laterite in the fine aggregate is able to resist higher load with increase in age and temperature up to 500°C. They achieved compressive strength of up to 30.44N/mm² for laterized concrete with 25% laterite and 75% sand at 500°C. According to Salau and Balogun (2014), laterized concrete can be classified as normal weight concrete as the density of all test specimens of 28 day curing age exceeds 2000 Kg/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) ^[34] that 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.

Further research conducted by Adebola and Aluko (2022) ^[1] opined that the 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) was

compared with that of normal concrete. He concluded 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 Sajeev *et al.* (2017) [31], lateritic soil abounds locally and its use mainly limited to civil engineering work like road construction and land fill operation. It is less utilized in the building industry except in filling work. In lieu of abundant of lateritic soil and its availability, its optimum use is building production could positively affect the cost of building leading to the production of more affordable housing units (Ogunleye, 2023) [19]. Its use in the building production is not yet generally accepted because there are no sufficient technical data in it, hence limited its wider applicability in building construction work (Udoeyo *et al.*, 2010) [34]. However, they are limited to using it as sub grade material and filling material in road construction and as a building block in some places. Along with some laboratory experimental studies on replacement of fine aggregate by laterite soil in concrete was done by some researchers. To the best of author's knowledge, there have been no systematic studies reported on the processing and characterization of lateritic soil, to obtain good quality lateritic fine aggregates, to be used in concrete.

Materials and Methods

Materials

The various natural and raw processed materials that were employed in this study were presented and described fully in this chapter to aid the robustness of this research work.

Laterite soil

In this study, laterite soils beneath the earth surface was sourced from borrow pit of Ile-Ojuji for a depth between 500 mm – 1500 mm. The choice of these locations was as a result of presence of abundance laterites on the virgin region and there are numerous building structures that are coming up from these axes of which these laterite soils can be employed in their concrete works by the site engineers. Grade 15 concrete was adopted to produce concrete cubes of 150 mm × 150 mm × 150 mm for each laterite type to partially replace river sand. Furthermore, 200 mm × 100 mm and 100 mm × 50 mm of cylindrical concrete for splitting tensile strength and sorptivity water absorption.

Fine aggregate

River sand of size range finer than 4.75-micron aperture size was used as fine aggregate. This contains airspace and locally sourced within Akure, Ondo state, Nigeria.

Coarse aggregate

The coarse aggregate used in this study was 15 mm size and it comprises of unified crushed stone, which was sourced from local quarry within Ondo state. The aggregate satisfied British Standard recommendations (BS 882, 1992).

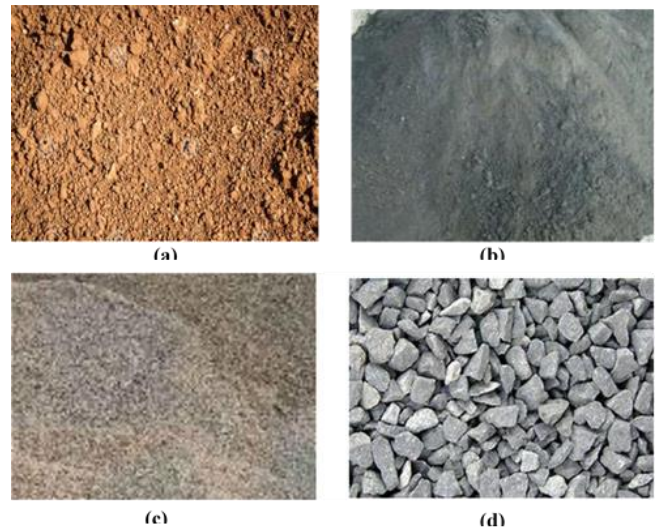


Plate 3.1: (a) Laterite (b) Cement (c) Fine Aggregate (d) Coarse Aggregate

Water

The potable water employed for this study was obtained from borehole within the campus of the Federal Polytechnic, Ile-Oluji, Ondo state, Nigeria. The sourced water was used for mixing the laterite concrete. The water satisfied the requirements of concrete mixing water that is free from any suspended particles as noted in British standard (BS EN, 1997).

Apparatus and equipment

Tools or equipment are basic needs that aid the smooth conduct of any research or project works, these proffer safety, accuracy and reliable result that will be in accordance with the relevant code of practice. Some of the major tools and equipment used in the course of this study is highlighted as follows,

a. Slump cone

Slump cone is the equipment used to test fresh hydraulic-cement concrete, which is known as concrete slump test. The tools were used to determine the workability of fresh concrete in accordance with (BS EN 12350-2, 2009a).

b. Cube mold

The cube mold that conformed with (BS EN 12390-2, 2019) was employed for the preparation of hardened concrete. The molds were coated lightly inside, that aided the easy removal of the specimen after 24 hours of casting.

c. weighing scale

The scale tool used for the measurement of materials that is in-line with BS EN 12390-2:2019 was employed accurately. The usage was conformed to the standard application for the calibration of weighing materials for the utilization of hard concrete.

d. Compressive strength test machine

Usage of compressive strength testing machine on hard

concrete is very paramount to determine the concrete strength. In this study the guideline for the use of code (IS 14858, 2000): requirements for compressive testing machine were adopted.

e. Vicat apparatus

The vicat apparatus used in this study followed the path of (BS EN 197-1, 2000). The apparatus was employed for testing the setting times of cement. The process adhere with the standard that enveloped the needs of the apparatus utilized for determination of consistency of standard cement paste, initial and final setting times.

f. Shovel

Shovel is a tool used for digging, lifting, and moving bulk materials, such as soil, coal, gravel, snow, sand, or ore. Most shovels are hand tools consisting of a broad blade fixed to a medium-length handle. Shovel blades are usually made of sheet steel or hard plastics and are very strong.

Methods

Material preparation

Prior to the use of the materials for production of laterized concrete samples, certain preparatory measures were put in place to ensure the materials be in good condition for use. The following were the measures taken on each material.

Mix design

The mix design was done for the purpose of concrete casting of various mixes with the help of all the above preliminary investigation test outcomes as shown in Tables 3.1 and 3.2.

Table 3.1: Mix Proportion of concrete

Material	Quantity (kg/m ³)
Cement	2.2
Fine Aggregate	7.5
Coarse Aggregate	24.7
Water	1.32

Table 3.2: Specific mix proportion for the lateritic concrete

Cement (kg/m ³)	Laterite (%)	Fine Aggregate (kg/m ³)		Coarse Aggregate (kg/m ³)
		Sand	Laterite	
2.2	30	5.25	2.25	24.7
2.2	20	6.0	1.5	24.7
2.2	10	6.75	0.75	24.7
2.2	0	7.5	0	24.7

Material testing and characterization

Various tests were done on the materials to aid their use in this study these includes physical, chemical, and mechanical tests, which described as follows:

Specific gravity, and water absorption of aggregates

The specific gravity, water absorption of fine and coarse aggregates were carried out following the procedure of (BS EN 1097-6, 1995) by weighed the jar plus sample plus water.

Atterberg limits

Each of the soils were subjected to laboratory test to determine their basic measurement of the critical water contents of a fine-grained, its shrinkage limit, plastic limit, and liquid limit in accordance with (BS 1377, 1990). Depending on its moisture content, soil may appear in one of four regions solid, semi-solid, plastic and liquid. In each region, the consistency and behavior of soil are different, and therefore, it is applicable to engineering properties. Also, the boundary between each region can be defined based on a

change in the soil's behavior. These resulted firstly by weighed of an empty can followed by weighed the wet sample plus the can which were later oven dried for 24 hours with their values been taken. The specimen was weighed again after oven dried to determine the moisture content of the sample. This process was repeated for all the samples as shown in Plate 3.2. The liquid limits were achieved for the samples by pounding the oven dried specimen and sieved using sieve 425 aperture to get 200 g of soil followed by adding little water to form pest and covered the pest with polythene for 24 hours. The sample were later taken and rolled to obtain 100 mm long and 3 mm in diameter for plastic limits before taken to it moisture content can and subject the sample for oven dried again, and water was added and later subjected the sample to Casagrande machine to observe its closeness. Between 18 to 20 blows sample was taken to determine their shrinkage limits.



Plate 3.2: Laboratory process of Atterberg limits test

Particle gradation

Particle gradation (particle size distribution) test is an essential test used for establishing the workability requirement of concrete mix. In this study, the British standard sieve sizes in accordance with the requirements of (BS 812-2, 1996) was adopted to determine particle gradation, by separation of material samples into common fractions. The wet sieving method was adopted, and soil samples of 100 g were sieved using sieve number 200 or 75 micron following by oven dried the sample at 100 °C for 24 hours. The sieves were arranged in a chronological order of opening with the pan supported at the base to enable collect the finest part of the sample soil that was not retained any sieve. Each sample retained by the sieves were collected, weighed and divided by percentage of weighed sample, and their values were used as obtained percentage weight retained. These process were repeated on all the aggregates.

$$\text{Fineness modulus, } F_m = \frac{\sum(\text{Cumulative percentage retained on specified sieve})}{100}$$

$$\text{Coefficient of uniformity, } C_u = \frac{D_{60}}{D_{10}}$$

$$\text{Coefficient of gradation, } C_c = \frac{D_{30}^2}{D_{60} \times D_{10}}$$

Where D_{60} is the diameter of soil particles for which 60% are finer and 40% are coarser, D_{30} is the diameter of soil particles for which 30% are finer and 70% are coarser, and D_{10} is the diameter of soil particles for which 10% are finer and 90% are coarser.

Workability

Mostly in cementitious mixed workability tests such as slump, compacting factor and Vee-Bee, are usually carried out on fresh concrete mixes in order to determine the suitability of the mixture for the required construction application. Only slump and compacting factor tests were performed in this study, and it was in accordance with the requirements of ((BS EN 12350-2, 2009b) after mixing the concrete specimen the slump cone was arranged and poured the concrete inside the cone in three layers to get to the brim, by applied 15 blow in every layer using tamping rod, the surface of the cone were clean and the slump value were taken for the control sample of the concrete as shown in Plate 3.3. The fully compacted control sample were later transferred to compacted apparatus to determined its partially compacted values, and these processes were repeated for all the laterite concrete.



Plate 3.3: Concrete slump test and compaction processes

Concrete curing

In every good concrete works strength development is attributed to proper curing of the concrete by permitting the hydration of ordinary Portland cement that acted as a binder for strength development, (Olawuyi *et al.*, 2020). In this study, portable water were used to cured all the cubes including the cylindrical concretes inside the curing tank for their appropriate curing age attainments.

Strength of Laterized Concrete

Concrete that contains laterite as its admixture in different proportion required strength and durability determination to ascertain it used performance. Compressive strength is the

ability of material or concrete to carry the loads on its surface without any crack or deflection (Mathew and Paul, 2014). Its formula for any material is the load (P) applied at the point of failure to the surface area (A) of the face on which load was applied. This implies that, stress (σ) will set in on the surface of the concrete, and this will be mathematically stated in equation as:

$$\sigma = \frac{P}{A}$$

Where P is the applied load (N), A is the surface area (mm²), and σ is the stress resultant (N/mm²).

This test were performed on the specimen as explained above based on American Society for Testing Materials ASTM C39/C39M (2000). The mixing of the concrete cube test were conducted manually at the concrete laboratory. Firstly, cement and fine aggregate were mixed together on a watertight none-absorbent platform until the mixture is thoroughly blended and is of uniform colour, coarse aggregate was added and mixed together with the sand-cement mixture until the coarse aggregate are uniformly distributed throughout the batch. Then, water was added and the process continued until the concrete appears to be homogeneous and of the desired consistency.

With the sampling of cubes for test, each mold was cleaned, with oil applied fairly on the internal surfaces to allow easy removal of the specimen after 24 hours of casting. The specimen were filled into the molds in layers of approximately 5cm thick and each layer were compacted with 25 stroke using bullet nus of 16 mm in diameter and 600 mm long followed by levelling the top surface, smoothening and labelling as shown in Plate 3.4. After 24 hours, the test specimens was demolded and submerged in water for curing under conducive temperature for specified curing ages. The tests on hardened laterized concrete performed during this study were highlighted as follows.

Compressive Strength

A control specimen containing a mixture of 100% of river sand, Ordinary Portland Cement, coarse aggregate and water were used to cast concrete cubes of 150 mm × 150 mm × 150 mm sizes as shown in Plate 3.4, and cured for a period of 7, 14, 28 and 56 days under the temperature of 24°C, with relative humidity of 92% for the specified curing duration. Their compressive strengths were determined. Other specimens were also prepared by replacing river sand (fine aggregate) with each type of lateritic soil at 10%, 20% and 30% for production of laterized concrete cubes with their compressive strengths determined in line with the aforementioned curing ages. A total of 48 cubes of concrete were cast, as summarized in Tables 3.3 and 3.4 respectively. This follows the production of triplicate samples on each mixed, and their average strength of a triplicate were taken as the strength property of the concrete at the respective age. Mass of each specimen cube were taken after 24 hours of removing the concrete cubes for every age of curing period then, compressive strength properties of the concrete specimens were determined using an Universal Testing Machine (UTM).



Plate 3.4: Showcasing the mixture of laterite concrete cubes specimen

Table 3.3: The trials and percentages of Ile-Oluji lateritic soils

Trial	Type C of Lateritic Soil
1	10%
2	20%
3	30%

Table 3.4: Mix Proportion of Concrete Admixture for Each Curing Period.

Series	Cement replace. (%)	River sand replace. (%)	Coarse aggregate replace. (%)	Laterite replace. (%)	Curing days	No. of cubes
Control	100	100	100	00	7,14,28 and 56	12
Lat. I ₁₀	100	90	100	10	7,14,28 and 56	12
Lat. I ₂₀	100	80	100	20	7,14,28 and 56	12
Lat. I ₃₀	100	70	100	30	7,14,28 and 56	12
Cubes total	-	-	-	-	-	48

Split Tensile Strength

Concrete cylindrical specimens of diameter 100 mm and length 200 mm was produced using already mixed concrete specimens and filled them inside the cylinder into a triplicate section and compacted with a desired number of blows as shown in Plate 3.5. The cylindrical concretes were then cured for a specified curing age, later subjected them to tensile testing machine in order to determine their splitting tensile

strengths that is in accordance with (ASTM, C496 / C496-04). Their splitting tensile values were calculated using the following equation

$$split = \frac{2p}{\pi LD} \text{ (N/mm)} \quad (3.2)$$

Where P is the applied force (N), L is the length of sample (mm), and D is the diameter of the sample (mm).



Plate 3.5: Splitting tensile strength concreting process

Durability Assessment

Durability of concrete is to determine how the concrete can resist weathering action, chemical and abrasion in order to maintain its desired engineering properties. The concrete durability depend on the degree of environmental exposure and properties desired. The performance of sorptivity test using water was adopted in this study to measure the rate of absorption of water into unsaturated concrete through capillary suction.

Sorptivity for water absorption test

The sorptivity tests was conducted in accordance with (ASTM, C1585). Using concrete specimens of size 100 mm in diameter and 50 mm height obtained from the prepared concrete mixes. The cylindrical concretes were taken and placed into an evaporation chamber at $100 \pm ^\circ\text{C}$ and 80% relative humidity for three days, the surface of the oven dried

concrete specimens were sealed via melted candle wax leaving only one face which was meant to contact liquid to enable for one-directional flow liquid. After coating the concrete samples, the initial weighed were taken as (W_1) then the samples were kept partly immersed to a depth of 5 mm in liquid for 30 minutes as shown in Plate 3.5. Then the concrete samples were removed and blotted off the excess liquid on its surface and took the final weighed as (W_2) therefore, change in mass ΔW (g) at time t (min), area at which the specimen surface was exposed A (mm^2) and density of water d (g/mm^3) were utilized to calculate the sorptivity values for the concretes by using the following equation Jayeshkumar and Umrigar, (2013):

$$s = \frac{I}{2t}$$

Where: $I = \Delta w / Ad$

Δw = change in weight = $W_2 - W_1$

A = surface area of the specimen subjection for water penetration
d = density of water.

t = time exposed (m)
S = rate of sorptivity (mm/min)



Plate 3.5: Various sections of sorptivity and water absorption laboratory test.

Results and Discussion

Laterized Concrete Laboratory Assessment

All laterite samples collected were investigated in the laboratory and various test were carried out to determine their physical and chemical properties, which were described as shown in Plate 4.1. The laterite soil obtained from Ile-Oluji laterite (Lat. I) goes with reddish-brown coloured. Their weights followed by their inherent liquid limit, plastic limit, plastic index and as well as linear shrinkage were determined, the summary of their results were tabulated showed in Table 4.1. Each laterite were employed to cast the concrete that contains laterite-fine aggregate (Lafacon) where the river sand were substituted by each laterite at 10%, 20% and 30%. The laterite-fine aggregate concrete (Lafacon) were utilized to cast 36 concrete cubes used to investigate compressive strength of the concrete, 36 cylindrical concrete of 200 mm by 100 mm sizes to checkmate the split tensile strength on the concrete together with 36 quantities of 100 mm by 50 mm sizes of cylindrical concrete to determine the sorptivity water absorption of the concrete.

Atterberg Limit

Table 4.1 shows the classification characteristics of the laterite used and the liquid limit, plastic limit, plasticity index, and linear shrinkage were evaluated for the laterites. The Lat. I values were also evaluated as 15.50, 4.35, 11.10, and 9.10 respectively. Based on AASHTO system of soil classification, the laterite used is classified to be A-2-6 which is silty or clayey gravel and sand.

Table 4.1: Values of Atterberg Limits

Laterite types	Liquid limit %	Plastic limit %	Plastic index %	Linear shrinkage (mm)
Lat. I	15.50	4.35	11.10	9.10

Particle Gradation

The results of the particle gradation carried out on the fine aggregates (river sand) and laterite as shown in the particle size distribution curves in Figures 4.1 and 4.2 respectively revealed that the soils are well-graded. Also, BS 882:1992-2002 specified that at least 86% of the particles of fine aggregate should pass 5.00 mm metric sieve and not more than 15% should pass through the 0.150 mm metric sieve for sand, conditions to which the two aggregates complied. The fineness modulus is an empirical factor which were found to be the same for fine aggregate and Lat. I as 2.0 (see Tables 4.2 and 4.3). Also, coefficient of uniformity of the fine

aggregate and Lat. I were obtained as 4.35 while their coefficient of gradation were obtained as 2.54. According to ASTM C136/C136M-19, fineness modulus of fine aggregate range from 2 to 4. Hence, all the four samples fell within the range but Lat. I. This may in part be responsible for the increase in strength observed in a good number of the specimens when laterite was incorporated into the concrete. From the values of uniformity coefficient and coefficient of gradation obtained, they show that the soil is well graded because the value of C_u is between 4 and 6 while C_c is between 1 and 3.

Table 4.2: Control Values for Sieve Analysis

Sieve size	Weight retained (g)	Percentage weight retained (%)	Percentage passing (%)
Cover	-	-	100
4.75	0.80	0.80	99.20
2.36	1.50	1.50	97.70
1.70	0.80	0.80	96.90
1.18	1.90	1.90	95.00
0.425	27.00	27.00	68.00
0.212	34.10	34.10	33.90
0.150	18.40	18.40	15.50
0.075	1.20	1.20	14.30
Pan	14.30	14.30	00.00

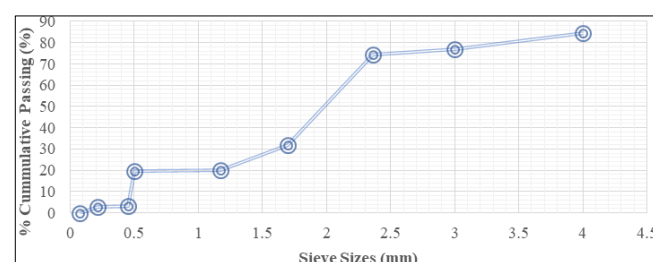


Fig 4.1: Particle Size Distribution Curve of river sand finer

Table 4.3: Lat. I Values for Sieve Analysis

Sieve size	Weight retained (g)	Percentage weight retained (%)	Percentage passing (%)
Cover	-	-	100
4.75	14.10	7.05	92.95
2.36	10.50	5.25	87.70
1.70	2.30	1.15	86.55
1.18	6.40	3.20	83.35
0.425	35.70	17.85	65.50
0.212	15.90	7.95	57.55
0.150	6.70	3.35	54.20
0.075	1.40	0.70	53.50
Pan	107.00	53.50	0.00

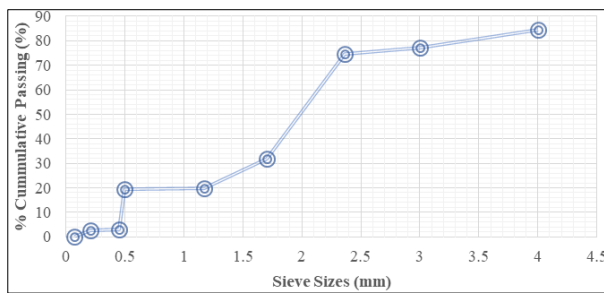


Fig 4.2: Particle Size Distribution Curve of Lat. I

Effect of Average Weight on the Lateritic Concrete Strength

The constituent of concrete that contains laterite-sand coarse aggregate plus ordinary Portland cement was done by mixed of 40 kg of river sand which was been replaced by 10%, 20%, and 30% of laterite respectively in each of the laterite types with cement of 20% and coarse aggregate of 80% values kept constant in all the trials as showed in Table 4.4. In this study, It was noticed that increase in river sand replacement in every trial led to the increase in volume of water required in every mixed of concrete specimen, this happened as a result of the rate of plastic contents that present in laterite compare to its counterpart at which it was been replaced.

Table 4.4: Average weight of Lat. I

Control (%)	Weight of OPC (kg)	Weight of river sand (kg)	Weight of laterite (kg)	Weight of coarse (kg)	H ₂ O (Kg)	Fully compact (kg)	Partially compact (kg)	Slump (cm)
Lat. I								
10	20	36	4	80	15.3	17.6	16.7	6
20	20	32	8	80	18.8	17.4	17.0	5
30	20	28	12	80	21.5	17.4	16.6	5

Effect of Laterite on the Compressive Strength of Concrete

In this section, the effect of river sand partially replaced with laterite on the compressive strength of lateritic concrete was discussed. Also, the laterite has significant effect on the compressive strength of lateritic concrete. With an increase in the lateritic content from 0% through 10, 20 to 30%, it was observed that there was a slight drawdown in the compressive strength before picking up again for the various curing ages. The compressive strength of Lat. I₁₀ specimen with 10% laterite has the highest strength of 11.45 N/mm² at 56 curing age. Also, at 56 curing age, a difference of 4.49 N/mm² in strength increment were evaluated which resulted in 64.8% compressive strength gain by Lat. I₁₀. Therefore, it can be concluded that Lat. I having the same properties as used in this research can conveniently be used to replace river sand up to 10% as fine aggregate in concrete without fear of any considerable loss in strength.

Effect of Curing Age on Compressive Strength of Lateritic Concrete

The control sample for this experiment contains Ordinary Portland Cement (OPC) as the only binder, and fine aggregate. However, the fine aggregate was varied with a replacement level up to 30% by laterite. The concrete was expected to gain strength with age (see Table 4.5, 4.6, 4.7, and 4.8). However, all the concrete specimen increased in compressive strength from 7, through 14, 28 to 56 days. The maximum strength of 11.45 N/mm² was obtained from the mix containing 10% laterite (Lat. I₁₀) at 56 days. The average strength gain for all the control mixes (0%) up to 30% lateritic content after 7 days of curing was 52.9% of the age 14th day, 50.9% of the 28th day, and 0% of the 56th day strength. Hence, the rate of strength gained reduced with age. The values of compressive strength at 7-, 14-, 28-, and 56-days against control at different replacement levels. It was observed that Lat. I that replaced river sand by 10% has close range of strength of 7.6 N/mm² to their control concrete sample than other types of laterite used for the study. The average strength value of Lat. I increases than the other lateritic concrete samples. The value of control concrete sample decreases and recorded as 10.64 N/mm² while lateritic concrete sample at 20% replacement Lat. I recorded as at 14 days of curing age.

Table 4.5: Summary of average compressive strength of the concrete at age 7

Replacement %	Weight (kg)	Density (kg/m ³)	Load at failure (N)	Strength (N/mm ²)
Control 0	8.3	2449.38	199160	8.90
Lat. I ₁₀	8.1	2390.12	170260	7.60
Lat. I ₂₀	8.3	2449.38	148870	6.60
Lat. I ₃₀	7.9	2350.61	105580	4.70

Table 4.6: Summary of average compressive strength of the concrete at age 14

Replacement %	Weight (kg)	Density (kg/m ³)	Load at failure (N)	Strength (N/mm ²)
Control 0	8.30	2449.37	239400	10.64
Lat. I ₁₀	8.00	2370.37	193200	8.60
Lat. I ₂₀	7.33	2291.36	213200	9.50
Lat. I ₃₀	8.13	2409.87	178380	7.80

Table 4.7: Summary of average compressive strength of the concrete at age 28

Replacement %	Weight (kg)	Density (kg/m ³)	Load at failure (N)	Strength (N/mm ²)
Control 0	8.50	2427.67	235580	10.50
Lat. I ₁₀	8.20	2348.64	166920	7.40
Lat. I ₂₀	8.40	2407.90	201040	8.93
Lat. I ₃₀	8.30	2459.26	172590	7.67

Table 4.8: Summary of average compressive strength of the concrete at age 56

Replacement %	Weight (kg)	Density (kg/m ³)	Load at failure (N)	Strength (N/mm ²)
Control 0	8.00	2370.37	156530	6.96
Lat. I ₁₀	8.20	2429.62	258260	11.45
Lat. I ₂₀	8.23	2449.37	245370	10.90
Lat. I ₃₀	7.93	2362.83	187260	5.57

Effect of Laterite on the Split Tensile Strength of Lateritic Concrete

The average splitting tensile strength at the age of 7, 14, 28, and 56 days of all mixes are shown in Tables 4.9, 4.10, 4.11, and 4.12. The result of each replacement level is the average

of three cylindrical samples. The tensile strength showed an increasing pattern for 7, 14, 28, and 56 days when the percentage replacement increases up to 15.9% and 17.5% and starts to increase by 10% and 30% for Lat. I had a 14% higher tensile strength than the control mixes at 20%. The reduction

in strength as the percentage of replacement increase is was due to the silty content of the laterite. As the loading increased, the crack started to form within the concrete cylindrical samples. The smooth texture of the laterite allows the crack to propagate faster once loaded.

Table 4.9: Summary of average split tensile strength of the concrete at age 7

Substitut (%)	Mass (kg)	Load (N)	Splitting tensile strength (N/mm ²)
Control 0	3.20	40700	1.30
Lat. I ₁₀	2.50	26800	0.80
Lat. I ₂₀	1.80	21600	0.60
Lat. I ₃₀	1.60	18300	0.50

Table 4.10: Summary of average split tensile strength of the concrete at age 14

Substitute (%)	Mass (kg)	Load (N)	Splitting tensile strength (N/mm ²)
Control 0	3.71	54300	1.70
Lat. I ₁₀	4.00	41400	1.30
Lat. I ₂₀	4.30	49400	1.50
Lat. I ₃₀	3.90	39400	1.20

Table 4.11: Summary of average split tensile strength of the concrete at age 28

Substitute (%)	Mass (kg)	Load (N)	Splitting tensile strength (N/mm ²)
Control 0	4.10	30377	32.00
Lat. I ₁₀	4.60	56556	29.00
Lat. I ₂₀	4.30	70695	36.50
Lat. I ₃₀	4.20	43551	25.00

Table 4.12: Summary of average split tensile strength of the concrete at age 56

Substitute (%)	Mass (kg)	Load (N)	Splitting tensile strength (N/mm ²)
Control 0	4.20	20579	65.90
Lat. I ₁₀	4.10	43506	45.60
Lat. I ₂₀	4.10	14781	47.34
Lat. I ₃₀	3.80	60378	30.33

Effect of Laterite on the Sorptivity of lateritic Concrete

Sorptivity was carried out to determine the concrete durability. Tables 4.13, 4.14, 4.15, and 4.16 show the change in water absorption as a function of the square root of time on various lateritic replacement of 10, 20, and 30% for Lat. I. It

was observed that Lat. I decreases in sorptivity with the curing age up to 14 days. However, 10% replacement level of Lat. I was found to increase the sorptivity by 66% at 28-day curing age. Hence, it can be concluded that the sorptivity rate in 10% Lat. I has long term sorptivity.

Table 4.13: Average values of sorptivity test at 7 days

Samples. (%)	W ₁ (g)	W ₂ (g)	ΔW (g)	Sorptivity × 10 ⁻⁰⁴ (mm/min ^{0.4})
Control 0	1148.33	1179.00	30.67	7.13
Lat. I ₁₀	1140.33	1166.00	25.67	5.97
Lat. I ₂₀	976.00	1002.66	26.66	6.20
Lat. I ₃₀	1029.00	1056.00	27.00	6.28

Table 4.14: Average values of sorptivity test at 14 days

Samples. (%)	W ₁ (g)	W ₂ (g)	ΔW (g)	Sorptivity × 10 ⁻⁰⁴ (mm/min ^{0.4})
Control 0	1136.66	1160.33	23.67	5.50
Lat. I ₁₀	1079.30	1098.00	19.00	4.42
Lat. I ₂₀	1001.00	1015.00	14.00	3.25
Lat. I ₃₀	969.67	991.00	21.33	4.96

Table 4.15: Average values of sorptivity test at 28 days

Samples (%)	W ₁ (kg)	W ₂ (kg)	ΔW (kg)	Sorptivity × 10 ⁻⁰⁴ (mm/min ^{0.4})
Control 0	1095.00	1115.33	20.33	4.73
Lat. I ₁₀	1095.33	1122.66	27.33	6.35
Lat. I ₂₀	1052.33	1073.33	21.00	4.88
Lat. I ₃₀	957.66	982.33	24.67	5.73

Table 4.16: Average values of sorptivity test at 56 days

Samples. (%)	W ₁ (g)	W ₂ (g)	ΔW (g)	Sorptivity × 10 ⁻⁰⁴ (mm/min ^{0.4})
Control (0)	1181.33	1196.00	14.67	3.41
Lat. I ₁₀	2255.00	2279.33	24.33	5.66
Lat. I ₂₀	974.00	986.66	12.66	2.94
Lat. I ₃₀	1099.66	1115.33	15.66	3.64

Model Development

Regression models were developed to predict the compressive strength of lateritic concrete at 7, 14, 28, and 56 days. A regression model was proposed to predict the compressive strength of Lat. I. for the prediction model, we have the dependent variable as compressive strength and the independent variables outlined as S_c represents compressive strength, L as liquid limit, P as plastic limit, S as shrinkage limit, S_t as split tensile strength, S_o as sorptivity, S_L as slump, R as lateritic percentage replacement. Some of the predictors such as liquid limit, plastic limit, shrinkage limit, curing days, and sorptivity were found to be constant which indicates that they have insignificant implication on the prediction model. The output from the model showed that the relationship between the independent and dependent variables was significant at $F(3, 14) = 68.859$, $p = 0.000$. Furthermore, the variation accounted for the result of the model is 93.7%. Therefore, the model showing curing days as predictors is significant as a prediction model ($\beta_0 = 9.560$, $p = 0.000$ for percentage replacement, $\beta_0 = 1.2$, $p = 0.000$ for curing age, $\beta_0 = 2.713$, $p = 0.000$ for split tensile strength) with correlation coefficient of 0.999866. The model to predict the compressive strength C as a function of the predictors is stated in Equation 4.1 while the corresponding compressive strength prediction model is expressed in Equation 4.2. The data gotten from the regression analysis are shown in Table 4.17.

Three general regression equation for the compressive strength for the days is expressed thus:

$$S_c = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_5 + a_6x_6 + \dots + \text{intercept} \quad (4.1)$$

$$S_{\text{Lat.C}} = 0.146842S_t + 0.042868R_p + 2.712895 \quad (4.2)$$

Where S_t is the split tensile strength, S_L is the slump, and R_p

is the percentage replacement while $S_{\text{Lat. I}}$ are the compressive strength of the lateritic concrete for Lat. I.

4.10 Model Evaluation

Model evaluation is very important in data analysis. Three main metrics were used for evaluation in this model namely, R square/Adjusted R square, mean square error (MSE)/root mean square error (RMSE), and mean absolute error (MAE). Hence, the only challenge with regression analysis is that the number of observations cannot be the same as the number of samples.

4.10.1 R Square

From Table 4.18, it was through the R square metric that most of the values tends toward 1.0 which is an indication that there is a better fit between predicted and actual value. The best R^2 obtained was 1.0 at 28th day for of Lat. I.

4.10.2 Root Mean Square Error

Root Mean Square Error (RMSE) was used to identify the differences between the actual and predicted values. For a good fit, their value should be close to zero. By comparison, RMSE gives outlier more weight by squaring to amplify deviation. Therefore, RMSE is more sensitive to outliers and reflects the variation of error.

Table 4.17: Summary Output of Lat. I regression Statistics

Regression Statistics	
Multiple R	1
R Square	1
Adjusted R Square	65535
Standard Error	0
Observations	3

Table 4.18: ANOVA Statistics of the Observations of Lat. I

Laterite Type		df	SS	MS	F	Significance F
Lat. I	Regression	9	1.3338	0.1482	#NUM!	#NUM!
	Residual	0	0	65535		
	Total	9	1.3338			

4.10.3 Correlation

The correlation coefficients for the sorptivity and split tensile

strength are shown in Tables 4.19 and 4.20 while the interrelated correlation is shown in Tables 4.21.

Table 4.19: Correlation Coefficients on Sorptivity

Correlation	Curing Age	Control	Lat. I ₁₀	Lat. I ₂₀	Lat. I ₃₀
Curing Age	1				
Control	-0.93973	1			
Lat. I ₁₀	0.19197	-0.02562	1		
Lat. I ₂₀	-0.64072	0.780358	0.60379	1	
Lat. I ₃₀	-0.85122	0.853871	0.343862	0.909778	1

Table 4.20: Correlation Coefficients on Split Tensile Strength

Correlation	Curing Age	Control	Lat. I ₁₀	Lat. I ₂₀	Lat. I ₃₀
Curing Age	1				
Control	0.987637	1			
Lat. I ₁₀	0.962124	0.988061	1		
Lat. I ₂₀	0.924019	0.960347	0.991833	1	
Lat. I ₃₀	0.906764	0.946566	0.984947	0.998949	1

Table 4.21: Correlation Coefficients of Lat. I

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	2.712895	0	65535	0	2.712895	2.712895	2.712895	2.712895
Liquid Limit	0	0	65535	0	0	0	0	0
Plastic Limit	0	0	65535	0	0	0	0	0
plastic Index	0	0	65535	0	0	0	0	0
Linear Shrinkage	0	0	65535	0	0	0	0	0
Weight	0	0	65535	0	0	0	0	0
28 day slit tensile strength	0.146842	0	65535	0	0.146842	0.146842	0.146842	0.146842
Sorptivity	0	0	65535	0	0	0	0	0
Slump (mm)	0	0	65535	0	0	0	0	0
Percentage Replacement	0.042868	0	65535	0	0.042868	0.042868	0.042868	0.042868

Conclusion and Recommendations

Conclusion

The following conclusions were drawn from the result of the investigations:

- The compressive strength of all laterite concrete specimens increased with age but decreased with increase in the replacement level of sand.
- The compressive strength of lateritic concrete cubes at the rate of all days was optimized at 30% lateritic sand.
- The split tensile strength of lateritic concrete cylinders at the rate of all days was optimized at 30% lateritic sand to increase the strength by 14% of Lat. I at 20%.

Recommendations

It is recommended that Lat. I. at 10% yields long-term optimal compressive strength.

Contribution to Knowledge

This research work has developed a regression model for predicting the compressive strength and durability of concrete containing laterite of different index properties. Also, enlightens contractors the basic assessment factors needed to be considered during the production of Ile-Oluji lateritic concrete. Furthermore, it provide the range of the index properties of laterite for which its inclusion cause an increase in the strength or durability of concrete and the range for which a reduction occur.

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