# EVALUATION OF PROPERTIES OF LATERITE - RICE HUSK FIBRE CEILING TILES PRODUCED WITH LOCUST BEAN POD SOLUTION AS BINDER

**BY**

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**MTECH/SET/2018/8338**

**DEPARTMENT OF BUILDING**

**FEDERAL UNIVERSITY OF TECHNOLOGY**

**MINNA**

**NOVEMBER, 2023**

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**A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF TECHNOLOGY IN CONSTRUCTION TECHNOLOGY.**

**NOVEMBER, 2023**

# DECLARATION

I hereby declare that this thesis titled **“Evaluation of Properties of Laterite - Rice Husk Fibre Ceiling Tiles Produced With Locust Bean Pod Solution As Binder’’** is a collection of my original research work and it has not been presented for any other qualification anywhere. Information from other sources (published or unpublished) and their contributions has been duly acknowledged**.**

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# CERTIFICATION

The thesis titled **“Evaluation Of Properties Of Laterite - Rice Husk Fibre Ceiling Tiles Produced With Locust Bean Pod Solution As Binder’’** by Neku, Mathew Ndoma (MTECH/SET/2018/8338) meets the regulations governing the award of the degree of Masters of Technology (M.Tech) of the Federal University of Technology, Minna and it is approved for its contribution to scientific knowledge and literary presentation.

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# DEDICATION

This work is dedicated to THE ALMIGHTY GOD, who made Heaven and the Earth, the one who was, who is and who is to come. He gave me the grace to be among the living. May His name be praised forever.

# ACKNOWLEDGMENT

Glory be to God for the great things he has done, the one who was, who is and who is to come. He gave me the grace to be among the living. May His name be praised forever. He bestowed His mercies on me in countless ways and saw me through the successful completion of this program. To him I shall forever be grateful.

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# ABSTRACT

The pursuit for locally sourced economical and environmentally safe materials has been on the increase in the development of composite ceiling tiles over the years. These locally sourced materials are organic materials from plants and livestock such as rice husk, locust bean pod, feathers, maize husk and bamboo fibre. Therefore, this study incorporated laterite (LAT) and Rice Husk Fibre (RHF) in the development of composite ceiling tiles. The ceiling tiles were developed from Laterite-Rice Husk Fibre (LAT-RHF) using Cement and Locust Bean Pod Solution (LBPS) as the binders. The ceiling tiles were made by varying the composite percentage composition of the LAT-RHF (70/30, 60/40, 50/50, 40/60 and 30/70). The LAT-RHF to binder ratio was fixed to 0.6 while the LBPS at 50 g/l, 30 g/l and 10 g/l concentrations were incorporated using 400 x 400 x 40 mm specimens for the density and water absorption tests. 450 x 450 x 75 mm for the strength properties tests (compressive and flexural)in accordance to ASTM D7433 (2013) and ASTM C367/C367 (2009)Standards. Constant pressure of 5MN/m$^2$ was used for the process using manual pressing. The specimens were allowed to cure for 14 days after oven-drying for 24 hours under the temperature of 80$^0$C. The physico-mechanical properties (such as moisture content, density, water absorption, compressive and flexural strength) were evaluated. The results revealed that all the samples shows an increase in flexural strength as the LAT contents increases and the RHF decreases. The mix incorporating 60% LAT and 40% RHF, had the best performance for flexural strength at 50 g/l, 30 g/l and 10 g/l LBPS concentrations having strength values 0.75 N/mm$^2$, 0.72 N/mm$^2$ and 0.68 N/mm$^2$ respectively. There is greater increase in the rate of water absorption from 2hrs duration when compared to 24 hours duration with a value of 25%. It was discovered that the higher the concentration of the LBPS the lower the water absorption. An increasing trend of water absorption rate was also observed with an increase in fibre contents up to 70% with a mix incorporating 70% RHF exhibiting the highest water absorption at all LBPS concentrations incorporation levels 50, 30 and 10 g/l LBPS respectively). Furthermore, Higher increase was discovered in the densities from 1100 kg/m$^3$ (70:30) to 1200 kg/m$^3$ (60:40), and which consecutively decreased to 1050 kg/m$^3$ (50:50), 950 kg/m$^3$ (40:60) and 910 kg/m$^3$ (30:70) as the laterite replacement also decreases from 70% to 50%, subsequently to 40% and 30% at 50 g/l LBPS concentration while a comparable trend was maintained in its compressive strength performance. Therefore, a binary blend of LAT: RHF with 60/40 and 70/30 compositions (LFBCT$_2$ and LFBCT$_1$) should be adopted at 50 g/l LBPS concentrations for good strength performance.

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| RHF | Rice Husk Fibre |
| LBPW | Locust Bean Pod Waste |
| LBPS | Locust Bean Pod Solution |
| PC | Portland Cement |
| OPC | Ordinary Portland Cement |
| S-S | Silica Sesquioxide |
| ($CO_2$-e) | Carbon Dioxide Emission |
| (C-S-H) | Calcium Silicate Hydrate |
| (C-A-S-H) | Calcium Alumino-Silicates Hydrate |
| (N-A-S-H) | Sodium Alumino-Silicates Hydrate |
| $SiO_3$ | Silica or Silicon Dioxide |
| $Al_2O_3$ | Aluminium Oxide |
| $Fe_2O_3$ | Iron Oxide |
| CaO | Calcium Oxide |
| XRF | X-ray Florescence |
| BS | British Standard |
| ASTM | American Standard for Testing Materials |

# CHAPTER ONE

# 1.0 INTRODUCTION

## 1.1 Background to the Study

Building is one of the products of technology and an essential need of every member of a society according to Agbede *et al*. (2016). Relatively, building should not be costly to procure and should provide necessary comfort for the users. A building is made up of the structure itself and the non-structural components like cladding, interior walls and ceilings. According to Bachman and Dowty (2008), many structural components assembled on site to make up building include ceiling tiles, partition walls and exterior curtain walls. Thus, a building is composed of various components including ceiling tiles that serve different purposes for the building users (Agbede and Joel, 2011; Nnamdi, 2011).

Chuldley and Greeno (2014) also stated that, ceiling is one of the secondary elements (non-structural components) in a building which is attached to the underside of suspended floor or roof above. Hence, ceiling has its own functions in buildings. On the other hand, CGC (2010) reveals some functions of ceiling that include aesthetics, acoustic control, durability, fire-resistance, thermal insulation and accessibility to the plenum in the case of drop ceilings. However, to achieve some of the functional needs of a ceiling tile, the ceiling tiles must possess good workability property. The workability property enables further manipulation of ceiling tiles to attain desired good outlook and easy fixing during construction (Kartini, 2011; Onyemachi, 1994). To achieve effective performance of ceiling tiles, effective material with suitable properties is needed.

Seeley (2010) stated that, the common materials used for ceiling tiles/boards are asbestos, wood (solid or manufactured), Polyvinyl Chloride (PVC) and Plaster of Paris (POP). South

African Building Interior System Association, SABISA (2013) outlined standard materials for use in ceiling construction as plasterboard, plasterboard cove cornice, softwood rendering and batten, fibre-cement board and softwood studs for timber frame in buildings. These outlined materials possess different properties that include absorption of moisture and swelling, brittleness, fibrous and high cost. Such characteristics pose problems of maintenance/procurement and health to the building owners and users, as the materials to be used in construction of a building are not expected to endanger human health in any form, both during construction and while dwelling in the building (Occupational Safety and Health Administration, OSHA, 2002; Seeley, 2010; SABISA, 2013). OSHA (2002) stated that asbestos particles enter human body through inhalation which can cause disabling or fatal diseases such as asbestosis, an emphysema-like condition, lung cancer, mesothelioma, a cancerous tumor that spreads rapidly in the cells of membranes covering the lungs and body organs and gastrointestinal cancer. Hence, the need for affordable and safe local materials.

Wood work activities in Nigeria has resulted in uncontrolled toxic waste. This uncontrolled waste is associated with the atmospheric air and consists of pollutants such as dusts and particles (Ohijeagbon *et al.*, 2021). A report has shown that daily generation of wood residue in Nigeria is estimated at 104,000 $m^3$ and 294,000 tons per year (Ohijeagbon, 2012). Several years later, Ohijeagbon *et al.* (2021) stated that as at 2010, an estimated value of 5.2 million tons of wood residue was produced each year in Nigeria. Hence, there is an increased pollution and environmental waste rate. Ceiling boards are commonly made from agro-industrial wastes particles including planar shavings, wood chips, and sawdust, which are obtained from wood waste.  as well as other organic materials such as corn cobs, rice husks, rice straw, feathers, sugarcane bagasse, and so on (Kim, 2019). Previous studies, Kumar

(2012); Aguwa et al., (2015); Aguwa, (2010); Aguwa, (2012); Akabi *et al.*, (2005); Hassan & Umar (2005); Hombostel, (1991); Okunlola *et al*., (2011) revealed that wood species such as beach pine, scots pine and Norway spruce have been in use in the development of ceiling boards. The wood species exhibited a good durability and strength properties. Portland cement on the other hand is with its detrimental effect of ozone depletion due to the carbon-dioxide emission ($CO_2$) thus, necessitate its augmentation that now led to the development and incorporation of Locust Bean Pod Solution (LBPS).

However, this present work aims at using laterite, rice husk as fibre and African locust bean pod solution (LBPS) as alternative binder to Portland cement for the development of LBPS/cement bonded ceiling tiles. The use of available local materials can help in the waste disposal management problems by converting waste into wealth.

## 1.2 Statement of the Research Problem

Housing production in Nigeria nowadays is accompanied with numerous challenges which includes cost of construction materials, high demand for housing and lack of promotion of the use of locally and naturally available material as reported by Agbede *et al*. (2016). These may be accounted to lack of practical knowledge on the applications of locally available materials. The demand for ceiling materials in building industry has increased over the years as a result of over dependence on the modern (conventional) building materials, which are so expensive that low income earners cannot afford to building houses of their own. As a result, converting agricultural wastes into use in construction industry will provide alternative binder, less expensive ceiling materials which is within the reach of the low-income earner.

Also, as a performance standard, it is recommended that thermal conductivity of ceiling boards should be within 0.50-0.15 kW/MK (Ebeh, 1997). All types of asbestos fibers are known to cause serious health hazards to humans. Amosite and crocidolite are considered the most hazardous asbestos fiber types; however, chrysotile asbestos has also produced tumors in animals and is a recognized cause of asbestosis and malignant mesothelioma in humans, and mesothelioma has been observed in people who were occupationally exposed to chrysalis, family members of those that are occupationally exposed, and residents who lived close to asbestos factories (Adewumi & Olalusi, 2017). Asbestos ceiling boards are fragile, pose health risks and relatively costly. Therefore, there is a compelling need to produce alternative products that are cheap, using local organic materials that could pose little or no health hazards. (Badejo & Giwa, 1985; Biju *et al*., 2018).

As a result, Rice husk and Locust bean solution are the main basic raw materials for this research work with laterite and locust bean husk considered as waste materials and the commonest disposal method is incineration. The main focus of this study is to further explore the potentials in the use of inexpensive and locally available waste materials in the production of low-cost building materials that are environmentally friendly as well as enhance waste-to-wealth principle (Dhanalakshmi, 2015).

## 1.3 Aim and Objectives of the Research

The aim of this study is to evaluate the properties of laterite-rice husk fibre ceiling tiles produced with locust bean (*Parkia Biglobosa*) pod solution (LBPS) as binder with a view to promoting the use of alternative materials for sustainable building production.

The specific objectives are to:

i) Examine the characterization and production of the ceiling tiles prototypes

ii) Study the impact of LBPS and laterite-rice husk fibre proportions on the density of ceiling tiles

iii) Determine the effect of LBPS and laterite-rice husk fibre proportions on the ceiling tiles water absorption performance

iv) Evaluate the influence of LBPS and laterite-rice husk fibre on the strength (compressive and flexural) performance of the ceiling tiles.

## 1.4 Scope of the Study

This study was mainly an experimental work towards developing an alternative binder for ceiling tiles production using locust bean pod solution (LBPS) as alternative binder to Portland cement stabilizing laterite and Rice Husk Fiber (RHF) at varied mix proportions (70:30, 60:40, 50:50, 40:60, and 30:70) using 10, 30 and 50g/l of LBS concentrations as affirmed in the work of Aguwa and Okafor, (2012) to have better performance when compared with other concentrations as reported that the higher the concentration of the LBPS the higher the strength performance. Furthermore, the work also involved appropriate characterization (particle size distribution, X-ray florescence, specific gravity, plastic limit, liquid limit, plasticity index, moisture content) of the constituent materials. Evaluation of hardened properties (density, water absorption, compressive and flexural strength) of the ceiling tiles was carried out after 14 days of curing in accordance with the work of Ohijeagbon *et al*. (2021).

## 1.5 Significance of the Study

The outcome of this research offers information on the utilization Locust Bean Solution, Rice Husk Fiber and laterite as an alternative binder in ceiling board production. The utilization of the LBS, RHF and laterite as binder will lead to the reduction of the amount of waste generated, reducing pollution due to alkaline taint and sustainable material with low $CO_2$ emission will be achieved. Many recent studies on the search for alternative binders for the production of ceiling board, concrete and mortar had been centered on the partial replacement of the conventional material (cement, glass fibers and iron fills) with pozzolans such as Rice Husk Ash (RHA), (Kim, 2019; Agbede *et al*., 2016; Kartini, 2011; Jimoh & Apampa, 2014) and others utilize laterite due to its high percentage of $SiO_2$ as partial replacement of cement (Joshua, 2016; Vladimir *et al.*, 2011; Biju *et al.*, 2018; Ola, 2013; Adebisi *et al.*, 2013; Kolapo *et al.*, 2007; Ma & Eggleton, 1999; Alao, 1983).

The challenge, therefore, is not only to source alternative cementitious materials but a great deal of research is required to explore major and significant processing and reactivity issues with a view to establishing performance level in strength and durability of ceiling board made from such binders which will also be environmentally friendly. The results of this study will impact on the industry by opening new research opportunities, thus adding to the knowledge-base on the development of alternative binder for ceiling board production. This will also add more potential for modified cement products to the industry that can be of the same use as a binder. Looking from the standpoint of energy saving, the utilization of alternative binders to cement as a construction material is now a worldwide issue.

## 1.6 Limitations of the Study

This study will evaluate the properties of Laterite Rice Husk Fiber Ceiling Tiles produced with Locust Bean (*Parkia Biglobosa*) solution as Binder. The tests carried out was limited to Particle Size Distribution, X-ray Fluorescence, Liquid Limit, Plasticity Index, Moisture content, Specific gravity, Density, Water absorption and Flexural strength as the machines and equipment's required for tests such as Acoustics, Sound resistance and Fire resistance was not readily available. Tests on yield line patterns were not a subject in this study.

# CHAPTER TWO

# 2.0 LITERATURE REVIEW

## 2.1 Ceiling Tiles

Ceiling tiles are horizontal slab covering the upper section of a room or internal space. A ceiling board is generally not structural but is a shell concealing the details of the structure. However, the ceiling might be holding up building materials such as heat or sound insulation while in modern buildings, electric lights, smoke detector, security cameras and signage are commonly attached to ceilings (Ohijeagbon, 2012; Kim, 2019; Ohijeagbon *et al.*, 2021).

Ceiling boards are commonly made from agro-industrial wastes particles including planar shavings, wood chips, and sawdust, which are obtained from wood waste. They can as well be made from other organic materials, which are corn cobs, rice husks, rice straw, feathers, sugarcane bagasse, and so on (Kim, 2019). Ceiling boards are engineered plane piece of wood product used to shield an upper part of an enclosed space, adding beauty and aesthetics to the space. It helps to protect a space from the transmission of extreme temperature and regular incursion of reptiles and rodents (Kumar, 2012).

The significance of ceiling boards cannot be exaggerated as evident in its use in constructions. Previous researches revealed that wood species such as beach pine, scots pine and Norway spruce have been in use in the development of ceiling boards (Sanjeevamurthy & Srinivas, 2012). Kumar, (2012) developed a standard composite ceiling board from waste paper and rice husk for low cost construction work which exhibited a good water absorption, density, and flexural strength properties. Koh (2018) and Shujie *et al*. (2014) worked on the development of ceiling boards from waste paper, fire retardant, and cement. The results revealed that the compressive strength was highest at 100% fiber waste paper content with a value of 0.66 N/mm$^2$, which is the standard value required for the compressive strength of commercial ceiling board. An investigation by Shujie *et al*. (2014) on the production of agro-waste composite ceiling board produced from saw dust, rice husk, and maize husk revealed there was increment in the tensile strength with a decrease in density as the wood dust content increased. Shujie *et al*. (2014) investigated the physico-mechanical properties of particleboards produced from wood, bamboo, and rice husk. The results revealed that the utilization of rice husk produced a poor quality of particleboard while the wood and bamboo gave better particle boards with a performance that met the European standard requirement. Other material used for the development of ceiling boards is waste tea leaves, Shujie *et al*., (2014)

The prospect of using poplar chopped strands in the development of wood composite that was cement-bonded for building utilization was investigated with addition of $CaCl_2$, reported by Ohijeagbon *et al*. (2021). $CaCl_2$ was added as cement setting accelerator. The properties of the board developed improved with an increase in the cement setting accelerator. More so, the physico-mechanical properties of the composite boards were equivalent or superior to the commercially available cement-bonded wood composites. Ohijeagbon *et al*. (2021) reported that ceiling tiles was produced in cement-bonded composite boards using core fibers of coconut husk. The study was to find solution to the potential problem in the cement-coir composites process. The results showed improvement in the physico-mechanical properties of the coir after pre-treatment while the thermal and the mechanical properties of the cement-coir composites were very close to the conventional wood-wool cement board. Koh, (2018) examined the effect of microwave irradiation pre-treatment in combination with an alkali substance (NaOH) and some other pre-treatment methods on the composite characteristics of bamboo-fibre cement.

The fibre roughness, ductility, and toughness in the composites were improved using the microwave pretreatment methods when compared to the other methods. Teak wood has been used in the production of bio-fuel and also mixed with coal for the development fuels briquettes in previous studies (Ohijeagbon., 2012; Ohijeagbon *et al*., 2021). Teak wood saw dust has also been mixed with pulverized polypropylene plastic in the production of wood-polypropylene plastic-cement composite boards (Ohijeagbon *et al*., 2021). This study however, based on the production of ceiling board from local raw materials such as Rice Husk Fibre (RHF), Locust Bean Pod Solution (LBPS) incorporated lateritic soil and Portland cement (PC) as the main binder. However, the usage of these local materials will help in the waste disposal management problems by converting the residues into wealth.

In the study of thermal properties of ceiling materials for interior surfaces that can cover the upper limits of the room, they are not generally considered as structural element but finished surfaces, concealing the underside of roof structure or the floor of store. In some places, zinc-made roofs without ceilings are very common, thus there is intense heat transfer to the internal environment, which may cause thermal discomfort to the inhabitants. One way to reduce the thermal discomfort is by the use of radiant barrier (such as ceiling board) which reduces the heat flux. However, the knowledge of thermal properties of different materials is very important in the choice of the type of materials to be used as a radiant barrier since the heat flow through any building depends on the thermal properties of the materials used in the building. The study of the thermal properties of materials will help one to know whether materials are suitable to use as ceiling materials in our houses, schools and industries.

Heat is propagated in the interior spaces in buildings through roof coverings and walls and partly through ceiling panels by the process of conduction and radiation. This is because the common materials used as roofing sheets are materials like zinc and aluminum which have high thermal conductivity. To reduce the intensity of this heat, there is need to use materials of tolerable thermal responses as ceiling materials in buildings. Though the various ceiling types vary in their insulation property, good insulating materials will have high value of thermal resistivity. This implies that, different types of ceiling materials will have different thermal behaviors.

Insulator is a material used to inhibit or prevent the conduction of heat or electricity. Proper selection of insulating materials is based on their thermal properties which include:

i) thermal conductivity
ii) thermal absorptivity
iii) thermal diffusivity
iv) specific heat capacity

The primary function of insulator in buildings are to:

i) conserve energy
ii) reduce heat loss or heat gain
iii) maintain a temperature condition
iv) maintain the effective operation of equipment or chemical reaction
v) assist in maintaining product at constant temperature
vi) prevent condensation
vii) create comfortable environmental condition and protect personnel.

In the study of acoustic properties of ceiling boards, it is very important to distinguish between sound absorption and sound transmission loss. Sound absorbing materials control sound within spaces and function by allowing sound to pass through them relatively easily. They are generally porous and absorb sound as a result of many interactions. Conversely, a material or system, that provides a good sound transmission loss is usually non-porous and a good reflector of sound. Noise is generally controlled within a space using sound absorbing materials. Sound absorption relates to the percentage that effectively disappears when the sound wave hits a body or surface (Ohijeagbon *et al*., 2021). Sound absorption is evaluated by measuring the reverberation time of a room. The reverberation time is defined as the time taken for the noise (sound pressure level) to fall to 60dB below its original level when a sound source ceases to operate. If the reverberation time is long then the room will be acoustically uncomfortable for most activities. If the reverberation time is too short then sounds such as music may appear flat and lack character. Assuming that the material has greater sound absorption than the room surface on which it is installed, the reverberation times which are again measured will now be shorter than in the empty condition. A hard-concrete surface has a very low sound absorption coefficient (less than 0.05 at most frequencies), whereas a thick carpet and underlay can approach 1.0 value. Acoustic consultants use the absorption coefficients of materials to estimate the reverberation times of specific buildings. However, in many rooms for example small offices, it is sufficient to specify totally, covering one or two surfaces with a good sound absorbing product such as carpet or a mineral fibre tile ceiling.

### 2.1.1 Production materials for the ceiling tiles

Ceiling tiles are composed of different local raw materials such as Rice Husk Fibre (RHF), incorporated in lateritic soil, Locust Bean Pod Solution (LBPS) and Portland cement (PC) as the main binder. The composite being at a very low cement content.

#### *2.1.1.1 Locust bean pod*

The African locust bean tree, "*Parkia biglobosa*" is a perenial tree legume, belonging to the sub-family Mimosodeae and family leguminosae (Campbell-Pratt, 1980). *Parkia biglobosa* is an important multipurpose tree from the savannah zone of West Africa. The plant increases soil fertility, grows to about 15 m in height and has dark, evergreen, pinnate leaves. Its fruit is a brown, leathery pod of about 10 to 30 cm long and contains gummy pulp of an agreeable sweet taste, in which lies a number of seeds. The pods are edible and are often used for livestock feed. It is a widespread savanna tree and it is recognized easily by its bright red pendulous flowers as showing in Plate 2.1.

(a) (b)

**Plate 2.1:** (a) *Parkia biglobosa* tree with seeds (b) *Parkia biglobosa* seeds and pod (Campbell-Pratt, 1980).

The seeds of the locust bean are used for food seasoning in almost all parts of Nigeria and it is popularly known as “Dawadawa” in northern Nigeria while the Yoruba call it "Iru”. As reported by Campbell-Pratt (1980), the fruit is also sweet and can be consumed directly by people while the pod is used in making gums in the industries. According to Akabi *et al.* (2005), seeds of *Parkia biglobosa* were found to be rich in lipid, protein, carbohydrate, soluble sugars and ascorbic acid. Research by Aliero, (2004) showed that the seeds contain 54% fat and 30% protein in addition to vitamins and minerals such as Calcium, Potassium and Phosphorus. The trees serve as wind break and provide shade (Okunlola *et al.,* 2011). Studies carried out by Tee *et al.*, (2009) revealed that locust bean trees and ironwood trees contribute significantly to nutritional well-being of the people of North-Central Nigeria and that their monthly net incomes from products of these trees compared favourably with the national minimum wages of N7500 (USD59 equivalent) per month. As a result, many of them were living above the national minimum wage.

The seeds are used extensively as seasoning and also nutritious additives to soups and stews as well as good source of essential amino acids (Hassan & Umar, 2005). The fruit pulp analyzed showed moisture content of 8.41%, protein 6.56%, fat 1.80%, crude fibre 11.75%, ash 4.18% and carbohydrate of 67.30% (Germah *et al.*, 2007). The locust bean seed produced by the Parkia tree is embedded in a yellowish, sweet tasting edible pulp. The pods, containing locust bean seeds, resemble that of a soybean pod that starts out as a bright green and turns dry and deep brown as it matures on the tree. The pods are collected and soaked in water for at least four days and the extract is now used to mould mud blocks for building purposes. At other times, the pods are spread over mud walls and as soon as rain begins to fall on the pods, the leachate percolates down the wall. These buildings and fence walls have been found by the natives to withstand over a long period of time under varying weather conditions such as rains, wind and heat (Aguwa & Okafor, 2012).

The African locust bean (*Parkia biglobosa*) has a wide distribution ranging across the Sudan and western coast of Africa in Senegal. Concentrated locust bean pod extract is used to impart water resiliency to floors, walls and ceramics pot. The tannins present in the husk act to bind the soil by their polymeric nature and render the surface impervious to water, sealant to pot and creates a dark, mottled surface.

#### *2.1.1.2 Leaching process of Locust Bean Pod*

The process of leaching was employed in the extraction of a soluble constituent from the pod by means of a solvent. The method used for the extraction is determined by the proportion of soluble constituent present, its distribution throughout the solid and the nature of the solid and the particle size. Generally, leaching process is divided into three major parts; the change of phase of the solute as it dissolves in the solvent, the diffusion through the solvent in the pores of the solid to the outside of the particle and the transfer of the solute from the solution in contact with the particles to the main bulk of the solution. The smaller the particle sizes the greater the interfacial area between the solid and liquid, and therefore the higher the rate of transfer of materials and the smaller is the distance the solute must diffuse within the solid as already indicated. In most cases, the solubility of the material which is being extracted will increase with increase in temperature and this will also increase the rate of extraction. The liquid chosen should be a good selective solvent and its viscosity should be sufficiently low for it to circulate freely and in this case, water was used. Generally, a relatively pure solvent will be used initially, but as the extraction proceeds, the concentration of the solute in the solvent increases and the rate of extraction will progressively decrease first, because the concentration gradient will be reduced and because the solution will become more viscous. Agitation of the solvent is important because this increases the eddy diffusion and therefore the transfer rate from the surface of the particles to the bulk of the solution (Aguwa, 2010; Ohijeagbon *et al.* (2021).

### 2.1.2 Rice Husk Fibre

Rice husk (RH) is a major agriculture bye-product obtained from the food crop of paddy. For every four tons of rice, one ton of rice husk is produced. The husk is disposed of either by dumping it in an open heap near the mill site or on the roadside to be burnt. Burning rice husk (RH) generates about 15-20% of its weight as ash. The ash being very light is easily carried by wind and water in its dry state. It is difficult to coagulate thus contributes to air and water pollution. Cumulative generation of ash requires a large space for disposal. Global production of rice was estimated to be around 600 million tons per year, majorly of which is grown in Asia (Duggal, 2008). The milling process of rice crops generates a bye-product commonly referred to as rice husk, which is the hard-protecting covering of grains of rice. Rice husk ash is obtained from the combustion of rice husk in the boiler, which is collected from the particulate collection equipment located upstream to the stack of rice–fired boilers (Duggal, 2008; Neville, 2012). Prior to the combustion process, rice husk constituted 75 – 80% organic substance, and 15 – 20% of inorganic substance. The burning is an effective way of removing the organic substance while generating energy, leaving behind inorganic ash majorly consisting of Silica.

Rice (*Oryza sativa L. genus*) is the primary source of daily food intake and has become the world’s second most important cereal crop sector due to the demand of billions of human beings. In 2019, approximately 756 million metric tons of rice were produced globally, and

90% of the total output came from Asia. In Malaysia, about 700,000 hectares of paddy are planted on the extensive agricultural land, yielding more than 800,000 tonnes of rice husk (RH) and stalk waste annually (Manickam *et al.*, 2015). These wastes should never be burned, due to various reasons, such as the ashes, harmful gases, and fumes that contribute to air pollution (Athira *et al*., 2019). Typically, the RH can be used as biochar, extracted silica, or husk itself. In general, RH is a hull to protect seeds or grains. It is formed from rigid materials, is water-insoluble, and is abrasive, with a high level of cellulose–silica structures. The exterior of the hulls consists of silica covered with a cuticle, with a small amount of silica content at the innermost epidermis. Recently, several attempts have been made to utilize these waste materials in composite structures (Athira *et al*., 2019).

The study of RH as a filler has been of interest to researchers since the 1970s. The studies present a comprehensive review of the physical, mechanical, and thermal durability of RH composites between 2017 and 2021, and it details the knowledge gaps that need to be filled in the respective research areas. Furthermore, it discussed the potentials of RH composites to be used in photonics, construction materials, and automotive and furniture applications, based on their strength and thermal characteristics.

#### ***2.1.2.1 Flexural strength of RH composites***

In order to characterize the bending properties of the composite material, the most classical test used to characterize this behaviour is the flexural test (three or four points). A study by Zhang *et al*. (2018) reported that the bending strength of a RH biochar/High Density Polyethylene (HDPE) composite reached 53.7 N/mm$^2$, which was far beyond wood–plastic composites. It was indicated that the biochar behaved as a rigid grain and locked the movement of a particle in the polymer chains. Hidalgo-Salazar and Salinas (2019), analyzed a RH-reinforced Polypropylene (PP) composite and recorded an increase of 75% in flexural strength for the RH/PP composite compared with neat PP. They attributed the increase in bending properties to the stiffening effect of RH in the PP matrix. Singh *et al.*, (2019) also measured the flexural strength of a fully recycled RH-reinforced corn starch matrix composite and mentioned that the maximum flexural strength was 19.60 N/mm$^2$ for a RH/corn starch composite with 15 wt % RH content. Flexural modulus is a material characteristic that is significantly influenced by the morphology and crystallinity of polymers. In particular, the heterogeneous structure of the surface layers is important for high values of flexural modulus. Using a compatibilizer, Chen *et al.*, (2018) used an ethylene-glycidyl methacrylate (E-GMA) copolymer as a compatibilizer between recycled HDPE and recycled PET, and maleic anhydride polyethene (MAPE) as a coupling agent between the filler and matrix. They reported an increase in flexural strength of 62% with the increase of RH concentration in the polymer blends of recycled HDPE and recycled PET. It was discovered that the use of a compatibilizer increased the strength of the RH composite with the matrix blend. The coupling agent also improved the flexural strength of the RH/PP composites, and an increase of 46% was reported by Raghu *et al*., (2018). Moreover, when comparing the effect of silane coupling and compatibilizer MAPE on interfacial adhesion properties in RH/HDPE composites. Sun *et al*. (2019) found that the bending strength and flexural strength were improved by 11.5% and 40.7%, respectively. It was observed that the flexural modulus increased with the increase in RH and the technical cellulose fiber amount. It was obvious that the flexural modulus reached higher values at higher quantities of cellulose fibers (20–30 mass%). Furthermore, there was no positive effect on the flexural modulus with a variety of plasma surface treatments of technical cellulose fibers or grafted maleic anhydride (PLA-g-MAH/PLA/30CeF). The smallest effect on the flexural modulus was noted for ozone-treated fillers (Behalek *et al*., 2020). Kumar *et al*,. (2019) reported an increase of 33% in the flexural strength for RH/bauhiniavahilii-weight/sisal epoxy composites compared to unfilled composites at all filler loadings. The effects of hybridized RH with groundnut shell (GNS) reinforced with PP were obtained by Guna *et al.* (2020). The maximum flexural strength of the hybrid composites was obtained with a 20/60/20 GNS/RH/PP ratio, which was 40% higher than the non-hybrid composites. This could suggest that a higher loading of small fillers was inclined to extensive de-lamination, and the misalignment of the filler in the matrix thus decreased the strength properties.

#### *2.1.2.2 Impact strength of RH composites*

Singh *et al*., (2019) reported that the impact energy of RH/corn starch composites increased with the increase of the amount of RH content. The impact strength reached 0.362 J for composites with 15 wt % RH content. The mercerization of fibers improved the impact strength, and Bisht and Gope, (2018) reported that the impact strength of RH flour–epoxy composites were highest at 8% NaOH concentration. The reason for the increase of the impact strength was due to the mercerization treatment, which improved the adhesion between the matrix and fiber by way of removing the voids on the surface of the untreated RHs. Surface modification by silane treatment of a PVC matrix in RH–PVC composites also increased the impact strength to 44%, as reported by Singh *et al*., (2019). The use of coupling agents, as studied by Raghu *et al*. (2018), showed that the impact strength of RH–PP composites decreased with increasing filler loadings. Jiang *et al*. (2021) explored the possibility of reinforcing RH–PVC composites with basalt fibers (BF) and found a noticeably increase in impact strength, whereby the BF acted as a reinforcing agent and strengthened the mobility of the matrix chains. Additionally, the aspect ratio of BF was higher than RH, thus the shift of the stress from the matrix to the fiber was more effective.

### *2.1.2.3 Water diffusion behaviour of RH composites*

The water diffusion behavior of fiber-reinforced composites is dependent on the relative mobility of penetration between the water molecules and polymer parts. In general, this obeys Fick's diffusion theory, and three classes of diffusion can be determined (Deo & Acharya, 2010; Shakeri & Ghasemian, 2010). The measurement of the kinetic diffusion mechanism was evaluated based on Fick's theory and the fitting of experimental values, as follows:

$$\log \log \left(\frac{Mt}{M\infty}\right) = \log \log k + n \log \log t \tag{2.1}$$

where Mt and M∞ are the water absorption at time t and the saturation point, respectively. k and n are constants. The diffusion mechanism is reflected in the value of n. When the rate of diffusion of the infiltrate is less than the polymer part, Case I of the Fickian diffusion mechanism is obtained. For this case, the value of $n = 0.5$, where the saturated condition corresponding to a time is rapidly gained and conserved inside the composite (Miao *et al*., 2017). However, when $n = 1.0$, this indicates that the diffusion activity is faster than the relaxation process (Siriwardena *et al*., 2003). The mechanism is distinguished by the progressive barrier between the bulging outer part and the inner glassy part of the synthetic polymer. In Case II, an equilibrium penetration diffusion is reached at a constant velocity. The non-Fickian is justified at a $0.5 < n < 1.0$ diffusion mechanism and does not obey the Fickian laws. At this condition, Melo *et al*., (2020) used a Langmuir-type model to closely interpret the physical phenomenon of water absorption relaxation of natural fibre composites.

In some cases, when n is larger than 1, it is known as Super Case II kinetics (Lee *et al*., 2004); however, when $n < 0.5$, this can be classified as 'Less Fickian' behaviour.

### 2.1.3 Lateritic soil

Laterite soils are generally used for construction, especially in the Civil and Building construction. Laterite soil in its natural state generally has low bearing capacity and low strength due to high content of clay (Ogunribido, 2012). When laterite soil contains a large amount of clay materials, its strength and stability cannot be guaranteed under load especially in the presence of moisture (Ogunribido, 2012). When this soil consists of high plastic clay, plasticity of the soil may cause cracks and damage on building components or any other Civil Engineering construction projects. The improvement in the strength, durability and water penetration of laterite soil in recent times has, therefore, become imperative. This search for improvement has geared up researchers towards using stabilizing materials that can be sourced locally at very low cost. This is based on the growing cost of the conventional building materials, especially Portland cement, coupled with the need for the economic utilization of industrial and agricultural wastes for beneficial engineering purposes. Thus, the possible use, such as of rice husk ash and calcium carbide waste as additives to laterite for building construction in Nigeria will reduce or eliminate the environmental hazards caused by such waste (Agbede and Joel, 2011).

There is a wide range of stabilizers that are locally available (such as sugarcane straw ash, rice husk ash, coconut husk ash, fly ash, bottom ash, waste steel slag, and locust bean pod ash) for the construction industries. The choice and sustainability of a particular stabilizer depends largely on its availability, nature of project, individual preference, durability, proximity and economic consideration.

In view of the increasing demand for safe and cost-effective engineering in modern technology, construction materials in their natural forms may not satisfy all technology-engineering requirements. Hence, the necessity for stabilization of laterite materials to enhance their properties. This explains why efforts are being directed to material conversion of industrial wastes and bio wastes to engineering products and materials (Ogunribido, 2012)

Stabilization has been defined by Thagesen, (1996), as any process by which a soil material is improved and made more stable. Garber and Hoel, (2000) described soil stabilization as the treatment of natural soil to improve its engineering properties. The primary aim of soil stabilization is to increase its resistance to destructive weather conditions. Kerali (2001) noted that high clay soils require very high proportion of stabilization or a combination of stabilizers to achieve results, especially when using local additives. By so doing, some important changes can be made to the traditional earth construction especially in the production of bricks, and this can enormously improve the performance of the laterite soil while keeping its desirable characteristics. Howe (1992) stated that, most soil materials which have been thought not useful have found application in many areas of engineering work. This is due to the improvement made on these soil properties through stabilization, which leads to increase in soil strength, stiffness, durability, reduction in swelling and water penetration. The technological capability to use local additives in stabilizing laterite materials for building construction in the rural areas may be seen in two different ways. First and foremost, one must identify suitable soils and their limit states and secondly, one must be able to improve on the natural characteristic weaknesses of the earth material and to standardize such improvements for incorporation into modern housing designs and programmes without losing their desirable natural characteristics.

#### *2.1.3.1 Laterite as a building material: strengths and weaknesses*

Laterite earth has been widely used for building construction in tropical and subtropical regions of the world where they are readily- available and economical, compared to other natural stones (Varghese and Bysu, 1993; Osadebe and Nwakonobi, 2007). However, laterite has not been extensively used in constructing medium to large size building roof structures, probably because of lack of adequate data needed in the analysis and design of roof structures built of laterite soils. This underscores the need for more research efforts in this area. According to Adoga (2008), laterite is a highly- weathered material, rich in oxides of Iron, aluminum or both. It is nearly devoid of base and primary silicates but may contain large number of Quarts, and Kaolinite. Laterite historically, is the oldest and most widely known and used building material (Aliyu and Yar'adua, 2012). According to Rigassi (2000), laterite earth structures are completely recyclable, that is, they return to the earth without polluting the soil. Using laterite for building up the environment will be a strong component in the future of humankind (Norton,1997; Kasthurba *et al.*, 2007).

The properties that make laterite suitable for building purposes are: its plasticity when wet and its ability to harden when dry. Laterite clay has some special characteristics that make it differ from other soils. These include the fact that it tends to harden on exposure to air and the darker the laterite is, the harder, heavier and more resistant to moisture it is. Also, laterite is found to have pozzolanic reaction when mixed with lime and other stabilizers. Therefore, laterite clay has some strength that makes it a building material. These are: laterite has very high thermal capacity that enables it to keep the inside of a building cool, when the outside is hot and vice-versa. It is a good noise absorbent, it is easy to work on using simple tools and skills, it is resistant to fire, it is cheaper than most alternative walling/roofing materials and readily available on most building sites.

These qualities encourage and facilitate self-help and community participation in building houses. According to Kasthurba *et al.* (2007), in spite of the popularity and good qualities of laterite, the material has the following weaknesses as a building material when not stabilized with cement and other modes of stabilization:

i) It has low resistance to water penetration resulting to crumbling and structural failure,

ii) It has a very high shrinkage (swelling ration resulting to major structural cracks when exposed to changing weather condition),

iii) It has low resistance to abrasion and requires frequent repairs and maintenance when used in building construction.

In order to overcome these weaknesses and make deficient laterite soils useful and meet the engineering requirements, researchers in the likes of Moses, (2010); Alhassan & Mustapha, (2007); Osinubi and Stephen, (2006); Osunubi and Eberemu, (2005), have focused on the use of potentially, cost-effective materials that are locally- available from industrial and agricultural wastes, in order to improve and stabilize the properties of laterite soils. With the advent of improved technology in earth construction, clays will find better place in the provision of affordable houses, especially for rural dwellers.

#### *2.1.3.2 Stabilization of laterite for building construction*

Laterite generally has a very low bearing capacity and high swelling and shrinkage characteristics. It is, therefore, important to know the characteristics of the clay content whether it is expansive, stable or unstable (Burrough, 2002). This information is necessary to determine the nature/type of stabilization (this technique involves the addition of natural or processed binders to earth such as straw, cow dung, cement, lime and bitumen to improve certain properties of laterite) to adopt. The stabilization technique can be broken down into two categories namely: mechanical and chemical stabilization.

Compaction or mechanical stabilization is one of the oldest means of stabilization. Soil particles are re-arranged, that is, by changing the gradation through mixing with other soils and then demystified or by undercutting the existing soils and replacing them with granular material to improve the soil's engineering properties of strength, permeability and compressibility. An existing soil may have poor strength or stability because of excess clay, silt or fine sand. If a suitable soil was located within a reasonable distance, blending soils together could affect an improvement in the existing soil (Nwoke and Ugwuishiwu, 2011).

Chemical stabilization of laterite has been used for close to half a decade now. The concern of engineers has been to make poor engineering soil much better. Chemicals most often used are organic in nature and are mainly industrial wastes, which pose environmental problems (Nwoke and Ugwuishiwu, 2011). In the presence of organic matter, where a soil contains a certain amount of fine that cause plastic behaviour of soil, stabilization is often recommended (Nwoke and Ugwuishiwu, 2011). Stabilization is a process used to improve soil characteristics and it involves the use of different kinds of agents. These agents include:

cement, lime, bitumen, and fly ash. These chemicals have been used either singly or in combination with one another.

As a result of new developments in laterite buildings globally, new techniques have been introduced while the old ones are gradually phasing out. According to Burrough, (2002), the new techniques can give earth buildings far increased performance than the old techniques. Nwoke and Ugwuishiwu, (2011) in their study noted that laterite in an un-stabilized form will have limited durability. Burrough (2002) also stated that even the best of laterite and water mixture to produce mud paste can develop cracks. Therefore, it is important to introduce other materials to the mix to prevent water from penetrating. Stabilization of laterite increases its resistance to destructive weather condition in one or more of the following ways:

i) By cementing the particles of the soil together leading to increase in strength and cohesion,
ii) By reducing movement (shrinkage and swelling) of the laterite when its moisture content varies due to weather conditions,
iii) By making soil waterproof or at least less permeable to moisture, (Nwoke and Ugwuishiwu, 2011).

Since the inception of the process of stabilization, most soil materials, which have been thought not useful, have found value in areas of engineering especially in Civil Engineering and Building Construction. In spite of the enormous advantages of stabilization for earth construction, it is important to note that different types of soils and stabilizers exist. Therefore, there is no one way to solve all cases (Burrough, 2002; Nwoke and Ugwuishiwu, 2011). In this case, caution should be taken when processing any laterite-based materials because the procedures of laterite stabilization with local additives are often not the same standards set for cement-based materials or cement mixes. This is because the hardening process of materials other than cement, require a different approach to other procedures. It is, therefore, necessary to standardize mix proportions of the local additives that will give the laterite material the desired water resistance and durability as a standard for general application in earth building construction.

### 2.1.4 Cement

In general terms, cement is a binder, a substance with adhesive and cohesive properties which sets and hardens independently and binds other materials together into a compact whole. The most commonly used cements are hydraulic cements, meaning they set when mixed with water. Cement is an essential ingredient in concrete production because it acts as the vital binding agent. Cement used in construction is characterized as hydraulic or non-hydraulic. Hydraulic cements (such as Portland cement) harden because of hydration, chemical reactions that occur independently of the mixture's water content; they can harden even underwater or when constantly exposed to wet weather. The chemical reaction that results when the anhydrous cement powder is mixed with water produces hydrates that are not water-soluble. Non-hydraulic cements (such as lime and gypsum plaster) must be kept dry in order to retain their strength.

Early types of cement included lime, gypsum, lime plus pozzolana, and lime plus clay. Natural pozzolans (truss or pumice) and artificial pozzolans (ground brick or pottery) are also used in concretes.

Modern hydraulic cements can broadly be categorized as either pozzolanic or non-pozzolanic.

i) Non-pozzolanic: cement such as Portland cement is produced by grinding clinker with a small amount of gypsum into a powder to make 'Ordinary Portland Cement' often referred to as OPC.

ii) Pozzolanic: cements on the other hand are those obtained by either inter-grinding and/or blending part of Portland clinker with pozzolanic materials such as fly ash. These are referred to as Portland cement blends. Alternatively, by direct mixing of pozzolanic material with an alkaline substance most economically using lime and does not involve the use of Portland clinker. These are known as non-Portland hydraulic cements. An example of non-Portland hydraulic cements is a mixture of fly ash with lime. The hydration products that produce strength are essentially the same as those produced by Portland cement. A pozzolanic material is that which contain active silica ($SiO_2$) and is not cementitious in itself, but will, in a finely divided form combine chemically with lime in the presence of water at ordinary temperatures to form a strong cementing material. They include: fly ash, volcanic ash, burnt shale, ash from some burnt plant materials (such as rice husk ash) and siliceous earths. Pozzolanic reaction is a simple acid-base reaction between calcium hydroxide ($Ca(OH)_2$), and silica. Simply, this reaction can be schematically represented as follows:

$$3Ca\,(OH)_2 + 2SiO_2 \rightarrow 3CaO.2SiO_2.3\,H2O \qquad (2.2)$$

or summarized in abbreviated notation of cement chemists as

$$3CH + 2S \rightarrow C_3S_2H_3 \qquad (2.3)$$

Pozzolanic cement, is known to have a number of advantages over OPC when used in concrete production and include the following:

i) The pozzolanic reaction continues for many years with the effect that compressive strength as well as the flexural strength of concrete will continue to increase for a long time. This unique characteristic is one of the main reasons many great ancient structures have lasted for over two thousand years.

ii) They improve closer packing of concrete particles in the fresh state leading to overall reduced porosity of the hardened cement paste, which will in turn minimize ingress of harmful chemicals such as chloride ions. This results in increased resistance to chloride ion attack and also protects steel reinforcement from corrosion hence producing a more durable concrete.

iii) Since pozzolanic reaction in concrete proceeds for a long time, it has the effect of removing calcium hydroxide from concrete and by so doing, it preempts the reaction of the calcium hydroxide with acids which forms salts that can be leached out by soft water leaving cavities in concrete which has detrimental effects.

iv) Most of the pozzolanic materials mentioned above are either naturally occurring with little alternative use, or are industrial wastes. Thus, their use in cement production lowers production costs and also reduces environmental pollution by reducing the amount of gasses generated during the production of clinker hence resulting in green cement.

v) Improved Durability**:** The benefits and characteristics of natural Pozzolanas mentioned above clearly explain why the ancient structures built by the Romans have survived over 2000 years of weathering.

# CHAPTER THREE

# 3.0 MATERIALS AND METHODS

## 3.1 Materials

The materials used in the test includes Laterite, Locust Bean Pod Solutions (LBPS), Portland cement (C 1), Rice Husk Fibre (RHF) and Water.

### 3.1.1 Cement

Portland Cement type C II/A-LL, 42.5 N from Dangote Cement Company as shown in Plate 3.1(a) conforming to BS EN 197-1 (2011) and NIS 444-1 (2003) was used as main binder (PC) throughout the investigation. The cement was obtained from local cement merchant in Minna and effort was made to ensure that the supply is gotten from the most recent stock and kept in dry position.

### 3.1.2 Rice Husk Fibre

The rice husk (RH) used in this research work as presented in Plate 3.1(b) was collected from a local grain mill in Garatu village along Minna-Bida Road, Bosso LGA, in Niger State. The collected Rice husk was then sorted to remove dirt and pebbles. The fibre was then later sun-dried for 2 days (6hrs/day) to remove the moisture content and then screened to two different sizes of 1.0 mm and 1.7 mm.

### 3.1.3 Laterite

The sample was collected at Minna town in Niger State. The criteria for selecting soil for this research was based on literature and field tests which include the soil classification, the plasticity index, chemical composition, moisture content, specific gravity and depth for soil extraction. Hence, the soil was extracted at depth between 0.5m and 1.5m below ground level to avoid any organic material.

(a)

(b)

(c)

**Plate 3.1: (a) Portland cement (b) Rice husk fibre and (c) Lateritic soil**

### 3.1.4 Locust bean pod solutions

Locust bean pods were sourced for and collected from trees around Badegi village, Minna, Niger State, Nigeria. The epicarps (outer leathery cover of the pods) of the locust bean pods were cut to various sizes not exceeding 50 mm in length for the purpose of weighing and the particle size distribution was carried out before soaking for twenty-four hours in clean water for the purpose of extraction in 50g/l concentrations.

### 3.1.5 Water

Clean potable water as specified by BS EN 1008 (2015) available within the concrete laboratory of Department of Building, School of Environmental Technology, Federal University of Technology, Minna was used for mixing of the mortar and other laboratory use in accomplishing the work.

## 3.2 Methods

The work was mainly experimental and the approach adopted for the study is discussed under the following sub-heads: Materials characterizations (physical and chemical), density, water absorption, drying shrinkage test, compressive and flexural strength properties.

### 3.2.1 Preliminary tests

The characterization of the constituent materials such as the determination of the physical and chemical properties of laterite, LBPS, RHF and cement were carried out. Various test was done which includes chemical analysis test (XRF) of the laterite and LBPS as well as liquid limit, plastic limit and plasticity index (for laterite only), specific gravity, moisture content and particle size distribution analysis (laterite and RHF) of the constituent materials.

### 3.2.2 Sieve Analysis

The laterite and RHF particle size analysis were done in line with AASHTO, (1986) classification and ASTM D1037 (1999) standard (Ohijeagbon *et al*., 2021). A 500 g and 40 g weight of laterite and RHF were measured and positioned in a set of sieves arranged in descending order of fineness and then placed on a mechanical shaker. The shaking process was carried out for 15 minutes, (Ohijeagbon *et al*., 2021). Seven different sieve sizes of 4.75, 2.36, 1.7, 1.0mm, 500µm, 250µm, and 150 µm were used. The weight of RHF and laterite retained and total weight of sample were given as $W_r$ and $W_t$, respectively while the percentage retained on sieve was evaluated for each specimen based on Equation (3.1). The cumulative percentage passing through sieve is expressed in Equation (3.2) as the difference between the percentage weight of total sample (%$W_{ts}$) and the percentage weight of retained sample (%$W_{rs}$). The fineness modulus was determined using Equation (3.3).

$$\text{Percentage retained on sieve} = = \frac{Wr}{Wt}\ x\ 100 \tag{3.1}$$

$$\text{Percentage passing through the sieve} = \%W_{ts} - \%W_{rs} \tag{3.2}$$

$$\text{Fineness modulus} = \frac{\%\ of\ total\ cumulative\ weught\ retained\ 80\ mm\ and\ 0.15\ mm}{100} \tag{3.3}$$

### 3.2.3 Experimental program

This research investigated the varying composition of laterite and RHF (70:30, 60:40, 50:50, 40:60, and 30:70) as independent variables on the density, water absorption, compressive and flexural strength tests as dependent variables of ceiling tiles production while trial mix was conducted prior to the casting of the experimental specimens and the composite mix LAT: RHF of 60:40 exhibited the best performance. Hence, the control variable for this research is the composite mix LAT: RHF of 60:40 incorporating Portland cement with binder/composite ratio of 0.6 respectively using 30% of the total materials as the water (Ataguba, 2016; Ohijeagbon *et al.*, 2021).

### 3.2.4 Preparation of specimens

The ceiling tiles were developed through different proportioning of the base materials (laterite and RHF) and the binders (cement and LBPS) as shown in Table 3.1. Rice husk fibre of 1000 µm sieve size was adopted as a result of the result of the analysis.

The production procedures involved blending of the LAT/RHF in ratios (as described in 3.2.2) together with the binders (cement/LBPS), the blend was mixed manually using a stirrer.

**Table 3.1: Proportioning of the constituent materials**

| Category | Sample ID | LAT: RHF (%) | Binders: Composite |
|---|---|---|---|
| Control | LFCCT | 60:40 | 0.6 |
| A (50g/l of LBPS) | LFBCT$_1$ | 70:30 | 0.6 |
| | LFBCT$_2$ | 60:40 | 0.6 |
| | LFBCT3 | 50:50 | 0.6 |
| | LFBCT$_4$ | 40:60 | 0.6 |
| | LFBCT$_5$ | 30:70 | 0.6 |
| B (30g/l of LBPS) | LFBCT$_6$ | 70:30 | 0.6 |
| | LFBCT$_7$ | 60:40 | 0.6 |
| | LFBCT$_8$ | 50:50 | 0.6 |
| | LFBCT$_9$ | 40:60 | 0.6 |
| | LFBCT$_{10}$ | 30:70 | 0.6 |
| C (10g/l of LBPS)) | LFBCT$_{11}$ | 70:30 | 0.6 |
| | LFBCT$_{12}$ | 60:40 | 0.6 |
| | LFBCT$_{13}$ | 50:50 | 0.6 |
| | LFBCT$_{14}$ | 40:60 | 0.6 |
| | LFBCT$_{15}$ | 30:70 | 0.6 |

*LFCCT-LAT: RHF cement ceiling tiles, LFBCT-LAT: =RHF biglobosa ceiling tiles,
*The 1-5, 6-10 & 11-15 denote 10, 30 and 50g/l LBPS concentrations respectively.

The mixture was gradually poured into a mould (using 400 x 400 x 40 mm for water absorption, density and compressive strength tests while 450 x 450 x 75 mm for flexural strength test) lubricated with hydraulic oil and compaction was done using a manual pressing method at room temperature while the samples were all oven dried under a temperature of $80^{o}$C for 24 hours (Ataguba, 2016; Ohijeagbon *et al.*, 2021; ASTM D7433, 2013, ASTM

C367/C367 2009). The curing of ceiling tiles was 7 days and it was then allowed to dry for another 14 days.

The LFCCT (laterite: fibre cement ceiling tiles) mix was the control incorporating Portland cement as the binder while in category A, mixes ($LFBCT_1$-$LFBCT_5$), B ($FLCT_6$-$FLCT_{10}$) and C ($FLCT_{11}$-$FLCT_{15}$) incorporated LAT: RHF with cement totally substituted by LBPS at 50 g/l, 30 g/l and 10 g/l concentrations respectively.

### 3.2.5 Moisture content analysis

This parameter of RHF was determined according to ASTM D1037 (1999) standard (Ohijeagbon *et al*., 2021). An empty can was weighed and the mass recorded as $M_x$. The damp husk sample was placed in the container and weighed and the mass recorded as $M_s$. The husk sample was oven dried. The dried husk sample in the container was weighed and its mass recorded as $M_y$. The moisture content was evaluated using equation (3.4).

$$\text{Moisture content (Mc)} = \frac{Ms - My}{My - Mx}\ x\ 100 \qquad (3.4)$$

### 3.2.6 Density evaluation

Density was evaluated in accordance with ASTM D1037 (2012) standard, (Ohijeagbon *et al*., 2021). The ceiling tiles produced was sun-dried for 3 days (3 hrs/day) to a constant mass and the dry mass of the ceiling tiles ($M_D$), was measured using a weighing balance. The volume of the ceiling tiles was calculated as: V = l x b x t. the density $p$, was calculated using the equation (3.5).

$$\rho = \frac{MD}{V} \qquad (3.5)$$

Where MD = dried mass of ceiling tiles, ρ = Density (kg/m$^3$), l = length, b = breadth and t = thickness.

### 3.2.7 Water absorption test

The water absorption (WA) capacity of the ceiling tiles was done in accordance with ASTM D1037 (1999) and ASTM D7433-(2013) standard (Ohijeagbon *et al*., 2021; Ataguba, 2016). The experimental samples were immersed in water for 2 hours and 24 hours at room temperature to examine the short and long-term percentage water resistance properties respectively. The experiment was carried out 3 times and the average value for percentage water absorption was recorded for both phases of 2 hours and 24 hours. The mass of dried ceiling tiles was recorded as $M_D$ and the mass of ceiling tiles after immersing in water for 24 hours was recorded as Ms (Ohijeagbon *et al*., 2021) and thus, equation (3.6) was utilized to evaluate the percentage water absorption of the ceiling tiles.

$$\text{WA (\%)} = \frac{MS-MD}{MD}\ x\ 100 \qquad (3.6)$$

Where $M_s$ = mass of the saturated ceiling tiles, $M_D$ = mass of the dried ceiling tiles.

### 3.2.8 Compressive strength

The compressive strength of each ceiling tiles specimen is the ratio of optimum load at failure to the cross-sectional area of the ceiling tiles. Compressive test was done according to ASTM D1037 (2012) standard as reported by Ohijeagbon *et al*. (2021) using universal testing machine (Model No. JYS-2000A Class 1) and Universal Testing Machine (Model No. CAP: 20T/200KN). The load was gradually applied on the tiles specimen until failure and the load measurement (Pc) was documented. The experiment was carried out three time and the average compressive strength (r) was evaluated using Equation (3.7).

$$\sigma = \frac{Pc}{Ac} \tag{3.7}$$

where PC = optimum load applied until failure (N), AC = specimen cross-sectional area ($mm^2$) and σ = compressive strength of the test specimen ($N/mm^2$).

### 3.2.9 Flexural test

Flexural strength (FS) was determined by evaluating the axial bending strength of the tiles in accordance with ASTM D1037 (1999) and ASTM C367/C367 (2009) standard reported in Ohijeagbon *et al*. (2021) and Ataguba (2016) respectively using Universal Testing Machine. A concentrated bending load was applied at the center of a beam using three-point loading on a length of 450 x 450 x 75 mm. Flexural strength was calculated by load deflection and the ultimate load was recorded and estimated using the formula in Equation (3.8).

$$FS = \frac{3PL}{2BD2} \tag{3.8}$$

# CHAPTER FOUR

# 4.0 RESULTS AND DISCUSSION

## 4.1 Materials Characterization

The materials were characterized in order to draw inferences on its acceptability and performance of the constituent mixes. This is discussed in the preceding sections.

### 4.1.1 Chemical composition of the lateritic soil

Table 4.1 shows the results of the chemical analysis performed on the lateritic soil. The chemical composition of the sample shows the presence of 17.86 wt. % of $Fe_2O_3$ followed by 53.37 wt. % of $SiO_2$ and 23.34 wt. % of $Al_2O_3$ and feeble content of 0.84 wt. % of $K_2O$ and 1.37 wt. % of CaO. This result agrees with the petrographic and mineralogical studies which indicated that quartz, iron-rich minerals and alumino-silicates are the dominant phases in both the parent rock and its derived products.

**Table 4.1: Chemical Properties of the lateritic soil used**

| Element (oxides) | Concentration (%) |
|---|---|
| Silica as $SiO_2$ | 53.367 |
| Aluminum as $Al_2O_3$ | 23.342 |
| Iron as $Fe_2O_3$ | 17.876 |
| Calcium as CaO | 1.366 |
| Magnesium as MgO | 0.454 |
| Sulphate as $SO_3$ | 0.236 |
| Sodium as $Na_2O$ | 0.000 |
| Potassium $K_2O$ | 0.838 |
| $Mn_2O_3$ | 0.131 |
| $P_2O_5$ | 0.139 |
| Cl | 0.005 |
| $TiO_2$ | 2.197 |
| $Cr_2O_3$ | 0.030 |
| ZnO | 0.004 |
| SrO | 0.015 |

Rossiter (2004) compiled the classification of soils according to the degree of laterization by evaluating silica-sesquioxide (s-s) ratio [$SiO_2$/ ($Fe_2O_3$ + $Al_2O_3$)]. Accordingly, soils having S-S ratio greater than 2 are considered as non-lateritic soils. For lateritic soils, this S-S ratio lies between 1.30 and 2 and for the true laterites the ratio is less than 1.30. The soil under investigation has the S-S ratio to be 1.30 suggesting that it is lateritic soil and also according AASHTO classification regarded as class A-2-7 laterite.

### 4.1.2 Particle size distribution (PSD) of laterite

Figure 4.1 presents the particle size distribution of the laterite examined in this study. From Figure 4.1, the soil can be classified as fine to medium laterite sample with % passing through 0.075mm sieve not greater than 35%.

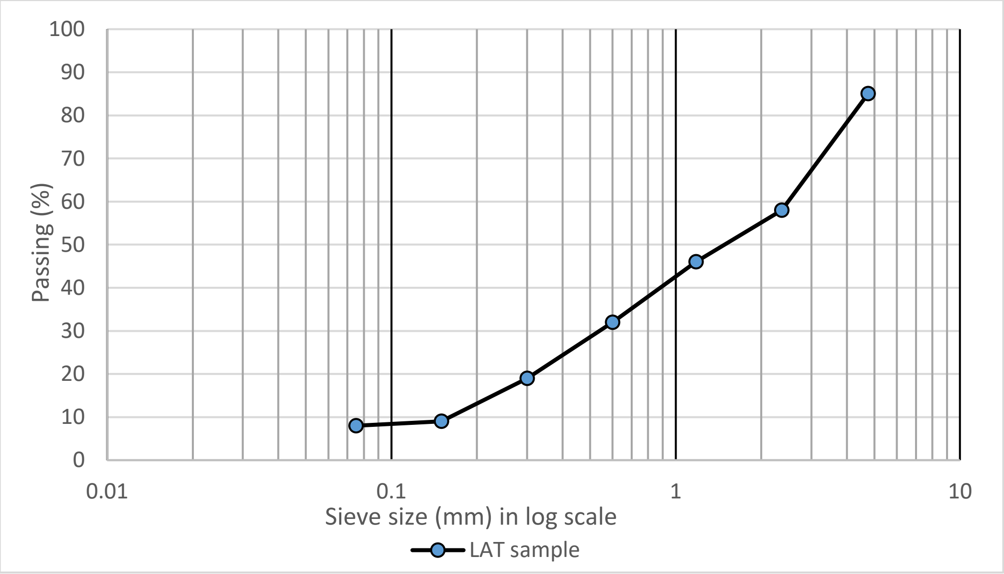

**Figure 4.1: Particle size distribution curve for Laterite sample**

According to the AASHTO method of soil classification, the soil was further classified as A-2-7. For the A-2 group, the maximum value for materials passing through 0.725mm sieve is 35%, the minimum liquid limit value for A-2-7 group is 41%, and plasticity index is expected to have minimum value of 11%. Furthermore, the natural moisture content for the soil sample is 14.75% while according to Emesiobi (2000) who reported the classification of soil in relation to moisture content for different soil types indicated that natural moisture content in soil may range from between 5% to 50% in gravel and sand. Hence, the result of the sample shows that the value falls into the category of gravel and sand. Also shown in Table 4.2 is the specific gravity of the sample carried out, the specific gravity gave the value of 2.67 and this value is suitable in accordance with Ogunribido (2012) who affirmed that the standard range of values of specific gravity of soils lies between 2.60 and 2.80. Lower Specific gravity value indicates a coarse soil, while higher values indicate a fine-grained soil.

**Table 4.2: Summary of other properties of the lateritic soil**

| Property | Values | AASHO Requirement for A-2-7 |
|---|---|---|
| % passing 75 um Sieve size | 8 | ≤ 35 |
| Fineness Modulus | 3.51 | 2.0 to 4.0 |
| Liquid Limit (%) - LL | 47.7 | ≥ 41 |
| Plastic Limit (%) - PL | 23.32 | |
| Plastic Index (%) = LL - 30 | 24.38 | ≥ 11 |
| Natural moisture Content | 14.75 | |
| Specific Gravity | 2.67 | |
| Silica-sesquioxide (S-S) ratio | 1.30 | |

### 4.1.3 Properties of the rice husk fibre and binder

Table 4.3 presents the moisture content, bulk density, sieve analysis as well as fineness modulus (FM) of the Rice Husk Fibre (RHF) that was used for the ceiling tiles development while Table 4.4 shows the oxides composition of the LBPS incorporated. The percentage moisture content of the RHF was 9.50% which implied that the fibre contributed exceedingly to the moisture content while producing the ceiling tiles. Furthermore, the bulk densities of the fibre was 0.235 (approx. 0.24) g/cm$^3$. Cement has the highest density of 3.15 g/cm$^3$, which improved the density of the ceiling tiles based on its proportion. Table 4.3 also presented the summary of the results of the sieve analysis of the RHF. It was observed that, the sieve size 500 µm of RHF had the highest percentage of weight retained of 30.15%. The other sieve sizes of 1000, 1700 and 250 µm had percentage weight retained of 25.13, 21.60 and 15.1%, respectively.

**Table 4.3: Summary of physical properties of the constituent materials**

| Sample | Mc (%) | Bulk Density (g/cm$^3$) | MMR (%) | FM |
|---|---|---|---|---|
| RHF | 9.50 | 0.235 | 30.15 | 3.12 |
| Cement | -- | 2.16 | -- | -- |

*Mc - Moisture content, MMR - Maximum mass retained, FM - Fineness modulus

It was also deduced that to produce a larger quantity of ceiling boards using the RHF, sieve sizes of 1000 µm was selected for its production, this is because smaller particle sizes tend to absorb water more than larger particle sizes hence the choice of 1000 µm which is of average particle size. Furthermore, the RHF had the fineness modulus value of 3.12, and hence, the particle size distribution was as a result of the intensity of the grinding and the required material densification.

Furthermore, Table 4.4 shows that the combined percentage of Silica ($SiO_2$), Iron Oxide ($Fe_2O_3$) and Alumina ($Al_2O_3$) is 50.70%. This is more than 50% minimum requirement recommended by ASTM C 618 (2012) for a good class N pozzolans. The presence of Silica ($SiO_2$) and Iron Oxide ($Fe_2O_3$) is responsible for the formation of cementitious compounds.

**Table 4.4: Oxide composition of locust bean pod solution**

| Element | Concentration (%) |
|---|---|
| MgO | 0 |
| $Al_2O_3$ | 0 |
| $SiO_2$ | 46.2203 |
| $P_2O_5$ | 0 |
| $K_2O$ | 33.5274 |
| CaO | 14.8564 |
| $TiO_2$ | 1.9126 |
| $Fe_2O_3$ | 4.4833 |

## 4.2 Hardened Properties of the Laterite Fibre Ceiling Tiles

The influence of the LBPS concentration and the LAT: RHF compositions on the density, water absorption, compressive strength and flexural strength were discussed below,

### 4.2.1 Density of the Ceiling Tiles

The density of the laterite-fibre ceiling tiles of all the specimens with varying LBPS concentrations replacement and LAT: RHF is presented in Figure 4.2 and different studies have proved that the density of the ceiling tiles increases as the binder (LBPS) concentration increases while the content of the fibre ratio to LAT decreases, this is mainly due to the increase in the reacted products. Figure 4.2 illustrates the density of the ceiling tiles with varying LAT: RHF contents and LBPS concentration and increase was discovered in the densities from 1100 kg/m$^3$ (LFBCT$_1$_70:30) to 1200 kg/m$^3$ (LFBCT$_2$_60:40), and which consecutively decreased to 1050 kg/m$^3$ (LFBCT$_3$_50:50), 950 kg/m$^3$ (LFBCT$_4$_40:60) and

910 kg/m$^3$ (LFBCT$_5$_30:70) as the laterite replacement also decreases from 70% to 60%, subsequently to 40% and 30% at 50 g/l LBPS concentration.

Furthermore, the results followed the same trend as the LBPS concentration decreases to 30 g/l and as well as to 10 g/l, it was discovered that as the concentration of the LBPS decreases, the density of the samples decreases which is also in correlation with the work of Aguwa & Okafor, (2012) and the trend achieved in its compressive and flexural strength as discussed forward in Figure 4.4 and 4.5. The densities were found at 30 g/l LBPS concentration to be 980 kg/m$^3$, 1170 kg/m$^3$, 975 kg/m$^3$, 930 kg/m$^3$ and 905 kg/m$^3$ for LFBCT$_6$ (70:30), LFBCT$_7$ (60:40), LFBCT$_8$ (50:50), LFBCT$_9$ (40:60) and LFBCT$_{10}$ (30:70) respectively and as well as 965 kg/m$^3$, 1100 kg/m$^3$, 950 kg/m$^3$, 900 kg/m$^3$ and 880 kg/m$^3$ for FLCT$_{11}$ (70:30), FLCT$_{12}$ (60:40), FLCT$_{13}$ (50:50), FLCT$_{14}$ (50:50) and FLCT$_{15}$ (70:30) respectively at 10 g/l LBPS concentration incorporation.

The density of all the samples irrespective of the LBPS concentrations were observed to be lower in comparism with the reference mix (LFCCT) that incorporated LAT: RHF and cement with the value of 1350 kg/m$^3$ which simply means that the mix incorporating cement is well packed in comparism with LFBCT$_{1-15}$ as a result of the progress in the hydration and formation of additional C-S-H when reacted with the lateritic soil while the composite mix 60: 40 with 50 g/l LBPS concentrations exhibited similar behavior by having a proximal density of 1200 kg/m$^3$. The trend of the result shows that increasing the laterite contents as well as the LBPS concentrations at RHF reduction resulted in an increase in the densities of the samples, this is because the cement is denser than the fibre and denser materials may give a better strength for composite tiles which is a good characteristics of a ceiling tile.

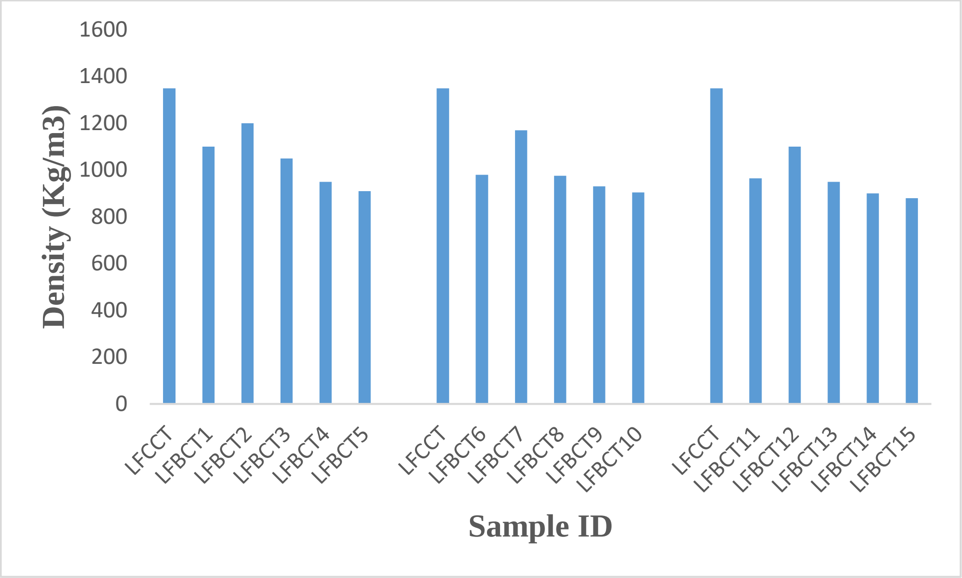

**Figure 4.2: Density of ceiling tiles**

### 4.2.2 Water absorption

Figure 4.3 illustrates the water absorption rate of the ceiling tiles samples with different compositions of LAT: RHF at varying LBPS concentrations (50 g/l, 30 g/l and 10 g/l) after 2 hours and 24 hours. There was a great increase in the rate of water absorption from 2hrs duration compared to 24 hours duration with a value of 25%. It was discovered that the lower the LBPS concentrations the higher the water absorption. An increasing trend of water absorption rate was observed with an increase in the fibre contents up to 70% with a mix incorporating 70% RHF ($LFBCT_5$, $LFBCT_{10}$ and $LFBCT_{15}$) which happened to be the highest water absorption at 50 g/l, 30 g/l and 10 g/l LBPS concentrations respectively and later decreased slightly for the ceiling tiles incorporated LAT: RHF at the ratio of 40/60, 50/50, 60/40 and 70/30.

The reference mix (LFCCT) had the lowest absorption rate of 2% and 6% at 2 hours and 24 hours respectively while the mix $FCLT_{15}$, $FCLT_{10}$ and $FCLT_5$ having the highest absorption rate with the values 16% and 22%, 11% and 21%, 10% and 18% at 10 g/l, 30 g/l and 50 g/l LBPS concentrations respectively. The absorption rate was consecutively decreased up to 7% and 10%, 4% and 7%, 3% and 7% for mix FLCT$_{12}$, FLCT$_{7}$ and FLCT$_{2}$ at 10 g/l, 30 g/l and 50 g/l LBPS concentrations respectively.

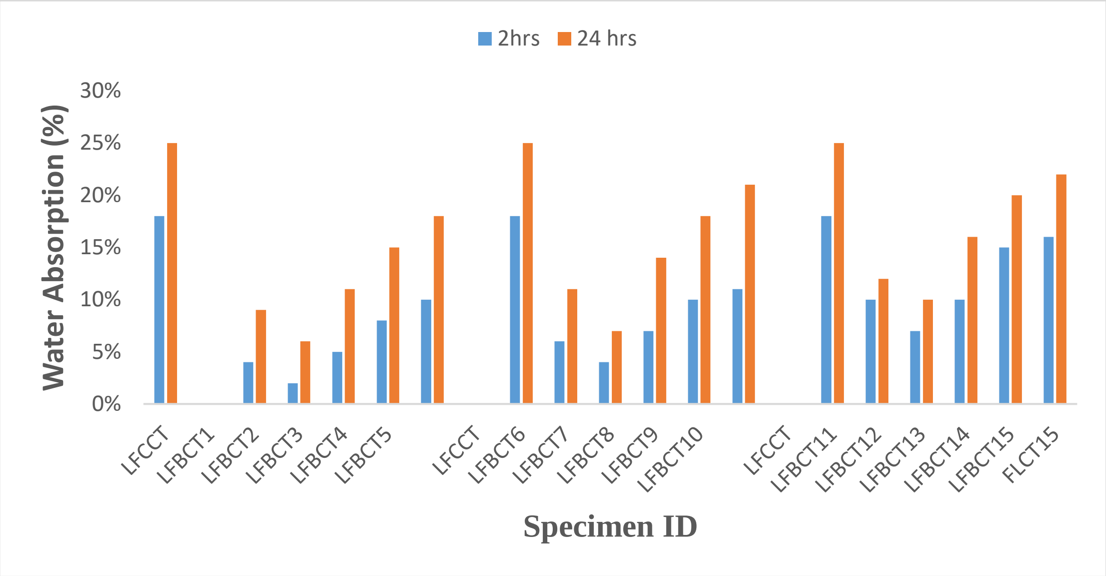

**Figure 4.3: Water absorption of ceiling tiles**

Furthermore, the results also show a decrease in the concentration of the LBPS at an increase as the RHF incorporated increases the rate of water absorption and this could be attributed to hydrophilic nature of the fibre (Ohijeagbon *et al*., 2021) and hydrophobic nature of binder. The water absorption values confirmed the claim that lignocelluloses generally tend to rise the hydrophilic nature of cement-bonded fibre composites due to large number of porous structures which accelerates water penetration through capillarity (Ataguba, 2016; Ohijeagbon *et al*., 2021).

### 4.2.3 Compressive strength

The compressive strength of the laterized- fibre ceiling tiles is presented in the Figure 4.4 and for the reliability of each of the data collected to be proved without a significant outlier, the data were averaged by three numbers of specimen with standard deviation among the different specimens. The LAT:RHF cement ceiling tiles (LFCCT) products developed higher compressive strength of 1.70 N/mm$^2$ when compare to the mixes incorporated LAT:RHF with LBPS as binder at 30 g/l and 10 g/l concentration (LFBCT$_8$, LFBCT$_9$, LFBCT$_{10}$, LFBCT$_{13}$, LFBCT$_{14}$ and LFBCT$_{15}$) having the values of 1.62 N/mm$^2$, 1.65 N/mm$^2$, 1.68 N/mm$^2$, 1.60 N/mm$^2$, 1.63 N/mm$^2$ and 1.65 N/mm$^2$ respectively while the ceiling tiles with the mix ID LFBCT$_6$, LFBCT$_7$, LFBCT$_{11}$ and LFBCT$_{12}$ had compressive strength closer to the LFCCT (reference mix) with 1.78 N/mm$^2$, 1.82 N/mm$^2$, 1.72 N/mm$^2$ and 1.76 N/mm$^2$ at the same 30% and 10 g/l LBPS concentrations.

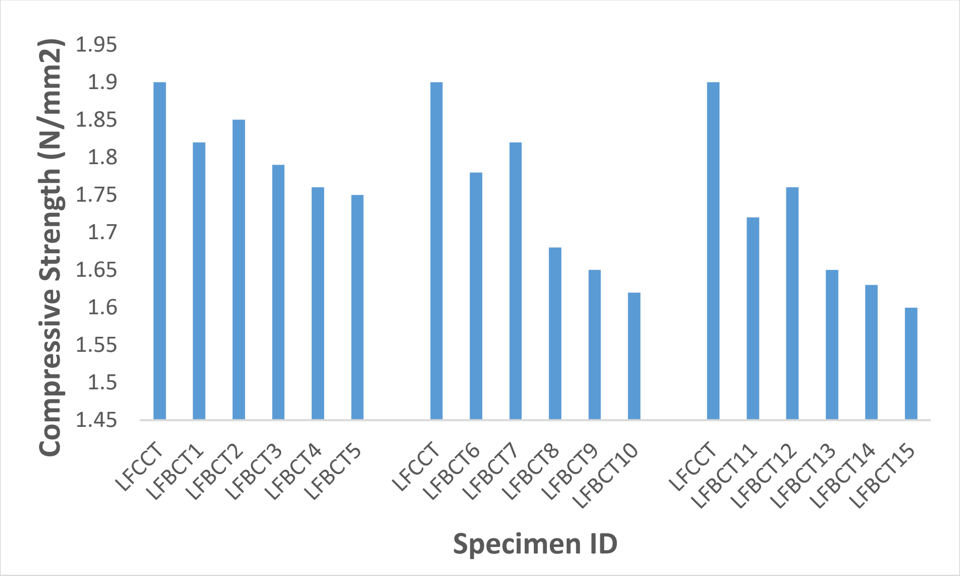

**Figure 4.4: Compressive strength values of ceiling tiles**

Furthermore, with reference to Figure 4.4, an upward trend in the compressive strengths was observed with increase in the replacement levels of laterite and LBPS. The highest compressive strength achieved was with $LFBCT_2$ (60/40) and $LFBCT_1$ (70/30) mix of 1.85 $N/mm^2$ and 1.82 $N/mm^2$ at 50 g/l LBPS concentrations. Hence, the gradual increase in the LBPS concentrations led to an increase in the strength properties of the ceiling tiles in agreement with the work of Aguwa and Okafor (2012). The results revealed that as the LBPS concentration decreases, the strength increases which is also in correlation with the density as discussed (Figure 4.2).

### 4.2.4 Flexural strength

The results of the flexural strength properties of the ceiling tiles mixtures cured at ordinary ambient temperature is presented in Figure 4.5. The results revealed that all the samples shows an increase in flexural strength as the LAT contents increases while the RHF decreases and the mix incorporating 60% LAT and 40% RHF ($LFBCT_2$, $LFBCT_7$, $LFBCT_{12}$), 70% LAT and 30% RHF ($LFBCT_1$, $LFBCT_6$, $LFBCT_{11}$) had the best performance for flexural strength at 50 g/l, 30 g/l and 10 g/l LBPS concentrations with tensile strength values (0.75 N/mm$^2$, 0.72 N/mm$^2$ and 0.68 N/mm$^2$) and (0.72 N/mm$^2$, 0.68 N/mm$^2$ and 0.64 N/mm$^2$) respectively. Hence, the tensile strength followed by the samples incorporated 50/50, 40/60 and 30/70 LAT:RHF with the specimen numbers (LFBCT$_3$, LFBCT$_8$, LFBCT$_{13}$), (LFBCT$_4$, LFBCT$_9$, LFBCT$_{14}$) and (LFBCT$_5$, LFBCT$_{10}$ and LFBCT$_{15}$) with the flexural strength values (0.69 N/mm$^2$, 0.67 N/mm$^2$ and 0.63 N/mm$^2$), (0.66 N/mm$^2$, 0.55 N/mm$^2$ and 0.53 N/mm$^2$) and (0.65 N/mm$^2$, 0.52 N/mm$^2$ and 0.51 N/mm$^2$) at 50 g/l, 30 g/l and 10 g/l LBPS concentrations while the reference sample incorporated only the Portland cement and LAT:RHF (LFCCT) had the highest strength values of 1.50 N/mm$^2$.

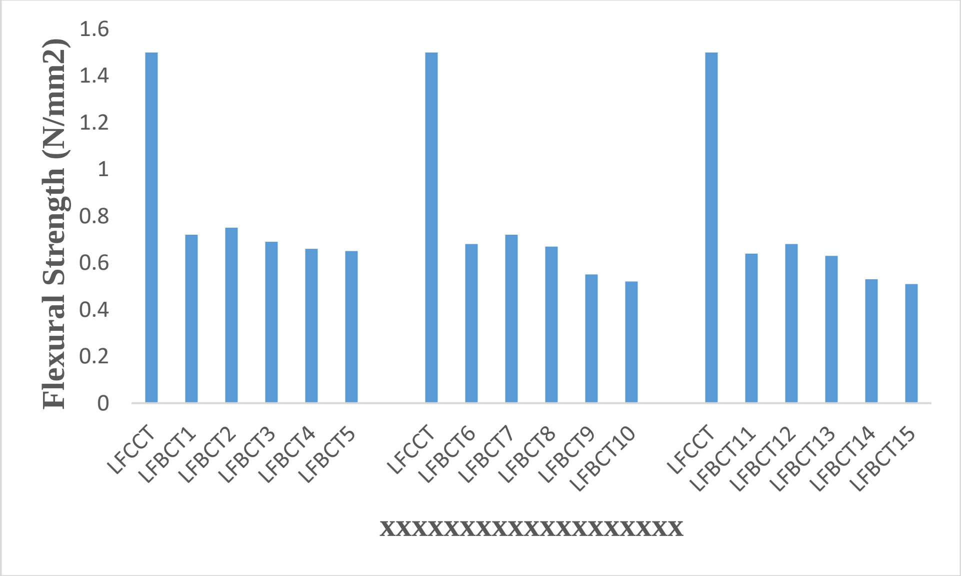

**Figure 4.5: Flexural strength values of ceiling tiles**

Furthermore, it was discovered from the results that the flexural strength increases as the laterite contents replacement level increases with a decrease in RHF from 70% to 30% at every 10% interval with the ceiling tiles sample mixes LFBCT$_2$, LFBCT$_{7,}$ and LFBCT$_{12}$ (60/40 at 50 g/l, 30 g/l and 10 g/l LBPS concentrations respectively) having the highest flexural strength values as discussed earlier after the reference mix (LFCCT). This can be explained by the addition of laterite augmenting the RHF contents in the presence of LBPS, contributed to higher rate of calcium ions ($Ca^{2+}$) and Aluminium ions (Al) in the ceiling tiles matrix (Aguwa and Okafor, 2012; Ohijeagbon *et al*., 2021).

## 4.3 Summary of Findings

The following are the inferences deduced from the study:

i) The composition of the laterite and the LBPS chemical oxide conforms to Class F and Class N of ASTM-C618 (2015) respectively which is the minimum requirement for pozzolans and can therefore be used as SCMs with the required physico-chemical properties.

ii) Higher trend is observed in the density with an increase in the RHF at a decrease in laterite contents replacement.

iii) The ceiling tiles absorption rate resulted to an increment as the concentration of the LBPS increases while the reference mix that incorporating only the LAT: RHF and Portland cement yielded the lowest absorption rate.

iv) The strength properties (compressive and flexural strengths) of the LAT: RHF is maximum at all the highest LAT contents and at a increase in LBPS concentrations up to 50 g/l (for all the mixes). However, the LFCCT (the control mix incorporated only the LAT: RHF and Portland cement) showed the highest strength performance in comparison with the ceiling tiles incorporated LBPS as the binder.

v) The mix $LFBCT_2$ and $LFBCT_1$ (ceiling tiles incorporated 60% LAT/40% RHF and 70% LAT and 30% RHF at 50 g/l LBPS concentrations) performed best and exhibited the highest strength properties (density, compressive and flexural) of the LAT: RHF ceiling tiles after the reference mixture.

# CHAPTER FIVE

## 5.0 CONCLUSION AND RECOMMENDATIONS

### 5.1 Conclusion

The study explored the development of Laterite: fibre-based ceiling tiles using locust beans pod solutions (LBPS) as the binder at 50g/l, 30g/l and 10g/l LBPS concentrations. The physico-mechanical properties of cement/LBPS-bonded ceiling tiles developed from laterite incorporating rice husk fibre (RHF) has been determined. The moisture content in the range of 5–15% has been recommended. The density of the ceiling was between 0.60 and 0.85 g/cm$^3$. All the samples had water resistant capacity that are less than 40% based on available standards. The strength properties of the ceiling tiles produced from LAT: RHF was of an improved quality than that of samples produced from RHF only. In conclusion, ceiling tiles with better physico-mechanical properties can be produced technologically from LAT: RHF at 60/40 and 70/30 proportions using LBPS at 50 g/l as a binder. Hence, industrial production of the tiles is achievable which will boost waste management sector through making wealth from waste.

### 5.2 Recommendations

The study hereby recommends that:

i) Binary blend of laterite and RHF with 60/40 and 70/30 compositions ($LFBCT_2$ and $LFBCT_1$) should be adopted at 50 g/l LBPS concentrations for good water absorption, density and strength performance.

### 5.3 Areas for further Studies

i) The effect of the LBPS and the LAT: RHF compositions should be further explored on other strength properties.

ii) The effect should be also be investigated on durability properties of ceiling tiles in terms of fire resistance and sound insulation.

## 5.4 Contribution to Knowledge

A thorough explanation and better insight on the rate of water absorption and strength development of RHF/laterite ceiling tiles is provided in this research. Therefore, the optimum synthesis of RHF/laterite and binders binary blended ceiling tiles is obtained in this research and the outcome can be applied to ceiling tiles production.

Furthermore, it provided a new improved ceiling tiles for the construction industry in Nigeria and as well created the opportunity for the industrial technical education curriculum planners to draw curriculum on the production principles of recycle RHF/laterite ceiling tile, provided additional material for architect to recommend for building construction, provided a new easy to use ceiling tiles with less risk of damages and danger to health for the builders and made additional means of managing wastes for the waste managers in Nigeria as a whole

Also, the environmental issue associated with portland cement production is minimized through this research. Maximizing the utilization of waste products by improving and promoting the waste materials such as RHF and locust beans pod waste (LBPW) are of great benefit to building structures as eco-friendly technology. Instead of disposing the RHF and LBPW in landfill or ash ponds, utilizing them in the production of ceiling tiles will create a reduction in wastage and pollution.

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# APPENDIX A

## A. Materials

**PLATE A.1: Fresh Sample of slate**

**PLATE A.2: Sample after Drying**

PLATE A.3: Dried Sample of slate

# APPENDIX B

## Appendix B: Testing under load

**PLATE B.1: Test sample before loading**