

LIMESTONE CALCINED CLAY CEMENT.

BY

**ADESINA TEMITOPE VINCENT
MAT NO: ENG1704068**

**DEPARTMENT OF STRUCTURAL ENGINEERING
FACULTY OF ENGINEERING
UNIVERSITY OF BENIN**

**SUBMITTED IN PARTIAL FULFILMENT OF THE AWARD OF BACHELOR OF
ENGINEERING (B.ENG) IN STRUCTURAL ENGINEERING**

SEPTEMBER, 2023.

CERTIFICATION

This is to certify that this report was carried out by Adesina Temitope Vincent with Mat No Eng1704068 in the Department of Structural Engineering, Faculty of Engineering, University of Benin, in partial fulfilment of the requirement for the award of Bachelor of Engineering (B. ENG) in Structural Engineering.

.....
PROJECT COORDINATOR
ENGR. E. ORIA-USIFO

.....
DATE

.....
PROJECT SUPERVISOR
ENGR. S.A. ADEGBEMILEKE

.....
DATE

.....
HEAD OF DEPARTMENT
ENGR. DR. (MRS) N.I. IHIMEKPEN

.....
DATE

DEDICATION

This Project is dedicated to God Almighty for the wonderful work He has done in my life and for seeing me through all the hurdles and also to my beloved Parents for their support to consider our Education a priority.

ACKNOWLEDGEMENT

I hereby Appreciate God Almighty for giving me the grace, opportunity and strength to complete my project successfully. Also, we would want to thank the of Civil and Structural Engineering, university of Benin, our able Supervisor Engr. Samuel Adegbemileke for his inspirational guidance and instructions throughout the course of this project. His listening ears and well directed counsel has fostered in us a deep sense of appreciation and affinity for Engineering design and more. Also special thanks to the Head of Department Dr Ngozi. I. Ihimekpen. Also, we want to appreciate Prof. O.U. Orie, Prof. S.O. Osuji, Prof. J.O. Okovido, Prof. A.N. Aniekwu, Engr. Prof. H.A.P Audu, Engr. Prof. S.D. Iyeke, Engr. E. Oria-Usifo, Engr. Dr. R.I. Uwasabor, Engr. Dr. Engr (Dr) Ebuka Nwankwo, Engr. Dr. R Ogirigbo, Engr. Dr. N. Kayode-Ojo, Engr. Dr. A. Rawlings, Engr. Dr. A.I. Agbonaye, Engr. Dr. L.O. Bobor, Engr. Dr. R. Liaboya, Engr. Dr. U. Ukeme, Engr. Dr. S.A. Adegbemileke, Engr. J.O. Ogbeide, Engr. P.N. Ogbeifun, Mr. O. Oriakhi, Engr. B. Omosefe, Mr. C, Okolie, Mr. O. Osasu, Mr.N. Oghoyafedo, Engr. U. K. Ogbonna for their positive support and assistance in the process of my undergraduate . I will also like to say a big thanks to every staff in the Civil/Structural Laboratory, Also we want to thank Faculty of Engineering and University of Benin as a whole. Our special thanks also goes to our colleagues during this period of project work. I say thank you all

ABSTRACT

This paper aims at assessing the return on investment and carbon mitigation potentials of five investment alternatives for the limestone calcined clay cement in a long-term horizon appraisal (15 years). Anticipated growing demand for cement. This research has explored the beneficial contribution of a new available technology, LC³ cement, resulting from the combination of clinker, calcined clay and limestone, with a capacity of replacing up to 30% or 40% of clinker in cement. Increasing the production of conventional blended cements instead brings only marginal economic benefits without supporting the needed increase in production capacity.

The conducted study also shows that, in spite of the extra capital cost required for the calcination of kaolinite clay, LC³ drops production costs in the range of 15–25% compared to conventional solutions.

A coarse sharp sand from sea was gotten with gypsum, calcined clay, limestone, granite and opc was taken to the laboratory for proper research in which 40% and 30% of calcined clay was being use for the research with gypsum, coarse aggregate, limestone, fine aggregate and opc using it likewise with coarse aggregate and fine aggregate as control.

In this research we are able to obtain the comprehensive strength for 3days,7days, 14days and 28 days. The sieve analysis was gotten, bleeding, workability, setting time, porosity, segregation and water absorption.

Table of Content

Title page.....	i
Certification.....	ii
Dedication	iii
Acknowledgement.....	iv
Abstract	v
Table of content.....	vi
CHAPTER ONE: INTRODUCTION	
1.0 Introducion.....	1
1.1 Statement of the research problem.....	2
1.2 Aims and Objectives.....	2
1.3 Scope of study.....	3
CHAPTER TWO: LITERATURE REVIEW	
2.1 Calcined Clay.....	4
2.2 Low Carbon binder.....	6
2.3 Limestone Calcined Clay Concrete.....	7
CHAPTER THREE: METHODOLOGY	
3.1 The Slump Test.....	12
3.2 Porosity.....	12
3.3 Bleeding Test.....	12
3.4 Water Absorption Test.....	13
3.5 Compressive strength test.....	13
3.6 Materials Used.....	13
3.6.1 Water	13
3.6.2 Sand Validity of the instrument	14
3.7 Equipment, Materials Used.....	14
3.8 Ordinary portland cement.....	15
CHAPTER FOUR: DATA ANALYSIS, INTERPRETATION OF RESULTS AND DISCUSSION FINDINGS	
4.1 Sieve Analysis test values.....	17
4.2 OPC (Control) test values.....	17
4.3 Uzebba (40%) Strength test values.....	18

4.4 Uzebba (20%) compressive Strength test values	20
4.5 Uzebba (30%) compressive Strength test values (Hair drying).....	21
4.6 Water absorbtion test values at (800°c,700°c, and 600°c).....	23
4.7 Initial and final setting time	24
4.8 Bleeding test value	24
CHAPTER FIVE: SUMMARY OF FINDINGS, CONCLUSION AND	
RECOMMENDATIONS	
5.1 Conclusion.....	25
5.2 Recommendation.....	26
References.....	27

CHAPTER ONE

1.0 Introduction

The contemporary cement industry is grappling with sustainability challenges, particularly in terms of decreasing carbon emissions and utilizing alternative raw materials. Calcined clay (CC) emerges as a viable solution to address these issues. Prominent global cement companies are acutely aware of the mounting pressure to reduce carbon dioxide emissions, prompting concerns about the way forward. Consequently, national cement associations are devising localized strategies, and the Cement Sustainability Initiative (CSI) is prioritizing this matter. Policies aimed at mitigating climate change have been established to curtail greenhouse gas emissions into the atmosphere. This research topic becomes significant as it has the potential to make a substantial contribution to the construction industry, both technically and financially, provided it proves to be feasible.

CC, short for calcined clay, is gaining popularity as an eco-friendly, partial substitute for clinker in cement production. Clay is an abundant natural resource, and after undergoing high-temperature calcination, it acquires new physical properties, making it suitable as a supplementary cementitious material (SCM).

Limestone calcined clay cement (LC3) is an eco-friendly cement designed to reduce carbon dioxide emissions by 30% compared to ordinary Portland cement during manufacturing. LC3 results from an ongoing collaboration between EPFL and partners in India and Cuba, aiming to develop low-carbon and resource-efficient raw materials for cement production.

The primary components of limestone calcined clay cement include clinker, calcined clay, gypsum, and limestone. When substantial amounts of calcined clay and ground limestone are

incorporated into concrete mixtures, the aluminates from the clay interact with the calcium carbonates from the limestone.

Calcined clay cements, including LC3, represent a promising new technology that will assist the cement industry in lowering emissions and progressing towards a more sustainable environment..

1.2 Statement of problem.

Clinker-based cement production is associated with high electrical and thermal consumption costs for industries. Additionally, it ranks among the major contributors to CO₂ emissions, a significant environmental pollutant. This is primarily due to the substantial CO₂ emissions associated with Portland cement production, which accounts for approximately 4 billion tons of cement currently being manufactured, releasing 1.5 billion tons of carbon dioxide into the atmosphere. Consequently, the cement industry stands as the second-largest emitter of harmful gases.

In light of these challenges, calcined clay cement emerges as a promising alternative that can effectively reduce overall production costs. Consequently, this project aims to evaluate the strength characteristics of LC3 and certain rheological properties of ternary blended cement.

1.3 Aims and Objectives.

The project aims at checking how we can reduce clinker content in cement.or reducing cement content in concrete.

Objectives

- a. Optimizing aggregate gradients
- b. Use of water reducing admixtures.
- c. Also to reduce binder content in concrete mixtures

1.3 Scope of Study

This research will see the limestone calcined clay cement been tested for so many things like;

- i. The workability test.
- ii. Setting time
- iii. Porosity
- iv. Segregation
- v. Bleeding test.
- vi. Water absorption test will be carried out on the concrete.

CHAPTER TWO

2.0 Literature Review

2.1 Calcined Clay.

Calcined clay is a cementitious material that holds great potential due to its abundant availability for meeting the growing demand for eco-efficient cement-based materials. It accomplishes this by reducing the need for clinker or cement content in concrete, thereby helping address the issue of carbon dioxide emissions in the building industry. Cement production alone is responsible for a significant portion of global carbon dioxide emissions [Damtoft et al., 2008].

Clay, which is abundant and cost-effective, is widely distributed worldwide. Its mineral composition varies greatly, leading to extensive research on the possibility of using clay from specific deposits as supplementary cementitious materials through the calcination process [Scherb et al., 2019; Nawel et al., 2020; Maier et al., 2020; Tironi et al., 2012].

Muscovite, a clay mineral, also exhibits pozzolanic activity after appropriate heat treatment, although the results can be mixed. Some studies have shown limited effectiveness of this treatment, particularly at lower temperatures [Ambroise et al., 1985; He et al., 1996; Scherb et al., 2018].

To reduce the carbon footprint of the cement industry, blended cements have gained attention, which combine ordinary Portland cement (OPC) or clinker with supplementary cementitious materials (SCMs) [Juenger et al., 2011; Lothenbach et al., 2011]. Blast furnace slag is a common SCM derived from pig iron production [Giergiczny, 2019; Zhang et al., 2022].

Limestone-calcined clay-cement (LC3) is considered a promising alternative for sustainable and high-performance cements, with comparable strength development to portland cement [Zunino and Scrivener, 2019].

Calcined kaolinitic clay, rich in reactive silicate and aluminate, is a core reactive phase that can enhance the mechanical performance and durability of cementitious materials by reducing porosity [Scrivener et al., 2018; Matschei et al., 2007; Skibsted and Snellings, 2019]. Slightly more optimistic conclusions about the durability of concrete with cement blended with calcined clay were formulated by Pierkes et al. [Pierkes et al., 2018].

Efforts have been made to develop a cost-effective and environmentally friendly binder known as Limestone-Calcined Clay Cement (LC3), which consists of calcined clay, limestone, and clinker in specific proportions [Yu et al., 2021; Liu et al., 2022].

Calcined kaolinitic clays are obtained by heating raw kaolinitic clays and are mainly found in tropical and subtropical climates [Global Soil Regions, US Department of Agriculture - Natural Resources Conservations Service, 2005; Murray, 2007].

Given the need for heating and cooling in buildings, there is a demand for improved thermal insulation systems to reduce energy consumption [Awoyera et al., 2022].

To enhance the reactivity of calcined clays and reduce impurities, purifying clay materials to increase the clay fraction in raw materials is a promising approach [IEA, 2009; International Energy Agency, 2018].

The utilization of lightweight aggregates in LW cementitious renders can lower thermal conductivity, reducing the transfer of heat from the exterior to the interior of buildings, thanks to their low porosity and thermal conductivity [Shi et al., 2022].

2.2 Low Carbon Binder

Limestone-calcined clay cement (LC3) offers a sustainable alternative to Portland cement, which is crucial as the demand for housing and civil engineering infrastructure grows rapidly in Nigeria and other African nations due to urbanization and population growth [Schmidt et al., 2021]. Decreasing the thermal conductivity of rendering mortar in buildings can help reduce energy consumption for heating and cooling, and LC3 utilizes industrial by-products like fly ash, blast furnace slag, and silica fume, along with natural pozzolana, to create low-carbon cements [Shoukry, 2019; Shoukry et al., 2014].

LC3, composed of limestone, calcined clay, clinker, and gypsum, is often referred to as the "future cement" due to its potential to address future challenges. LC3 is cost-effective and requires minimal modifications to existing cement plants [Cancio Díaz et al., 2017]. It shows promise as a low-clinker cement alternative to traditional Portland cement, with ongoing research in India evaluating its properties over four years [Anonymous].

The consumption of fossil fuels is a major contributor to CO₂ emissions and environmental issues. Portland cement is a known environmental offender in the cement industry [Mohammed et al., 2020]. Clay minerals are gaining attention for their low carbon footprint, as they can serve as supplementary cementitious materials [Medjigbodo et al., 2018].

Studies indicate that LC3 production releases significantly less carbon dioxide compared to conventional cement, highlighting its potential to reduce energy and raw material consumption [Scrivener et al., 2018]. The combination of calcined kaolinitic clays and limestone in LC3 offers a promising approach to lower production costs and reduce CO₂ emissions by reducing clinker content [Arya and Xu, 1995].

To achieve similar workability in LC3 blend as in plain Portland cement, the authors utilized a polycarboxylate superplasticizer called SP490 from Mapei, as discussed by C. He, B.

Osbaeck, and E. Makovicky in their research on the adsorption of water on metakaolin particles and its impact on workability (Cement and Concrete Research, 25, 1995).

Evangeline Lalrinmawii et al. examined various physical and mechanical properties of mortar, replacing sand and cement partially with recycled AAC and cellular lightweight concrete (CLC) blocks (IOP conference series. Mater Sci Eng 2020).

Baiano et al. stressed the importance of environmentally friendly and ideally carbon-neutral approaches to energy production (J Mater Res Technol 2021) in light of the high energy consumption and CO₂ emissions associated with cement production. They suggested using pozzolans as a replacement material in cement clinker to mitigate these issues.

When selecting clay for calcined clay pozzolana production, past experience with the clay's performance under service conditions and experimental investigations are valuable guides, as noted by Avet F., Maraghechi H., and Scrivener K. (14th International Conference on Durability of Building Materials and Components, Ghent, Belgium).

In addressing the high energy consumption and CO₂ emissions associated with cement production, the most straightforward solution is to incorporate pozzolans as replacement materials for cement clinker, as discussed by Madloul, N. A., Saidur, R., Hossain, M. S., and Rahim, N. A. (Renewable and Sustainable Energy Reviews, 15, 2011). This approach leads to reduced energy consumption and lower CO₂ emissions due to the reduced clinker content.

Limestone calcined clay Concrete

For nearly two centuries or even longer, Portland cement has demonstrated remarkable reliability as a construction material under a wide range of environmental conditions (Janotka I, Puertas F, Palacios M, Kuliffayová M, Varga C. Metakaolin sand–blended-cement pastes: rheology, hydration process and mechanical properties. Constr Build Mater 2010;791:802–

24). The enduring success of Portland cement concrete can be attributed to its status as one of the most widely manufactured materials globally, despite various advancements in its production and use (Frías M, Sánchez de Rojas MI, Cabrera J. The effect that the pozzolanic reaction of metakaolin has on the heat evolution in metakaolin-cement mortars. *Cem Concr Res* 2000;209:216–30).

Concrete stands as the most produced material worldwide, with approximately 4,200 million metric tons of cement being produced annually, and this number continues to rise (Cembureau, *World Statistical Review 2004 - 2014*, Cembureau, (2017). N.H. Müller, J., A blueprint for a climate friendly cement industry, WWF International, (2008)). Cement is highly advantageous due to its affordability, accessibility, ease of use, and the fact that producing 1 kg of concrete generates fewer emissions compared to other construction materials like steel and ceramics (Concrete CO2 Fact Sheet, National Ready Mixed Concrete Association, (2008). G.P. Hammond, C.I. Jones, Embodied energy and carbon in construction materials, *Proceedings of Institution of Civil Engineers: Energy*, 161 (2008) 87-98).

When General Purpose (GP) cement is substituted with other materials, there is a noticeable reduction in concrete workability. To achieve the desired consistency, superplasticizers are often required, which is similar to the reference GP cement concrete (Medjigbodo, G., Rozière, E., Charrier, K., Izoret, L., Loukili, A. "Hydration, shrinkage, and durability of ternary binders containing Portland cement, limestone filler and metakaolin", *Construction and Building Materials*, 183, pp. 114–126, 2018).

The compressive strength of concrete at different stages depends on factors such as the amorphous material derived from the kaolinite content in clays, the structural order/disorder, and physical elements that influence the rate of pozzolanic reaction (Badogiannis E, Kakali G,

Dimopoulou G, Chaniotakis E, Tsivilis S. Metakaolin as a main cement constituent. Exploitation of poor Greek kaolins. *Cem Concr Compos* 2005;197:203–27).

One notable characteristic of LC3 is its higher specific surface area compared to other cements, primarily due to the fine particles of calcined clay it contains. Although LC3 may exhibit twice the Blaine measurements of other cements, the water-to-cement ratio required to achieve a standard consistency does not increase as significantly (EN 196-5 Standard: methods for testing cement. Part 5. Pozzolanicity test for pozzolanic cements. Qijun Yu, Sawayama K, Sugita S, Shoya M, Isojima Y. The reaction between rice husk ash and $\text{Ca}(\text{OH})_2$ solution and the nature of its product. *Cem Concr Res* 1999;37:29–43).

The physical and chemical properties of LC3 have been extensively studied in comparison to other cements. The fine particles of calcined clay contribute to its higher specific surface area, as observed in various standard tests (CEN "EN 12350-2 Testing fresh concrete - Part 2: Slump-test", European Committee for Standardization, Brussels, Belgium, 2010. CEN "EN 12390-3 Testing hardened concrete-Part 3: Compressive strength of test specimens", European Committee for Standardization, Brussels, Belgium, 2012).

Shrinkage is a critical parameter in certain applications of concrete, such as high-performance concrete, repair concretes, mass concretes, prestressed concrete, and shotcrete. Controlling shrinkage is essential as it can have a negative impact on the final performance of concrete (Sánchez, M. A., Molina, W. M., García, H. L. C., Guzmán, E. M. A., Acosta, A. A. T., Ortega, J. M. P. "Properties of Portland Cement Mortar with Substitutions of Natural and Expanded Perlite", *Periodica Polytechnica Civil Engineering*, 62(2), pp. 508–516, 2018).

The suitability of chemical admixtures with LC3 is limited because the surface characteristics of particles play a crucial role in the adsorption and functionality of most types of admixtures. These characteristics, including morphology and surface charge, differ between clay particles

and clinker (B.Yudiesky Cancio Díaz, Sofia Sánchez Berriel, Urs Heierli, R. Aurélie Favier, Inocencio: “Limestone calcined clay cement as a low-carbon solution to meet expanding cement demand in emerging economies,” *Development engineering* 2(2017)18).

Modern cements predominantly consist of blended cements that incorporate Supplementary Cementitious Materials (SCMs). The reactivity of these blended cements is traditionally assessed by measuring compressive strength at 7 days or 28 days of hydration (Avet F., Scrivener K. Investigation of the reactivity of various grades of kaolinitic calcined clays used as partial clinker substitute. 2nd International Conference on Advances in Cement and Concrete in Africa. Dar Es Salaam, Tanzania).

The primary concern regarding the durability of concrete infrastructure is the corrosion of steel reinforcement caused by the penetration of chloride ions, which can come from sources like seawater or de-icing salts (Zhenguo Shi et al., 2017). The rate and extent of ion movement in concrete depend on the physical pore structure at both nano and micro scales, as well as the chemical and physical binding of chloride ions to certain hydrates, specifically AFm phases and C-A-S-H.

Antoni et al. (2012) demonstrated that blended cements containing calcined clay and limestone can match the mechanical performance of traditional Portland cement. Marl, a readily available material, has been used in the production of Portland cement and can offer superior physical and mechanical properties compared to metakaolin as a supplementary cementitious material. Additionally, marl can be calcined at a lower temperature.

It is believed that the higher specific surface area of natural marl compared to Portland cement leads to increased pozzolan-lime reaction and pozzolanic activity in tests (ISO 1920-8) related to pozzolanic activity.

Numerous studies have examined the durability of cementitious materials incorporating calcined kaolinite clay, either in binary or ternary (LC3) blends. Researchers such as Shi et al. (2017) have used pure metakaolin in blends with limestone at a 35% replacement level and a clay/limestone ratio of 4.

Traditional Portland cement primarily consists of 95% clinker, and its production is energy-intensive and responsible for a significant portion of CO₂ emissions in the cement industry. By reducing clinker content through Supplementary Cementitious Materials (SCMs), substantial reductions in CO₂ emissions can be achieved (E. L'Hôpital et al., 2016).

There is an ample supply of calcined clay available, which can meet the increasing demand for materials to replace cement. Justnes, in their research, highlighted that calcined marl, a new type of mineral additive, has the potential to serve as an alternative to high-quality fly ash, metakaolin, and silica fume. This finding is in line with studies conducted on LC3, which is produced through the co-grinding or blending of its components to create a uniform mixture. Most research on LC3 has focused on clays primarily composed of kaolinite, although some studies have explored illite and montmorillonite, noting that their reactivity tends to be lower than that of kaolinite. LC3 has demonstrated its ability to address sustainability across environmental, economic, and societal dimensions, particularly in terms of safety and engineering performance.

JK Lakshmi Cement Ltd. achieved a significant milestone by becoming the first cement company to produce LC3 and LC2. Their production process proved to be feasible with existing technologies, albeit requiring some basic adjustments. An important factor discovered in this experiment was the need to control the particle size distribution of the cement.

CHAPTER THREE

3.0

METHODOLOGY

From this experiment we will be able to find out the materials used and the necessary experiments carried out.

Laboratory test method was applied and the test carried out include;

- The Slump test.
- Porosity
- Bleeding test.
- Water absorption test will be carried out on the concrete.
- Compressive strength test

3.1 The Slump Test: The strength of concrete in a specific mix is significantly impacted by how well it's compacted. Therefore, it's crucial to ensure that the mix has the right consistency for easy transportation, placement, and finishing without any segregation issues. The slump test is a widely used and straightforward method for assessing the uniform application of different concrete weights in real-world conditions. Another test, known as the flow table or slump-flow test, checks if the concrete maintains its shape after removing the cone.

3.2 Porosity: Porosity refers to the measurement of void volume within concrete. These voids must be connected and have a certain size. More porous concrete tends to be more permeable. It's important that the voids allowing moisture movement are interconnected and of a specific size. Discontinuous or narrow entrance pores can impede moisture flow.

3.3 Bleeding Test: The bleeding test identifies the separation of water from a concrete mix due to gravitational settling of solid materials. Excessive bleeding can lead to issues like

green shrinkage, sand streaking, laitance formation, non-uniform strength, water-filled voids under aggregate, increased permeability, and cold weak joints in placed concrete. Various methods have been proposed to measure concrete bleeding, but complete satisfaction hasn't been achieved. The method discussed here involves using a pipette to suck water from tracks on the concrete's surface immediately after casting, considering water evaporation. Three different tests with samples of varying initial heights are performed, and comparing their results determines if bleeding is localized. The major result is the average bleeding rate without channels, which is assessed for repeatability.

3.4 Water Absorption Test: Also known as the Cobb Test, this procedure measures the amount of water absorbed within a specific timeframe. It's a practical way to determine the liquid absorptiveness or resilience of various materials, including treated and untreated papers, boards, and fabrics. The test involves measuring the average dry weight of cube samples before and after submerging them in water at different percentages (10%, 20%, 30%, 40%) and then calculating the water absorption ratio. This ratio indirectly assesses durability.

3.5 Compressive Strength Test: The compressive strength test is a mechanical evaluation that determines the maximum load a material can endure before breaking. A compression testing machine gradually applies force to the test item, typically in the form of a cube, prism, or cylinder. Compressive strength testing on a cube or cylinder is the standard method, as recommended by different codes, to assess various properties of concrete.

3.6 Materials Used

3.6.1 Water

Water plays a vital role in concrete. It reacts with cement, leading to the setting and hardening of the material, while also assisting in the mixing, placement, and compaction of fresh concrete. According to Abruckle (2007), water used in concrete should be safe for

consumption or obtained from an approved source. Previous research indicates that for concrete to attain the necessary workability and strength in both its fresh and hardened states, the water used for mixing and curing must meet specific quality standards. It should be devoid of impurities such as suspended solids, organic matter, and salts, which could negatively impact the concrete's setting, hardening, strength, and durability. Water is utilized in concrete production, aggregate washing, mortar and brick formation, as well as various construction tasks like casting, painting, terrazzo finishing, plastering, and more. After the concrete is cast, water is applied to it in a process called curing to enhance its strength. According to BS Standards, water used for mixing and curing must be clean and free from substances like oils, acids, alkalis, salts, sugar, organic materials, or any other elements that might harm concrete or steel. Generally, potable water is considered suitable for concrete mixing.

3.6.2 Sand

Regarding sand, we perform a sieve analysis test. This test is employed to evaluate the particle size distribution of a granular material by passing it through a series of sieves. A typical sieve analysis involves using a set of nested sieves with wire mesh.

3.7 Equipment and Materials Used

- i. Testing samples (fine and recycled aggregates)
- ii. A collection of sieves with known sizes and a bottom pan
- iii. Mechanical shaker
- iv. Weighing balance

3.8 Ordinary Portland Cement

Cement is a crucial component of concrete. The cement manufacturing process involves grinding raw materials, intimately mixing them in specific proportions, and then subjecting them to high temperatures in a kiln (typically between 1300 to 1500 degrees Celsius). This process is necessary to determine various properties of cement.

tests are done. The tests done are:

i. Initial Setting Time

The initial setting time of cement signifies the moment when the cement paste commences to lose its malleability. In theory, the initial setting time for concrete is the duration from the introduction of water to the cement until a 1 mm square-section needle can no longer penetrate the cement paste, which is positioned inside Vicat's mold, approximately 5 mm to 7 mm from the bottom of the mold.

ii. Final Setting Time

The final setting time of cement is the point at which the cement paste completely relinquishes its malleability. It is crucial that cement neither sets too quickly nor too slowly. This period encompasses the time from when water is mixed with the cement until a 1 mm needle leaves an impression on the paste inside the mold, while a 5 mm attachment fails to make any impression.

iii. Fineness of Cement

Fineness measures the total surface area of cement. Finer cements possess a greater surface area. Fineness impacts the rate of hydration, the pace of strength development, shrinkage, and the speed of heat evolution. The experiment is conducted following BS Standard.

iv.

Soundness of Cement

The examination of cement's soundness aims to ensure that the cement does not exhibit any subsequent expansion that may affect its quality. Cement unsoundness is typically caused by an excess of lime, magnesia, or an excessive proportion of sulfates. The Le Chatelier's method is employed for this experiment, with the acceptable value for soundness being 1 mm.

CHAPTER FOUR

4.0 DISCUSSION OF RESULTS.

Table 4.1: Sieve Analysis test values.

Sieve Numbers	Sieve Sizes (mm/ μ m)	Mass Recorded (g)	Percentage of mass retained	Cumulative Percentage of mass retained	Percentage of mass passing
1	2.36mm	12	2.4	2.4	97.6
2	2.00mm	7	1.4	3.8	96.2
3	1.18mm	50	10	13.8	86.2
4	6.00 μ m	109	21.8	35.6	64.4
5	425 μ m	32	6.4	42	58
6	300 μ m	64	12.8	54.8	45.2
7	212 μ m	177	35.4	90.2	9.8
8	150 μ m	15	3	93.2	6.8
9	75 μ m	23	4.6	97.8	2.2

Table 4.2: OPC (Control) Test Values.

Days of Curing	Weight (g)	Density (kg/m ³)	Failure Load (KN)	Compressive Strength (N/m ²)
Control 3Days	291	2328	29.07	11.63
Control 3Days	289	2312	35.46	14.13
Control 3Days	285	2280	32.46	12.98
Control 7Days	269	2152	29.03	11.61
Control 7Days	272	2176	41.42	16.52

Control 7Days	271	2168	39.8	15.75
Control 14Days	277	2216	34.42	13.77
Control 14Days	271	2168	33.24	13.30
Control 14Days	284	2272	21.92	8.77
Control 28Days	273	2184	38.49	15.4
Control 28Days	273	2184	34.21	13.68
Control 28Days	271	2168	26.57	10.63

Table 4.3: Uzebba (40%) strength test values.

Days of curing	Sample temperature (°C)	Weight (g)	Density (kg/m ³)	Failure Load (KN)	Compressive Strength (N/m ²)
3 Days	800	291	2328	27.17	10.87
	800	281	2248	26.32	10.53
	800	280	2240	19.42	7.77
	700	281	2248	21.89	8.76
	700	289	2312	15.25	6.1
	700	289	2248	19.75	7.9
	600	319	2312	19.03	7.61
	600	281	2552	19.39	7.76
	600	280	2248	17.6	7.04
	7 Days	800	280	2240	32.28
800		288	2240	28.64	11.45
800		285	2307	30.31	12.13
700		282	2280	14.07	5.63
700		287	2256	26.71	10.68
700		287	2296	24.99	10.0
600		283	2264	35.13	14.05
600		281	2248	20.85	8.34
600		281	2248	16.89	6.76
14		800	274	2192	18.07

Days	800	274	2192	16.35	6.54
	800	279	2232	18.71	7.48
	700	298	2384	17.67	7.07
	700	285	2280	17.42	6.97
	700	281	2248	16.35	6.54
	600	288	2304	12.64	5.06
	600	273	2184	11.28	4.51
	600	289	2312	13.35	5.34
28 Days	800	283	2264	17.64	7.06
	800	289	2312	30.17	12.07
	800	290	2320	28.61	11.44
	700	289	2312	22.75	9.10
	700	295	2360	19.57	7.83
	700	255	2040	17.32	6.93
	600	282	2256	19.39	7.76
	600	289	2312	19.07	7.63
600	259	2072	18.71	7.48	

Uzebba (30%) Strength Test Values.

Days of curing	Sample temperature (°C)	Weight (g)	Density (kg/m ³)	Failure Load (KN)	Compressive Strength (N/m ²)
3 Days	800	274	2192	32.53	13.01
	800	268	2144	26.07	10.43
	800	268	2144	24.6	9.84
	700	271	2168	34.17	13.67
	700	267	2136	30.03	12.01
	700	272	2176	30.39	12.16
	600	273	2184	22.46	8.98
	600	267	2136	25.67	10.27
600	270	2160	22.71	9.08	
7 Days	800	277	2216	45.67	18.27
	800	270	2160	39.99	15.1
	800	271	2168	37.21	14.88
	700	276	2208	40.03	16.01

	700	269	2152	44.81	17.92
	700	270	2160	41.42	16.57
	600	269	2152	31.03	12.41
	600	273	2184	21.85	8.74
	600	268	2144	37.63	15.05
14 Days	800	270	2160	37.35	14.94
	800	270	2160	30.21	12.08
	800	271	2168	36.17	14.47
	700	269	2152	56.67	22.67
	700	268	2144	55.74	22.30
	700	274	2192	52.35	20.94
	600	272	2176	43.92	17.57
	600	269	2152	35.74	14.30
600	271	2168	46.88	18.75	
28 Days	800	268	2144	38.13	15.25
	800	270	2160	50.13	20.05
	800	272	2176	40.17	16.07
	700	274	2192	26.57	10.63
	700	270	2160	29.28	11.71
	700	272	2176	34.56	13.82
	600	272	2176	29.78	11.91
	600	278	2224	21.96	8.78
600	270	2160	24.92	9.97	

Table 4.4: Uzebba (20%) Compressive Strength Test Values.

Days of Curing	Sample temperature (°C)	Weight (g)	Failure Load (KN)	Compressive Strength (N/m²)
3 Days	800	274	32.53	12.91
	800	268	26.07	11.45
	800	268	24.6	12.13
	700	271	34.17	14.05
	700	267	30.03	8.34
	700	272	30.39	6.76

	600	273	22.46	5.63
	600	267	25.67	10.68
	600	270	22.71	10.0
7 Days	800	277	45.67	18.27
	800	270	39.99	15.1
	800	271	37.21	14.88
	700	276	40.03	16.01
	700	269	44.81	17.92
	700	270	41.42	16.57
	600	269	31.03	12.41
	600	273	21.85	8.74
	600	268	37.63	15.05

Table 4.5: Uzebba 30% Compressive Strength Test Values (Air Drying)

Means of curing	Days of Curing	Weight (g)	Density (kg/m ³)	Failure Load (KN)	Compressive Strength (N/m ²)
3Days Air Curing 30%	Control 3days	291	2328	10.03	4.11
	Control 3days	278	2224	16.53	6.61
	Control 3days	301	2408	15.96	6.38
7Days Air Curing 30%	Control 7days	281	2248	19.03	7.61
	Control 7days	282	2256	27.32	10.93
	Control 7days	282	2256	27.67	11.07
14Days Air Curing 30%	Control 14days	288	2304	43.4	17.36
	Control 14days	291	2338	34.67	7.89
	Control 14days	289	2328	41.3	10.9
28Days Air Curing 30%	Control 28days	289	2356	27.45	12.07
	Control 28days	287	2296	42.64	17.06
	Control 28days	291	2328	36.93	14.77

Means curing of	Sample temperature (°C)	Weight (g)	Density (Kg/m³)	Failure Load (KN)	Compressive Strength (N/m²)
Air Curing 3 Days	800	260	2080	19.57	7.83
	800	280	2240	20.75	8.30
	800	283	2264	20.35	8.14
	700	283	2264	8.64	3.46
	700	283	2264	18.85	7.54
	700	278	2224	5.00	12.5
	600	285	2280	11.6	4.64
	600	284	2272	10.39	4.16
	600	291	2328	10.78	4.31
Air Curing 7 Days	800	290	2320	43.81	17.52
	800	324	2592	40.88	16.352
	800	302	2416	32.14	12.856
	700	290	2320	10.25	4.1
	700	278	2224	13.1	5.24
	700	286	2288	21.07	8.428
	600	280	2240	13	5.2
	600	275	2200	18.75	7.5
	600	277	2216	19.21	7.684
Air Curing 14 Days	800	297	2376	50.66	20.26
	800	287	2296	34.16	13.66
	700	277	2216	39.74	15.90
	700	273	2184	27.24	10.90
	600	275	2200	24.92	9.97
	600	276	2208	31.62	12.65
Air Curing 28 Days	800	270	2160	27.15	10.86
	800	295	2360	22.13	8.85
	800	291	2328	32.49	13.00

	700	281	2248	26.6	10.64
	700	284	2272	31.69	12.68
	600	292	2336	31.69	12.68
	600	283	2264	35.17	14.07

Table 4.6: Water Absorption Test values at (800°C, 700°C & 600°C)

Duration		1 Hour	1 Hour	30 mins	30 mins	30 mins	30 mins	
Temperature of Sample (°C)	Initial mass (g)	1 st Oven dry weight(g)	2 nd Oven dry weight(g)	3 rd Oven dry weight(g)	4 th Oven dry weight(g)	5 th Oven dry weight(g)	6 th Oven dry weight	
800	271	269	265	264	263	263	-	
800	273	270	275	264	263	262	-	
800	273	271	266	265	264	263	-	
700	273	269	262	260	258	255	-	
700	262	256	248	247	245	243	-	
700	268	265	260	259	258	255	-	
600	256	245	235	233	231	227	-	
600	269	267	263	262	261	258	-	
600	270	266	261	260	259	258	-	
Control	276	272	264	263	262	259	-	
Control	276	272	262	261	262	259	-	
Control	278	270	263	262	260	259	-	
			10 mins	20 mins	30 mins	1 hour	24 hours	72hours
800	260	266	268	270	269	272	272	
800	261	265	269	270	270	272	273	
800	262	267	270	270	271	272	273	
700	255	261	265	265	270	272	273	
700	241	254	256	256	258	259	259	
700	255	260	263	263	265	267	268	
600	227	246	249	249	250	251	252	
600	259	264	267	267	268	269	270	
600	257	262	265	265	267	269	270	
Control	259	270	273	273	274	274	275	
Control	258	269	272	273	274	274	275	
Control	258	270	272	272	273	274	275	

Table 4.7: Initial and Final Setting Time.

SPECIMEN	VOLUME OF WATER (ml)	INITIAL SETTING TIME (Mins)	FINAL SETTING TIME (Mins)	AVERAGE
OPC 1	135ml	87	177	178.5
OPC 2	135 ml	89	180	
600 1	140 ml	90	190	191
600 2	140 ml	88	192	
700 1	145 ml	64	200	199
700 2	145 ml	68	198	
800 1	155 ml	92	216	217
800 2	155 ml	100	218	

Table 4.8: Bleeding Test Value.

SPECIMEN	AMOUNT OF BLEEDING WATER (g)	BLEEDING PERCENTAGE (%)
Control	16	3.2
600 °C Calcined clay	20	4
700 °C Calcined clay	25	5
800 °C Calcined clay	29	5.8

Discussion

For all the test carried out on compressive strength as the days increased the strength or failure load increased. For 30

For the bleeding test as the temperature for the bleeding test increased so also was the percentage increase.

For 40% replacement lower temperature made the compressive strength drop drastically.

In total we can see that the compressive strength for control are better than the replacement used but then the strength values we had for the are good to work with.

CHAPTER 5

5.0 CONCLUSIONS AND RECOMMENDATIONS.

5.1 Conclusion

Based on the experimental study on investigating the use of calcined clay. The following conclusions which are limited to the materials used in this study were brought out.

- a. Gradual increase in the setting time 600 to 700 and 800bwhich is now higher than the control.
- b. So as long as there is a gradual increase in the temperature the setting time follows suite.
- c. Water absorption. The OPC tends to absorb water better. This shows that the mix is worse than the ordinary Portland cement
- d. The bleeding test, the control is better suitable for it because it has the lowest bleeding temperature. The bleeding is more suitable in lower temperature. So if the temperature is reduced we have a lower bleeding.
- e. For calcined clay there is gradual increase in the compressive strength as the volume is been increased. They all showed good compressive strength when compared to the ordinary Portland cement OPC.

5.2 Recommendation

Developing an alternative use to cement in countries like Nigeria might be a major problem but irrespective of that the increase in demand due to our high population and fast rate of development with our need for low cost building materials because of the economy. In this we say this research has shown to a very measurable extent that the limestone calcined clay cement can represent a good alternative for normal Portland cement.

From the result gotten we can see that the compressive strength for control is closely followed by that of the calcined clay which makes it a suitable material for construction.

So in appropriate circumstances the calcined clay cement can be used to control the cost of production. This is because it provides a lower cement price.

References.

- Ambroise, J.; Murât, M.M.; Péra, J. Hydration reaction and hardening of calcined clays and related minerals V. Extension of the research and general conclusions. *Cem. Concr. Res.* 1985, 15, 261–268. [CrossRef] 25. He, C.; Makovicky, E.; Øsbæck, B. Thermal treatment and pozzolanic activity of Na- and Ca-montmorillonite. *Appl. Clay Sci.* 1996, 10, 351–368
- Antoni, M., Rossen, J., Martirena, F., Scrivener, K. "Cement substitution by a combination of metakaoline and limestone", *Cement and Concrete Research*, 42(12), pp. 1579–1589, 2012. <https://doi.org/10.1016/j.cemconres.2012.09.006>
- Avet F., Maraghechi H., Scrivener K. Analysis of chloride transport and binding in limestone calcined clay binders with various kaolinite content. 14th International Conference on Durability of Building Materials and Components. Ghent, Belgium
- Awoyera PO, Akinrinade AD, de Sousa Galdino AG, Althoey F, Kirgiz MS, Tayeh BA.
- B. Lothenbach, K. Scrivener, R.D. Hooton, Supplementary cementitious materials, *Cement Concr. Res.* 41 (2011) 1244–1256, <https://doi.org/10.1016/j.cemconres.2010.12.001>]
- B.Yudiesky Cancio Díaza, Sofia Sánchez Berriela, Urs Heierlic, R. Aurélie Favierd, Inocencio: "Limestone calcined clay cement as a low-carbon solution to meet expanding cement demand in emerging economies," *Development engineering* 2(2017)18
- Badogiannis E, Kakali G, Dimopoulou G, Chaniotakis E, Tsivilis S. Metakaolin as a main cement constituent. Exploitation of poor Greek kaolins. *Cem Concr Compos* 2005;197:203–27
- C. Arya, Y. Xu, Effect of cement type on chloride binding and corrosion of steel in concrete, *Cement and Concrete Research*, 25 (1995) 893-902)
- Concrete CO2 Fact Sheet, National Ready Mixed Concrete Association, (2008). G.P. Hammond, C.I. Jones, Embodied energy and carbon in construction materials, *Proceedings of Institution of Civil Engineers: Energy*, 161 (2008) 87-98
- Damtoft, J.S.; Lukasik, J.; Herfort, D.; Sorrentino, D.M.; Gartner, E.M. Sustainable development and climate change initiatives. *Cem. Concr. Res.* 2008, 38, 115–127

- E. L'Hôpital, B. Lothenbach, D.A. Kulik, K. Scrivener, Influence of calcium to silica ratio on aluminium uptake in calcium silicate hydrate, *Cement and Concrete Research*, 85 (2016) 111-121
- F. Zunino, K. Scrivener, The influence of the filler effect on the sulfate requirement of blended cements, *Cement Concr. Res.* 126 (2019), 105918
- H.H. Murray, *Applied Clay Mineralogy: Occurrences, Processing and Application of Kaolins, Bentonites, Palygorskite-sepiolite, and Common Clays*, Development in Clay Science, 2 (2007)
- Hamed Maraghechi, Francois Avet, Hong Wong, HadiKamyab, Karen Scrivener, (2018), Performance of Limestone Calcined Clay Cement (LC3) with various kaolinite contents with respect to chloridetransport, *Materials and Structures* 51:125, <https://doi.org/10.1617/s11527-018-1255-3>
- Janotka I, Puertas F, Palacios M, Kuliffayová M, Varga C. Metakaolin sand– blended-cement pastes: rheology, hydration process and mechanical properties
- Justnes, H. "How to Make Concrete More Sustainable", *Journal of Advanced Concrete Technology*, 13(3), pp. 147–154, 2015. Akgün, Y. "Alternatif puzolan kalsine marn içeren sürdürülebilir katkılı çimentolar
- K. Scrivener, F. Martirena, S. Bishnoi, S. Maity, Calcined clay limestone cements (LC3), *Cement Concr. Res.* 114 (2018) 49–56, T. Matschei, B. Lothenbach, F.P. Glasser,
- Lalrinmawii E, Sahu S, Sarkar P, Davis R. Feasible use of recycled foam concrete in cement mortar. In IOP conference series. *Mater Sci Eng* 2020 Sep 1;936(No. 1):012011. IOP Publishing
- M. Antoni, J. Rossen, F. Martirena, K. Scrivener, Cement substitution by a combination of metakaolin and limestone, *Cem. Concr. Res.* 42 (2012) 1579–1589. K.L. Scrivener, Options for the future of cements, *Indian Concr. J.* 88 (2014) 11–21
- M.C.G. Juenger, F. Winnefeld, J.L. Provis, J.H. Ideker, Advances in alternative cementitious binders, *Cement Concr. Res.* 41 (2011) 1232–1243, <https://doi.org/10.1016/j.cemconres.2010.11.012>.
- Maier, M.; Beuntner, N.; Thienel, K.-C. An Approach for the Evaluation of Local Raw Material Potential for Calcined Clay as SCM, Based on Geological and Mineralogical Data
- Martirena F, Favier A, Scrivener K (2018) Calcined Clays for Sustainable Concrete: Proceedings of the 2nd International Conference on Calcined Clays for Sustainable Concrete, Springer Avet F, Snellings R, Alujas Diaz A, Haha MB, Scrivener K (2016
- Medjigbodo, G., Rozière, E., Charrier, K., Izoret, L., Loukili, A. "Hydration, shrinkage, and durability of ternary binders containing Portland cement, limestone filler and metakaolin", *Construction and Building Materials*, 183, pp. 114–126, 2018

- Mohammed A, Rafiq S, Sihag P, Kurda R, Mahmood W, Ghafor K, et al. ANN, M5P-tree and nonlinear regression approaches with statistical evaluations to predict the compressive strength of cement-based mortar modified with fly ash. *J Mater Res Technol* 2020;9(6):12416e27
- Nawel, S.; Mounir, L.; Hedi, H. Effect of temperature on pozzolanic reaction of Tunisian clays calcined in laboratory. *SN Appl. Sci.* 2020, 2, 157.
- Neiße-Deiters, A.; Scherb, S.; Beuntner, N.; Thienel, K.-C. Influence of the calcination temperature on the properties of a mica mineral as a suitability study for the use as SCM. *Appl. Clay Sci.* 2019, 179, 105168
- Qijun Yu, Sawayama K, Sugita S, Shoya M, Isojima Y. The reaction between rice husk ash and Ca(OH)₂ solution and the nature of its product. *Cem Concr Res* 1999;37:29–43
- Saba AM, Khan AH, Akhtar MN, Khan NA, Kolor SSR, Petru M, et al. Strength and flexural behavior of steel fiber and silica fume incorporated self-compacting concrete. *J Mater Res Technol* 2021;12:1380e90
- Sánchez, M. A., Molina, W. M., García, H. L. C., Guzmán, E. M. A., Acosta, A. A. T., Ortega, J. M. P. "Properties of Portland Cement Mortar with Substitutions of Natural and Expanded Perlite", *Periodica Polytechnica Civil Engineering*, 62(2), pp. 508–516, 2018.
- Scherb, S.; Beuntner, N.; Thienel, K.-C. Reaction Kinetics of Basic Clay Components Present in Natural Mixed Clays. In *Calcined Clays for Sustainable Concrete*; RILEM Bookseries; Springer: Dordrecht, The Netherlands, 2018; Volume 16, pp. 427–433. ISBN 9789402412062
- Scherb, S.; Neiße-Deiters, A.; Beuntner, N.; Thienel, K.-C. Influence of the calcination temperature on the properties of a mica mineral as a suitability study for the use as SCM. *Appl. Clay Sci.* 2019, 179, 105168
- Schmidt, W.; Commeh, M.; Olonade, K.; Schiewer, G.L.; Dodoo-Arhin, D.; Dauda, R.; Fataei, S.; Tawiah, A.T.; Mohamed, F.; Thiedeitz, M.; et al.
- Scrivener K, John VM, Gartner EM (2016) Eco-efficient cements: Potential economically viable solutions for a low CO₂ cement-based materials industry. UNEP (United Nations Environment Program)
- Shoukry H, Shebl SS, Khalil IS. Preparation of ultra-fine silica particles and their application for enhanced strength of cement mortar. *Cement Wapno Beton* 2014 Jan 1;81:17e22.
- Tironi, A.; Trezza, M.A.; Scian, A.N.; Irassar, E.F. Kaolinitic calcined clays: Factors affecting its performance as pozzolans. *Constr. Build. Mater.* 2012, 28, 276–281
- Yu J, Wu HL, Mishra DK, Li G, Leung CK. Compressive strength and environmental impact of sustainable blended cement with high-dosage Limestone and Calcined Clay (LC2). *J Clean Prod* 2021;1(278):123616. Liu J, Zhang W, Li Z, Jin H, Tang L.

Z. Giergiczny, Fly ash and slag, *Cement Concr. Res.* 124 (2019), 105826, Y. Zhang, S. Zhang, Y. Chen, O. Çopuroglu, ~ The effect of slag chemistry on the reactivity of synthetic and commercial slags, *Construct. Build. Mater.* 335 (2022), 127493.

Zhenguo Shi, Mette R. Geiker, Barbara Lothenbach, Klaartje De Weerd, Sergio Ferreira Garzon, Kasper Enemark Rasmussen and Jørgen Skibsted,