PRECIPITATED CALCIUM CARBONATE AS PARTIAL CEMENT REPLACEMENT MATERIAL FOR CONCRETE PRODUCTION

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PRECIPITATED CALCIUM CARBONATE AS PARTIAL CEMENT REPLACEMENT MATERIAL FOR CONCRETE PRODUCTION

By

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Submitted

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I declare that this thesis entitled "**Precipitated Calcium Carbonate as partial cement replacement material for concrete production**" is my own work and has not been submitted to any university for similar purposes. All sources of material that are used for this thesis have been duly acknowledged through Proper citation. It is being submitted for partial fulfilment for the award of the degree of Master of Science in Civil Engineering (Construction Engineering and Management) at Adama Science and Technology University School of Civil Engineering and Architecture.

Desta Hussein Eresso	______________________	_______________
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I, hereby certify that I have read and evaluated this thesis entitled **"Precipitated Calcium Carbonate as partial cement replacement material for concrete production"** prepared under my guidance by **Desta Hussein Eresso** submitted in partial fulfilment of the requirements for the degree of Master of Science in Civil Engineering (Construction Engineering and Management). Therefore, I recommend that the candidate fulfil the requirements and hence he/she can submit the thesis to the department.

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APPROVAL PAGE

I/we, the advisors of the thesis entitled "**Precipitated Calcium Carbonate as partial cement replacement material for concrete production"** and developed by **Desta Hussein Eresso,** hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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We, the undersigned, members of the Board of Examiners of the thesis by **Desta Hussein Eresso** have read and evaluated the thesis entitled **"Precipitated Calcium Carbonate as partial cement replacement material for concrete production"** and examined the candidate during the open defence. This is, therefore, to certify that the thesis is accepted for partial fulfilment of the requirement of the degree of Master of Science in Civil Engineering (Specialization in Construction Engineering and Management.)

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ABSTRACT

Developing and emerging countries during their high growth phase consume a large quantity of cement because of their needs for infrastructure. To accommodate infrastructure demands, sustainability in the concrete construction industry has become a subject of great concern, precipitated calcium carbonate substitution strategy of cement is a most effective way for sustainability. Aim of this study is to investigate the effect of precipitated calcium carbonate powder on concrete production. PCC powder was directly incorporated and mixed with cement powder and other concrete ingredients to prepare concrete for further laboratory tests. Laboratory test was conducted by comparing control mix of grade C-25mpa, 360kg/m^3 cement content with experimental mix and concrete workability test, compressive strength test, and hardened concrete durability test of water penetration depth was conducted by keeping constant water to cementitious material ratio 0.5 for both mixes. Physical and chemical properties of precipitated calcium carbonate (PCC) tested and directly incorporated to concrete mix design proportion with replacement level of 10%, 15% and 20% to Portland cement. The experimental results showed that the concrete mix with PCC replacement possess a higher slump, from 50mm, 55mm, 65, and 75mm respectively for control mix, 10%, 15% and 20% PCC which increased the workability. The compressive strength of concrete containing 10% PCC powder shows remarkable improvement and exceeds control mix by 14.32%, 16.79% and 8.77% respectively for 3-, 7- and 28-days curing period. However, PCC with more than 10% replacement at 15% and 20% exhibit slight decrease in compressive strength. Moreover, PCC 10% incorporation also shows improvement on water penetration depth for hardened concrete durability evaluation which is 23.9mm and 23.8mm for control and 10% PCC at the age of 28 days curing duration. Eventually, PCC partial replacement effect can make the paste matrix and the interfacial transition zone between matrix and aggregate denser, which will improve the performance of concrete at optimum PCC content addition and this makes PCC powder the promising profound sustainable cementitious material for concrete production.

Keywords/terms: *Supplementary cementitious material, Precipitated Calcium Carbonate, Portland cement, workability, compressive strength*

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LIST OF ABBREVIATIONS/ ACRONYMS

PCC- Precipitated Calcium Carbonate

OPC- Ordinary Portland Cement

PPC- Pozzolanic Portland Cement

SCM- Supplementary cementitious material

CCF- Calcium carbonate fine

LP- Limestone powder

GLS- Ground limestone powder

UHPC- Ultra high performance concrete

ASTM- American society testing materials

LF- Limestone filler

MK- Metakaolin

GGBS- Ground granulated blast furnace

SF- Silica fume

ACI- American Concrete Institute

ERA- Ethiopian Road Administration

XRD-X-ray diffraction

LOI- Loss of ignition

SEM- Scanning electron microscope

TGA-Thermogravimetric analysis

LIST OF CHEMICAL FORMULAS

Formulas	**Name of Chemical Compound**
$CaCO_3$	Calcium Carbonate
SiO_2	Silicon dioxide
CaO	Calium Oxide
CSH	Calium silicate hydrate
C_3S	Tricalcium Silicates
C_2S	Dicalcium Silicate
C_3A	Tricalcium aluminate
C_4AF	Tetra calcium alumino ferrite
$Ca6Al_2(SO4)_3(OH)12{\cdot}26H_2O$	Ettringite
CH	Calcium hydroxide
Al_2O_3	Aluminum oxide
Fe_2O_3	Iron oxide
MgO	Magnesium oxide
$3CaO.Al2O_3.CaCO_3.11H_2O$	Calcium mono carboaluminate

CHAPTER 1

INTRODUCTION

1.1. General Background

Ethiopia is experiencing rapid urbanization and infrastructure development, which is driving the demand for cement. The emergence of a fast-growing middle class and the need to plug infrastructure development and urban housing deficits are expected to drive cement consumption growth. The cement industry is a key contributor to infrastructure development, providing the necessary building materials for roads, bridges, housing, and other infrastructure projects. Cement takes 10%–15% by volume of concrete and it's the most expensive concrete component and encompasses 45% of the total concrete cost(Quezon & Busier, 2018). These days, the construction industry is challenged by the scarcity of cement and price escalation of the cement market(Abebaw et al., 2021).

Considering that concrete is the most widely used construction material, cementitious blends can have a major impact on the environment and make a significant contribution to achieving sustainable infrastructure development goals. Therefore, the contemporary cement industry is faced with the challenges of producing more sustainable, less energy intensive products without sacrificing the mechanical or durability performance of the end product(Snellings et al., 2012). Sustainable cement production provide solution for cement demand by the production of cement in a way that minimizes its environmental impact and maximizes its social and economic benefits by using supplementary cementitious materials. Supplementary cementitious materials (SCMs) offer sustainable and performance advantages for those who construct buildings of all kinds. Their use as a partial replacement for Portland cement not only results in more durable, high-performance concrete but also lowers energy consumption and greenhouse gas emissions.

The effect of limestone powder in conventional cement and concrete is well known. Limestone powder has the nucleation effect in early hydration reaction that accelerates the cement hydration. It can also physically fill the void and increase the packing density of the system. As a consequence, LP increases the compressive strength of concrete at an early age. However, it may reduce the compressive strength at a late age because it does not have a pozzolanic reaction with cement unlike other SCMs such as slag, FA, and MK, and it requires higher water demand (Park et al., 2021). Calcium carbonate is wildly used in cementitious composites at different scales and can affect the properties of cementitious composites through physical effects (such as the filler effect, dilution effect and nucleation effect) and chemical effects.

Several efforts by many researchers worldwide have been carried out to develop cements which are not based on Portland cement clinker anymore. Many of these solutions could have considerable environmental benefits. However, for the time being either their technical suitability or their economic value and the availability of the constituents are often not verified. Therefore, the efficient use of Portland cement clinker in cement with an increased content of e.g. limestone is worth to be further investigated and developed(Palm et al., 2016).

Calcium Carbonate Fines (CCF's) are a limestone filler material that can help to accelerate the hydration of cement leading to earlier strengths and improving durability of concrete. This hydraulic material can also provide better packing density in concrete which can decrease permeability. Available in a powder form, CCF's are usually very light in color and can also provide aesthetic considerations for creating "white" structures. This study aims to investigate suitability of fine Precipitated Calcium Carbonate as partial cement replacement material in concrete production by direct addition of PCC to cement powder.

1.2. Statement of the Problem

Developing and emerging countries during their high growth phase consume a large quantity of cement because of their needs for infrastructure. The continued growth of the construction sectors has resulted in high demand for concrete materials. Due to infrastructure demands, with world population and urbanisation both on the increase, sustainability in the concrete construction industry has become a subject of great concern, interest and challenge. This leads to substitution strategy, consisting of the partial replacement of Portland cement with supplementary cementitious materials (SCMs), or the more common application of blended cements, is an effective way to improve the sustainability of the construction industries(Fantilli & Jóźwiak-Niedźwiedzka, 2021).As the compressive strength and flexural strength are the importance parameters for the cement mechanical properties, the future work should be undertaken on the effect of addition of calcite monohydrate(Photong & Pragot, 2022).

Numerous studies on Portland limestone cement focused on the effects of limestone on the cement performance, participation of limestone in the hydration reactions and the production process specifically intergrading of clinker and limestone. The use of limestone filler in combination with Portland cement is a common practice in many countries in the world for various reasons, while this practice has not been exercised in Ethiopia. In recent years, the cost of cements and cement-based construction materials in Ethiopia is increasing from time to time and there is a huge gap between demand and supply of cement throughout the country. This rise of cost and demand of cement is mainly due to limited production capacity and restricted types of cement produced in the country for the steady increase in demand of cement for construction (Gudissa & Dinku, 2010). So that, a lot of research efforts expected to introduce the SCM material application directly to cement clinker or concrete mix to achieve sustainability and the steady increase in demand of cement for construction.

By careful undertaking of physical and chemical properties characterization of PCC, this study aims to utilizes laboratory tests to analyze precipitated calcium carbonate as partial cement replacement material for concrete production by direct addition of PCC to concrete mix and examining the fresh concrete and mechanical properties of concrete paste, explore internal microstructure of hardened concrete and eventually, investigating durability properties made by incorporation of PCC.

1.3. Objective of the Study

1.3.1. General Objective

General objective of the study is to investigate suitability of fine Precipitated Calcium Carbonate as partial cement replacement material in concrete production.

1.3.2. Specific Objectives

- To examine the physical and mechanical properties of concrete with the incorporation of fine precipitated calcium carbonate.
- To Investigate the effect of fine precipitated calcium carbonate addition on the durability of hardened concrete properties.
- To compare the cost of concrete with ordinary Portland cement and with fine precipitated calcium carbonate.

1.3.3. Research Questions

The research study tries to address the following research questions;

- How effective is the addition of fine precipitated calcium carbonate in improving fresh and hardened properties of concrete?
- In what ways does the incorporation of fine calcium carbonate can influence the durability properties of hardened concrete?

- What is the cost of concrete mix with OPC and with fine precipitated calcium carbonate?

1.4. Significance of the Study

This paper deals with thorough investigation of concretes made of cements mixed with precipitated calcium carbonate as partial substitution between 10 and 20 percentage by weight of cement. The Article provide an insight and understanding for the construction sector on the application of precipitated calcium carbonate incorporation in concrete production. It gives better awareness on efficient resource utilization of supplementary cementitious material for sustainable cement and concrete production. Precipitated calcium carbonate blended Portland cements with their altered hydration, physical, mechanical and durability properties of concrete that are comparable to conventional concrete without compromising technical parameters standards. Hence, it can reduce the amount of cement consumed and cost associated with cement and concrete production.

1.5. Scope of the Study

This research was limited to the use of ordinary Portland cement of Dangote OPC grade 42.5N cement produced in Ethiopia, which is commonly used in the country's concrete production. PPC is not suitable for limestone powder incorporation as a partial cement replacement material because limestone does not show pozzolanic properties, PPC already contains pozzolanic material, and the addition of limestone powder may alter the chemical properties of the cement, affecting its performance. So that, the experimental study only uses ordinary Portland cement products Dangote OPC grade 42.5. Precipitated calcium carbonate sample from Batu Caustic Soda factory tested at geological survey of Ethiopia Laboratory for chemical composition analysis and particle size analysis test done at Ethiopian Conformity Assessment Enterprise for fineness value of PCC by 90µm sieve size to characterize the material physical property for partial cement replacement. Thereafter to prepare mix design, ingredients of concrete quality tests for cement powder, fine aggregate, and coarse aggregate properties done for comprehensive and thorough laboratory outcomes.

Percentage by weight of cement replaced by 10%, 15% and 20% of PCC and mixed thoroughly with fine aggregate and coarse aggregate at controlled mixing temperature and water to cement ratio but some modifications for cementitious material addition. Fresh concrete workability test, slump cone test analysed and cubes casted for further mechanical and durability tests of concrete. Moreover, knowledge about chemical and physical processes taking place in hardening binder gives possibility to develop new more advanced blends which can replace cement. The discussion was carried out drawn mainly based on the literature review on the subject and experimental laboratory results.

1.6. Organisation of the document

The thesis is presented in 5 chapters. The remaining four chapters are organized as follows.

Chapter 2 presents the literature review, with special reference to the topic that investigating suitability of fine Precipitated Calcium Carbonate as partial cement replacement material in concrete production.

In Chapter 3, the research methodology is discussed. After presenting the study's overall research methodology, the methodology adopted in individual objectives is discussed in this chapter.

Chapter 4 aims to show findings of the study and discussed results. To realize this aim, the study presents the findings and associated discussion in relation to objectives of the research aim.

Chapter 5 provides conclusion and recommendations of the research findings. The chapter closes with recommendations and stating future area of study.

Summary

In this chapter, the background and statement of the problem (motivation of the research) have been presented. Further, the study aim, associated objectives, scope of the study, significance of the study and the organization of the thesis to achieve these objectives have briefly been presented. In the next subsequent chapter, literature review of relevant journal articles related to research objectives and the gaps in the prior research have been presented.

CHAPTER 2

LITERATURE REVIEW

2. Introduction

Production of Portland cement impact on environment and the large use of cement-based building materials is a mounting problem. Cement acts as a binder in concrete and a proportion of the binder can be replaced by filler. Filler is a very fine-ground material, of about the same fineness as cement. The substitution strategy, consisting of the partial replacement of Portland cement with supplementary cementitious materials (SCMs), or the more common application of blended cements, is an effective way to improve the sustainability of the construction industries(Fantilli & Jóźwiak-Niedźwiedzka, 2021).

Supplementary cementitious materials (SCMs) are soluble siliceous, aluminosiliceous, or calcium aluminosiliceous powders used as partial replacements of clinker in cements or as partial replacements of Portland cement in concrete mixtures(Juenger et al., 2019). SCM's are added to concrete in addition to or as a partial replacement of Portland cement or blended cements and are usually considered as a part of the total cementing system.

Calcium carbonate fines (CCF's) are a limestone filler material that can help to accelerate the hydration of cement leading to earlier strengths and improving durability of concrete. This hydraulic material can also provide better packing density in concrete which can decrease permeability. Available in a powder form, CCF's are usually very light in colour and can also provide aesthetic considerations for creating "white" structures.

The use of limestone as a partial replacement for cement in ultra-high-performance concrete (UHPC) can improve workability and increase compressive strength, by replacing up to 54% of cement with limestone, UHPC mixes showed better workability and higher compressive strength (170 MPa at 56 days) compared to traditional mixes without limestone replacement (155 MPa). making it a viable option for construction projects(Ali et al., 2015). Therefore, the main discussion of this chapter is reviewing different literatures which focused on supplementary cementitious materials, particularly on the effects of precipitated calcium carbonate incorporation in the concrete property. It dealt with the physical, mechanical, and durability properties of fresh and hardened concrete.

2.1. Cement

Cement and cement concrete are common construction materials manufactured in large amounts. Cement is one of the most widely used binding materials which comprises about 11% of the concrete volume, is the most expensive concrete component and encompasses 45% of the total concrete cost(Getahun, 2021). The demand for cement has been increasing for many years which is an effect of global urbanization. It is growing alarmingly in the world as well as in Ethiopia. This economic growth correspondingly increases the demand for construction materials that are established, affordable, and reasonable for mass production. As a consequence, the cement industry worldwide is facing growing challenges in conserving material and energy resources, as well as reducing its CO_2 emissions. The environmental impact of the Portland cement production and the large use of cement-based building materials is a growing problem. Thus substitution strategy, consisting of the partial replacement of Portland cement with supplementary cementitious materials (SCMs), or the more common application of blended cements, is an effective way to improve the sustainability of the construction industries(Fantilli & Jóźwiak-Niedźwiedzka, 2021).

Pozzolana cement is integrated cement which is formed by synthesizing OPC cement with pozzolanic materials in a certain proportion. The main components of PPC are calcium oxide, silicon (IV) oxide, magnesium oxide, and aluminium (III) oxide. PPC consists of pozzolanic material, gypsum, and clinker. The pozzolanic material used in PPC can be either natural or artificial and includes materials such as fly ash, silica fume, rice husk, burnt clay, and pumicite. The chemical reaction between the pozzolanic material and calcium hydroxide liberated by the hydrating Portland cement forms cementitious compounds, making the concrete more impermeable and denser. Portland It is commonly known as PPC cement. PPC is not suitable for limestone powder incorporation as a partial cement replacement material because limestone does not show pozzolanic properties, PPC already contains pozzolanic material, and the addition of limestone powder may alter the chemical properties of the cement, affecting its performance.

2.2. Hydration of Cement

The hydration of Portland cement is a chemical reaction between the cement and water that results in the formation of hydrated compounds, which contribute to the strength of the final product. Here's how the hydration of Portland cement contributes to its strength: Formation of calcium silicate hydrate (CSH): The hydration of tricalcium silicate (C_3S) and dicalcium silicate (C_2S) in Portland cement results in the formation of CSH, which is the primary binder in cement. CSH contributes to the strength of the cement paste by filling the voids between the cement particles and forming a strong, interconnected network. Formation of calcium hydroxide (CH): The hydration of C_3S and C_2S also results in the formation of CH, which contributes to the early strength development of the cement. CH reacts with CSH to form additional strength giving compounds. Formation of ettringite: Gypsum is added to Portland cement to control its setting time. During the hydration process, gypsum reacts with C_3A to form ettringite, which helps to prevent flash setting of the cement. Ettringite also contributes to the strength of the cement paste. Continued strength development: The hydration of Portland cement continues for several weeks, during which time the strength of the cement paste increases. The continued reaction between the cement and water results in the formation of additional strength-giving compounds, such as monosulfate and hemicarbonate(Gabrov, 2008).

2.3. Supplementary Cementitious Materials

Based on the origin, SCMs can be distinguished in organic and inorganic admixtures. Moreover, depending on their nature, SCMs can be classified into natural pozzolans and industrial by-products. Incorporation of supplementary cementitious materials (SCMs) is an effective way to reduce the use of cement clinker and carbon dioxide emissions. Moreover, the incorporation of SCMs would not be detrimental to the mechanical properties and even enhances the durability of the resulting concrete with a proper mix design(Wang, Shi, Farzadnia, Shi, Jia, et al., 2018). Natural pozzolans such as limestone powder (LP), volcanic rock ashes, etc(Ndahirwa et al., 2022). Limestone powder is one of the alternatives recently attracted many researchers due to its wide availability and low cost. To properly use LS, researchers have conducted a lot of research on the action mechanism of LS in cement-based materials. The particle size and content of LS, polymorph of calcium carbonate, synergetic effect with alumina-rich supplementary cementitious materials (SCMs) influence effects of LS in concrete. It has been well-documented that limestone powder in concrete mainly showed filler, nucleation, dilution and chemical effects, and they were influence by the particle size, dosage, dissolution rate, polymorph of limestone powder, mineral composition of cement and supplementary cementitious materials(Wang et al., 2018).

2.3.1. Characterization of Supplementary Cementitious Materials

Limestone powder is crushed and ground from natural limestone. Limestone is mainly composed of skeletal fragment of organisms. Calcite, aragonite, vaterite and amorphous calcium carbonate are the available forms of mineral composition of limestone. It can also be formed from chemical precipitation of calcite or aragonite. Based on the method of formation, LS could be crystalline, clastic, granular or massive. It is known that calcium carbonate (CaCO3) is the chief component of limestone. Both the European and American standards specify that the calcium carbonate content of limestone for use as a cement component in concrete should not be less than 75% and 70% by mass, according to EN 197-1 and ASTM C595M (ASTM, 2018), respectively. Concrete strength decreases with the addition of GLS, and at an increasing rate with GLS content. However, this loss in strength of concrete may, to a limited extent, be modified by means of GLS fineness, design strength, curing and the w/c ratio(El-Moussaoui et al., 2019).

2.3.2. Methods for physical characterization of SCMs

Density, particle size distribution, shape and size are the fundamental physical characteristics of powders. The challenge in physical property characterization is to develop physical tests that can satisfactorily characterize key parameters. The techniques that are currently used for the characterization of cementitious materials include sieving, air permeability testing (Blaine), gas adsorption (BET), laser light scattering, and image analysis. Sieve analysis for particle size analysis is only considered in this study, even though it is not yet a widely validated and used technique.

Sieve analysis

The sieve analysis also called the gradation test is usually applied on particles diameter greater than 2mm. It consists on mechanically shaking the sieves column thereby allowing the material to pass through a set of sieves from bigger mesh to the smaller mesh size and weighing the quantity of material that is stopped by each sieve as a portion of the entire mass. The simplest means of assessing the fineness of SCMs is through a sieve analysis since it does not require the specialized instrumentation used in other methods. However, the information obtained from sieve analysis of a fine powder is more limited than that obtained through more sophisticated methods, as the most commonly used sieve analysis procedures for powders utilize only one sieve size. For example, ASTM C618 specifies a maximum of 34 % by mass retained on the no. 325 sieve (45 µm opening size) for fly ash and natural pozzolans when wet sieved. Like density testing, the standard method used is one for Portland cement, ASTM C430 ''Standard Test Method for Fineness of Hydraulic Cement by the 45-µm (No. 325) Sieve''(Arvaniti et al., 2015).

2.3.3. **Chemical composition of SCMs**

The chemistry of cementitious materials including SCMs is usually studied using numerous quantitative and qualitative techniques. The oxide compounds can be quantified with X-ray fluorescence spectrometry (XRF)(Arvaniti et al., 2015). The thermogravimetric analysis (TGA) can be used to determine the loss on ignition (LOI) and thermally unstable phases. On the other hand, X-ray diffraction (XRD) enables to study the mineralogical composition of the cementitious materials. Scanning electron microscopy (SEM) offers a wide range of possibilities to evaluate the microstructure (pore structure, particle shape, etc.). However, when equipped with the energy dispersive X-ray spectrometry (EDS), it can be used to detect chemical elements and their respective contents in a given cementitious material. Presents the fractions of major oxides in CFA, SF, GGBS, LP and MK. The top end of the bar chart indicates the average whereas, the upper and lower error bars represent maximum and minimum ranges, respectively. Actually, CFA is mainly composed by SiO_2 and Al_2O_3. Moreover, oxides such as Fe_2O_3, CaO, MgO can also be found in CFA but, their proportions remain minimal (less than 10% each). On the contrary, SF is almost entirely composed by SiO_2 representing about 95%. At the same time, the average amounts of Al_2O_3, Fe_2O_3, CaO and MgO in SF have been reported to be rather insignificant (lower than 1% each). The GGBS chemical composition tends to be well-balanced compared to other SCMs. In fact, the major oxides in GGBS include CaO, SiO_2, Al_2O_3 and MgO, typically accounting for 40%,33%, 13% and 7%, respectively. Furthermore, LP is mainly composed by CaO, representing more than 50% of its overall oxide compounds. It is worth mentioning that, unlike other SCMs, LP exhibits extremely high loss on ignition (LOI) estimated at about (35–45) % while CFA, SF, GGBS and MK account for up to 5.5%, 5%, 2% and 4%, respectively. As far as MK is concerned, the major oxides in MK

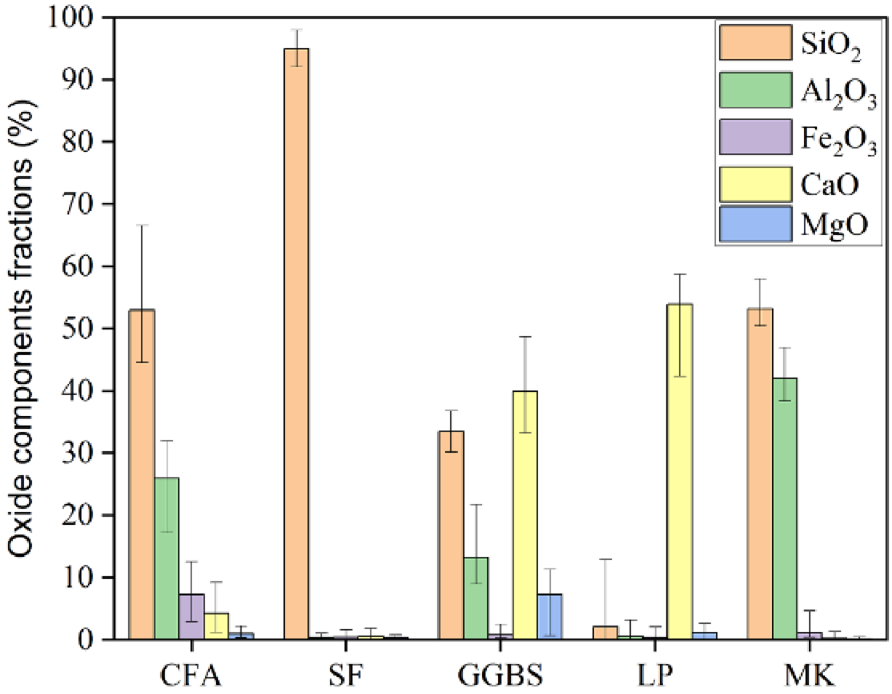

Figure 1 SCMs chemical composition (Ndahirwa et al,2022).

include SiO_2 and Al_2O_3, representing 53% and 42%, respectively. Additionally, MK can contains light amounts of Fe_2O_3, CaO and MgO (below 2% each)(Ndahirwa et al., 2022).

Limestone powder (LP), the powdery by-product of a limestone quarry, is made by crushing and grinding natural limestone and consists of calcite, aragonite, vaterite, and amorphous calcium carbonate. The chemical composition of LP depends on the source of the raw material, since limestone formation, minerals, processing, and refinement affect the composition. (Jhatial et al., 2023) tries to tabulate the chemical composition of LP of different source as indicated table below.

Table 1 Chemical composition of LP (Note: Sum * is the sum of pozzolanic oxides) (Jhatial et al., 2023).

Sample	SiO_2	AlO_3	Fe_2O_3	Sum	CaO	K_2O	MgO	SO_3	Na_2O	LOI
1	0.2	-	0.15	0.35	55.11	0.02	1.12	0.09	-	43.1
2	0.86	0.08	0.31	1.25	56.3	0.05	0.58	-	-	42
3	0.84	0.24	0.32	1.4	53.96	0.34	1.01	-	-	43.0
4	8.97	1.02	0.37	10.36	46.77	0.13	2.38	0.33	0.02	39.4

2.3.4. **Precipitated Calcium Carbonate**

The calcium carbonate that is precipitated from CO2 emissions is chemically similar to limestone however the precipitation process allows for controlled grain size and morphology of calcium carbonates(McDonald, 2022). Precipitated calcium carbonate (PCC) is a filler used in many applications, like papers, plastics, rubbers, paints, drugs and so on. Its high purity, well-ordered particle size and morphology makes it the white filler of choice(Jimoh et al., 2017). The advantage of PCC lies in the prospect of tailor making the products with definite particle morphology, particle size and distribution as well as specific surface area (BET). PCC is a refined natural form of limestone using techniques. Calcium carbonate occurs in different crystalline polymorphs at ambient pressure. There are anhydrous phases of aragonite, vaterite, calcite and hydrated phases of monohydrocalcite as well as hexahydrocalcite. The anhydrous CaCO3 can be classified as rhombic calcite, needle-like aragonite or spherical vaterite and among them calcite is known to be the most stable phase under ambient atmospheric conditions. Precipitated Calcium Carbonate (PCC) is utilized in concrete making primarily in its calcite crystalline form, which is the most stable and commonly occurring polymorph of calcium carbonate. This form is favoured due to its beneficial properties for concrete, including improved workability, durability, and strength. Precipitated calcium carbonates were added to Portland cement and their physical and mechanical properties determined. Portland cement with precipitated calcium carbonates have improved mechanical properties compared with ordinary Portland cement OPC. An increase in compressive strength of 27% compared to OPC is observed when 10% of Portland cement is replaced with nano-calcite(McDonald, 2022). In this research the word PCC and limestone powder used interchangeably and employs PCC as partial cement replacement material for concrete production.

2.3.5. Hydration Reaction of Cement with PCC

Filler effect, nucleation effect, dilution effect and chemical effect as distinctive action mechanisms of LS when combined with Portland cement. Before going further to hydration reaction and microstructural detail identifying action mechanism of LS is profound importance. The action mechanism of LS mainly depends on its particle size and amount. LS influences the properties of cement-based materials by its filler effect, nucleation effect, dilution effect and chemical effect. Incorporating proper fine limestone powder accelerates the hydration of C_3S, increases the hydration peak of C_3S and hydration heat of cement-based materials. However, it decreases the hydration peak of C_3S and hydration heat of cement-based materials if superfluous fine limestone powder or coarse limestone powder is incorporated(Shi et al., 2018).

Although the principal hydration products in composite cements are almost similar to those found in pure Portland cement, the added minerals affect the ettringite transformation to monosulfate hydrate. In limestone cements, $3CaO.Al_2O_3.CaCO_3.11H_2O$ is formed from the first days of hydration and is still present after 28 days(Voglis et al., 2005). $3CaO \cdot Al_2O_3 \cdot CaCO_3 \cdot 11H_2O$, also known as calcium monocarboaluminate, is formed during the hydration of calcium aluminate cement (CAC) in the presence of calcium carbonate (CaCO3) and water. In contrast to the use of fly ash and slag cement as cement replacement, that commonly reduce the first 20-hour hydration heat and prolong the initial setting time of cement, LF accelerates the early-age hydration of cement, especially when the particle is fine (e.g. fineness >10,000 cm2/g)(Panesar & Zhang, 2020). The addition of precipitated calcium carbonates leads to the formation of carboaluminate phases through solid state reaction with C3A, the same reaction pathway that limestone reacts with Portland cement(McDonald, 2022).

Reaction of C_3A with $CaCO_3$

The main component of CAC, monocalcium aluminate (CA, $CaO \cdot Al_2O_3$), reacts with $CaCO_3$ to form calcium monocarboaluminate.

$$C_3A + CaCO_3 + 11H_2O \rightarrow 3CaO \cdot Al_2O_3 \cdot CaCO_3 \cdot 11H_2O$$

This reaction is similar to the reaction of C_3A with calcium sulfate (gypsum) to form ettringite and monosulfate. The presence of $CaCO_3$ leads to the formation of monocarboaluminate instead of monosulfate(Gabrov, 2008).

The hydration reaction of $3CaO \cdot Al_2O_3 \cdot CaCO_3 \cdot 11H_2O$ (calcium monocarboaluminate) involves several key steps that occur when calcium aluminate reacts with calcium carbonate and water. Here's a breakdown of the main steps involved in this process.

Dissolution of Reactants

Calcium Aluminate (C3A): Upon mixing with water, calcium aluminate (3CaO·Al2O3) dissolves, releasing calcium ions (Ca^{2+}) and aluminate ions (AlO_2^-) into the solution.

Calcium Carbonate (CaCO3): Calcium carbonate also dissolves, contributing carbonate ions (CO_3^{2-}) to the aqueous phase.

Formation of Intermediate Phases

Hydration of C3A: The dissolved aluminate ions react with water to form calcium aluminate hydrates. This process can lead to the formation of various intermediate phases, including monocalcium aluminate hydrate (C-A-H) and other calcium aluminate hydrates.

Reaction with CO_3^{2-}: The carbonate ions from the dissolved CaCO3 can react with the calcium ions in solution, promoting the formation of calcium carbonate and influencing the overall hydration kinetics.

Formation of Calcium Monocarboaluminate

Precipitation of 3CaO·Al2O3·CaCO3·11H2O: As the reaction progresses, calcium monocarboaluminate precipitates out of the solution. The overall reaction can be summarized as follows:

3CaO·Al2O3+CaCO3+11H2O→3CaO·Al2O3·CaCO3·11H2O3CaO·Al2O3+CaCO3+11H2O→3CaO·Al2O3·CaCO3·11H2O

This step involves the combination of calcium ions, aluminate ions, and carbonate ions in the presence of water to form the stable solid phase, calcium monocarboaluminate.

Hydration of the Precipitate: The formed calcium monocarboaluminate can further hydrate, incorporating additional water molecules into its structure, which enhances its stability and contributes to the strength development of the concrete.

The ordinary Portland cement (OPC) phases consist of similar oxides as those found in the supplementary cementitious materials (SCMs). It is well known that the chemical composition, particle size distribution and specific surface area are the main factors influencing the pozzolanic activity of the SCM. Indeed, in most scenarios, SCMs with finer particles, often have higher specific surface area and possess a high level of reactivity. From chemistry standpoint, the SCMs pozzolanic reactions produce the same hydration products as OPC depending upon the amount of available calcium hydroxide (Ca (OH)2) also known as portlandite (CH)(Skibsted & Snellings, 2019). Normally, when cement comes in contact with water the hydration process occurs, resulting in the dissolution of cement soluble ions into the water to form hydration products such as ettringite Ca6Al2(SO4)3(OH)12·26H2O (C –S–H), aluminate ferrite tri (AFt), aluminate ferrite mono (AFm), hydrogarnet, etc. Whilst, from physical point of view, the hydration of cementitious materials plays a fundamental role in the refinement of pore structure and porosity reduction. according to previous studies, there seems to be a general agreement on the SCMs implication in the hydration of cement-based materials, hydration heat evolution and pozzolanic activity. (Jia et al., 2018) pointed out that the SCMs reactivity mechanisms can be classified into four main effects: filler effect, nucleation effect, dilution effect and chemical effect. The study of limestone indicates that additional factors operate here to give a much higher density of C-S-H nuclei on limestone surfaces. Consequently, limestone has a larger accelerating effect on the hydration due to the high number of nuclei while the growth rate of individual needles on limestone is not changed. The increased nucleation on limestone surfaces may be related to the dissolution of this phase, but also to a favourable surface structure, providing a “template” for C-S-H precipitation(E. M. J. Berodier, 2015).

As the average particle size of LP decreased from 32 to 6μm, the consumed $CaCO_3$ content at 3d increased from 0.67% to 1.71% while the consumed $CaCO_3$ content at 180d was about 2.4%. As the amount of LP increased from 25% to 50%, the consumed $CaCO_3$ content at 3d increased from 1.71% to 2.02% while the difference of consumed $CaCO_3$ content at 180d was limited(Wang et al., 2019).

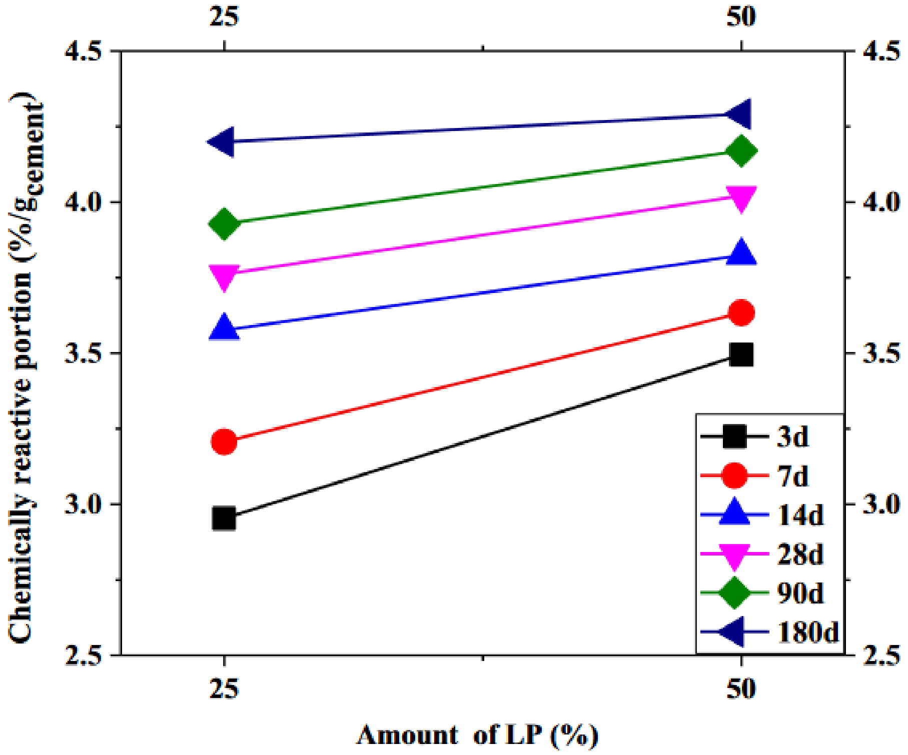

Figure 2 Effects of average particle size of LP on its reactive portion in cement pastes (PC:LP=75:25) (Wang et al,2019)

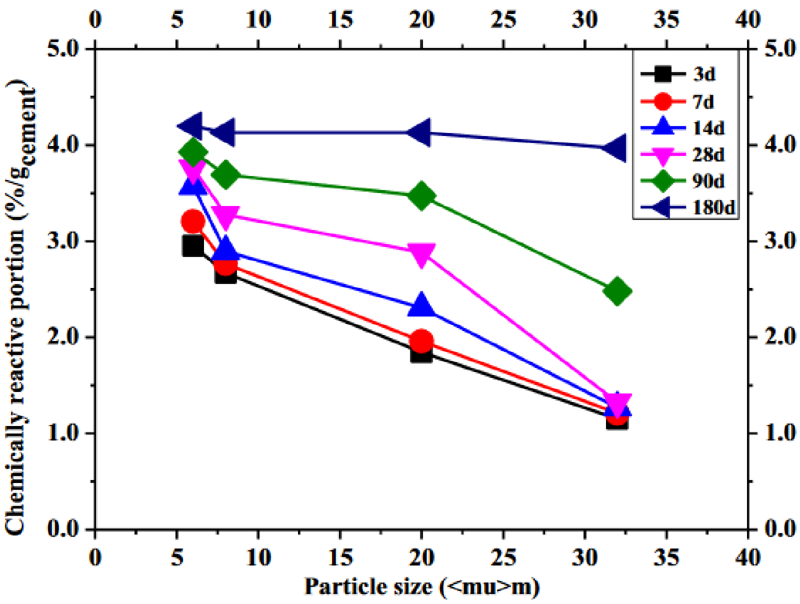

Figure 3 Effect of amount of LP (average particle size: 6 m) on its chemically reactive portion in cement pastes (Wang et al., 2019).

2.3.6. **Physical properties of concrete with PCC partial cement replacement**

Workability Test

The results indicate that $CaCO_3$ particles are finer than OPC and they act as filler in the concrete mixture. The slump of $CaCO_3$ concrete is higher than OPC concrete, which resulted in better workability(Ali et al., 2015).

2.3.7. Mechanical properties of hardened concrete made PCC partial cement replacement

Effects of LS on the compressive strength, elastic modulus, and flexural strength of concrete are complicated. In general, incorporating LS to replace cement paste or fine aggregates increases the mechanical properties of concrete. When LS is used to replace cement, effects of LS on the mechanical properties relies on its particle size and content. When a small quantity of fine LS is used to replace cement, it will improve the mechanical properties of concrete; when coarse or a large amount of fine LS was used to replace cement, it will decrease the mechanical properties of concrete(Wang, Shi, Farzadnia, Shi, & Jia, 2018). At a replacement level of ≤10%, LF can improve the compressive strength by 20%(Panesar & Zhang, 2020). However, a LF replacement level >10% typically leads to lower strength, greater porosity and greater permeability than the control mix.

Compressive Strength

At early age, the $CaCO_3$ concrete produces higher compression strength than the OPC concrete due to higher hydration rate and accelerator effect. However, at 28days the compression strength is a little lower than the OPC concrete(Ali et al., 2015). The compressive strength of concrete containing 100 kg/m3 limestone powder can meet the strength requirement. The filling effect of limestone powder can make the paste matrix and the interfacial transition zone between matrix and aggregate denser, which can improve the performance of concrete. Limestone powder does not have pozzolanic properties, but it is still unhydrated at the age of 28 d(Liu & Yan, 2010). the partial replacement of cement with LP content exceeding 60% (by mass) significantly decreased the pore structure density and strength of the ultra-high performance concrete (UHPC)(Ndahirwa et al., 2022). This severe reduction in compressive strength can be ascribed to multiple reasons: 1) excessive quantity of certain chemical compounds that do not find other essential compounds to interact with and therefore form hydrates, 2) increased porosity in the material's matrix, 3) retarded pozzolanic activity and 4) less amount of hydration products. It was reported (Wang et al., 2019)as the average particle size of LP decreased from 32 to 6μm, the contribution of physical effect of LP on the compressive strength of cement pastes decreased from 21.71% to 20.05% while the contribution of chemical effect increased from 0.32% to 1% at 28d, and the contribution of physical effect decreased from 21.19% to 20.03% while the contribution of chemical effect increased from 1.01% to 1.08% at 180d. As the amount of LP increased from 25% to 50%, the contribution of physical effect of LP on the compressive strength of cement pastes increased from 20.05% to 42.02% while the contribution of chemical effect increased from 1% to 2.66% at 28d, and the contribution of physical effect increased from 20.03% to 41.97% while the contribution of chemical effect increased from 1.08% to 2.84% at 180d.

2.3.8. **Internal microstructure and durability properties of concrete with PCC partial cement replacement**

The filler effect of LS refines the microstructure and reduces the porosity of cement-based materials. Its nucleation effect accelerates the hydration of C3S, increases the amount of hydration products and reduces the porosity of cement-based materials at early ages. Its dilution effect reduces the hydration peak of C3S, decreases the amount of hydration products and increases the porosity of cement-based materials. Its chemical effect promotes the appearance of third hydration peak, forms carboaluminate and reduces the porosity of cement-based materials(Wang et al., 2018).

The inclusion of limestone powder as a replacement for cement had a negative effect on permeability and durability in a dose-dependent manner. In rapid chloride penetration tests, the total charge passed through LP30 specimens was 2.47 times higher than that of LP10. These results are consistent with those pertaining to resistivity and absorption. Replacing more than 10% of the cement with limestone powder was shown to hinder the formation of hydration products required to fill the capillary pores and gel pores, resulting in a microstructure of lower density(Wei-Ting et al., 2020). Mortar and concrete with the incorporation of LF as cement replacement has similar carbonation resistance compared to concrete or mortar containing SCMs. LF is inferior to SCMs at the same replacement percentage in terms of improving the ability to resist sulphate attack and freeze/thaw action and to alleviate ASR.

Durability properties of hardened concrete

Water Permeability Test

The water absorption rate for CaCO3 concrete is lower than OPC concrete. This is due to the presence of ultrafine CaCO3 particles which reduce the pores inside the concrete, thus create better packing of particle between cement and CaCO3(Ali et al., 2015).

Finer LS can fill the voids of cement particles, reduce the porosity, and improve the water permeability of concrete. There was an optimum LS content for the water permeability of concrete when LS is added to replace 0–20 wt.% cement. The optimum LS content for the water permeability of concrete was 10%(Wang, Shi, Farzadnia, Shi, & Jia, 2018).

Rapid Chloride Penetration

When a small quantity of fine LS is added to replace cement, it mainly shows filler effect and reduces the chloride permeability of concrete. It was reported that adding LS to replace cement decreased the chloride permeability of concrete when the amount of LS (Blaine fineness: 399 m2/kg) and marble powder (Blaine fineness: 519 m2/kg) was less than 20%(Wang, Shi, Farzadnia, Shi, & Jia, 2018). The pores structure of concrete was refined by incorporating LS due to its filler and nucleation effects, thus, the chloride diffusion coefficient reduced as the LS content increased. At a replacement level of ≤10%, LF can reduce the rapid chloride permeability by 10%(Panesar & Zhang, 2020).

Sulphate Attack

The use of LS increases the risk of sulphate corrosion of concrete due to the formation of gypsum, ettringite and thaumasite, especially at low temperature environment. Thus, it should conduct a lot of researches before using LS under sulphate corrosion environment(Wang, Shi, Farzadnia, Shi, & Jia, 2018). The ‘‘thaumasite problem’’, correlated with the use of limestone cement concrete and calcareous aggregates. Recent research work shows that Portland limestone cement pastes are susceptible to the thaumasite formation, due to sulphate attack at 5 °C, after only a few months exposure to sulphate solutions(Voglis et al., 2005). However, cement-based materials with LF at a replacement level of ≤10% can achieve similar or superior performance to resist sulphate attack and freeze/thaw and to alleviate ASR, compared to control mixes (100% Portland cement)(Panesar & Zhang, 2020).

2.4. Research Gap

It is clearly seen from the literature review that all future cements will certainly have to be based on materials which are globally available in sufficient amounts. CaO, SiO_2 as well as Fe_2O_3 and Al_2O_3 are certainly key materials in this respect, magnesium oxide also seems to be available, even if the deposits might not be as close to the surface as today's quarries of the cement industry (Schneider et al., 2011). It was reported (Jhatial et al., 2023) the chemical composition of LP depends on the source of the raw material, since limestone formation, minerals, processing, and refinement affect the composition. However chemical composition of PCC varies based on source quarries and there is no well-established standard for incorporating PCC to directly to concrete mixing process.

The replacement of a part of the cement clinker does not need to have negative effects on the mechanical and durability performance of the so-called blended cement. To the contrary, many studies have indicated that particularly the durability of blended cements is substantially improved(Snellings et al., 2012).

The implementation of some SCMs is contingent on a better understanding of their reactivity, particularly in the case of impure calcined clays. An improved understanding of the reactivity of the minerals in these complex, heterogeneous materials is needed. Likewise, when calcined clays and other SCMs are combined with limestone and cement, the ensuing reactions, microstructural development, and their impacts on durability need further investigation. (Juenger et al., 2019).

Several efforts by many researchers worldwide have been carried out to develop cements which are not based on Portland cement clinker anymore. Many of these solutions could have considerable environmental benefits. However, for the time being either their technical suitability or their economic value and the availability of the constituents are often not verified. Therefore, the efficient use of Portland cement clinker in cement with an increased content of e.g., limestone is worth to be further investigated and developed (Palm et al., 2016).

Although a lot of work has been done in the last decades to investigate the performances of limestone Portland cement and the knowledge level is continuously extending, there is still disagreement on durability issues. In order to contribute to this discussion, an experimental study was carried out to assess the effect of the partial replacement of Portland cement with ground limestone in proportions of 10 and 20% on the properties of concretes with various binder contents, curing time and by keeping constant water/binder ratios. LP has the nucleation effect in early hydration reaction that accelerates the cement hydration. It can also physically fill the void and increase the packing density of the system. As a consequence, LP increases the compressive strength of concrete at an early age. However, it may reduce the compressive strength at a late age because it does not have a pozzolanic reaction with cement unlike other SCMs such as slag, FA, and MK, and it requires higher water demand (Park et al., 2021). It's in argue that Overall, the effectiveness of limestone powder in improving the workability, compressive strength and durability of concrete depends on various factors, including the purity of the limestone powder, the particle size distribution, and the amount used. Further research is needed to determine the most effective types of limestone powder for improving the workability, mechanical strength, durability and the microstructure of concrete.

This research, therefore, carries significance in providing comprehensive testing for OPC with fine PCC, including durability properties. Hence it becomes relevant to explore on the precipitated calcium carbonated as partial cement replacement material directly on concrete mixture and utilizing this waste as supplementary cementitious material through laboratory experiments.

CHAPTER 3

RESEARCH METHODOLOGY

3.1.Introduction

The first section designates the overall research design, materials used, test parameters, and specimen preparation, and then finally the experimental work to accomplish the research objectives.

3.2.Research Approach and Design

The purpose of these experimental research was to investigate the effect of Precipitated Calcium Carbonate as partial cement replacement material for concrete production using C-25 grade of concrete and observe the effects of Precipitated Calcium Carbonate addition directly to concrete mix on the workability of fresh concrete, the compressive strength of concrete, and water penetration depth of concrete.

3.3.Source of Data and Sampling

Data were collected in two phases that are included in primary data collection scheme: Phase one data were assessed to allocate the source of the concrete ingredient and precipitated calcium carbonate as an alternative supplementary cementitious material in concrete production and phase two data form laboratory test results. Concrete ingredients, coarse aggregate sourced and sampled from JMC crusher plant located at Km.29+600 LHS (Stock Pile), and fine aggregate from Awash River, Metahara. On the other hand, the PCC the partial replacement material sourced from Batu Caustic Soda factory.

3.4.Research Methodology Framework

Flow chart tries to show research plan, and methodologies carried out and undertaken to reach at research objectives and answer stated research problem.

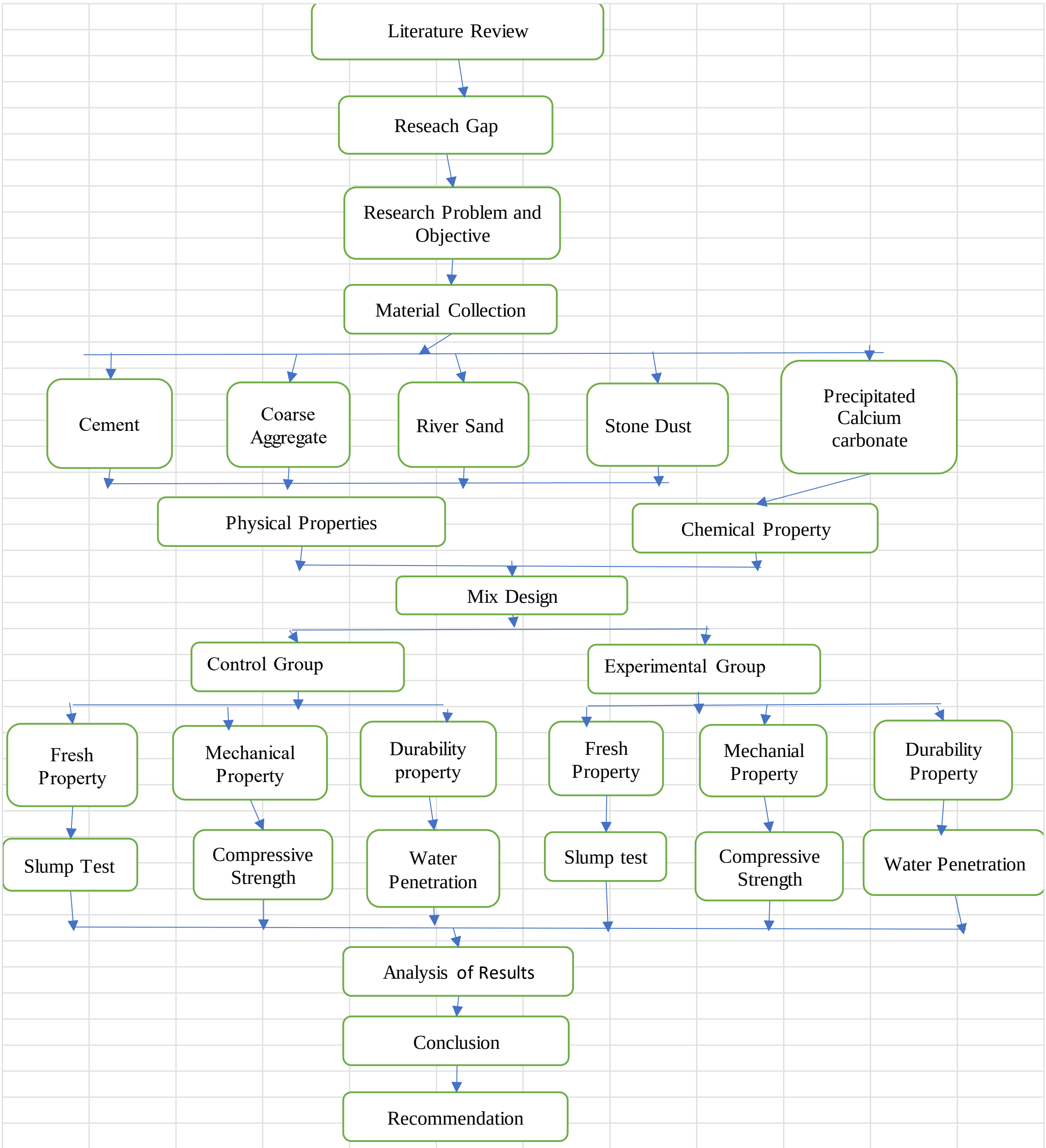

Figure 4 Research methodology framework

3.5.Materials

To explore the effect Precipitated Calcium Carbonate addition on concrete behaviour, Cement, amount of PCC and of water were selected as variable parameters. Aggregate properties and water to cement ratio treated as fixed parameters.

3.5.1. Cement

Ordinary Portland Cement Type I, Dangote Cement grade 42.5 which is produced in Ethiopia used for this research. Type-I Cement is suitable for general concrete construction when there is no exposure to sulphates in the soil. Type-I cement complies with ASTM C-150 and has been used as a binding material for all mix proportions. Portland pozzolanic cement (PPC) is not suitable for limestone powder incorporation as a partial cement replacement material because of it doesn't show pozzolanic properties, which are necessary for the chemical reaction between the pozzolanic material and calcium hydroxide liberated by the hydrating Portland cement to form cementitious compounds.

Dangote Cement PLC is the largest cement producer in Ethiopia and has annual production capacity of 2.5 tonnes and produces cement 32.5 and 42.5- grade cements to meet market demands. Manufacturing plant located in Oromia National Regional, West Shewa Zone, near Mugher Town at 90 KM distance from Addis Ababa.

3.5.2. Fine Aggregate

The essential component in concrete production, typical making up 35-45% of the total aggregate volume. Fine aggregates are aggregates passing through a 9.5mm sieve and predominantly retained on a 75µm (No.200) sieve. Fine can be sourced from natural sand which is obtained from river beds and manufactured by crushing hard stones and gravels. Blending proportion of 70% natural sand and 30% stone dust used in mix design of this

Figure 5 Fine aggregate quarry (Stock Pile) of JMC at Km.29+600 LHS

experiment. Fine aggregate for this specific experiment used from JMC sand Stock Pile 29+600 LHS and sourced from Awash River, Metahara. All quality control tests for concrete ingredient tests conducted. Gradation test, Specific gravity, water absorption and silt and clay content of fine aggregated conducted to meet compliance with standards.

3.5.3. Coarse Aggregate

Coarse aggregates are crucial in concrete production, and typically defined as particles greater than 4.75mm, commonly ranging from 9.5mm to 37.5mm. they constitute 60-80% of concrete volumes. It’s produced by crushing boulder and rocks to the required size to meet standards. Source of coarse aggregate used in the experimental investigation from JMC crusher plant located at Km.29+600 LHS (Stock Pile). Blending proportion of 20mm Agg. - 80% and 10mm Agg. - 20% used in mix design. Quality control tests conducted to coarse aggregate for the mix design purpose and for comprehensive investigations gradation test, specific gravity, unit weight, water Absorption and moisture content tests was conducted to meet ASTM standards.

Figure 6 Coarse aggregate quarry (Stock Pile) of JMC at Km.29+600 LHS

3.5.4. Precipitated calcium carbonate

PCC to be used as partial cement replacement for this study collected from Batu caustic soda factory. Batu caustic soda factory is the largest producer of PCC, hydrated lime, quick lime, Magnesium oxide, and sodium hydroxide. Precipitated calcium carbonate sample from Batu Caustic Soda factory tested at geological survey of Ethiopia Laboratory for chemical composition analysis and particle size analysis test done at Ethiopian Conformity Assessment Enterprise for fineness value of PCC by 90μm sieve size to characterize the material physical property for partial cement replacement.

Complete silicate analysis report showing analytical result in percent (%) element determined major oxides and minor oxides.

Table 2 Chemical composition of PCC

Weight of sample taken 250.00gm	
Major and Minor oxide of PCC	% by weight
SiO_2	3.94
Al_2O_3	0.96
Fe_2O_3	0.74
CaO	55.16
MgO	0.01
Na_2O	0.62
K_2O	0.01
MnO	0.02
P_2O_5	0.02
TiO_2	0.12
H_2O	1.12
LOI	35.85

Figure 7 PCC stock pile at Batu Caustic Soda Factory.

3.6.Research Methods

Research method is an experimental research type which carefully follow procedure and standards to perform the laboratory experiment. Explain the process and methodologies that are considered throughout laboratory experimental investigations. Slump cone workability test were carried out according to ASTM C 143 test for slump of Portland cement concrete on fresh concrete. And then, the experiments were further performed by production of concrete specimens on the basis of standard requirements to make valid the investigation. Hence, cube specimens were prepared in pre-determined proportion and then after curing ages of 7-, 14- and 28-days' ASTM C39 for compressive strength of cubes and water permeability test.

Physical property tests on cement

Normal consistency and setting time of cement

Normal consistency of cement determines the amount of water required to create cement paste that allows a Vicat plunger to penetrate to a depth of 33-35mm from the top of the Mold, or 5-7 from the bottom. The test is done for ensuring the workability and strength of the cement in construction application. Setting time of cement describes the duration it takes for cement paste to transition from plastic to hardened state. Initial setting time of cement is the time elapsed from when water is added to the cement until it starts losing its plasticity. Final setting is the time taken for the cement paste to completely lose its plasticity and attain sufficient firmness, usually up to 10 hours (600 minutes) for OPC. Normal consistency of Dangote OPC grade 42.5 is 27.5 % which is within the specification limit of AASTHO T – 129. Initial and final settings of Dangote 42.5 grade OPC 168min, and 283min respectively which compliance with standard AASTHO T – 131 specifications which is initial from 49 to 202 Minute and final setting time from 185 to 312 Minute.

Fineness of cement

Fineness of cement relates to the particles size distribution of cement, which significantly impacts its performance in construction. Finer cement has a larger surface area, enhancing the rate of hydration and strength development.

Table 3 Average fineness value of Dangote OPC 42.5 grade as per AASTHO T – 128 it meets the standard compliance

SL No	Description	Test.1	Test.2
1	Weight of Cement (A) gm	50.0	50.0
2	Weight of the residue Offer 15min of Sieving on 0.075mm Sieve (B) gm	0.7	0.8
3	% of Finess = 100 - (B/A) *100	98.6	98.4
4	Average % Finess		98.5

3.6.1. Physical Property Tests on Coarse Aggregate

Gradation of coarse Aggregate

After representative samples were obtained and sampled from crusher plant and sample of 10000g sieved in series of arranged sieves in descending order size for 15minutes on mechanical sieves shaker machine. Finally, weighing retained material and calculating the percentage of material retained and passing each sieve using cumulative weight data. Presenting results in a tabular format, including cumulative percentage passing each sieve and preparing graph using excel software application according to ERA technical specification. The grading requirement is according to ERA Tech. Spec, Table 8402-3 and for this specific study it done by Blending Proportion of 20mm Agg. - 80% & 10mm Agg. - 20%.

Weight of Sample: 10000g						
Sieve Size (mm)	Weight retained (g)	% retained	Cum % retained	% of passing	ERA lower limit	ERA upper limit
25	0.00	0.00	0.00	100	100	100
19	254.0	2.54	2.54	97.46	80	100
10	8042.0	80.42	82.96	17.04	10	40
4.75	1444.0	14.44	97.40	2.6	0	4
0.075	244.0	2.44	99.84	0.16	0	1

Table. Sieve analysis of coarse aggregate

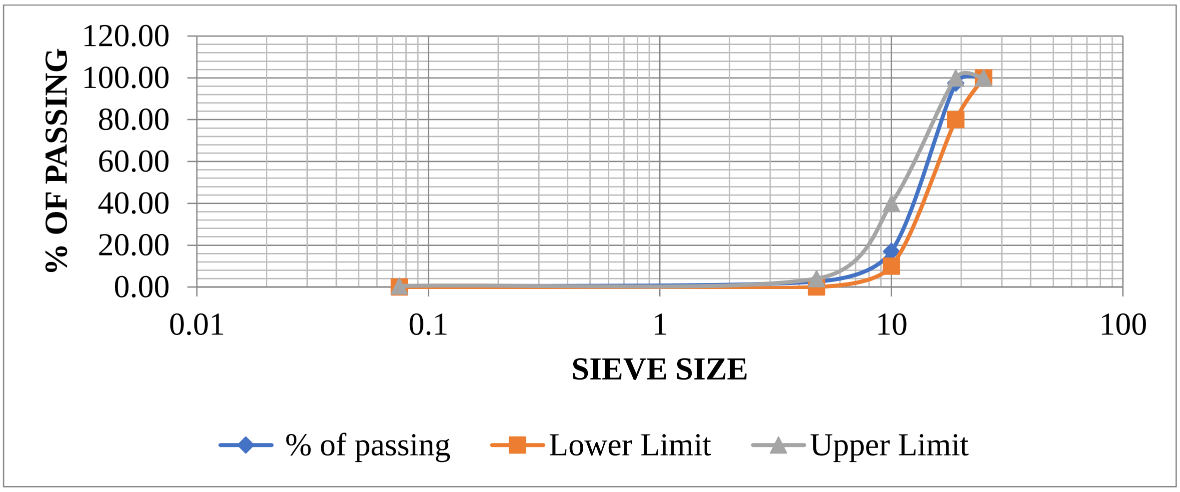

Figure 8 Gradation of coarse aggregate

Specific gravity and Water Absorption of Coarse Aggregate

The determination of specific gravity and water absorption of coarse aggregates is essential in evaluating their quality and suitability for construction applications. This process typically follows the guidelines established by AASHTO T 85, which outlines the necessary procedures and calculations. To begin, the coarse aggregate sample must be prepared by soaking it in water for a period of 15 to 19 hours to ensure it reaches a saturated surface dry (SSD) condition. This condition is critical as it allows for accurate measurement of the water absorbed by the aggregate without including excess surface moisture. After soaking, the aggregate is carefully dried with absorbent cloths until no visible moisture remains on its surface, ensuring that it appears damp but not shiny. There are several types of specific gravity measurements for coarse aggregates: Bulk Specific Gravity (Gsb): This is the ratio of the weight in air of a unit volume of aggregate to the weight in air of an equal volume of gas-free distilled water. It includes the weight of permeable and impermeable voids within the aggregate. Bulk Saturated Surface Dry (SSD) Specific Gravity (Gsb SSD): This measures the weight of the aggregate when it is saturated with water but with no water on the surface. It is crucial for calculating the water-cement ratio in concrete mixes.

Apparent Specific Gravity (Gsa): This ratio excludes the permeable pores and only considers the impermeable portion of the aggregate. The typical range of specific gravity for coarse aggregates used in construction is between 2.5 and Higher specific gravity values generally indicate stronger and denser materials, which can enhance the durability of concrete and asphalt mixes.

Water absorption is defined as the increase in weight of the aggregate due to water absorbed in its pores, excluding any water adhering to the surface. It is expressed as a percentage of the oven-dry weight of the aggregate. Typically, the water absorption of coarse aggregates should not exceed 2% by weight for most applications. Higher absorption rates can lead to issues with durability.

Table 4 Specific gravity and water absorption of coarse aggregate.

Description of sample	20mm size aggregate			10mm size aggregate		
	Test-1	Test-2	Average	Test-1	Test-2	Average
A = Weight of oven dry sample (g)	2537.1	2568.2		1234.6	1316	
B = Weight of SSD sample (g)	2558.2	2590		1251.6	1333.6	

C = Weight of sample in water (g)	1573.9	1595		775.3	824.5	
SSD Bulk Specific Gravity, B/(B-C)	2.599	2.603	2.601	2.628	2.620	2.624
Bulk Specific Gravity, A/(B-C)	2.578	2.581	2.579	2.592	2.585	2.589
Apparent Specific Gravity, A/(A-C)	2.634	2.639	2.636	2.688	2.678	2.683
Water absorption, percentage, 100 X (B-A)/A	0.83	0.85	0.84	1.38	1.34	1.36

Unit weight of coarse aggregate

To determine the unit weight of coarse aggregate, standard test methods such as ASTM C29/C29M and AASHTO T19 are commonly employed. The procedure involves two primary methods, Compacted Method, Fill the measure two-thirds full, repeat leveling and consolidation, then fill to overflowing and perform the same actions and finally, level the surface again to ensure no excess material is present. Loose Method, pour aggregate from a shovel into the measure from no more than 2 inches above its top until filled. Level off any excess material.This measurement is essential for accurate volume-to-weight conversions in concrete mix designs, ensuring that the right amount of aggregate is used to achieve desired strength and durability in concrete structures. The bulk density of aggregates affects the overall properties of concrete, including its strength, workability, and durability. A higher unit weight typically indicates denser aggregates, which can enhance the strength of the concrete mix.

Table 5 Unit weight of coarse aggregate.

Description	20mm size aggregate			10mm size aggregate		
	Tr-1	Tr-2	Tr-3	Tr-1	Tr-2	Tr-3
(Loose Density) Bulk Density of Material (g/cc)	1.342	1.350	1.346	1.504	1.513	1.505
Average			1.346	Average		1.507

(Rodded density) Bulk Density of Material (g/cc)	1.420	1.445	1.444	1.558	1.581	1.558
Average			1.436	Average		1.565

3.5.1 Physical property tests on fine Aggregate

Gradation of fine aggregates

It's a critical procedure used to determine the particle size distribution of fine aggregates. This test is essential for ensuring that the aggregates meet specific grading requirement for construction projects. For this specific research fine aggregate is used by blending river Sand 70% and stone dust 30% from aggregate production residue

Table 6 Sieve analysis of fine aggregate

Weight of Sample: 2000g						
Sieve Size (mm)	Weight retained (g)	% retained	Cum % retained	% of passing	ERA lower limit	ERA upper limit
10	0.00	0.00	0.00	100	100	100
4.75	54.6	2.73	2.73	97.27	95	100
2.36	274.3	13.72	16.45	83.56	68	86
1.18	471.5	28.58	40.02	59.98	47	65
0.6	412.7	20.64	60.66	39.35	27	42
0.3	411.8	20.59	81.25	18.76	9	20
0.15	272.8	13.64	94.89	5.11	0	7
0.075	40.0	2	96.89	3.11	0	2.5

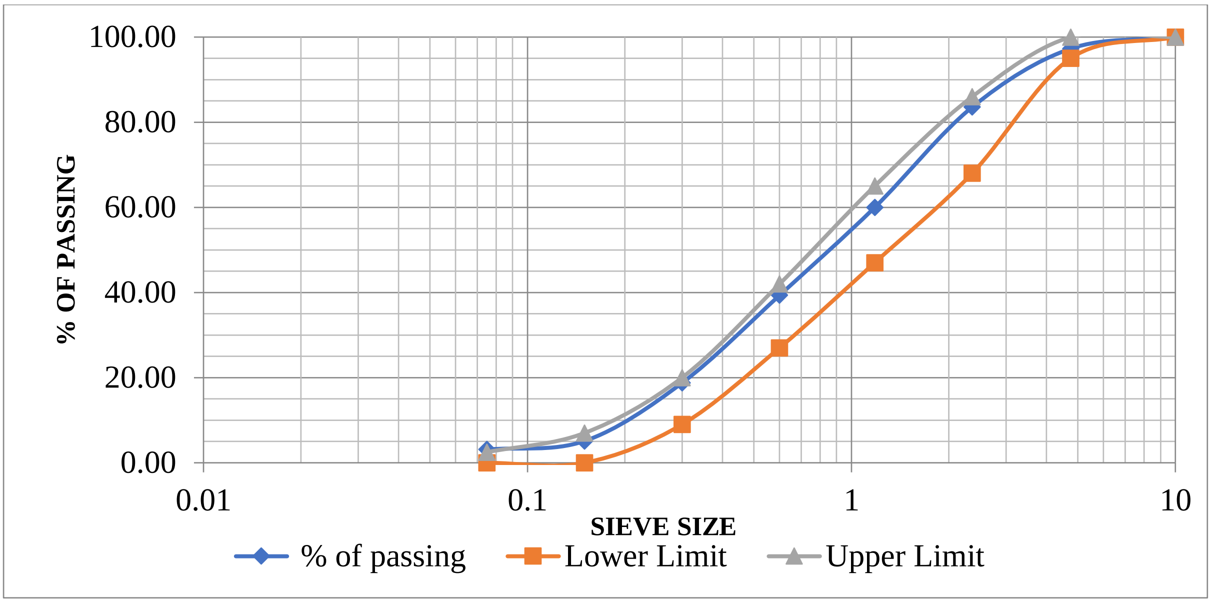

Figure 9 Gradation of fine aggregate

Silt and Clay Content

Silt and clay content in fine aggregate refers to the proportion of particles smaller than 150µm in sand. These fine materials adversely affect the strength and durability of construction material like concrete and mortar. excessive silt over 8% can reduce bonding capacity and increase water demand, leading to structural issue. For this specific experimental research silt content test was performed according to ASTM C117 and the result was obtained 1.1%. ASTM C33-18 Standard Specification for Concrete Aggregates states that the maximum amount of silt allowed in fine aggregate used in concrete is 3% by weight, which compliance with standard requirement.

Table 7 Silt and Clay content of fine aggregate.

Total weight of dry sample taken(W1) gm	300	300
Weight of dry sample after washing through 75µm sieve (W2)	296.7	296.7
Silt & Clay content= [(W1-W2)/W1)/x100] %	1.1	1.1

Specific gravity and Water Absorption of fine aggregate

It is an important property used in the design and analysis of concrete mixtures. Specific gravity is a measure of the density of the aggregate material relative to the density of water. There are different types of specific gravity, like: apparent specific gravity and bulk specific gravity. Bulk specific gravity refers to total volume of the solid including pores of the aggregate, and Apparent specific gravity refers to the volume of the solid is consider to include the impermeable pores but not the capillary ones. Water absorption is a measure of the porosity of the aggregate. It is the increase in the weight of aggregate due to water in the pore spaces compared to the dry condition, expressed as a percentage of the dry weight. These tests are critical for assessing the quality of fine aggregates and ensuring that they meet the necessary standards for use in concrete production.

ASTM C128 standard for specific gravity and water absorption of fine aggregate specifies that the specific gravity of fine aggregates shall fall between 2.5 and 2.7 and that the water absorption for concrete aggregate shall not exceed 3%. fine aggregate used in this experiment meet the ASTM standard's requirements for specific gravity, and water absorption.

Table 8 Table. Specific gravity and water absorption of fine aggregate.

Description of sample	Natural Sand			Stone Dust		
	Test-1	Test-2	Average	Test-1	Test-2	Average
A = Weight of Pycnometer + SSD sample + water (g)	2346.5	2347.1		2361.8	2362.2	
B = Weight of Pycnometer + water (g)	2048.5	2048.5		2049.9	2049.9	
C = Weight of SSD sample (g)	500	500		500	500	
D = Weight of oven dry sample (g)	489.9	490.1		491.1	491.4	
SSD Bulk Specific Gravity, C/{C-(A-B)}	2.475	2.483	2.479	2.658	2.664	2.661
Bulk Specific Gravity, D/{C-(A-B)}	2.425	2.433	2.429	2.611	2.618	2.614

Apparent Specific Gravity, D/{D-(A-B}	2.553	2.559	2.556	2.741	2.744	2.744
Water absorption, percentage, 100 X (C-D)/D	2.06	2.02	2.04	1.81	1.75	1.78

Unit weight of fine aggregate

The ASTM C29/C29M method focuses on measuring the bulk density (or unit weight) of aggregates in both compacted and loose states. This method involves filling a container with the aggregate, levelling it off, and weighing it to calculate the density based on the volume occupied. The significance of unit weight lies in its impact on the workability, strength, and durability of concrete. Variations in unit weight can indicate inconsistencies in aggregate gradation, which can lead to changes in water demand and workability during mixing. It is defined as the mass of the aggregate per unit volume, which can vary based on the moisture content and the method of compaction used during measurement. Understanding the unit weight of fine aggregate is crucial for mix design in concrete, as it impacts the proportions of materials needed to achieve desired strength and durability in construction projects. The minimum unit weight of Fine Aggregates must be 1420 kg/m3 in accordance with ASTM C29 Standard Test Method for Bulk Density "Unit Weight" and Voids in Aggregate.

Table 9 Unit weight of fine aggregate.

Description	Natural Sand			Stone Dust		
	Tr-1	Tr-2	Tr-3	Tr-1	Tr-2	Tr-3
Loose Bulk Density of Material (g/cc)	1.358	1.356	1.358	1.538	1.529	1.533
Average			1.357	Average		1.533
Rodded density Bulk Density of Material (g/cc)	1.470	1.486	1.486	1.671	1.696	1.705
Average			1.480	Average		1.691

3.5.2 Concrete Mix Design

The mix design method adopted is The American Concrete Institute, ACI manual 211-1-97. It provides a comprehensive framework for concrete mix design, focusing on achieving desired performance characteristics while ensuring material efficiency. Concrete mix design is the systematic process of selecting and proportioning the ingredients of concrete to achieve specific performance characteristics, such as strength, durability, and workability, while also considering economic factors. This process ensures that the concrete produced meets the required standards for its intended use.

Required Average Compressive Strength When Data Are Not Available to Establish a Standard Deviation.

Table 10 Required Average Compressive Strength.

Specified compressive strength, f'_c, MPa	Required average compressive strength f'_{cr}, MPa
Less than 21	$f'_c + 7.0$
21 -35	$f'_c + 8.5$
Over 35	$1.10\ f'_c + 5.0$

The average compressive strength from the test record must equal or exceed the ACI 318 required average compressive strength, f'_{cr}, in order for the concrete proportions to be acceptable. The f'_{cr} for the selected mixture proportions is equal to the larger of Equations 9-1 and 9-2 (for $f'_c \leq 35$ MPa.

$f'_{cr} = f'_c + 1.34S$ Eq. 9-1

$f'_{cr} = f'_c + 2.33S - 3.45$ (MPa) Eq. 9-2

were

f'_{cr} = required average compressive strength of concrete used as the basis for selection of concrete proportions, MPa (psi)

f'_c = specified compressive strength of concrete, MPa (psi)

S = standard deviation, MPa (psi)

So, Target mean strength for C-25 grade concrete is 33.5 N/mm^2. The detail procedures of mix design are presented and listed in Appendix. Volume of ingredients and quantities of mix proportion for unit cubic meter of concrete converted to one bag of cement for control concrete mix C-25 present in table below as follows.

Table 11 Concrete mix proportion for control group.

Parameters	Conversion quantity (Kg)
Cement	50
Water	27.5
Coarse aggregate (10mm)	44.1
Coarse aggregate (20mm)	102.6
Fine aggregate (natural sand 70%+stone dust 30%)	123.2

Concrete mix prepared by partial cement replacement with PCC percentage by weight of cement at 10%, 15% and 20% PCC replacement modified to the mix design of the control group mix. Water to cement ratio adjusted to water to cementitious material ratio for PCC incorporation. In all mixes water to cementitious was kept constant and only PCC amount is used by increasing from 10%, 15% and 20% percentage by weight of cement. The quantity of other ingredients other than cement also kept constant. The recommended amount of PCC to substitute cement was in argument in different journal articles reviewed in this study. However, for this study, the PCC replacement amount limited 10%, 15% and 20% and water to cementitious material ratio was adjusted to consider for PCC addition. Table with the above stated replacement amounts 49 samples were prepared for compressive strength, internal microstructure and permeability tests.

Table 12 . Concrete mix proportion of experimental and control group with 10%, 15% and 20% PCC converted to one bag of cement

Mix code	Cement (Kg)	PCC (Kg)	Water (Kg)	Coarse aggregate (Kg)		Fine aggregate (Kg)	
				20mm	10mm	N. sand	S. dust
10% PCC	45	5	30	97.2	41.6	78.2	33.78
15% PCC	42.5	7.5	30	97.2	41.6	78.2	33.78
20% PCC	40	10	30	97.2	41.6	78.2	33.78
Control mix	50	0	27.5	97.2	41.6	78.82	33.78

Table 13 Number of cube samples prepared for experimental and control mix with 10%, 15% and 20% PCC for different tests

% replacement	Compressive strength test (cube)			Permeability test (cube)
	3days	7days	28days	28days

10% PCC	3	3	3	3
15% PCC	3	3	3	3
20% PCC	3	3	3	3
Control mix	3	3	3	3

3.5.3 Batching and curing of concrete specimens

Concrete ingredients including PCC prepared carefully by weighing on a balance according to mix design proportion. After measuring the ingredients, weighted coarse aggregate was first added to the mixer and the then cement and PCC was added to the coarse aggregate and then the fine aggregate was to the mix and dry mixed for a minute. Then, water was added to the dry mixed concrete ingredients mixture and thoroughly mixed for two more minute. uniform mixing of the PCC and the concrete was ensured by mixing for certain period. The fresh concrete was checked for workability test by slump cone and filling the standard slump cone with three layers by rodding each layer with 25 times. Finally, record the value of slump cone obtained. Specified Mold of size 15cm×15cm×15cm concrete cube prepared for Compressive Strength and concrete permeability according to ASTM 192. Excess concrete on the top was removed with trowel after proper compaction and surface was smoothened. After casting, the specimens were stored in the laboratory with room temperature for 24 hours. After this period, the specimens were removed from the Molds, immediately

submerged in the clean and fresh water tank. The specimens were stored and cured until testing date.

Figure 10 Concrete batching and specimen preparation.

3.5.4 Fresh concrete property test

Workability test

Workability of fresh concrete is a critical property that determines how easily the concrete can be mixed, transported, placed, compacted, and finished. It is influenced by several factors, including the water/cement ratio, aggregate size and shape, and the use of admixtures. The most widely used method for assessing the workability of fresh concrete. It involves filling a cone-shaped Mold with concrete and measuring how much the concrete slumps when the Mold is removed. The slump value indicates the consistency of the mix, with specific ranges correlating to different workability levels. slump test done according to ASTM C143. It's done PCC addition to cement as partial replacement material by percentage by weight of cement 10%,15% and 20% by PCC to measure the workability of fresh concrete by different amount PCC inclusion to concrete mix.

3.5.5 Hardened Concrete property Tests

Compressive strength test

Compressive strength test was conducted to explore the effect of PCC addition to concrete as partial cement replacement material. For C-25 concrete grade by 10%, 15% and 20% of PCC addition by percentage by weight of cement to concrete mix. concrete sample were prepared for 3th, 7th and 28th days to explore the effect of PCC incorporation to concrete mechanical property and compressive strength. the experiments were performed by production of specimens on the basis of standard requirements to make valid the investigation. concrete

Figure 11 Compressive strength test machine at LEA-LASA Engineering consultant laboratory.

specimen of 15cm*15cm*cm15cm size was prepared to enable the full cross-section to be tested. Specimens was prepared according to ASTM C192/C192M-00 Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory. After the test specimens are made, their locations for identification were marked, and stored them in a laboratory environment for a day in accordance with ASTM C39/C39M-09 Standard Test Method for Compressive Strength of Cubic Concrete Specimens. At testing day by using compression machine, compressive stress was applied at the rate of 0.3Mpa/sec until the specimen fails, and record the maximum load attained. compressive strength was calculated by dividing the maximum load attained by the cross-sectional area of the specimen and corrected by correction factor. Finally, compressive strength results were reported according to ASTM C39/C39M-09.

3.5.6 Hardened concrete durability test

Permeability test

Water permeability tests of hardened concrete are essential for assessing the durability and performance of concrete structures, especially those exposed to water or moisture. These tests measure the ability of concrete to resist water penetration under pressure, which is crucial for applications in water-retaining structures, foundations, and other critical infrastructure. The test was conducted according to ASTM C1202, on 15-cm-thick concrete cubes that had been cured for 28 days and surface dried on air. Before directly starting the laboratory test, the top surface of the cubes was cleaned and smoothed. Then, the cleaned and smoothed concrete was placed on the permeability testing device, and the bolts were tightened at the top of the sample to prevent any leakage of water when pressure is applied.

3.5.7 Method of data analysis

Experimental laboratory test result data gathered and analysed based on a descriptive and quantitative approach. The process involves examining the fact of a statistical hypothesis relating to the stated research problem using a comparative experimental data analysis. The experiment was conducted by incorporation of PCC to the control mix exploring the effects of PCC on the fresh and hardened properties concrete specimens. The effect of partial replacement of PCC on the mix design compared to control mix. Graphical description and MS Excel program techniques were used for data collection and analysis of the recorded data.

3.1. **Summary**

This chapter emphases on the materials and method used with procedures followed in performing experimental research. Materials, methodology undertaken to achieve the research objective was according to standards and compliance to have a reliable result. The results and discussion of experimental activities will be broadly presented in the next chapter.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1. General

In order to contribute to this discussion, an experimental study was carried out to assess the effect of the partial replacement of Portland cement with ground limestone in proportions of 10%, 15% and 20% on the properties of concretes with constant water/binder ratios, and curing times of 3days, 7days and 28days. In particular, fresh concrete workability test, mechanical properties of hardened concrete compressive strength test, and concrete water permeability test were investigated.

The result reveals that concrete produced using PCC is far more accelerate early hydration reaction and attain early age strength compared to control mix. Moreover, the precipitated calcium carbonate has comparable strength with conventional concrete this leads to substitution strategy of supplementary cementitious materials (SCMs), an effective way to improve the sustainability of the construction industries.

4.2. Precipitated calcium carbonate as partial replacement of cement in concrete production and its effect on fresh concrete property.

4.2.1. Slump Test

As per ERA 2013 8405(h) Slump Required is 25mm -100mm. Following trial mix design, constant free water-cementitious material ratio of 0.5 were set for all PCC replaced concrete and the controlled one as well. The obtained results on figure show that the slump value for PCC in fresh concrete state was higher as compared to the OPC fresh concrete. The PCC fresh concrete was also more cohesive than OPC concrete, as the filler effect of fine PCC particles ensures the optimum water absorption of cement particles to promote complete hydration process which increase the cohesiveness and uniformity of the fresh concrete. The reason for this phenomenon can be attributed to the fineness of PCC powder. Fine PCC powder can physically dispersed cement flocks, thus freeing more paste to lubricate the aggregates and improving workability. Filler occupies the place of sand with smooth surface particles as filler particles cover voids which reduced the inter particle fraction that increase slump(Ali et al., 2015).

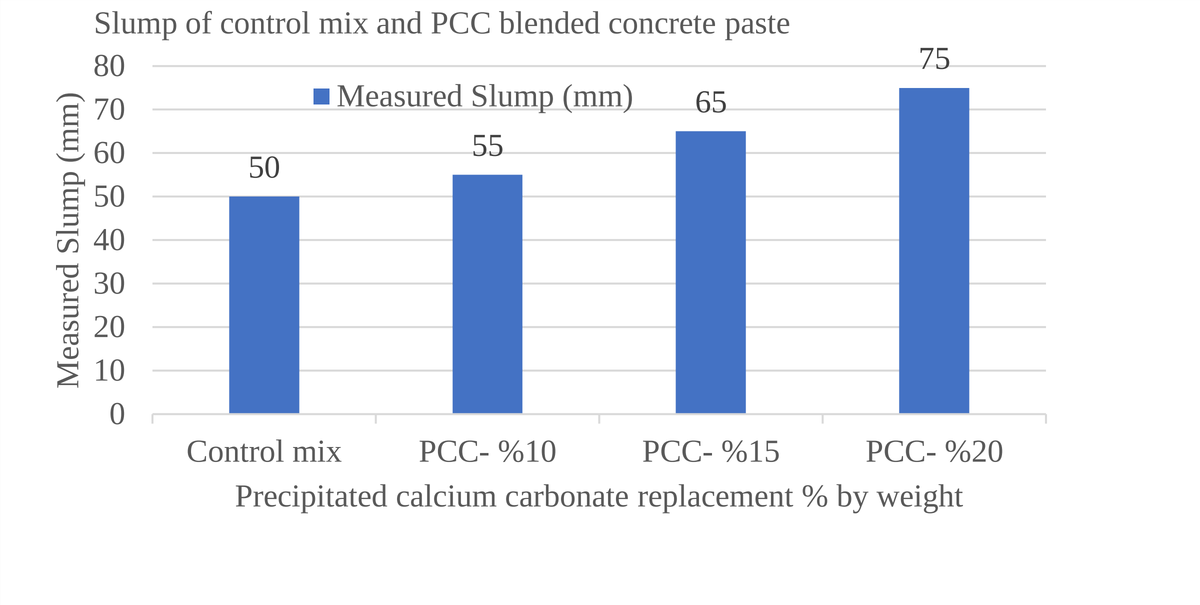

Figure 12 Slump measurement of control and PCC blended concrete paste.

The addition of fine calcium carbonate ($CaCO_3$) filler improves the flowability and workability of concrete. Mixes containing limestone powder exhibit high slump value of 55mm to 75mm as compared to the control mix which have slump value of 50mm. Moreover, as the amount of precipitated calcium carbonate (PCC) increases percentage by weight of cement 10%, 15% and to 20% the slump value also shows increment by 10% with 10% PCC replacement and with 15% and 20% PCC replacement the slump value shows better increment by 20%. The addition of PCC lead to introduction of calcium monocarboaluminate that can enhance the workability of concrete mixtures. This is primarily due to its filler effect, which helps to reduce the water-to-cement ratio (w/c) required for achieving desired consistency. The presence of finely ground calcium carbonate contributes to a more cohesive mix, facilitating easier handling and placement.

It was also reported (E. Berodier & Scrivener, 2014) limestone indicates that additional factors operate here to give a much higher density of C-S-H nuclei on limestone surfaces. Consequently, limestone has a larger accelerating effect on the hydration due to the high number of nuclei while the growth rate of individual needles on limestone is not changed. The increased nucleation on limestone surfaces may be related to the dissolution of this phase, but also to a favourable surface structure, providing a “template” for C-S-H precipitation.

Consequently, this nucleation effect of fine particles of calcium carbonate can serve as nucleation sites for hydration products, which can enhance the hydration process. This acceleration can lead to a more uniform distribution of hydration products, contributing to better workability.

Precipitated calcium carbonate can have filler and dilution effect on concrete. PCC acts as a filler that occupies voids between cement particles. This increases the packing density of the mixture, which can enhance workability by allowing for a smoother flow of the cement paste. And the addition of calcium carbonate can dilute the concentration of cement particles, which may lead to a reduction in viscosity. This can improve the flowability of the mixture, making it easier to work with during application.

The workability of fresh cement mixtures is also influenced by the particle size and content of calcium carbonate. Generally, an increase in the fineness of calcium carbonate improves workability. However, if the content is too high, it may lead to increased viscosity and reduced flowability due to particle agglomeration. The incorporation of calcium monocarboaluminate can lead to a reduction in the water-cement ratio required for achieving desired workability. A lower water-cement ratio typically results in higher strength and durability, further contributing to early strength development(Manninger et al., 2020).

In summary, the hydration reaction of $3CaO·Al2O3·CaCO3·11H2O$ significantly influences early strength development in concrete by accelerating hydration, forming stable hydration products, providing nucleation sites, reducing the water-cement ratio, and mitigating delayed setting times. These factors collectively enhance the mechanical properties of concrete in its initial stages, making it suitable for various construction applications. Finally, addition of PCC shows better flowability and workability of concrete, and this may also give a room for decreasing water to cementitious ratio to increase to attain the required specific concrete quality.

4.3. Precipitated calcium carbonate as partial replacement of cement in concrete production and its effect on mechanical concrete property.

4.3.1. Concrete Compressive Strength

Compressive strength indicates a satisfactory quality of concrete associated with the structure of the hydrated cement paste. Table represents the compressive strength results of diverse mixes with the limestone powder replacement at the ages of 3, 7, and 28 days. Compressive strength of concrete cube performed as per AASTHO T-140 and a correction factor Y=

(1.026X-2.483) used for measuring the true compressive strength of concrete cube. For these mixes, the compressive strength increased from 16.75Mpa to 19.15Mpa, 25.66Mpa to 29.97mpa at 3- and 7-days curing duration by 10%PCC replacement compared to control mix. This shows PCC powder can accelerate the hydration of cement, leading to higher early-age compressive strengths. The finer the limestone powder, the more pronounced this effect(Shi et al, 2018).

The presence of calcium monocarboaluminate in concrete promotes rapid hydration, which contributes to early strength development. This is particularly beneficial in applications where quick setting and strength gain are required, such as in precast concrete elements and rapid repair works (Manninger et al., 2020), (Feldman et al., 1965).

In contrary, 15%PCC and 20%PCC replacement shows reduction in compressive strength of concrete cube. Adding limestone powder as a partial replacement for cement results in a dilution effect, reducing the overall compressive strength of the concrete mix. Higher replacement levels lead to greater reductions in compressive strength(Thongsanitgarn et al., 2012).

Table 14 |Summary of compressive strength test for experimental and control group

Compressive strength test				
PCC replacement % by weight	Mix designation code	Test age		
		3day	7day	28day
		Test Results (N/mm^2) (Mpa)		
Control mix	0%PCC-C	16.75	25.66	36.6
PCC- %10	10%PCC-C	19.15	29.97	39.81
PCC- %15	15%PCC-C	13.25	20.17	31.41
PCC- %20	20%PCC-C	13.02	20.1	27.62

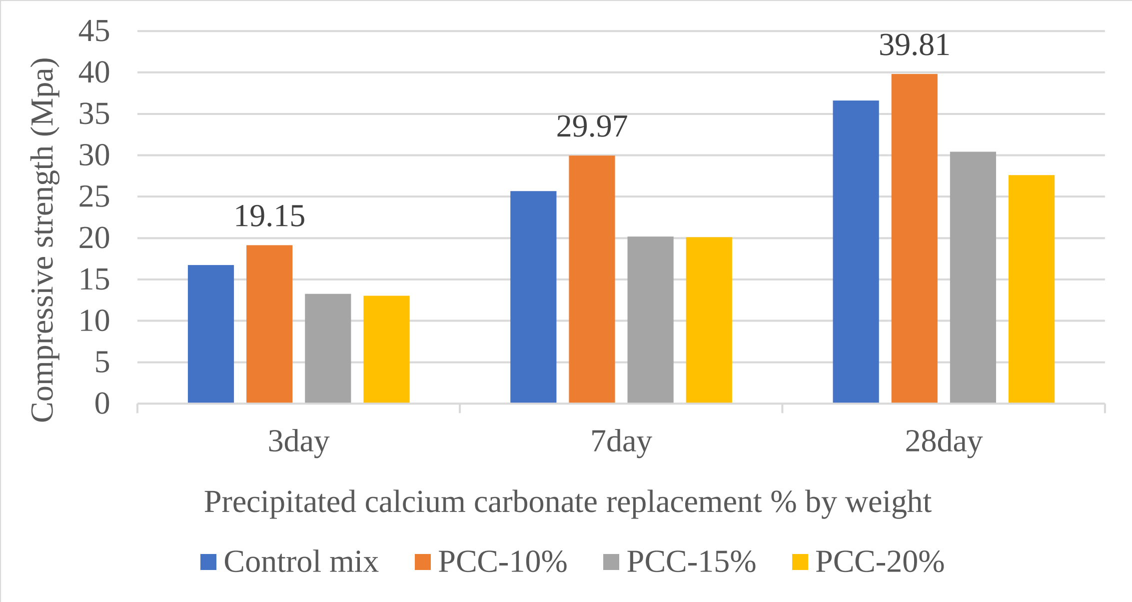

Figure 13 Compressive strength of cubes on 3rd, 7th, and 28th day.

Fig 13 shows the compressive strength of samples made of PCC as a function of water/binder-ratio and limestone content. Included are results tested on concrete samples specimens for 3, 7 and 28days curing.

Concrete made with PCC 10% exhibit remarkable improvement in compressive strength compared to control mix, 19.15mpa, 29.97mpa and 39.81mpa and 16.75mpa, 25.66mpa and 36.6mpa respectively at age of 3day, 7day and 28day curing of concrete specimens. However concrete with 15% and 20% PCC replacement decreases compressive strength of concrete with increasing of PCC amount at 3, 7 and 28 days of curing. Compressive strength of mixes containing precipitated calcium carbonate powder of 10% have 8.77% to 14.33 higher than control mix depending on the grade. The presence of limestone powder can improve the interfacial transition zone between the cement paste and aggregates. This leads to better adhesion and a stronger bond, increasing compressive strength(Kępniak et al., 2021).

However, adding more than 10% of PCC slightly decreases compressive strength. For long-term strength, the effects can vary. While moderate percentages (around 10-20%) of limestone powder can maintain or slightly improve compressive strength, higher replacement levels (above 20%) may lead to a decrease in compressive strength. This reduction is attributed to the dilution effect, where the non-cementitious nature of limestone powder reduces the overall cement content, thereby affecting strength development(Cao et al., 2019). The results showed that the limestone seems not to be totally inert component. The contribution of limestone to the compressive strength is also remarkable when higher amount of Portland cement clinker is replaced with limestone(Palm et al., 2016). The inclusion of limestone powder in concrete can enhance its compressive strength by improving the packing density of the mix. Limestone powder acts as a filler that helps to fill voids in the concrete matrix, thus reducing porosity and improving the overall mechanical properties.

(Wang et al., 2019) reported as the amount of LP increased from 25% to 50%, the contribution of physical effect of LP on the compressive strength of cement pastes increased from 20.05% to 42.02% while the contribution of chemical effect increased from 1% to 2.66% at 28d, and the contribution of physical effect increased from 20.03% to 41.97% while the contribution of chemical effect increased from 1.08% to 2.84% at 180d.

In cement hydration, nucleation is the initial step in the formation of calcium silicate hydrate (C-S-H), which is the primary binding agent in concrete. The presence of nucleating materials, such as limestone or ultra-fine calcium hydroxide, can facilitate the formation of C-S-H nuclei, leading to the acceleration of cement hydration. The nucleation effect is particularly pronounced during the early stages of cement hydration, such as the first hours and days. The acceleration of cement hydration by nucleation can lead to improved cement performance, such as increased compressive strength, reduced water demand, and improved workability. In summary, nucleation is a crucial step in cement hydration, and the presence of nucleating materials can accelerate the formation of C-S-H nuclei, leading to improved cement performance. The hydration of calcium monocarboaluminate leads to a denser microstructure, which reduces porosity and enhances the mechanical properties of concrete. This densification helps in improving the load-bearing capacity and overall performance of the concrete mix.

Formation of Calcium Carbo-silicate Hydrates: The interaction between calcium carbonate and the hydration products of cement can lead to the formation of calcium carbo-silicate hydrates, which contribute to the strength and durability of the cement matrix. The presence of calcium carbonate can modify the calcium-to-silicon (Ca/Si) ratio in the calcium silicate hydrate (C-S-H) gel, which is crucial for the mechanical properties of hardened cement paste.

At 28 and 56 days, the compressive strength of the experiment specimens still exceeded that of the control specimens: LP10 (+51%) and LP20 (+42.62%). It seems that the inclusion of limestone powder in cement-based composites can increase compressive strength; however, the magnitude of the improvements drops at replacement values exceeding 10%(Wei-Ting et al., 2020).

The hydration reaction cement with incorporation of PCC induces the formation of 3CaO·Al2O3·CaCO3·11H2O (calcium monocarboaluminate) plays a significant role in enhancing the early strength development of concrete. Calcium monocarboaluminate, is formed during the hydration of calcium aluminate cement (CAC) in the presence of calcium carbonate ($CaCO_3$) and water. The formation of calcium monocarboaluminate can lead to increased compressive strength due to its ability to fill voids and create a denser microstructure. Studies have shown that the incorporation of this compound can improve the overall compressive strength of concrete, especially in the early stages of hydration(Manninger et al., 2020).

Calcium carbonate plays a crucial role in the formation of calcium monocarboaluminate during the hydration of calcium aluminate cements. This relationship not only facilitates the development of desirable mechanical properties in concrete but also influences its long-term performance and durability. The interaction between these two compounds is essential for optimizing concrete formulations, especially in applications requiring rapid strength gain and enhanced durability.

4.4. Precipitated calcium carbonate as partial replacement of cement in concrete production and its effect on durability of hardened concrete.

4.4.1 Water penetration test

The presence of limestone powder can also influence the hydration process, promoting the formation of additional calcium carbonate and enhancing the microstructure. This contributes to lower permeability and, consequently, reduced water penetration depth. The responses for the ingress of water were investigated using Water depth penetration test. Water penetration depth test were conducted for samples at age of 28 days concrete from control and experimental group with replacement of 10%, 15% and 20% of Precipitated Calcium Carbonate. Each four samples composed of three 15cm*15cm*15cm cube specimens. The cube specimens placed on the apparatus tightened adequately to make sure there is no leakage throughout the test process. Following placement of the specimen, pressured water applied at the rate of 5kg/cm^2 for 72 hours. After 72hr test period, specimens were removed and split into two halves using compressive machine. This test was conducted at Gentium concrete production company.

Concrete that is impermeable is defined as having a water penetration depth of less than 50 millimeters (mm), and under aggressive conditions, less than 30 millimeters (mm) (Neville, 2012). Therefore, according to (Neville, 2012), "Properties of concrete", samples of concrete with 10% replacements are to be ranked as impermeable. the hydration products formed, including calcium monocarboaluminate, enhance the durability of concrete by providing resistance against sulfate attack and reducing permeability. This is crucial for structures exposed to aggressive environments, ensuring longevity and stability(Medveščček et al., 2006).

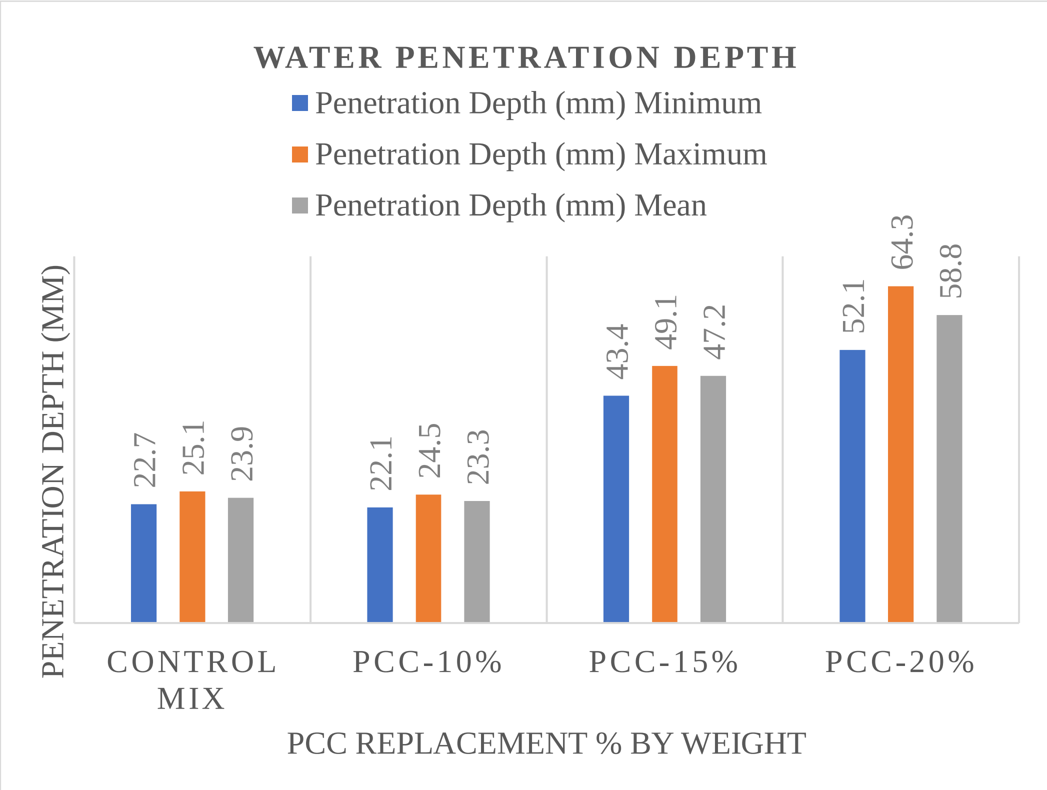

Figure 14 Water penetration test of cubes on 28th day with different level of PCC replacement.

The relationship between the compressive strength of concrete and the water penetration depth, particularly in the presence of limestone powder, is significant in determining the durability of concrete structures. the compressive strength of concrete is inversely related to water penetration depth, meaning that higher strength typically results in lower penetration depths. The inclusion of limestone powder can enhance this relationship by improving the microstructure and reducing porosity. The inclusion of limestone powder in concrete acts as a filler that helps to fill voids within the concrete matrix. This leads to a denser microstructure, which reduces the pathways for water to penetrate, thereby decreasing the water penetration depth(Mohanraj & Vasanth, 2022).

Studies indicate that concrete samples with higher compressive strength tend to exhibit lower water penetration depths. For instance, as the compressive strength increases from lower grades (e.g., C10) to higher grades (e.g., C50), the penetration depth of water decreases significantly. This suggests that stronger concrete is less permeable and more resistant to water ingress(pouyan, 2018). The presence of limestone powder enhances the durability of concrete by reducing its permeability. This is particularly beneficial in environments where water exposure is a concern, as it helps prevent water ingress that can lead to deterioration over time.

4.5. Cost Analysis of Concrete Mixture with Precipitated Calcium Carbonate

Cost comparison analysis for concrete control mix of concrete with OPC and concrete with PCC by partial substituting cement by keeping other ingredients of concrete the same for both mixes. And cost analysis was done based on market price of ingredients for concrete for C-25mpa for unit cubic meter of concrete.

Table 15 List of material price based on current market analysis

Item No	Material	Unit	Quantity	Price (Birr)
1	Cement OPC 42.5	Qtl	1	2200
2	Precipitated calcium Carbonate	Kg	1	3.45
3	Coarse Aggregate	m^3	1	1850
4	Fine Aggregate	m^3	1	1600
5	Water	m^3	1	50

Table 16 Cost of concrete mixture for C-25mpa, Control mix

Ingredient Materials	Quantity Required for 1m^3 of concrete (Kg/m$^{3)}$	Cost (Birr)
Water	198	9.9
Cement	360	7920

Coarse Aggregate	1055	1110.21
Fine Aggregate	887	933.68
	Total	**9973.79**

Table 17 Cost of concrete mixture with PCC 10% partial replacement of OPC

Ingredient Materials	Quantity Required for 1m^3 of concrete (Kg/m^3)	Cost (Birr)
Water	198	9.9
Cement	324	7128
Precipitated Calcium Carbonate (10%)	36	108.00
Coarse Aggregate	1055	1110.21
Fine Aggregate	887	933.68
	Total	**9289.79**

Table 18 Cost of Concrete mixture with PCC 15% partial replacement of OPC

Ingredient Materials	Quantity Required for 1m^3 of concrete (Kg/m^3)	Cost (Birr)
Water	198	9.9
Cement	306	6732
Precipitated Calcium Carbonate (15%)	54	186.30
Coarse Aggregate	1055	1110.21
Fine Aggregate	887	933.68
	Total	**8972.09**

Table 19 Cost of concrete mixture with PCC 20% partial replacement of OPC

Ingredient Materials	Quantity Required for 1m^3 of concrete (Kg/m^3)	Cost (Birr)
Water	198	9.9
Cement	288	6336
Precipitated Calcium Carbonate (20%)	72	186.30
Coarse Aggregate	1055	1110.21
Fine Aggregate	887	933.68

Total	**8576.09**

The results provided in Tables 16, 17, 18, and 19 show that an increase with amount of PCC incorporated for partial replacement of cement by percentage by weight decreases the total cost of concrete mix. Cost comparison analysis was done by comparing the cost incurred for control mix and with 10%, 15%, and 20% PCC partial replacement for OPC cement in concrete mixture. When compared to the control mix, cost of concrete mix decreases when the amount of PCC increases for all mixes of 10%, 15% and 20%. The cost is 9973.79 Birr/m^3, 9289.79 Birr/m^3, 8972.09 Birr/m^3 and 8576.09 Birr/m^3, for control mix, 10% PCC, 15%PCC and 20% PCC respectively.

However, cost comparison analysis was done for control mix and mixes with 10%, 15% and 20% PCC for partial replacement of cement for concrete production, cost reduction was seen by 6.86%, 10.04% and 14.01%, for 10%PCC, 15%PCC and 20%PCC respectively. Since 15%PCC and 20%PCC showed significant cost difference which can save the economy it doesn’t answer technical parameters for mechanical properties of concrete, compressive strength test and hardened concrete property test of water permeability test.

Moreover, 10%PCC inclusion in concrete mixture decreases cost of concrete by 6.86% compared to control mix while improving the desired technical parameters of concrete for compressive strength test and hardened concrete property test of water permeability test.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The effect of precipitated calcium carbonate was studied by replacing Portland cement with a precipitated calcium carbonate in concrete with replacement (10-20% by mass of binder), water/binder ratio (0.5) and binder content (360 kg/m^3). Workability, compressive strength and water penetration test were investigated. On the basis of results of experimental tests for the materials employed in this study, the following conclusions are drawn.

Concrete mix with PCC incorporation exhibits higher slump value 55mm, 65mm, and 75mm this shows better improvement on workability, compared to control mix specimens with slump value of 50mm. Addition of PCC induces the introduction of calcium monocarboaluminate can enhance the workability of concrete mixtures. This is primarily due to its filler effect, which helps to reduce the water-to-cement ratio (w/c) required for achieving desired consistency. The presence of finely ground calcium carbonate contributes to a more cohesive mix, facilitating easier handling and placement. The cement containing PCC powder demands less water than cements with Portland cement.

Compressive strength increased from 16.75Mpa to 19.15Mpa, 25.66Mpa to 29.97mpa at 3- and 7-days curing duration respectively by 10%PCC replacement compared to control mix. The addition of calcium carbonate (CaCO3), from which calcium monocarboaluminate is derived, can lead to a significant increase in compressive strength at early hydration stages. This material is known to enhance early strength development in cementitious systems. The hydration of calcium monocarboaluminate can accelerate the formation of ettringite, which contributes to increased strength within the first few days of curing. Compressive strength of mixes containing precipitated calcium carbonate powder of 10% have 8.77% strength higher than control mix at 28 days age. The presence of limestone powder can improve the interfacial transition zone between the cement paste and aggregates. This leads to better adhesion and a stronger bond, increasing compressive strength.

The inclusion of limestone powder as a replacement for cement had a negative effect on permeability and durability in a dose-dependent manner. Experimental results indicate that concrete with limestone powder shows significantly lower water penetration depths. at a replacement level of 10% and strength level of 39.81Mpa, the water permeability of concrete with limestone powder is lower than that of control mix concrete strength of 36.6mpa with the same water-cement ratio and mix proportions. This suggests that the addition of limestone powder effectively enhances the resistance of concrete to water penetration at optimum PCC replacement level.

The presence of precipitated calcium carbonate not only facilitates the formation of calcium monocarboaluminate but also influences the hydration kinetics, potentially enhancing the mechanical properties further. The interaction between $CaCO_3$ and the hydration products can lead to the formation of stable phases that improve strength and durability.

An increase with amount of PCC incorporated for partial replacement of cement by percentage by weight decreases the total cost of concrete mix by 6.86%, 10.04% and 14.01%, for 10%PCC, 15%PCC and 20%PCC respectively and 10%PCC inclusion in concrete mixture decreases cost of concrete by 6.86% compared to control mix while improving the desired technical parameters of concrete for compressive strength test and hardened concrete property test of water permeability test.

In terms of mechanical properties and permeability, it appears that up to 10% of the cement could be replaced with limestone powder without adverse effects.

5.2. Recommendations

The contradicting issues related to the amount of PCC used in concrete mix need designing of the standard specifications for all recognized SCMs by concerned body.

This research is limited to the use of PCC as supplementary cementitious material for concrete production, but the future study should consider the use of ternary cement for concrete production by adding pozzolanic material to PCC for enhanced and improved concrete property.

It’s recommended to conduct further research into the effects of PCC powder inclusion in hydration reaction, PH value and steel reinforcement to answer in depth technical requirements of concrete made with PCC powder partial replacement.

It’s also recommended to conduct research on the use of admixture on the effect of Precipitated calcium carbonate addition on concrete production and investigating physical, mechanical and durability properties of concrete made with PCC powder partial replacement.

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APPENDIX A

MATERIAL PROPERTIES TEST RESULTS

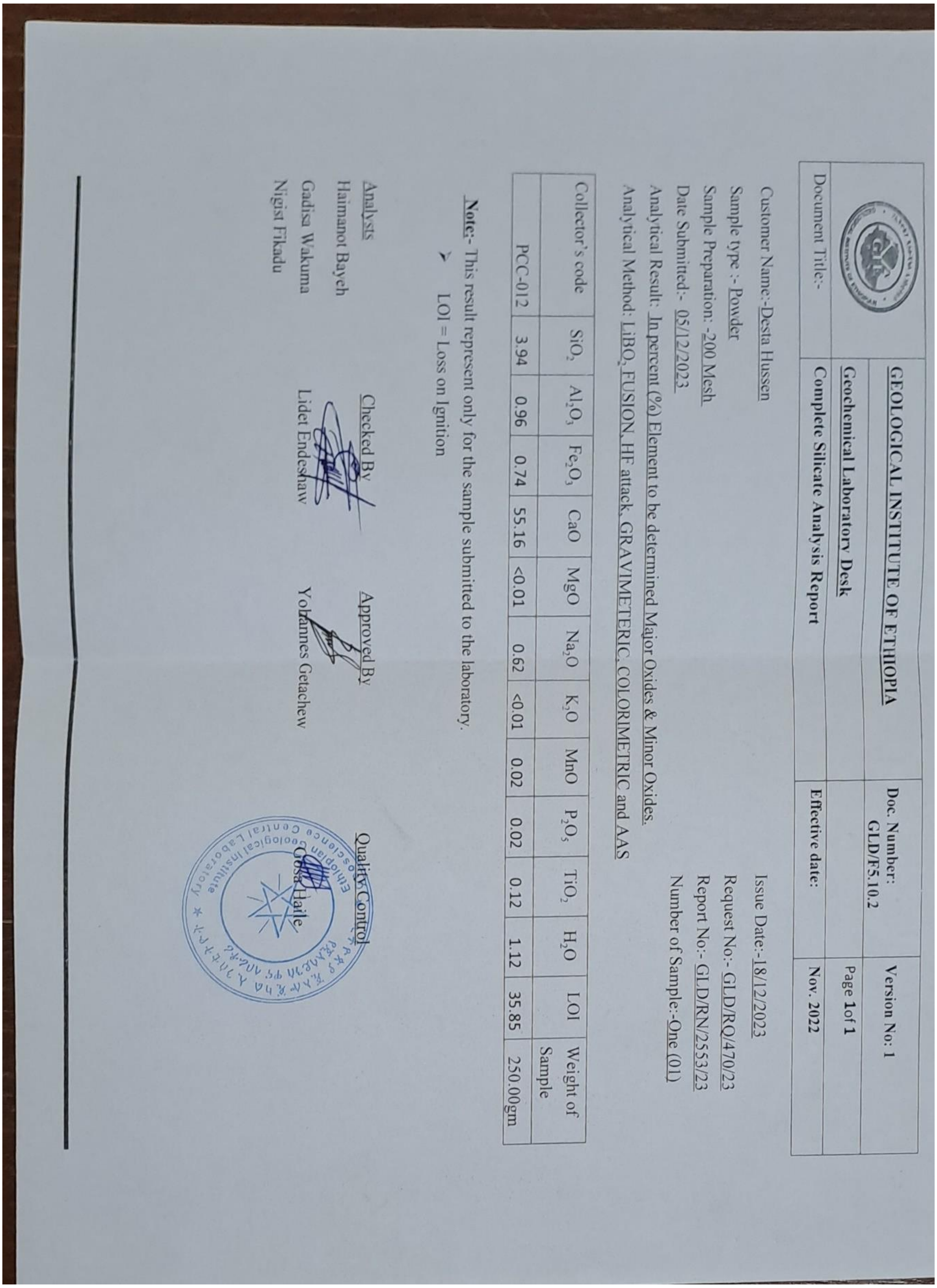
<table>
<tr><th colspan="6">INITIAL & FINAL SETTING TIME OF CEMENT
(As per AASTHO T - 131)</th></tr>
<tr><td colspan="6"></td></tr>
<tr><td colspan="2">Source / Brand of Cement</td><td colspan="2">Dangote Cement, OPC</td><td>Date of Sampling</td><td>1/28/2023</td></tr>
<tr><td colspan="2">Grade of Cement</td><td colspan="2">42.5 Grade</td><td>Date of Testing</td><td>1/28/2023</td></tr>
<tr><td colspan="2">Location</td><td colspan="2">LEA-LASA Laboratory</td><td>Sampled By</td><td>Desta Hussein</td></tr>
<tr><td>Proposed Use</td><td></td><td colspan="2">Concrete</td><td>Tested By</td><td>Desta Hussein</td></tr>
<tr><td colspan="2">RFI No.</td><td colspan="2"></td><td>Invoice No.</td><td></td></tr>
<tr><td>SL. No</td><td>Weight of Cement for Test, C (gm)</td><td>Water Added = Consistency (ml) x 0.85</td><td>Initial Setting Time (Min.)</td><td>Final Setting Time (Min.)</td><td>Remarks</td></tr>
<tr><td>1</td><td>400</td><td>93.5</td><td>168</td><td>283</td><td></td></tr>
<tr><td>2</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="5"></td><td rowspan="2">Specification Limit:</td><td>Initial Setting Time</td><td>49 to 202 Min.</td><td colspan="2" rowspan="5"></td></tr>
<tr><td>Final Setting Time</td><td>185 to 312 Min.</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Results:</td><td>Initial Setting Time</td><td>168 Min.</td></tr>
<tr><td>Final Setting Time</td><td>283 Min.</td></tr>
</table>

CONSISTENCY OF CEMENT (As per AASTHO T - 129)					
Source / Brand of Cement		Dangote Cement, OPC		Date of Sampling	1/28/2023
Grade of Cement		42.5 Grade		Date of Testing	1/28/2023
Location		LEA-LASA Laboratory		Sampled By	Desta Hussein
Proposed Use		Concrete		Tested By	Desta Hussein
RFI No.					
SL. No	Weight of Cement (gm)	Weight of Water added to Cement (gms)	Water added (%)	Reading (mm)	Remarks
1	400	104	26.0	21	
2	400	108	27.0	14	
3	400	110	27.5	10	

Results: Consistency 27.5 %

Specification For Standard Consistency penetration should be 10 +/- 1mm from bottom of Vicat apparatus

Precipitated calcium carbonate complete silicate analysis report



	GEOLOGICAL INSTITUTE OF ETHIOPIA	Doc. Number: GLD/F5.10.2	Version No: 1
	Geochemical Laboratory Desk		Page 1of 1
Document Title:-	Complete Silicate Analysis Report	Effective date:	Nov. 2022

Customer Name:-Desta Hussen
Sample type :- Powder
Sample Preparation: -200 Mesh
Date Submitted:- 05/12/2023

Issue Date:-18/12/2023
Request No:- GLD/RQ/470/23
Report No:- GLD/RN/2553/23
Number of Sample:-One (01)

Analytical Result: In percent (%) Element to be determined Major Oxides & Minor Oxides.
Analytical Method: $LiBO_2$ FUSION, HF attack, GRAVIMETERIC, COLORIMETRIC and AAS

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI	Weight of Sample
PCC-012	3.94	0.96	0.74	55.16	<0.01	0.62	<0.01	0.02	0.02	0.12	1.12	35.85	250.00gm

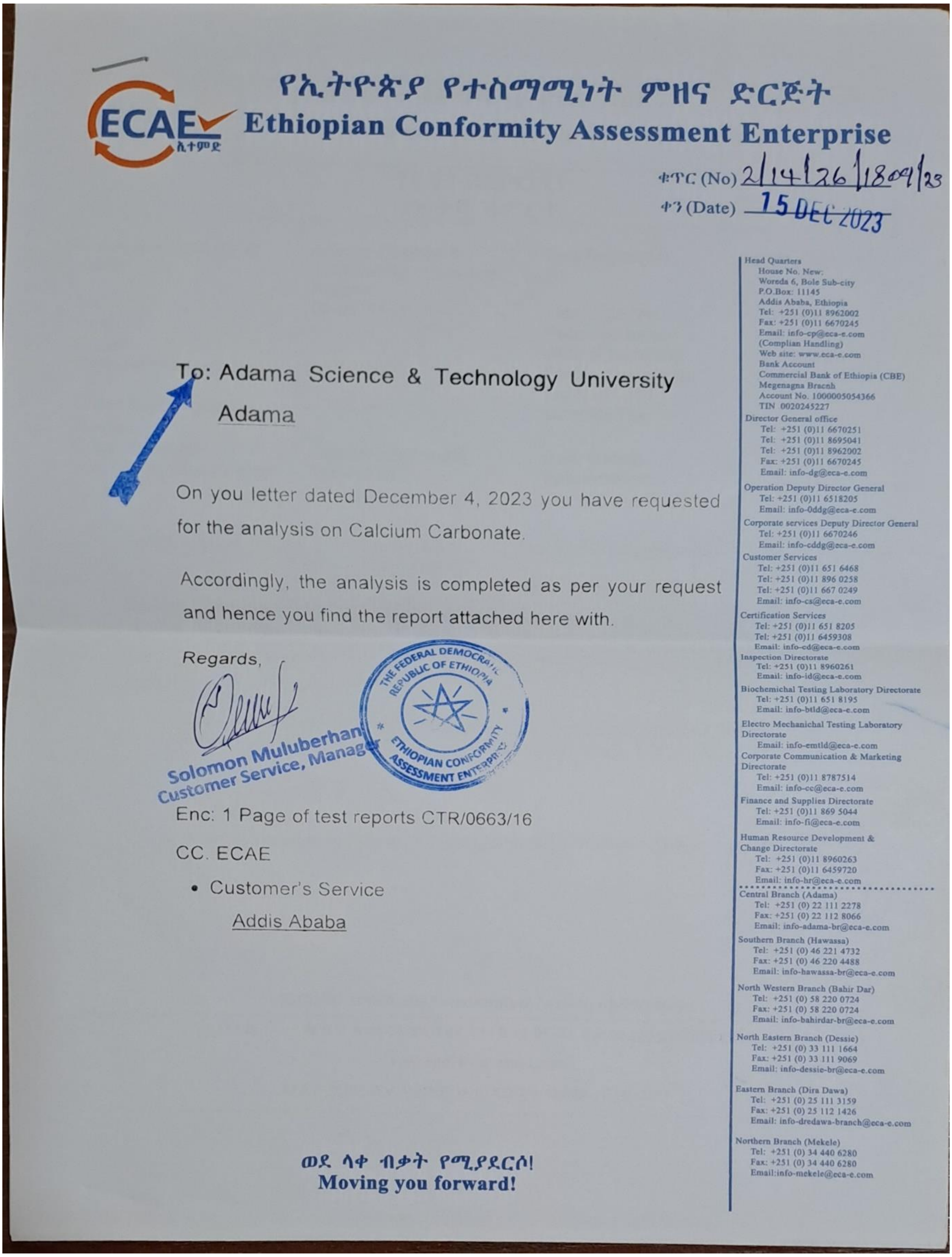
Note:- This result represent only for the sample submitted to the laboratory.

- LOI = Loss on Ignition

Analysts	Checked By	Approved By	Quality Control
Haimanot Bayeh Gadisa Wakuma Nigist Fikadu	Lidet Endeshaw	Yohannes Getachew	Gosa Haile

Ethiopian Geological Institute Geoscience Central Laboratory

Precipitated calcium carbonate sieve analysis test by 90µm sieve size



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Ethiopian Conformity Assessment Enterprise

ቁጥር (No) 2/14/26/1809/23
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Fax: +251 (0) 34 440 6280
Email:info-mekele@eca-e.com

To: Adama Science & Technology University
Adama

On you letter dated December 4, 2023 you have requested for the analysis on Calcium Carbonate.

Accordingly, the analysis is completed as per your request and hence you find the report attached here with.

Regards,

Solomon Muluberhan
Customer Service, Manager

THE FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA
ETHIOPIAN CONFORMITY ASSESSMENT ENTERPRISE

Enc: 1 Page of test reports CTR/0663/16

CC. ECAE

- Customer's Service
  Addis Ababa

ወደ ላቀ ብቃት የሚያደርስ!
Moving you forward!

ECAE	የኢትዮጵያ የተስማሚነት ምዘና ድርጅት Ethiopian Conformity Assessment Enterprise	Document No: TLD/F7.08-1	
		Copy No: -	Rev No: 3
Title:	TEST REPORT የፍተሻ ሪፖርት	Page No: 1 of 1	Effective Date: 26 Oct 22

Name and address of client	Adama Science & Technology University. Adama	Test Report No:	CTR /0663/16
Tel:	02-22-11-31-70	Test Order No:	CEI/1058/16
Fax:	--	Reported date:	12/12/2023
E-mail:	--	Date of sampling	Not Specified
Date sample Received:	04/12/2023	Place of sampling	Not Specified
Client Sample code: (Brand)	--	Sampled and submitted by	Client
Type of sample:	Calcium carbonate	Date tested:	11/12/2023
Lab Designated number:	16084019	Specification	----------

S/N	Characteristics tested	Specification/ Test Method	Standard Requirements			Test result	Comment
			Min	Nom	Max		
1	Particle size passed in 90µm , % by mass	ES ISO 5223:2015	-	-	-	97.83	-

Remark:

1. This test report relates only to the specific sample product which has been tested by ECAE testing laboratory.

Test report authorized by, Name: Fitsum G/Medhin Position Analyst -II Sign.

ISO/IEC 17025:2017 Accredited Testing Laboratory

✉ 11145 ☎ 011 6 46-05-69, Fax. 011 6 45-97-20, E-mail info-cs@eca-e.com

Web site: www.eca-e.com

BOLE SUBCITY, WOREDA 6, ADDIS ABABA, ETHIOPIA

APPENDIX B

CONCRETE MIX DESIGN

C-25 Concrete Mix Design

Concrete Mix Design

Date : 22-08-2024

1 Summary of requirements in specification

Regarding to the concrete characteristics prescribed by the specifications, those basic data are summarized in the Table 1/1 as follows:

Table 1/1 Summary Requirements

Parameters	Description	Reference
Type of cement	Ordinary Portland Cement	Dangote OPC
Class of Concrete	C25	ERA 3406 (b)
Cement content kg/m3	360	Intial quantity
Water/Cement Ratio	0.55	ACI -211
Standard devitation	8.5	
Compressive Strength (N/mm2)Concrete Cube after 28 day curing period	25	contaract Specifications
Slump Required	25-100mm	As per ERA 2013 8405(h)

2 All quality tests for aggregates are conducted monitoring consultants laboratory at Andhode - Agmasa Road project.

3 Flakiness index for coarse Aggregate is 23.87% Loss Angles Abrasion Value is 21.18%

4 The mix design method adopted is The American Concrete Institute, ACI manual 211-1-97

5 Source of Materials

Slno	Description of Material	Source
1	Dangote OPC cement Grade-42.5	Addis Ababa
2	Fine Aggregate	Awash River (Metahara)
3	Coarse Aggregate	JMC Crusher at km 29+600 LHS (Stock pile)
4	Coarse Aggregate	JMC Crusher at km 29+600 LHS (Stock pile)
5	Water	JMC bore well @ Crusher km 29+300 LHS

6 Laboraory Designe Data

Sl No	Descrption	Unit	Value
1	Bulk Specific gravity for coarse aggregate,10 mm (ssd)	gm/cm^3	2.869
2	Bulk Specific gravity for coarse aggregate, 20 mm (ssd)	gm/cm^3	2.876
3	Fineeness Modulus for Natural sand	%	3.16
4	Bulk Specific gravity for Natural sand (ssd)	gm/cm^3	2.563
5	Specific gravity for OPC cement	gm/cm^3	3.150
6	Water Absorption for coarse aggregate,10 mm	%	1.090
7	Water Absorption for coarse aggregate, 20 mm	%	1.009
8	Water Absorption for Natural sand	%	1.122
9	Natural Moisture Content for aggregate , 20 mm	%	0.130
10	Natural Moisture Content for aggregate , 10 mm	%	0.110
11	Natural Moisture Content for Natural Sand	%	0.120
12	Oven dried Loose unit weight for coarse aggregaates ,10 mm	Kg/m^3	1572
13	Oven dried Loose unit weight for coarse aggregaates , 20 mm	Kg/m^3	1558
14	Oven dried loose unit weight for Natural sand	Kg/m^3	1520
15	Oven dried Rodded unit weight for coarse Aggregate	Kg/m^3	1758

7 Target Mean Strength of concrete Cube after 28 days curing period

(Fck+ 8.3) (25+8.3)= 33.3 N/ Say 34 N/mm^2 ACI -214 R-9

From this value , the 7 days strength result will be calculated as 67%of the 28days mean strength, ie.= 23 N/mm^2

From this value , the 3 days strength result will be calculated as 40%of the 28days mean strength, ie.= 14 N/mm^2

8 Water Determination

From ACI 211-1-97 table A1.5.3.4 (a) water cement Ratio is taken as 0.55 and at the same time from the project specification table 8404-1, the 28days concrete Cube compressive strength is estimated to be Mpa, and 380 kg cement is taken for one m^3 Concrete mix,

Hence the quantity of mixing water will be (Cement Content x Wc Ratio) (380 X 0.55) 198 kg/m^3

9 coarse aggregate Determination

The quantity of corse aggregate estimated from ACI 211-1-23 table A1.5.3.6 for a fineness modulus of fine aggregate, 3.16 and nominal size of coarse aggregate 20mm indicates 0.60 m^3, therfore,the required dry mass for coarse aggregate will be calculated as

=	Volume of coarse aggregate			0.6	m3	
		(Volume of CA x Unit Weight of CA)				
=	1054.8 Kg	(Say that -	1055	Kg)		
		So, Coarse Aggregate (20MM)		70%	738.5	kg/m^3
		"	(10MM)	30%	316.5	kg/m^3

10 Fine Aggregate (Natural Sand) Mass determination

From ACI 211-23 table A1.5.3.7.1, the of a cubic meter of non air entrained concrete made with aggregate having nominal size of

20 mm is extrpolated to be = 2345 kg/m^3 Intrested 2500 kg/m^3

11 Volume of Coarse & fine aggregate for one metric cube of concrete

Volume of water	M^3	-	0.198	(wt of Water/(Sp.gr of water x 1000))
Volume of cement	M^3	-	0.114	(wt of Cement / Sp.gr of Cement x 1000))
Volume of coarse aggregate,10 mm	M^3	-	0.110	(wt of 10 mm CA /(Sp.gr of10 mm x 1000))
Volume of coarse aggregate, 20 mm	M^3	-	0.257	(wt of 20 mm CA /(Sp.gr of 20 mm x 1000))
Volume of non Air entrained concrete	M^3	+	0.000	
Total Volume	M^3		0.679	
Volume of fine Aggregate	M^3		0.321	(1- Total Vloume)

The given masses are

Water	kg	-	198
Cement	kg	-	360
Coarse Aggregate ; 10 mm	kg	-	316.5
Coarse Aggregate ; 20 mm	kg	_	738.5
Total mass of ingredients	kg	+	2500
The mass of Fine Aggregate	kg		887.0

12	Based on estimated concrete mass in Kg				% age
	Mass of water	kg/m^3	198.0	Total mass / Mass of water) *10	7.9
	Mass of cement	kg/m^3	360	'otal mass / Mass of Cement) *1(	14
	Mass of fine Aggregate (Natural sand)	kg/m^3	887	al mass / Mass of Natural sand)	35
	Mass of coarse aggregate,10mm	kg/m^3	317	:al mass / Mass of 10 mm Agg) *	13
	Mass of coarse aggregate, 20mm	kg/m^3	739	tal mass / Mass of 20 mm Agg) *	30
					100
	Toal Mass	kg/m^3	2500.0		

Water Absorption dose not become part of the mixing water & must be excluded from the adjustment in added water

13 There fore the actual quantity of materials required for 1 m^3 of concrete are:

Water	Kg	198
Cement	Kg	360
Coarse Aggregate (10mm)	Kg	317
Coarse Aggregate (20mm)	Kg	739
Fine Aggregate (Natural Sand)	Kg	887
Total quantity of materials	Kg	2500

14. Absorbed water dose not become part of the mixing water & must be excluded from the adjustment in added water

*Water Absorption		
Water Absorbed in Natural Sand	(kg)	10.0
Water Absorbed in coarse aggregate, 20mm	"	7.5
Water Absorbed in coarse aggregate,10mm	"	3.4
Total quantity of water absorbed by both of aggregates	"	20.9
*Natural moisture content:		
Natural Sand	(kg)	1.1
coarse aggregate, 20mm	"	1.0
coarse aggregate,10mm	"	0.3
Total	"	2.0
** Net water to be added with the mixing water	(kg)	-18.83

There fore the quantity of materials required for one meter cube of concrete are:

Water	(kg)	217
Cement	(kg)	360.0
Natural Sand	(kg)	895.9
Coarse aggregate, 20mm	(kg)	745.0
Course aggregate , 10mm	(kg)	319.6
Air entrained	(kg)	0.0
Total quantity of materials	(kg)	2537

***Laboratory trial batch weight is scale down to 0.027 0.0304 m^3

Water	(kg)	6.59
Cement	(kg)	10.94
Natural Sand	(kg)	27.23
Coarse aggregate 20mm	(kg)	22.65
Coarse aggregate 10mm	(kg)	9.72

*During mixing in Lab we added gms of additional water= Nil

15 Height of Measuring Box and Ratio Determination.

Table 15.1 provides calculation of the volume of aggregate for one bag of Cement.

Table 15/1: Volume of ingredient per bag of cement (50 kg)

Parameters	Dry mass after corection basic (kg/m3)	Conversion quantity (kg)	Loose density (kg/m3)	loose Volume (m3)	Size of Measuring Box Length (m)	Width (m)	Height (m)
Water	198	27.50					
Cement	360	50					
Coarse Aggregate (10 mm)	317	44.0	1572	0.028	0.5	0.4	0.14
Coarse Aggregate (20 mm)	739	102.6	1558	0.066	0.5	0.4	0.33
Fine Aggregate (Natural Sand 70%+Stone dust	887	123.2	1520	0.081	0.5	0.4	0.41
Total(kg)	2500.0	347.2	-	-	-	-	-

Loose volume of aggregate =Quantity per 50kg cement / loose unit wight.

To make suitable for handling, the box size will be

For 20 mm Aggregate	2 box each mix	0.16	Height	Box size (0.50 x 0.40 x 0.16m)
For 10 mm Aggregate	1 box each mix	0.14	Height	Box size (0.50 x 0.40 x 0.13 m)
For Fine Aggregate Natrual sand	2 box each mix	0.20	Height	Box size (0.50 x 0.40 x 0.19 m)

APPENDIX C

Fresh concrete measured slump test with different PCC replacement level

PCC replacement % by weight	Measured Slump (mm)
Control mix	50
PCC- %10	55
PCC- %15	65
PCC- %20	75

Summary of laboratory trial batches compressive test results

COMPRESSIVE STRENGTH OF CONCRETE CUBE (AASHTO T-140)											
LOCATION		*LEA-LASA CONSULTANT LABORATORY*						*RFI NO.*			
PART OF STRUCTURE		*Mix Design 0% PCC (Control mix)*						*SIZE OF CUBE*		*150X150X150*	
DATE OF CASTED		06/08/24					*USED CEMENT CONTENT*			*360 KG/CUM*	
DATE OF TESTED								*CONCRETE CLA*		*C -25*	
SOURCE OF AGGREGATE		*JMC CRUSHER PLANT*					*WATER CEMENT RATIO*			*0.55*	
SOURCE OF SAND		*AWASH RIVER (Matahara)*						*TYPE OF CEMEN*		*Dangote Cement*	
Correction Factor Y=(1.026X-2.483)											
Cube Strength											
Cube No.	Cast date	Test date	Age	Slump (mm)	Weight (g)	Unit Weight	Crushing Load (KN)	Corrected Load (KN)	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)	Remark
1	06/08/24	09/08/24	3day	65	8245.0	2.443	381.0	388.4	17.26	16.75	
2					8415.0	2.493	366.0	373.0	16.27		
3					8080.0	2.394	376.0	383.3	16.71		
1	06/08/24	13/08/24	7day		8255.0	2.446	579.5	592.1	26.31	25.66	
2					8090.0	2.397	566.0	578.2	25.16		
3					8220.0	2.436	574.0	586.4	25.51		
1	06/08/24	03/09/24	28day		8120.0	2.406	838.0	857.3	38.10	36.60	
2					8195.0	2.428	833.2	852.4	37.03		
3					8205.0	2.431	780.0	797.8	34.67		

COMPRESSIVE STRENGTH OF CONCRETE CUBE (AASHTO T-140)

LOCATION	*CONSULTANT LABORATORY*	*RFI NO.*	
PART OF STRUCTURE	*Mix Design 10% PCC*	*SIZE OF CUBE*	*150X150X150*
DATE OF CASTED	09/08/24	*USED CEMENT CONTI*	*360 KG/CUM*
DATE OF TESTED		*CONCRETE CLASS*	*C -25*
SOURCE OF AGGREGAT	*JMC CRUSHER PLANT*	*WATER CEMENT RATIO*	*0.55*
SOURCE OF SAND	*AWASH RIVER (Matahara)*	*TYPE OF CEMENT*	*Dangote Cement OPC (42.5 Grade)*

Correction Factor Y=(1.026X-2.483)

Cube Strength

Cube No.	Cast date	Test date	Age	Slump (mm)	Weight (g)	Unit Weight	Crushing Load (KN)	Corrected Load (KN)	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)	Remark
1	09/08/24	12/08/24	3day	55	8297.0	2.458	437.1	446.0	19.82	19.15	
2					8433.0	2.499	436.8	445.7	19.41		
3					8266.0	2.449	409.9	418.1	18.22		
1	09/08/24	16/08/24	7day		8260.0	2.447	649.9	664.3	29.53	29.97	
2					8245.0	2.443	679.1	694.3	30.18		
3					8430.0	2.498	679.3	694.5	30.19		
1	09/08/24	06/09/24	28day		8385.0	2.484	884.0	904.5	40.20	39.81	
2					8455.0	2.505	887.0	907.6	39.42		
3					8410.0	2.492	896.0	916.8	39.82		

COMPRESSIVE STRENGTH OF CONCRETE CUBE (AASHTO T-140)			
LOCATION	LEA-LASA CONSULTANT LABORATORY	RFI NO.	
PART OF STRUCTURE	Mix Design 15% PCC	SIZE OF CUBE	150X150X150
DATE OF CASTED	09/08/24	USED CEMENT CONTENT	360 KG/CUM
DATE OF TESTED		CONCRETE CLASS	C -25
SOURCE OF AGGREGATE	JMC CRUSHER PLANT	WATER CEMENT RATIO	0.55
SOURCE OF SAND	AWASH RIVER (Matahara)	TYPE OF CEMENT	Dangote Cement OPC (42.5 Grade)

Correction Factor Y=(1.026X-2.483)

Cube Strength

Cube No.	Cast date	Test date	Age	Slump (mm)	Weight (g)	Unit Weight	Crushing Load (KN)	Corrected Load (KN)	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)	Remark
1	09/08/24	12/08/24	3day	65	8245.0	2.443	290.0	295.1	13.11	13.25	
2					8415.0	2.493	300.0	305.3	13.33		
3					8080.0	2.394	299.5	304.8	13.31		
1	09/08/24	16/08/24	7day		8255.0	2.446	430.9	439.6	19.54	20.17	
2					8090.0	2.397	464.3	473.9	20.64		
3					8220.0	2.436	457.7	467.1	20.34		
1	09/08/24	06/09/24	28day		8292.0	2.457	685.6	700.9	31.15	31.37	
2					8225.0	2.437	669.6	684.5	29.76		
3					8180.0	2.424	747.1	764.0	33.20		

COMPRESSIVE STRENGTH OF CONCRETE CUBE (AASHTO T-140)			
LOCATION	*LEA-LASA LABORATORY*		
PART OF STRUCTURE	*Mix Design 20% PCC*	*SIZE OF CUBE*	*150X150X150*
DATE OF CASTED	09/08/24	*USED CEMENT CONTENT*	*360 KG/CUM*
DATE OF TESTED		*CONCRETE CLASS*	*C -25*
SOURCE OF AGGREGATE	*JMC CRUSHER PLANT*	*WATER CEMENT RATIO*	*0.5*
SOURCE OF SAND	*AWASH RIVER (Matahara)*	*TYPE OF CEMENT*	*Dangote Cement OPC (42.5 Grade)*

Correction Factor Y=(1.026X-2.483)

Cube Strength

Cube No.	Cast date	Test date	Age	Slump (mm)	Weight (g)	Unit Weight	Crushing Load (KN)	Corrected Load (KN)	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)	Remark
1	09/08/24	12/08/24	3day	75	8126.0	2.408	309.3	314.9	13.99	13.02	
2					8008.0	2.373	286.8	291.8	12.75		
3					8189.0	2.426	277.0	281.7	12.31		
1	09/08/24	16/08/24	7day		8229.0	2.438	448.7	457.9	20.35	20.10	
2					8315.0	2.464	445.5	454.6	19.80		
3					8225.0	2.437	453.2	462.5	20.14		
1	09/08/24	06/09/24	28day		8170.0	2.421	598.5	611.6	27.18	27.62	
2					8205.0	2.431	622.5	636.2	27.67		
3					8155.0	2.416	630.5	644.4	28.02		

Water penetration depth test for control mix and experimental group

	Penetration Depth (mm)							
PCC replacement % by weight	d1	d2	d3	d4	d5	Minimum	Maximum	Mean
Control mix	22.7	24.9	23.5	25.1	23.4	22.7	25.1	23.9
PCC-10%	24.5	23.9	22.1	23.8	24.6	22.1	24.6	23.8
PCC-15%	49.8	50.8	52.8	56.2	51.9	49.8	56.2	52.3
PCC-20%	52.1	57.9	61.2	58.3	64.3	52.1	64.3	58.8

APPENDIX D

Sample Photo Taken During the Research


9.17