



**ADDIS ABABA UNIVERSITY**  
**ADDIS ABABA INSTITUTE OF TECHNOLOGY**  
**SCHOOL OF MULTI- DISCIPLINARY ENGINEERING**  
**CENTER FOR MATERIALS ENGINEERING**

---

Experimental Study on PPC and Citric Acid Influence on Compressive Strength of  
Reinforced Concrete

---

*A thesis submitted to the School of Graduate Studies of Addis Ababa  
University in Partial Fulfillment of the requirement for the Degree of Master  
of Science in Materials Engineering*

**By: - Abebech Haileselassie Manaye**

**Advisor: - Dr. Sintayehu Nibert**

**June, 2025**

**Addis Ababa, Ethiopia**

---

ADDIS ABABA UNIVERSITY  
ADDIS ABABA INSTITUTE OF TECHNOLOGY  
SCHOOL OF MULTI-DISCIPLINARY ENGINEERING  
CENTER FOR MATERIALS ENGINEERING (CME)

---

Experimental Study on PPC and Citric Acid Influence on Compressive Strength of  
Reinforced Concrete

---

**By: - Abebech Hailesilassie**

The document confirms **Abebech Hailesilassie** thesis named “Experimental Study on PPC and Citric Acid Influence on compressive Strength of Reinforced Concrete” submitted to Addis Ababa university institute of technology, in partial fulfillment of the requirements for the award of the Master of Science degree in Materials Engineering, is the result of my original work carried out under the guidance of Dr. Sintayehu Nibert. It adheres to the university's rules and reaches the required levels of uniqueness and excellence.

**Approved by the Board of Examiners**

|                     |           |       |
|---------------------|-----------|-------|
| Dr. Amare Aregahegn | _____     | _____ |
| (Chairman Person)   | Signature | Date  |

|                     |           |       |
|---------------------|-----------|-------|
| Dr.Sintayehu Nibert | _____     | _____ |
| (Advisor)           | Signature | Date  |

|                     |           |       |
|---------------------|-----------|-------|
| Dr.Anteneh Maregn   | _____     | _____ |
| (Internal Examiner) | Signature | Date  |

|                     |           |       |
|---------------------|-----------|-------|
| Dr. Georgies Alene  | _____     | _____ |
| (External Examiner) | Signature | Date  |

## DECLARATION

This thesis, "Experimental Study on PPC and Citric Acid Influence on Compressive Strength of Reinforced Concrete," is my original work, I hereby declare. I have duly acknowledged all sources of information and help received in the course of the preparation of this thesis. This work has not been submitted to any other university or institution for the award of any degree, diploma, or other similar title or recognition.

**Candidate Name**

**Signature**

**Date**

Abebech Haileselassie Manaye

\_\_\_\_\_

\_\_\_\_\_

**Advisor**

**Signature**

**Date**

Dr. Sintayehu Nibert

\_\_\_\_\_

\_\_\_\_\_

## ACKNOWLEDGMENT

I would like to express my heartfelt gratitude to God for providing me with health, strength, and guidance throughout this thesis.

I also wish to thank Dr. Sintayehu Nibert for his exceptional support and invaluable guidance throughout the course of this thesis. His expertise and insights were crucial in shaping the direction of my work.

I extend my thanks to Mr. Biniam Fentahun & Wubet for their support and encouragement while I was doing the laboratory work.

Finally, I would also like to acknowledge the contributions of Mr. Solomon Melese, My work place supervisor, for graciously allowing me the flexibility and permission to undertake this thesis alongside my work commitments.

Thank you for your unwavering commitment and assistance.

## TABLE OF CONTENTS

|  |                                     |
|--|-------------------------------------|
| DECLARATION.....   | iii                                 |
| ACKNOWLEDGMENT.....                                      | iv                                  |
| LIST OF TABLES .....                                     | vii                                 |
| LIST OF FIGURES .....                                    | viii                                |
| LIST OF ABBREVIATIONS .....                              | ix                                  |
| ABSTRACT.....  | x                                   |
| CHAPTER ONE .....  | 1                                   |
| INTRODUCTION .....                                       | 1                                   |
| 1.1. Background .....                                    | <b>Error! Bookmark not defined.</b> |
| 1.2. Statement of the problem .....                      | 2                                   |
| 1.3. Objectives.....                                     | 4                                   |
| 1.3.1. General Objective .....                           | 4                                   |
| 1.3.2. Specific objectives .....                         | 4                                   |
| 1.4. Significance of the research .....                  | 4                                   |
| 1.5. Scope of the study .....                            | 5                                   |
| CHAPTER - TWO.....                                       | 7                                   |
| LITERATURE REVIEW.....                                   | 7                                   |
| 2.1. Introduction .....                                  | 7                                   |
| 2.2. Concrete Ingredients .....                          | 7                                   |
| 2.2.1. Cement.....                                       | 7                                   |
| 2.2.2. Water .....                                       | 14                                  |
| 2.2.3. Aggregate.....                                    | 14                                  |
| 2.2.4. Admixtures.....                                   | 15                                  |
| 2.3. Past studies .....                                  | 18                                  |
| CHAPTER – THREE .....                                    | 26                                  |
| 3. MATERIALS & METHODS .....                             | 26                                  |
| 3.1. Introduction .....                                  | <b>Error! Bookmark not defined.</b> |
| 3.2. Experimental Procedures.....                        | 26                                  |
| 3.3. Concrete ingredients' Used .....                    | 26                                  |
| 3.3.1. Cement (Dangote, PPC & OPC).....                  | 26                                  |
| 3.3.2. Fine aggregate (River Sand) .....                 | 26                                  |
| 3.3.3. Coarse aggregate (02 & 01 coarse aggregate) ..... | 27                                  |

|   |   |    |
|---|---|----|
| 3.3.4.  | Citric Acid.....  | 27 |
| 3.3.5.  | Water.....  | 27 |
| 3.4.  | Methods.....  | 27 |
| 3.4.1.  | Assembling of concrete raw materials.....                     | 27 |
| 3.4.2.  | Testing Concrete ingredients (Material characterization)..... | 28 |
| 3.4.3.  | Concrete Mix design.....                                      | 41 |
| 3.4.4.  | Mixing and casting.....                                       | 44 |
| CHAPTER FOUR.....   |   | 50 |
| RESULTS AND DISCUSSION.....   |   | 50 |
| 4.1.  | Setting time.....   | 52 |
| 4.2.  | Workability.....  | 54 |
| 4.3.  | Compressive Strength Test Results.....                        | 56 |
| 4.4.  | Cost Comparison.....  | 59 |
| CHAPTER FIVE.....   |   | 60 |
| CONCLUSION.....   |   | 64 |
| REFERENCES.....   |   | 66 |
| APPENDIX- 1.....  |   | 69 |
| Completed Mix design using DOE Techniques.....                                  |   | 69 |
| APPENDIX 2:.....  |   | 70 |
| Compressive strength Test Results (7 <sup>th</sup> & 56 <sup>th</sup> day)..... |   | 70 |
| APPENDEX-3.....   |   | 73 |
| Gallery.....  |   | 73 |

## LIST OF TABLES

|   |    |
|---|----|
| Table2.1 Major compounds in Portland cement .....   | 8  |
| Table2.2 Properties of the major constituents of Portland cement .....                            | 8  |
| Table3.1 Sieve analysis result for coarse aggregate (02 & 01 blended) .....                       | 29 |
| Table3.2 Specific Gravities and Absorption Capacity of Coarse aggregates.....                     | 32 |
| Table3.3 Particle size distribution for Fine Aggregate.....                                       | 37 |
| Table3.4 Specific gravities and absorption capacity of fine aggregate.....                        | 40 |
| Table3.5 DOE mix design concrete raw material Amounts.....  | 41 |
| Table3.6 Moisture content and absorption capacity of the aggregates .....                         | 42 |
| Table3.7 Adjusted Concrete Raw Materials Quantity.....  | 42 |
| Table3.8 Designation of Concrete Mixes.....   | 48 |
| Table3.9 Quantities of concrete ingredients for each mix for 1m <sup>3</sup> of concrete .....    | 43 |
| Table3.10 Quantities of concrete ingredients for each mix for 0.1m <sup>3</sup> of concrete ..... | 44 |
| Table 4.1 28 <sup>th</sup> day Compressive Strength Results of Binder Composition .....           | 51 |
| Table 4.2 Effect of citric acid on the initial & final setting time .....                         | 53 |
| Table4.3 Slump test results .....   | 54 |
| Table4.4 28 <sup>th</sup> day Compressive strength test results .....                             | 57 |
| Table4.5 Summary of Compressive Strength Results.....   | 58 |
| Table4.6 Cost comparison between M <sub>0</sub> and M <sub>3</sub> .....                          | 60 |

## LIST OF FIGURES

|   |                                     |
|---|-------------------------------------|
| Figure2.1 Dispersion effects of fly ash particles .....   | 12                                  |
| Figure3.1 Gradation curve for coarse aggregate.....       | 30                                  |
| Figure3.2 Gradation curve for fine aggregate.....         | 38                                  |
| Figure4.1 Cement Setting Time .....                       | 53                                  |
| Figure4.2. Slump Length .....                             | 56                                  |
| Figure4.3. 28 <sup>th</sup> day Compressive Strength..... | 58                                  |
| Figure4.4. Cost Comparison .....                          | <b>Error! Bookmark not defined.</b> |

## LIST OF ABBREVIATIONS

|              |  |
|--------------|--|
| PPC .....    | Portland Pozzolana Cement                  |
| CA .....     | Citric Acid                                |
| OPC.....     | Ordinary Portland cement                   |
| DOE .....    | Design of Environment                      |
| ACI.....     | American Concrete Institute                |
| ASTM .....   | American Society for Testing and Materials |
| 01 agg. .... | 01 coarse aggregate                        |
| 02 agg ..... | 02 coarse aggregate                        |
| RMC.....     | Ready Mixed Concrete                       |
| W/C.....     | Water to cement ratio                      |
| ETB .....    | Ethiopian Birr                             |

## ABSTRACT

The aim of this experimental study is to investigate the combined effect of partially replacing ordinary Portland cement (OPC) with Portland Pozzolana Cement (PPC) and incorporating citric acid by weight of PPC as chemical admixture on the compressive strength performance of reinforced concrete. PPC, known for its environmental benefits and long-term strength development, is evaluated alongside citric acid, which acts as a set retarder and potential performance enhancer. The experimental work includes tests on setting time, workability, and compressive strength for concrete mixes incorporating varying dosages of citric acid with PPC. The experimental research involved creating concrete samples specifically for C-30 concrete grades, a common choice for reinforced concrete projects, having water cement ratio of 0.50. Concrete samples are created using OPC, PPC and also PPC mixed with citric acid & slump in the range of 50 – 100mm. Citric acids was added to retard the setting time, to enhance the workability & ultimate compressive strength of concrete. Setting time, Slump & compressive strength tests for 0.1%, 0.2%, 0.3% & 0.4 % additions of citric acid by weight of Portland Pozzolanic Cement were performed. Cost comparison was also done between concrete mixes made with OPC and PPC with Citric acid.

The laboratory results assure that the optimum dosage of citric acid is 0.3% by weight of PPC cement. This dosage causes a delay in initial and final setting time of 1hr 50 min & 3hr 10 min, respectively; 15% water reduction; a comparable compressive strength result with OPC mix and meets the requirements listed in ACI 301; and an increase in slump length of 55% relative to reference concrete.

The laboratory test result shows that as compared with the reference mix, satisfactory setting time, slump & compressive strength result was obtained from concrete mix made with PPC in combination with Citric acid. Moreover, the combination of PPC and citric acid demonstrates promising potential for sustainable and performance-optimized reinforced concrete. This study contributes valuable insights for engineers and researchers seeking to enhance the performance and sustainability of concrete construction materials.

**Key words:** OPC = Ordinary Portland cement, PPC = Portland Pozzolana Cement, Concrete, CA = Citric acid, Setting time, Workability, Compressive Strength

## CHAPTER ONE

### INTRODUCTION

#### 1.1.Introduction

Cement concrete, frequently employed as a composite construction material, is characterized by its substantial compressive capabilities contrasted by its weaker tensile strength. It is pivotal in infrastructure and sizable engineering endeavors, where resilience is essential. In Ethiopia, the production and utilization of Ordinary Portland Cement (OPC) and Portland Pozzolana Cement (PPC) are prominent for construction activities. Typically, OPC's rapid strength gain makes it the go-to option for structural components, while PPC, with its delayed strength development, is preferred for masonry and finishing jobs.

However, the escalating costs of concrete construction are becoming an alarming issue. This surge in price is attributed to the voracious demand for concrete and the limited availability of essential raw materials, particularly the exclusive reliance on OPC for structural integrity.

Now a day, alternative materials for ordinary Portland cement are mandatory for concrete technology. Due to its higher strength at early age ordinary Portland cement is mainly & mostly used type of cement in reinforced concrete, so it didn't satisfy the demand of the construction industry alone & most of the time it has seen lack of cement then after concrete cast delay. Moreover, Portland cement is expensive & energy intensive material. In addition to the ordinary Portland cement, Portland Pozzolana cement (PPC), and recently Portland limestone cement (PLC) is available in Ethiopian market. However, due to the slower strength development & lower strength of concrete result at early age Portland Pozzolana cement (PPC) is not being widely used for reinforced concrete. It mostly used for non-structural works like plastering, mortar & screed concrete. Survey findings reveal that "at present PPC is rarely utilized in structural concrete construction".

In response, material engineers are tasked with the urgent need to unearth more economical substitutes for OPC without compromising quality.

Numerous scholars are proactively investigating the feasibility of substituting cement with an array of cost-efficient substances like bagasse ash, rice husk, waste paper sludge ash, bamboo leaf ash, and bamboo fiber. This approach not only aims to mitigate the environmental

burdens of cement manufacture but also aspires to deliver concrete that is both affordable and quality-competitive.

This study examines the synergistic effects of PPC and Citric acid on concrete properties. Both PPC and Citric acid are readily accessible in Ethiopia, with PPC being hybrid cement composed of 70% clinker, 5% gypsum, and 25% fly ash. Portland Pozzolanic Cement's heat during hydration is significantly lower than that of OPC, a result of the Pozzolanic reaction between the Pozzolanic material and the calcium hydroxide from OPC hydration—a reaction that absorbs some of the heat produced during the hydration process. Additionally, PPC contains a reduced proportion of tricalcium silicate, further diminishing its heat generation during hydration. This inherent characteristic of PPC is counterbalanced by the incorporation of Citric acid.

As Classifiable under ASTM C-494 as a type D admixture—both water-reducing and retarding—Citric acid serves to diminish water levels for enhanced strength or maintain strength while reducing water and cement content. The addition of Citric acid in the mix likely intensifies the cement's hydration process, yielding a finer pore structure in the resultant mortar when compared to that produced by OPC. Hence, this critical analysis underscores the importance of examining the combined effects of PPC and Citric acid, presenting a promising avenue for both cost reduction and ecological sustainability in the construction sector.

## 1.2. Statement of the problem

Ethiopia currently produces cement in three forms i.e. OPC, PPC & PLC. However most of the construction sector uses OPC for concrete production due to its high early strength. This leads to imbalance between supply and demand & caused rising of concrete cost due to the scarcity of raw materials. The extensive use of Ordinary Portland Cement (OPC) in concrete production poses significant economic and environmental challenges. Rising concrete costs due to OPC shortages and its carbon-intensive manufacturing process necessitate the exploration of alternative materials that can partially replace OPC without compromising the compressive strength of concrete at lower cost.

Ordinary Portland cement is the type of cement mostly used for reinforced concrete because of its high strength at the 28<sup>th</sup> age of concrete. In Ethiopia, Portland Pozzolana cement is

mostly used for plaster & brickwork due to its slower strength development. “This statement is also supported by the previous data collected from a survey which states that only 3.26% of consulting firms use Portland Pozzolana cement for structural purposes, while the rest 96.74% are mostly using OPC” [1]. It turns out that when we use PPC for making concrete it just doesn't hit the strength you want after 28 days. On the other hand if you go for Pozzolana Portland cement it's a whole different story - you get some extra perks too.

- Concrete structures last longer because water can't seep through them as much.
- It stands up better to the harmful effects of substances like alkalies sulfates chlorides and chemicals.
- Improved ease of use
- It releases heat slowly as it sets.
- Because PPC is very fine it sticks to bits of stone and sand better making the concrete more packed together.
- Better surface finish

In Ethiopia's construction industry, it's becoming increasingly common for PPC (Portland Pozzolana Cement) not to be the preferred choice for making reinforced concrete. Many consider PPC to be a less effective type of cement because it takes longer to reach the same strength as OPC (Ordinary Portland Cement). Therefore, this study focuses on examining how mixing PPC as a partial replacement for OPC and citric acid affects reinforced concrete, particularly in achieving the desired compressive strength after 28 days, and in reducing concrete cost. By incorporating citric acid, the early-age compressive strength of concrete made with PPC can be enhanced than PPC based Concrete. As a Type D water-reducing and retarding admixture, citric acid serves several functions: it reduces the water required, improves the concrete's compressive strength, and delays the setting time. The choice of Type D admixture is intentional. Ethiopia's warm and sunny climate calls for concrete that takes longer to set, providing more time for handling and placing it properly. This extended setting time is particularly beneficial for ready-mixed concrete, which often needs to be transported from the mixing site to the construction location, sometimes over a considerable distance and traffic jam. The slower setting allows for a more manageable and precise application.

While PPC offers long-term durability and environmental benefits, the influence of citric acid on its setting time, strength development, and overall performance is not well-documented.

This research addresses the lack of experimental data regarding the combined use of PPC and citric acid to evaluate their suitability and effectiveness in reinforced concrete construction.

Concerns have also been expressed over cement concrete's increasing cost. The high demand for concrete and the scarcity of raw materials are the root causes of the cost increase [5]. Finally, a comparison of the cost of concrete mixes was made using OPC versus PPC with citric acid and the cost reduction is illustrated.

### 1.3. Objectives

#### 1.3.1. General Objective

- To investigate the potential of using Portland Pozzolana Cement (PPC) combined with citric acid as an effective material for reinforced concrete, focusing on its impact on setting time, workability, and compressive strength.

#### 1.3.2. Specific objectives

- To evaluate the compressive strength development of reinforced concrete made with PPC and citric acid after 7, 28 and 56 days of curing w/c are standard age of concrete.
- To determine the optimal proportion of citric acid to PPC that maximizes the concrete's performance without compromising the quality.
- To investigate the workability and setting time of concrete mixtures incorporating PPC and citric acid under typical Ethiopian climate conditions.

### 1.4. Significance of the research

PPC acts as an affordable substitute for OPC, and citric acid is a great and possible mineral addition to cement. PPC combined with citric acid will reduce the cost of concrete while simultaneously improving its setting time, workability & compressive strength because PPC and citric acid blended concrete are more affordable and of higher quality through time, they are therefore significant.

This study holds significant importance in the context of Ethiopia's construction industry and the broader field of Materials engineering. The experimental investigation of PPC (Portland Pozzolana Cement) combined with citric acid as an alternative material for reinforced concrete applications addresses several key issues:

**1. Sustainable Construction Practices:** The study promotes the use of PPC, a more environmentally friendly and cost-effective alternative to Ordinary Portland Cement (OPC). This aligns with global efforts to reduce the carbon footprint of the construction industry while ensuring strong and durable structures.

**2. Enhanced Concrete Performance:** By exploring the effects of citric acid as a retarding and water-reducing admixture, the research has the potential to enhance early-age strength and increase the setting time of concrete. This could contribute to better workability, particularly in Ethiopia's hot and dry climate.

**3. Local Context:** The study's findings are especially relevant for Ethiopia, where the construction sector faces challenges such as hot weather conditions, the transportation of ready-mix concrete over long distances and traffic jam. The use of citric acid can help address these issues, making concrete easier to handle and apply.

**4. Contribution to Knowledge:** The research adds to the scientific body of knowledge on the use of PPC and citric acid in reinforced concrete, offering valuable insights for both academic research and practical applications in the construction industry.

**5. Cost-Effectiveness:** By improving the performance of PPC-based concrete without relying heavily on expensive materials like OPC, this study could offer a more affordable and locally sustainable solution for concrete production.

#### 1.5. Scope of the study

The scope of this study is defined by several key parameters, outlining both the geographical and technical boundaries of the research:

**1. Geographical Scope:** The research is focused on the context of Ethiopia, particularly considering the local climate conditions (hot and dry weather) and construction practices. However, the findings may also be applicable to similar climates and developing countries with similar construction challenges.

**2. Material Scope:** The study examines the use of PPC as partial replacement for OPC, with citric acid added as a water-reducing and retarding admixture. The research does not extend to other types of cement or admixtures, keeping the focus on these specific materials.

**3. Concrete Mix Proportions:** The study explores proportions of OPC, PPC and various percentage of citric acid to determine the optimal mix for reinforced concrete applications. Other types of concrete admixtures or additives are not included in this research.

**4. Testing Parameters:** The research evaluates concrete samples for compressive strength at various curing intervals (7, 28 and 56 days), workability, and setting time. The study does not consider other potential properties of concrete, such as shrinkage or thermal conductivity, unless they are directly related to the specific goals of the study.

**5. Experimental Scope:** The study is primarily experimental, conducted in a controlled laboratory setting. The research does not include full-scale construction site testing or long-term field performance assessments of the concrete mixtures.

**6. Reinforced Concrete Applications:** The study focuses specifically on reinforced concrete, which is widely used in construction for its strength. It does not explore the suitability of PPC and citric acid for other types of concrete applications, such as prestressed concrete or non-structural uses.

In summary, the scope of this thesis is centered on the combined effect of PPC and citric acid in reinforced concrete, within the Ethiopian climate and construction environment, with an emphasis on early-age strength, setting time, and workability, while keeping the study focused on specific material properties and experimental conditions.

## CHAPTER - TWO

### LITERATURE REVIEW

#### 2.1. Introduction

Concrete made with Portland Pozzolana Cement (PPC) generally has lower early-age compressive strength than Ordinary Portland Cement (OPC) concrete. To enhance OPC concrete properties, various chemical admixtures—such as plasticizers and retarders—are commonly used. Combining PPC as a partial replacement for OPC with citric acid will improve workability, setting time, and compressive strength compared to PPC-only concrete. Since cement is the most expensive concrete component, the materials and methods section will detail the properties of the mix ingredients (cement, water, citric acid, aggregates) and review previous research on PPC use in reinforced concrete.

#### 2.2. Concrete Ingredients

##### 2.2.1. Cement

Ethiopia now produces cement in three forms: Ordinary Portland Cement (OPC), Portland Pozzolana Cement (PPC), and Portland Lime Cement (PLC).

##### 2.2.1.1. Ordinary Portland cement (OPC)

It is used when particular qualities are not required; it is now the most extensively utilized form of cement in Ethiopia's building sector and throughout the world.

##### 2.2.1.1.1. Constituents of Portland cement

The cement's precise composition is determined by the raw materials used in its manufacturing. The primary elements of Portland cement are created by carefully grinding, blending, and burning these basic materials.

##### *A. Major compounds of Ordinary Portland cement*

Ordinary Portland cement contains four primary ingredients, as illustrated in Table 2.1. The four components account for roughly 90% of the cement weight. “This is why these four are known as 'major compounds' or 'major components'” [2].

Table2.1 Major compounds in Portland cement [3]

| Name of compound              | Oxide composition   | Abbreviation          |
|-------------------------------|---|-----------------------|
| Tri-calcium silicate          | $3\text{CaO}.\text{SiO}_2$                                | $\text{C}_3\text{S}$  |
| Di-calcium silicate           | $2\text{CaO}.\text{SiO}_2$                                | $\text{C}_2\text{S}$  |
| Tri-calcium aluminate         | $3\text{CaO}.\text{Al}_2\text{O}_3$                       | $\text{C}_3\text{A}$  |
| Tetra-calcium alumino-ferrite | $4\text{CaO}.\text{Al}_2\text{O}_3.\text{Fe}_2\text{O}_3$ | $\text{C}_4\text{AF}$ |

The  $\text{C}_3\text{S}$  and  $\text{C}_2\text{S}$  make approximately 68-75% of Portland cement. “These are the most essential components that contribute to the strength of hydrated cement paste” [4]. The following table summarizes the properties.

Table2.2 “Properties of the major constituents of Portland cement” [2]

| Compound             | $\text{C}_3\text{S}$ | $\text{C}_2\text{S}$ | $\text{C}_3\text{A}$ | $\text{C}_4\text{AF}$ |
|----------------------|----------------------|----------------------|----------------------|-----------------------|
| Rate of Hydration    | Fast (hours)         | Slow (days)          | Instantaneous        | Very Fast (minutes)   |
| Strength Development | Fast (days)          | Slow (weeks)         | Very Fast (one day)  | Very Fast (one day)   |
| Ultimate Strength    | High                 | High                 | Low                  | Low                   |
| Heat of Hydration    | Medium               | Low                  | Very high            | Medium                |

### B. Minor components of ordinary Portland cement

Gypsum, MgO, and alkali sulfates are the three secondary ingredients of cement that are most significant.

**Gypsum:** Gypsum is added to Portland cement to stop flash generation, which is brought on by  $\text{C}_3\text{A}$ 's quick reaction.

**Alkalies:** ( $\text{Na}_2\text{O}$  and  $\text{K}_2\text{O}$ ) can increase the PH value of concrete up to 13.5, which is good for reinforcing steel protection. However, “high alkali content can also cause durability problems such as alkali-aggregate reactions and leaching” [4].

#### 2.2.1.1.2. Hydration reaction of Portland cement

The process of cement reacting with water is known as "hydration of cement". The two primary components of cement, calcium silicates  $\text{C}_3\text{S}$  and  $\text{C}_2\text{S}$ , and aluminates  $\text{C}_3\text{A}$  and  $\text{C}_4\text{AF}$ , when combined with water, form the hard mass known as hydrated cement paste [3].

C3S and C2S are Portland cement's most crucial ingredients when it comes to strength development. Although the hydration reaction cannot be expressed in exact stoichiometric equations as indicated below, it can be expressed as a guide [2].

The following are the phases of the hydration process of Ordinary Portland cement.

❖ **Pre-induction period**– Alkali sulfates instantly dissolve and release  $\text{SO}_4^{2-}$ ,  $\text{Na}^+$ , &  $\text{K}^+$ .  $\text{Ca}^{2+}$  and  $\text{SO}_4^{2-}$  are released when gypsum dissolves. C-S-H begins to precipitate on the cement particles as C3S begins to dissolve. Ettringite precipitates on the cement particle surface as a result of C3A's liquid phase dissolution and reaction with  $\text{Ca}^{2+}$  and  $\text{SO}_4^{2-}$  ions. Similar to C3A, the ferrite phase hydrates as well. Although it is brief, this stage has the highest rate of hydration.

❖ **Induction (dormant) period** - The plastic paste that formed at this time is unchanged. This is because the first precipitation of calcium silicate hydrate and calcium alumino hydrate during the pre-induction phase created a layer on the cement particle surface that acted as a barrier to additional hydration, resulting in a notable slowdown in the rate of hydration.

❖ **Accelerated period** - The C3S reaction rate dramatically increases. C4AF hydrates more slowly while C2S and C3A hydrate more quickly.

❖ **Deceleration period** – Because there is less unreacted cement, the hydration rate decreases. And while the C3S and C2S keep hydrating, the C-S-H keeps forming. At this point, C2S contributes more to the formation of C-S-H. Until the cement is hydrated or all of the water has been used, the hydration process is ongoing [5].

A few variables influencing the rate of hydration include

- ✓ **The fineness of cement**- Early on, the hydration rate of cement is directly correlated with its fineness, even though the final degree of hydration remains unaffected by the cement's fineness.
- ✓ **Temperature** - Cement paste hydrates more quickly at higher temperatures.
- ✓ **Admixtures** – Accelerating and retarding admixtures can be used to accelerate & retard the rate of hydration, respectively.
- ✓ **Age of paste** - The hydration rate is highest in the early stages of hydration. But after a while, the rate of hydration progressively declines and eventually stops altogether.
- ✓ **Water to cement ratio** - Early on, the water-to-cement ratio has little effect on

hydration; nevertheless, as time goes on, the rate of hydration decreases in proportion to the cement-to-water ratio. “The reduction in space available for the hydration products at a very low water-cement ratio may be the cause of this effect of the ratio of water to cement” [2].

#### 2.2.1.2. Portland Pozzolana Cement (PPC)

PPC is the most commonly used and accessible type of blended cement in Ethiopia, despite the existence of other varieties. “Portland Pozzolana cement, as defined by Ethiopian Standard (ES), is cement made from a uniform mixture of finely ground Portland clinker and less than 35 percent by mass of Pozzolana” [24]. Conversely, PPC is defined by ASTM C-595 as a hydraulic cement made of fine Pozzolana and Portland or Portland blast furnace slag cement blended in a close and consistent mixture. The production of fine Pozzolana can be achieved through three methods: mixing finely divided Pozzolana with Portland cement or Portland blast-furnace slag cement, grinding Portland cement clinker and Pozzolana separately, or combining the two techniques. “Between 15 and 40 percent of the Portland Pozzolana cement's mass is made up of Pozzolana” [6].

In Europe, blended cement varieties are already extensively utilized, and in the US, they are just starting to be introduced. The percentage of blended cement produced in India rose from 32.58% in 1999 to roughly 56% in 2005, and it is expected to continue rising [7]. However, high-clinker cement continues to rule the global market. More than 98% of concrete produced today is made using Portland cement, which is typically composed of more than 75% Portland clinker [8].

#### **Pozzolana**

According to ASTM 618, Pozzolana is a siliceous or siliceous and aluminous material that, when combined with lime (which is created when Portland cement is hydrated), can chemically react to acquire cementitious properties. However, Pozzolana does not have these properties by itself and can only do so when it is finely divided and moist [9]. Volcanic ashes, volcanic tuffs, trass, and zeolites are examples of natural Pozzolana. Industrial co-products that contain vitreous silica, such as silica fumes, fir ashes, calcined clays and shales, and rice husk ash, are also considered Pozzolana. “At room temperature, this vitreous (amorphous) silica combines with the lime generated from the hydration of C3S and C2S to form C-S-H, which is comparable to the lime formed from the direct hydration of C3S and C2S” [10].

Addisu Fentaw [2014] researched the applications of Portland Pozzolana and Derba ordinary Portland cement in the manufacturing of structural concrete. According to the research, pumice, a naturally occurring material with a lower activity rating, is the Pozzolana used in the production of PPC [11].

In a similar vein, Nigus G/Egziabher [2005] conducted research in Ethiopia comparing the characteristics of concrete produced using three distinct cement brands (both OPC and PPC). Furthermore, his research indicates that less Pozzolanic volcanic materials are utilized as Pozzolana in the manufacturing of Portland Pozzolana cement. In addition, the Pozzolana used in the creation of PPC is pumice and volcanic basalt [12]. Consequently, these investigations concluded that this Pozzolana ultimate strength could not be as high as that of active Pozzolana due to their less Pozzolanic property.

### ***Pozzolanic reaction of cement***

When Pozzolanic materials are finely crushed and combined with dissolved calcium hydroxide in water, they react to generate calcium silicate and calcium aluminate compounds rather than hardening on their own.

The lime generated during C3S and C2S hydration is converted into calcium silicate hydrate through a Pozzolanic reaction. Consequently, the following can be used to express the hydration of blended cement containing a Pozzolana. The cement paste set and hardened as a result of the C-S-H gel's formation. The gel causes the paste to stiffen and subsequently harden by filling the void left by the cement grains and acting as a bridge between them. "As the gel continues to form, the capillary pores gradually fill, the paste's porosity lowers, and its strength increases" [2].

#### ***2.2.1.2.1. Pozzolanic materials impact on the hydration reaction***

Compared to Portland cement, Pozzolanic materials contain significantly less calcium. In order for Pozzolanic reactions to occur in Portland Pozzolana blends, calcium silicates in Portland cement must first form calcium hydroxide (CH). As soon as the CH production begins, the siliceous and aluminous components of the Pozzolana react with this hydration product. As a result, hydrated cement with Pozzolana inclusions always has a lower CH content than hydrated Portland cement. In addition to influencing the Pozzolanic reactions, Pozzolana also alters Portland cement's hydration kinetics and hydration products [5].

Four perspectives can be used to analyze some of the physical impacts of Pozzolanic materials on hydration:

**Cement dilution effect:** This occurs when Pozzolanic material is used in place of some cement. More replacement corresponds to less cement because, of course, using less cement means using less moist material.

**Dispersion effect:** Particles in Portland cement mixtures with water often exhibit some coagulation. Any ultra-fine mineral powder that is mixed with the cementitious mixture disperses the cement particles and increases the surface area that can be hydrated by the cement. Thus, adding Pozzolanic materials would increase cement hydration for a given amount of cement. Figure 2.1 for cement with fly ash incorporation shows this effect. But if a lot of Pozzolanic material is used, this could be inhibited.

**Nucleation effect:** By offering more places for the precipitation of hydration products, it helps Portland cement hydrates more quickly. This has to do with how fine the Pozzolanic materials are and how well they bind to cement hydrates.

“The hydration process is accelerated by a reduction in the thickness of the first layer of hydrates that form on the cement particle surface” [5].

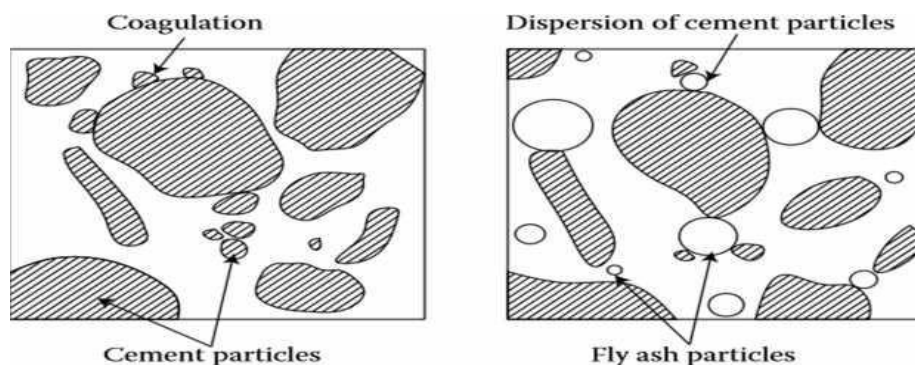


Figure2.1 Dispersion effects of fly ash particles

#### ***2.2.1.2.2. Pozzolanic materials' impact on concrete's strength***

Concrete's ability to reach its maximum strength is delayed when Portland cement and Pozzolanic materials are combined. Standard specimens made with these blended cement types continue to gain strength for up to 56 or even 91 days after they are left to cure past the recommended 28 days. The increase in strength is not as noticeable after this. Because Pozzolanic materials react slowly with water and the lime released by hydration reactions at room temperature, the strength increases between 28 days and 56 or 91 days. As a result, recommendations have been made to measure compressive strength at 56 or 91 days rather than the 28 days that have been the standard up until this point [13]. Both types of cement were used in an experimental investigation to look at the characteristics of dry-cast concrete (OPC and PPC). Its compressive strength development was also assessed at 1, 7, 14, 21,

28, and 56 days of age. Consequently, the compressive strengths of PPC-made dry-cast concrete with different water-to-cement ratios at the age range of 1 to 21 days, it was discovered that there was a significant difference in 0.3, 0.4, and 0.5 point. “But at the age of more than 56 days, the compressive strength results are getting closer to each other due to the Pozzolanic reaction” [14].

#### ***2.2.1.2.3. Pozzolanic materials’ advantages when used in cement***

Significant cost and energy savings can be obtained by partially substituting Portland cement with natural Pozzolana and industrial byproducts. This is due to the fact that these materials are typically available for much less money than Portland cement, which is an expensive and Energy-intensive material, Examples of beneficial by-products from other industrial processes that can be used to partially replace cement are fly ash and ground granulated blast-furnace slag (GGBS).

The following are some benefits of using these Pozzolanic minerals as additions in concrete mixers or in the manufacturing of cement:

- ✓ Lowering CO<sub>2</sub> emissions;
- ✓ Lowering primary energy consumption;
- ✓ “Preserving quarried material and landfill space for industrial waste” [15].

An experimental investigation was conducted on the sulfate resistance of Portland Pozzolana cement and blends containing varying amounts of fly ash or silica fume in place of Portland cement. Aside from that, ASTM Type I, II, and V cement was used to make the reference mortars. When mortar bars were exposed to sulfate attack in a 5 percent solution, it was discovered that Portland Pozzolana cement mortars with the least amount of sulfate expansion after 52 weeks had the best test results. According to study results, significant sulfate resistance that is on par with or higher than Type II and V can be obtained by employing Portland Pozzolana cement [16]. Portland Pozzolana blended cement has the following benefits over regular Portland cement: -

- ❖ Reduced expenses
- ❖ Enhanced durability
- ❖ Reduced heat generated during hydration
- ❖ “Improved sulfate resistance, workability, and resistance to the alkali-aggregate reaction” [17] .

### 2.2.2. Water

Because the phases in Portland cement must chemically react with water in order to generate paste, mortar, or concrete strength, water is an essential component of Portland cement. Water makes up 15 to 25 percent of the volume of concrete mixture on average. Water has two purposes: it keeps us hydrated and makes things workable. When making concrete, one must carefully consider the water-to-cement ratio and the total amount needed, as concrete must be both strong and workable. Concrete that has too much water will become weaker, and concrete that has too little water will not work.

- ✓ The free water in freshly mixed concrete is known as mixing water. Its roles include creating hydration products through reaction with the cement powder, acting as a lubricant to enhance the workability of the fresh mixture, and preserving the space in the paste needed for the hydration products to form.
- ✓ Only a brief period of time is the curing water in contact with the concrete. The allowed levels of impurities are still limited, even though they might contain more organic and inorganic materials than mixing water [4].

### 2.2.3. Aggregate

Aggregates play a crucial role in the properties and performance of concrete, making up 70 to 80 percent of its volume.

#### 2.2.3.1. Aggregates Effects on concrete

- **Fresh concrete:** The quantity, kind, surface texture, and gradation of the aggregate have a significant impact on the behavior of fresh concrete, including fluidity, cohesiveness, and rheological behavior. The aggregate choice must satisfy the end-user's requirements, i.e. the type of structure to be built.
- **Hardened concrete:** Aggregates significantly affect the strength, thermal stability, stiffness, and wear resistance of concrete. Additionally, “they significantly impact the reduction of moisture-related deformations (e.g. g. shrinkage) of concrete, which makes working with pure paste and rich mortars exceedingly challenging” [18].

### 2.2.3.2. Aggregates Classification

Several categories exist for aggregates based on factors including size, source, and unit weight.

Aggregates can be divided into fine and coarse categories based on size

- **Coarse aggregates:** mostly retained aggregates on No. 4 (4.75mm) sieve.
- **Fine aggregates:** aggregates that are mostly retained on a No. 200 (75 $\mu$ m) sieve after passing through a No. 4 (4.75mm) sieve. River sand is the most often utilized fine aggregate.

As per the source, aggregates can be categorized as follows:

- **Natural aggregates:** are natural deposits that are extracted into aggregates (such as crushed stone, sand, and gravel) without altering the process of manufacturing.

“By unit weight, aggregates can be classified as ultra-lightweight, lightweight, normal weight and heavy-weight aggregates” [4].

### 2.2.4. Admixtures

“Admixtures are ingredients in concrete other than Portland cement, water, and aggregates that are added to the mixture immediately before or during mixing” [19]

“As per ASTM C-494, admixtures can be classified as water-reducing admixtures, retarding admixtures, accelerating admixtures, water-reducing and retarding admixtures, water-reducing and accelerating admixtures, water-reducing, high range admixtures, and water-reducing, high range, and retarding admixtures” [18].

Primarily, additives are utilized to reduce the expense of concrete construction, achieve particular concrete characteristics more effectively than with alternative techniques, maintain the intended quality of concrete during the mixing, transportation, placement, and curing phases in bad weather, and address certain emergencies that might occur during the concreting process [19].

#### 2.2.4.1. Water-reducing & retarding admixture (Type D-Citric acid)

Citric acid is widely recognized for its dual role as a water-reducing agent and a set-retarding admixture in cementitious materials. Its ability to enhance workability and delay setting time makes it a valuable additive in concrete technology. However, identifying the appropriate dosage is critical, as excessive amounts can significantly extend setting time and adversely

affect strength development. This study places particular emphasis on determining the optimal dosage of citric acid, especially in combination with Portland Pozzolana Cement (PPC). The combined effect of citric acid and PPC on key properties—namely setting time, workability, and compressive strength—has not been explored, making this investigation a novel contribution to the understanding of their interactive influence on reinforced concrete performance.

Admixtures that reduce and delay the release of water usually rely on hydroxylated polymers, hydroxycarboxylic acids, or lignosulfonates. These water reducers work via similar mechanisms. “To limit the attraction between particles (due to van der Waals forces) and lower the viscosity of the cement paste, fresh concrete will be adsorbed onto the surface of cement particles” [20].

The chemical makeup of water reducers, the fineness and composition of the cement, the temperature of the concrete, the amount of cement, and the presence of additional admixtures are some of the factors that affect how effective they are on concrete. There are various applications for water-reducing additives in concrete construction.

- Decrease the quantity of water needed for mixing to achieve a specific slump in the concrete. Decrease both cement and water at the same time to maintain the same strength and workability.
- Reduce cement content,
- Retard setting time
- “Increase slump” [20].

Given that an excessive dosage may cause bleeding, excessive air entrainment, segregation, and other problems, and a low dosage may cause fluid loss. Making the best possible use of admixtures in concrete is crucial. Therefore, to achieve the necessary strength and workability, it’s critical to determine the ideal dosage of water-reducing and retarding admixtures. The optimal dosage for the needed strength and workability can be found by running trial experiments with different additive dosages.

Use of citric acid as an admixture in concrete production has been the subject of several studies, particularly its effects and properties. These studies have found that citric acid, unlike other carboxylic acids, acts as an effective calcium chelator.

This means that it can bind with calcium ions present in cementitious materials, resulting in the formation of citrate complexes. Concrete's setting time may be delayed as a result of these citrate complexes' ability to slow down the cement's hydration process. In addition to its retarding effect, according to Zhu, Yu, and Li (2021) “citric acid has been found to improve the inject ability of cementitious materials, making it a useful admixture for improving the workability and flow ability of concrete”. Furthermore, Purnomo, S. Sumarni, and I. N. Saputro in (2019) said that “citric acid has been observed to negatively affect the compressive strength of concrete when used in higher concentrations”. Therefore, it is important to carefully evaluate the dosage of citric acid used in concrete production to ensure that desired strength requirements are met. Additionally, citric acid has been found to have no significant effect on the morphology of ettringite, a mineral phase formed during the hydration of cement. Overall, the addition of citric acid as an admixture in concrete production has both positive and negative effects. On the positive side, it can effectively retard the setting time, improve workability, and enhance the inject ability of concrete. However, it should be used cautiously to avoid compromising the compressive strength of the concrete. Furthermore, the presence of citric acid can decrease the concentration of free calcium ions and reduce the dissolution of calcium phosphate in the concrete. This can be beneficial in certain applications, such as brushite cements, where stabilization of pH and prolonged setting time are desired. In conclusion, citric acid has been studied as an admixture in concrete production and has shown various effects and properties. It acts as a calcium chelator, retarding the hydration process of cement and delaying the setting time of concrete. Additionally, it improves inject ability, workability, and flow ability of concrete.

In summary, the addition of citric acid as an admixture in concrete production has the following effects and properties: Retards the setting time of concrete by chelating calcium ions and forming citrate complexes. These effects result in a delayed hydration process and Improves the inject ability, workability, and flow ability of concrete, Decreases the amount of water required for a workable concrete mixture, Reduces the viscosity and enhances the dispersibility of the cementitious system.- Can negatively affect the compressive strength of concrete when used in higher concentrations.- Does not significantly affect the morphology of ettringite, a mineral phase formed during cement hydration. Overall, it is important to carefully evaluate the dosage and consider the specific requirements of the concrete application when using citric acid as an admixture to ensure the desired strength and

performance of the concrete are achieved while managing any potential negative effects on compressive strength.

### **2.3. Past studies**

Various studies have been conducted exploring the different applications of Portland Pozzolana Cement and Citric acid separately.

**Addisu Fentaw (2014)** conducted a comparative study titled “Study on the Uses of Derba Ordinary Portland and Portland Pozzolana Cements for Structural Concrete Production”, which focused on evaluating the performance of OPC and PPC in producing different strength grades of structural concrete. In his experimental program, OPC and PPC were sourced from a single cement manufacturer, and mix proportions for normal, intermediate, and high-strength concrete were prepared by varying only the type and quantity of cement—using less cement in the OPC mix while keeping all other mix design parameters constant. Compressive strength tests carried out at 3, 7, and 28 days revealed that concrete made with OPC consistently outperformed PPC in terms of compressive strength, particularly at 28 days. This strength difference was attributed to the low pozzolanic activity of the natural pumice used in the PPC, which resulted in slower and less efficient pozzolanic reactions. However, despite its lower strength, PPC-based concrete demonstrated significant advantages in terms of durability. The study concluded that PPC concrete exhibited better workability, higher resistance to chemical attack, and superior impermeability due to its denser microstructure, making it more effective in resisting the ingress of gases and liquids compared to OPC concrete.

This study is directly relevant to the current research, which explores the combined effect of PPC (as a partial replacement for OPC) and citric acid on the compressive strength of reinforced concrete. While Addisu’s work highlighted the durability benefits of PPC and its limitations in achieving high early strength, it did not explore the use of any chemical admixtures that could potentially improve the hydration process or early-age performance. Moreover, the study focused solely on binary binder systems and did not consider ternary combinations such as OPC-PPC blends modified with admixtures. The current research aims to address this gap by investigating how citric acid, known for its hydration-controlling properties, can be used to enhance both the compressive strength and durability

characteristics of PPC-blended concrete. In particular, this study seeks to determine whether citric acid can mitigate the strength limitations of PPC while preserving or even enhancing its beneficial effects on impermeability, shrinkage control, and corrosion resistance.

**Nigus G/Egziabher (2005)**, in his study titled “Comparison of Concrete Properties Produced Using Muger, Messobo, and Diredawa Cements”, examined the performance of various Ethiopian cement brands in producing concrete of different strength grades—normal, intermediate, and high. The research involved both Ordinary Portland Cement (OPC) and Portland Pozzolana Cement (PPC), and all mix design variables were kept constant aside from the cement type. The results consistently indicated that concrete made with OPC achieved higher compressive strength compared to PPC, particularly at early ages. However, the gap in compressive strength between OPC and PPC was observed to narrow with increasing curing age, suggesting that PPC's pozzolanic contribution to strength gains becomes more significant over time. The study identified two main reasons for PPC's lower strength performance: first, the pozzolanic materials used in Ethiopian PPC production—typically natural volcanic ash—exhibit relatively low reactivity; and second, the hydration processes associated with PPC, particularly the reactions involving dicalcium silicate ( $C_2S$ ) in clinker and the silicates in the pozzolana, require extended moist curing periods. In this research, curing was limited to only 3 and 7 days, which was insufficient to activate the full pozzolanic potential of PPC.

This study is highly relevant to the present research, which investigates the combined effect of PPC and citric acid on the compressive strength of reinforced concrete. Nigus's findings underscore the challenge of achieving high early and ultimate strength with PPC, primarily due to the low pozzolanic activity and limited curing duration. This limitation provides a basis for exploring chemical admixtures such as citric acid, which are known to influence hydration kinetics, improve dispersion, and potentially enhance early-age strength development. Furthermore, the current study introduces a ternary cement system—partially replacing OPC with PPC and modifying it with citric acid—aiming to optimize both strength and durability. The use of citric acid may also compensate for the short curing periods often encountered in practice by improving hydration efficiency. In this way, the present research addresses a critical gap left unexamined in Nigus's work: the potential for chemical enhancement of PPC-blended concrete systems to overcome strength and curing limitations.

**Dhanya Sathyan (2018)**, in her study titled “Optimization of Superplasticizer in Portland Pozzolana Cement Mortar and Concrete”, explored the influence of different families of superplasticizers on the performance of concrete made with Portland Pozzolana Cement (PPC). The research incorporated four distinct superplasticizer families—Polycarboxylate Ether (PCE), Lignosulphate (LS), Sulfonated Naphthalene Formaldehyde (SNF), and Sulfonated Melamine Formaldehyde (SMF)—with two commercial brands selected from each family. Concrete and mortar specimens were prepared using these combinations, and compressive strength was tested at 7 and 28 days. The results demonstrated that the addition of superplasticizers significantly enhanced the compressive strength of PPC-based concrete compared to the control mixes without admixtures. This improvement was attributed to the better pore structure, increased particle dispersion, and enhanced compaction facilitated by the water-reducing effects of the admixtures. Moreover, when used at optimized dosages, the variation in compressive strength among different superplasticizer families was found to be minimal, indicating that a wide range of chemical admixtures could be effectively used with PPC to improve its mechanical performance.

This study holds considerable relevance to the present research, which investigates the combined effect of PPC and citric acid—a water-soluble organic acid—on the compressive strength of reinforced concrete. While Sathyan's study focused on commercially available superplasticizers, the current research seeks to explore the potential of citric acid, a non-traditional admixture, in modifying the hydration behavior of PPC-based systems. The findings by Sathyan support the idea that PPC's inherent limitations in strength can be addressed through chemical enhancement, particularly by improving particle dispersion and compaction, which citric acid is also known to influence. However, a key research gap remains: the effect of **organic acids like citric acid**, which may behave differently than conventional superplasticizers, especially in terms of **setting time, long-term strength development, shrinkage behavior, and compatibility with pozzolanic binders**. This gap forms the foundation of the present investigation, which aims to determine whether citric acid can not only enhance the strength but also improve the overall performance and durability of PPC-based concrete when used in a ternary blend with OPC.

**Rajendra (2013)** conducted a comparative study on the performance of fly ash in cement through two distinct methods: blending fly ash directly with Ordinary Portland Cement (OPC), and incorporating it into clinker during the production of Portland Pozzolana Cement (PPC). The primary focus of the research was on evaluating the compressive strength of concrete prepared from these two cement types. Compressive strength tests performed at 7 and 28 days revealed that PPC concrete exhibited superior performance compared to the concrete made by blending fly ash with OPC. Additionally, the study examined the economic and environmental implications of fly ash use. It was observed that a 25% substitution of fly ash for OPC achieved the same target strength (M20) while significantly reducing cement consumption—only 253 kg/m<sup>3</sup> was needed, compared to 350 kg/m<sup>3</sup> in PPC-based mixes. This substitution approach demonstrated cost-effectiveness and environmental sustainability, with potential savings in energy and an estimated reduction of 126 million tons of CO<sub>2</sub> emissions if fly ash were fully utilized in partial cement replacement rather than being blended during clinker grinding.

This research provides important insights relevant to the present study, which evaluates the effect of PPC in combination with citric acid on the compressive strength of reinforced concrete. Rajendra's findings affirm that PPC, despite its traditionally lower reactivity compared to OPC, can achieve high strength when processed effectively or combined with active pozzolanic materials like fly ash. The environmental benefit of reduced cement usage also aligns with the sustainability aspect of this thesis. However, Rajendra's study primarily focuses on fly ash as a mineral additive and does not explore the role of **organic chemical admixtures** such as citric acid in modifying hydration kinetics, workability, or long-term performance. This leaves a research gap regarding how organic admixtures interact with PPC systems to influence strength development and durability properties. The current study seeks to fill this gap by investigating whether the use of citric acid in PPC-blended systems can further enhance compressive strength and contribute to both economic and environmental benefits.

**Olusola and Opeyemi (2012)** investigated the impact of acidic admixtures on concrete properties, with a particular focus on the effects of high concentrations of nitric acid. Their findings revealed that elevated levels of nitric acid had a detrimental effect on the compressive strength of concrete, primarily due to the disruption of the normal hydration process and the degradation of cementitious compounds. However, the study also noted those

certain organic acids and their salts—particularly **citric acid and citrate salts**—have been widely used in concrete, mortar, and plaster formulations as **retarding admixtures**. These substances help **delay the setting time** and **reduce water demand**, thereby improving the workability of cementitious materials. Unlike strong mineral acids, citric acid acts more mildly and can contribute positively to the physical and rheological characteristics of concrete when used in appropriate dosages.

The insights from this study are directly relevant to the present research, which investigates the use of **citric acid in combination with PPC as a partial replacement for OPC** to enhance the compressive strength of reinforced concrete. While Olusola and Opeyemi's findings emphasize the damaging effects of strong acids like nitric acid, they also distinguish **citric acid as a functional admixture** capable of improving workability and potentially optimizing hydration behavior. However, the study stops short of quantitatively analyzing the **structural performance or long-term compressive strength** of concrete modified with citric acid. This identifies a critical research gap: the need to evaluate the **combined mechanical and durability performance** of concrete incorporating PPC and citric acid as a ternary system. The present research seeks to fill this gap by experimentally assessing how citric acid dosage, in combination with PPC replacement levels, influences compressive strength, setting time, and other performance indicators of reinforced concrete.

**Purnomo et al. (2019)** examined the influence of citric acid on the compressive strength of concrete bricks, with specific attention to how varying concentrations of the acid affect structural performance. The study revealed that **higher concentrations of citric acid led to a noticeable reduction in compressive strength**, indicating a threshold beyond which the retarding effect of the acid negatively impacts cement hydration. Notably, concrete bricks containing **0.15% citric acid by weight** already showed a measurable decrease in strength compared to control specimens. The authors attributed this to the strong chelating effect of citric acid, which can **inhibit the early formation of calcium silicate hydrate (C-S-H)**, the primary strength-giving phase in cementitious materials, especially when overdosed.

These findings are particularly relevant to the current study, which explores the **combined effect of Portland Pozzolana Cement (PPC) and citric acid** on the compressive strength of reinforced concrete. While citric acid is known for improving workability and retarding the setting time, Purnomo et al.'s results underscore the importance of dosage control, as

excessive quantities may compromise strength development. Unlike Purnomo's study, which focused on concrete bricks and did not consider blended binders such as PPC, the present research aims to evaluate **whether optimal doses of citric acid can improve the performance of PPC–OPC binary cement systems** without incurring strength penalties. This reveals a research gap in understanding how **citric acid interacts with pozzolanic components**, and whether it can mitigate the traditionally slower strength gain of PPC while avoiding the detrimental effects observed at higher dosages.

**Tinnea and Young (1977)** conducted early foundational research on the retarding behavior of citric acid in cementitious systems, specifically demonstrating that **citric acid significantly delays hydration** in the system composed of **C<sub>3</sub>A (tricalcium aluminate), gypsum, portlandite, and water**. Their work indicated that citric acid interferes with the early formation of hydration products by interacting with calcium and aluminum ions, thereby **inhibiting ettringite formation** and extending the setting time. Building on this understanding, Möschner et al. (2009) investigated the **mechanism of citric acid's influence on the hydration of Portland cement** and confirmed that the retardation effect is primarily due to its ability to **slow the dissolution of clinker grains**, particularly the calcium silicates responsible for strength development. These studies collectively confirm that while citric acid is effective as a set-retarder, its impact on strength gain depends largely on dosage, cement chemistry, and curing conditions.

These insights are highly pertinent to the current research, which examines the combined effect of **PPC and citric acid on the compressive strength of reinforced concrete**. Given that PPC already exhibits slower early hydration due to its pozzolanic content, the addition of citric acid—though beneficial for workability—could further delay strength development if not carefully optimized. The work by Tinnea and Young, as well as Möschner et al., provides mechanistic support for this concern, highlighting the **delicate balance required when using organic retarders in blended cement systems**. However, neither study addressed the behavior of citric acid specifically in PPC-containing mixes, nor its long-term impact on compressive strength in reinforced concrete structures. This constitutes a notable research gap that the present study seeks to address by evaluating the performance of OPC–PPC–citric acid blends in terms of **compressive strength, workability, and setting characteristics**, thus contributing to more sustainable and high-performing concrete mix designs.

Based on previous studies conducted by various researchers, concrete made with Portland Pozzolana cement (PPC) generally does not reach the same compressive strength as concrete made with Ordinary Portland Cement (OPC) after 28 days. These studies highlight that pumice and volcanic basalt are the most commonly used Pozzolana in Ethiopia. One explanation for the lower final strength of PPC concrete compared to OPC concrete is that the Pozzolanic material in PPC has a lower Pozzolanicity than that in OPC. However, PPC offers advantages over OPC in terms of concrete workability, impermeability, and resistance to chemical attacks. PPC alone may fail to achieve the desired compressive strength within 28 days. Therefore, this study focuses on the suitability of combining PPC with citric acid as a water-reducing and retarding admixture for reinforced concrete. This is particularly important because PPC develops strength more slowly than OPC, as noted in previous studies, which is why it is not commonly used for reinforced concrete.

The pozzolanic reaction of PPC contributes to long-term volume stability by refining the pore structure and reducing drying shrinkage compared to ordinary Portland cement (OPC) (Bentz & Jensen, 2004; Mehta & Monteiro, 2014). When citric acid is introduced in appropriate dosages, it further modifies the hydration kinetics, potentially delaying the onset of autogenous shrinkage and reducing internal stresses during the early curing period (Ramachandran et al., 2002). Regarding corrosion resistance, PPC has been shown to improve the impermeability of concrete through its denser microstructure, thereby limiting chloride ion penetration and delaying reinforcement corrosion (Song & Saraswathy, 2007). The chelating properties of citric acid may also contribute to improved corrosion performance by stabilizing iron ions and affecting the local pH environment, although excessive amounts could lead to adverse effects (Mindess, Young, & Darwin, 2003). In terms of thermal resistance, PPC-blended concrete generally exhibits enhanced fire endurance due to its lower calcium hydroxide content and better thermal compatibility (Kodur & Phan, 2007). The role of citric acid in thermal resistance is less direct but may influence the microstructural development in ways that enhance thermal stability when used in controlled dosages (Péra, Husson, & Guilhot, 1999). Overall, the synergistic effect of PPC and citric acid offers promising potential for enhancing the durability-related properties of reinforced concrete, although optimization of their proportions is crucial to avoid negative side effects, particularly related to setting time and strength development.

**Research gap:** There is no studies' investigating the synergetic effect of combining PPC and Citric acid in reinforced concrete. This study addresses that gap by examining their combined effect on setting time, workability and compressive strength of reinforced concrete.

**Hypothesis:** - Partial replacement of OPC with PPC in combination with optimum dose of citric acid will enhance the setting time and workability and will give comparable compressive strength with OPC based reinforced concrete.

## CHAPTER – THREE

### 3. MATERIALS & METHODS

#### 3.1. Research Methodology

This Thesis Consist Laboratory Examination. The experimental procedure encompasses a comprehensive framework for material characterization, concrete mix design, mixing, casting, and testing. Initially, the properties of constituent materials are evaluated to ensure conformity with specified standards. The concrete mix is then designed by determining appropriate proportions of materials to achieve the desired strength and workability. Subsequently, the mixing process is followed by casting the concrete into molds for specimen preparation. Once the specimens are cured, they undergo testing to assess key parameters such as compressive strength.

#### 3.2. Experimental Procedures

The laboratory tests were performed in the Addis Ababa Institute of Technology, Materials Testing laboratory and yencomad construction Plc. laboratory. The laboratory examination involves concrete raw materials testing, mix designing, and setting time, slump & compressive strength tests. The slump & compressive strength tests were performed for the C-30 concrete. The concrete mixes were made with OPC, PPC, & PPC with citric acid.

#### 3.3. Concrete ingredients' Used

##### 3.3.1. Cement (Dangote, PPC & OPC)

The characteristics of a concrete mixture can be significantly impacted by the varying properties of different cement types and brands. In many cases, it may be unnecessary to test cement that has already been extensively used and proven in concrete production. Globally, Ordinary Portland Cement (OPC) is the prevailing choice for most construction projects. However, in this particular study, a locally manufactured variant, Dangote Portland Pozzolana Cement, was utilized to explore its potential applications.

##### 3.3.2. Fine aggregate (River Sand)

In this study, the fine aggregate utilized was derived from Natural River, specifically sourced from Alagea. Before employing these fine aggregates in the preparation of concrete specimens, it is essential to conduct a series of critical assessments. These evaluations include determining the specific gravity, absorption capacity, sieve analysis, fineness modulus, silt content, and moisture content of the fine aggregates to ensure their suitability for concrete production.

### 3.3.3. Coarse aggregate (02 & 01 coarse aggregate)

There are two varieties of coarse aggregate, 01 coarse aggregate and 02 coarse aggregate, which start to retain at 9.5 mm and 19 mm size sieves, respectively, depending on size. Both 01 and 02 coarse aggregates, which had been crushed from basalt for this experiment, were used to make the coarse aggregate. Before utilizing coarse aggregate in concrete, its Aggregate Crushing Value, soundness, density in relation to water, water-absorbing capability, wet content, and gradation must all be determined.

### 3.3.4. Citric Acid

Before utilizing it for a concrete mixture, it is necessary to examine its properties and initial and final setting times. It is gathered in solid shape from the market. Citric acid of this type is anhydrous. To enhance the concrete's performance in terms of setting time, workability, and compressive strength, a water-reducer & set retarder, was utilized in this study.

### 3.3.5. Water

In the pursuit of optimal concrete mixture quality, it is essential to utilize potable water in the experiment. However, in circumstances where access to potable water is limited, it is crucial to conduct thorough tests on the available water source to detect and eliminate any impurities that could compromise the integrity of the concrete.

## 3.4. Methods

All of the components that went into making the concrete samples were prepared, and some of them had their corresponding physical characteristics examined, to ensure their acceptability. The DOE (Departments of Environment) processes were used to develop the raw materials for the C-30 concrete class, and the wet content and aggregates' ability to absorb water were taken into account when adjusting the mix ratio. Based on saturated surface dry conditions, the masses of all raw components were determined. The concrete could be mixed with a reasonable level of consistency using the mechanical mixer that was employed. To evaluate the mix's workability and consistency, slump tests were conducted on each batch. To determine the compressive strength of each concrete mix, cube specimens were prepared for each concrete mix and were subjected to compression testing after being cast, de-molded, and watered on their respective test days.

### 3.4.1. Assembling of concrete raw materials

Throughout the experiment, the Dangote brand of PPC and OPC type cement was utilized. In accordance with the test specifications, aggregate samples were prepared by sourcing natural sand from concrete suppliers, and basaltic coarsely crushed stones (01 & 02) from Yencomad Crusher, a reputable aggregate producer. Additionally, cement, and citric acid, were procured from the market, while water was obtained from the AAiT & Yencomad Crusher Compound.

It is crucial to have an adequate supply of high-quality aggregates, as this is a vital aspect of the experiment.

Subsequently, the citric acid was transported to the compound, where it underwent a thorough examination of its setting time.

#### 3.4.2. Testing Concrete ingredients (Material characterization)

Physical testing on both fine and coarse components was consequently used to assess the quality and physical characteristics of the aggregates.

##### 3.4.2.1. Tests for coarse aggregates

The investigation delved into the intrinsic properties of the coarse aggregates, encompassing their particle size distribution, bulk density, capacity to absorb water, moisture content, and resistance to crushing forces.

#### **A. Sieve analysis (01 & 02 aggregates)**

An essential ingredient in the creation of concrete is aggregate, a hard, inert substance made up of different-sized pieces. Use of clean, complete, strong, and durable aggregates devoid of dangerous materials and weak fragments is crucial for producing high-quality concrete. Natural aggregates were used in this investigation.

The bulk of concrete is composed of aggregates, which account for roughly 65-75% of its volume. As such, the ultimate quality of the concrete is significantly influenced by the properties of the aggregates. The gradation is a crucial component of aggregate quality.

To evaluate the dispersion of aggregate particle sizes, a technique called screen evaluation is employed, which involves using a set of sieves to determine the aggregate grading and fineness modulus. The fineness modulus indicates the uniformity, fineness, and coarseness of the aggregate, which in turn affects the various qualities of the resulting concrete. According to the Ethiopian Standard, coarse aggregates should fall within a specific size range of 75 to 4.75mm. To meet the gradation criteria outlined by the Ethiopian Standard, two types of coarse aggregates (01 and 02) were blended throughout this study.

#### **Apparatus**

The apparatus used for this test included a digital weighing balance for accurate measurement of sample weights, a standard set of IS sieves with varying mesh sizes, a spoon for sample handling, a mechanical sieve shaker to facilitate consistent shaking, and a sieve brush for cleaning the mesh to avoid obstruction and ensure accuracy.

## Procedure

The grading procedure began by weighing 20 kg of coarse aggregates. This representative sample was then reduced using the quartering method to obtain a smaller, manageable portion. From the quartered material, a 2 kg sample was carefully selected for the sieve analysis. This sample was placed on the topmost sieve of the stack, which had the largest aperture size, and the entire set was mounted on the sieve shaker. The shaker was operated for approximately two minutes to allow thorough separation of particles based on size.

After shaking, the material retained on each sieve was collected and weighed individually. These weights were recorded systematically. The data obtained was then used to calculate the fineness modulus of the aggregate, and a grading chart was prepared to classify the aggregate based on standard grading curves.

## Test output

Table 3.1 Sieve analysis result for coarse aggregate (02 & 01 blended)

| <b>Sieve opening<br/>(mm)</b> | <b>Mass<br/>Retained (gm.)</b> | <b>Individual<br/>(%) Retained</b> | <b>Cumulative<br/>Coarser (%)</b> | <b>Cumulative<br/>Passing (%)</b> | <b>Percent passing<br/>(ES C.D3. 201)</b> |
|-------------------------------|--------------------------------|------------------------------------|-----------------------------------|-----------------------------------|---|
| 37.5                          | 0                              | 0                                  | 0                                 | <b>100</b>                        | <b>100</b>                                |
| 19                            | 80                             | 4                                  | 4                                 | <b>96</b>                         | <b>95 – 100</b>                           |
| 9.5                           | 1320                           | 66                                 | 70                                | <b>30</b>                         | <b>25 – 55</b>                            |
| 4.75                          | 500                            | 25                                 | 95                                | <b>5</b>                          | <b>0 – 10</b>                             |
| Pan                           | 100                            | 5                                  | -                                 | -                                 |   |

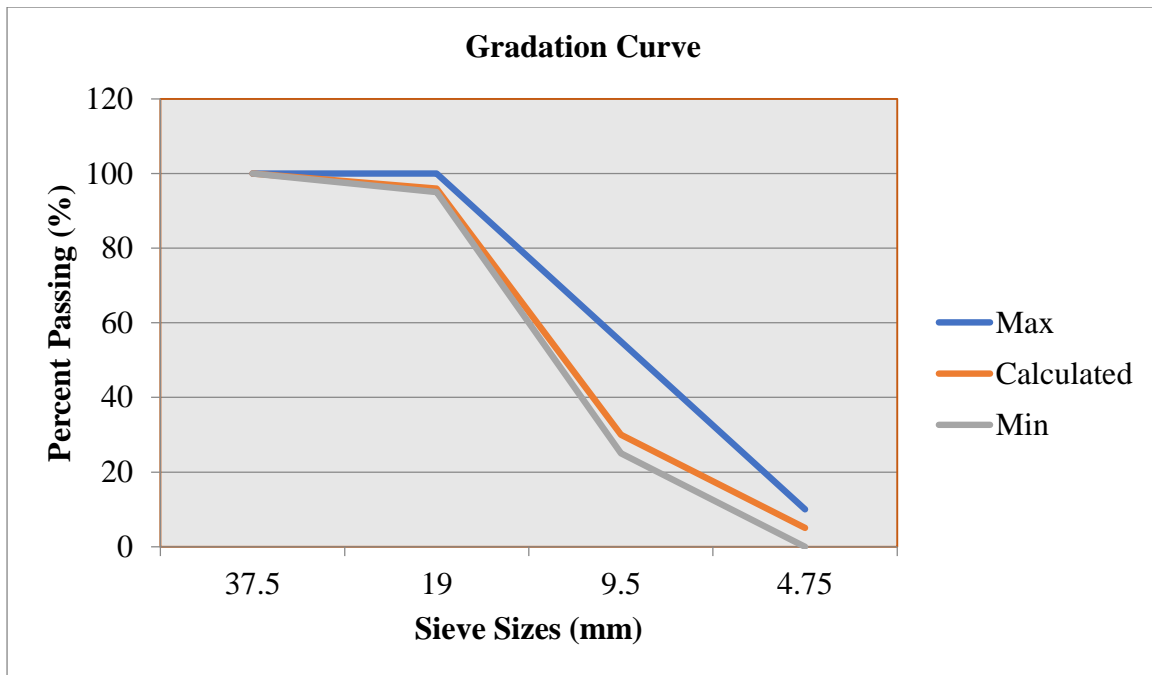


Figure 3.1 Gradation curve for coarse aggregate

Consequently, the blended coarse aggregate samples are found to be compliant with the gradation requirements outlined by the Ethiopian Standard, thereby ensuring the production of concrete that meets the required standards.

### B. Specific gravity and absorption capacity

The arrangement of aggregate pores, encompassing their dimensions, capacity, and interconnected pattern, has a profound impact on their water retention capabilities, permeability, and overall density

$$\text{Specific gravity} = \frac{\text{weight of substance}}{\text{weight of the same volume of reference substance typically water}}$$

In a solid material characterized by its porous nature, water molecules are drawn into the open pores through a process of absorption, ultimately occupying the available spaces within the material's structure.

### Apparatus

The apparatus used in this test included a digital weighing balance for precise mass measurements, a wire basket or bucket made of 3 mm mesh with a capacity ranging between 4000 cm<sup>3</sup> and 7000 cm<sup>3</sup> and approximately equal height and diameter, and suitable suspension equipment to hang the sample container in water from the center of the weighing balance.

This setup facilitated the accurate measurement of aggregate weights both in air and submerged in water. The specific gravity was computed using the standard formula based on the differences in weight, while the water absorption percentage was determined by measuring the difference between dry and saturated surface-dry conditions of the aggregate sample. These values provided essential insights into the aggregate's suitability for concrete production, particularly in terms of density and porosity

### **Preparing the test specimen**

Quarter the sample to select an approximate 5 kg sample size of aggregate, and then discard any material that passes the 4.75 mm sieve size.

### **Procedure**

The test procedure commenced by thoroughly cleaning the coarse aggregate sample to remove any dust or fine particles adhering to its surface. The cleaned sample was then oven-dried at a temperature of  $110 \pm 5^\circ\text{C}$  to ensure complete removal of moisture. After drying, the sample was allowed to cool to room temperature for a period ranging from one to three hours. Following this, the sample was immersed in water at room temperature and left undisturbed for 24 hours to allow the aggregates to achieve a saturated state.

Once the soaking period was complete, the sample was removed from the water and carefully surface-dried. This was done by rolling the aggregates in a large piece of absorbent cloth to remove excess surface moisture without drawing water from within the pores. Larger particles were handled individually to ensure that no visible water remained on the surface. It was important to complete this process quickly to avoid moisture loss from the pores. The surface-saturated sample was then weighed, and the weight was recorded as the saturated surface-dry (SSD) condition, denoted as weight B.

Immediately after obtaining the SSD weight, the sample was placed into the wire basket, which was submerged in room-temperature water for underwater weighing. Care was taken to ensure that the sample was fully immersed and that any entrapped air was removed by gently agitating the basket underwater. The submerged weight was then recorded as weight C. Following this, the sample was removed from water and again allowed to air-cool for one to three hours. It was then oven-dried to a constant weight at a temperature of  $110 \pm 5^\circ\text{C}$ . The final dry weight of the sample was recorded as weight A. These three measurements—A (oven-dry), B (SSD), and C (submerged)—were subsequently used to calculate both the specific gravity and water absorption of the coarse aggregates.

### Calculation

#### Measured quantities: 02 coarse aggregate

A = 4518 gm.

B = 4700 gm.

C = 2900 gm.

#### Measured quantities: 01 coarse aggregate

A = 4231 g

B = 4420 g

C = 2650 g

Table3.2 Specific Gravities and Absorption Capacity of Coarse aggregates

|                     | Bulk specific gravity | Bulk specific gravity (SSD basis) | Apparent specific gravity | Absorption capacity     |
|---------------------|-----------------------|-----------------------------------|---------------------------|-------------------------|
| <b>Formulas</b>     | $\frac{A}{B - C}$     | $\frac{B}{B - C}$                 | $\frac{A}{A - C}$         | $\frac{B - A}{A} * 100$ |
| <b>Results (02)</b> | 2.51                  | 2.61                              | 2.79                      | 4.03%                   |
| <b>Results (01)</b> | 2.39                  | 2.5                               | 2.68                      | 4.47%                   |

### C. The moisture content of coarse and fine aggregates:

Engineers are aware that the water-to-cement ratio significantly affects how well concrete specimens operate. Generally, the assumption used to determine a design water-cement ratio is that the aggregates are in a saturated surface dry state, which means they are not absorbing or releasing water from the mixture. But in practice, this perfect situation doesn't happen very often. While aggregates with less moisture than the saturation limit draw water out of the mixture, those with more moisture add to the concrete mix. The computed water-cement ratio is greatly impacted by this disparity, which in turn impacts the workability of new concrete and the strength of the hardened concrete. Finding the aggregates' moisture content is crucial to fixing these discrepancies.

#### Apparatus

The apparatus used for determining the moisture content of both coarse and fine aggregates included a digital weighing scale for precise mass measurement, a drying oven capable of

maintaining temperatures between 105°C and 110°C, a metal plate for holding samples during drying, and a scoop for handling the aggregates.

## Procedure

The procedure began by accurately measuring 2 kg of coarse aggregate and 500 grams of fine aggregate samples. These samples were placed separately on plates labeled as 02 and 01 for coarse aggregates and A for fine aggregates. Each sample was then oven-dried for approximately 24 hours at a temperature maintained between 105°C and 110°C to remove all moisture content. After drying, the samples were allowed to cool naturally for about one hour inside a desiccator to prevent moisture absorption from the surrounding air.

Once cooled, the dried aggregates were weighed, and the weights were recorded as the oven-dry mass (B). Using the initial wet mass and the oven-dry mass, the moisture content (w %) of each sample was calculated separately by applying the standard formula. These values were essential for adjusting mix proportions in concrete design to ensure consistency and accuracy.

## Formula

$$w(\%) = \frac{A - B}{B} * 100$$

### For 02

#### Test results:

$$A = 1843.2\text{g}$$

$$B = 1800\text{g}$$

#### Calculation:

$$w(\%) = \frac{A - B}{B} * 100$$

$$w(\%) = \frac{1843.2 - 1800}{1800} * 100 = 2.41 \%$$

### For 01

#### Test results:

$$A = 1650\text{g}$$

$$B = 1600\text{g}$$

$$w(\%) = \frac{A - B}{B} * 100$$

$$w(\%) = \frac{1650 - 1600}{1600} * 100 = 3.13 \%$$

## **D. Aggregate crushing value**

It calculates the total load-carrying capability.

### **Apparatus**

The apparatus used to determine the aggregate crushing value (ACV) comprised British Standard (BS) sieves with diameters of 14 mm, 10 mm, and 2.36 mm, an open-ended steel cylinder for containing the aggregate sample, a tamping rod with a 16 mm circular cross-section for compaction, a weighing scale with a minimum capacity of 3 kg and an accuracy of 1 g for precise measurements, and a compression testing machine capable of applying a load of up to 400 kN.

### **Getting the test sample ready:**

The materials for the standard test need to pass the 14mm and stay on the 10mm BS test sieve before testing. The aggregate needs to be examined once the surface has dried. If heating is utilized, the drying procedure shouldn't take more than four hours. Testing the aggregate before it has reached room temperature or heated to 1100C is not possible.

The quantity of aggregates utilized in a single test needs to be selected so that the material in the test cylinder is 100 mm deep after tamping. Finding the right amount is simple: fill the cylindrical measure with the chosen material up to one-third of its height in three layers, compact each layer 25 times by letting it fall freely, and then level it off using the tamping rod as a straight edge.

Calculate the mass of the material (mass A) in the test sample.

### **Procedure**

The procedure began by placing the test sample into the steel cylinder, followed by the insertion of the plunger. The load was applied gradually and evenly using the compression testing apparatus, reaching the required force of 400 kN within ten minutes. Upon completion of loading, the crushed aggregate particles were carefully removed by tapping the outside of the cylinder over a clean tray to avoid loss of material.

Next, the entire crushed sample was sieved through a 2.36 mm BS test sieve for approximately one minute or until no more material passed through the sieve. The mass of

the aggregate passing through the sieve was then measured and recorded as mass B. This value was used to calculate the aggregate crushing value, which provides an indication of the aggregate's resistance to crushing under gradually applied compressive load, critical for assessing suitability in concrete production.

### **Calculation**

$$\text{Percentage fines} = \frac{B}{A}$$

### **Test results:**

$$A = 3070\text{g}$$

$$B = 768\text{g}$$

### **Calculation**

$$\text{Percentage fines} = \frac{768}{3070}$$

$$\text{ACV} = 25 \%$$

#### 3.4.2.2. Tests for fine aggregate (river sand)

##### **A. Silt content**

The natural or artificial disintegration of rocks and minerals results in the formation of fine aggregates. However, these deposits are not solely composed of sand; they often contain finer-grained particles such as dust, loam, and clay. The presence of these impurities in the sand used for mortar or concrete production significantly compromises the bonding between the constituents, thereby diminishing the overall strength of the mixture. As a consequence, the mixture rapidly deteriorates due to the weakening effect of these finer particles.

Therefore, it is crucial to assess and compare the silt concentration to established limits. According to Ethiopian standards, if the silt content exceeds 6%, it is recommended to either wash the sand to remove the impurities or discard it altogether to ensure the production of high-quality mortar or concrete.

### **Apparatus**

The apparatus utilized for the silt content test included a graduated glass jar or cylinder with a minimum capacity of 100 milliliters, a pan for sample handling, a spoon for transferring fine aggregate, a funnel to facilitate pouring, and tap water for mixing.

### **Procedure**

The procedure began by placing 30 milliliters of the fine aggregate sample into the graduated cylinder. The cylinder was then filled with tap water until approximately three-quarters full.

The mixture was vigorously shaken for one minute to ensure thorough dispersion of particles within the water.

Following agitation, the cylinder was left undisturbed for about one hour to allow silt and finer particles to settle and accumulate above the fine aggregate layer. After this settling period, the thickness of the silt layer that formed on top of the washed fine aggregates was carefully observed and recorded. The thickness measurement served as an indicator of the silt content in the fine aggregates, which is critical for assessing the cleanliness and suitability of aggregates for concrete production.

### **Formula**

$$\text{Silt content (\%)} = \frac{A}{B} * 100$$

### **Where:**

A = volume of silt set down over the washed fine aggregate

B = volume of the original fine aggregate sample

### **Test results:**

#### **For river sand**

A = 6ml

B = 150ml

$$\text{Silt content (\%)} = \frac{A}{B} * 100$$

$$\text{Silt content (\%)} = \frac{6}{150} * 100 = 4\% < 6\% \dots\dots\dots \text{Ok!}$$

Ethiopian regulations prohibit the use of fine aggregate for buildings if it contains more than 6% silt.

### **B. Sieve analysis**

The nominal maximum size of fine aggregates is 4.75 mm, with a size range of 9.50 mm to 150mm.

### **Equipment**

The equipment used for grading fine aggregate is identical to that employed for coarse aggregate grading.

## Procedure

Initially, a representative sample of fine aggregate weighing 2 kilograms was taken. This sample was quartered to ensure uniformity and reduce size, from which a 500-gram portion was carefully weighed for testing. The sieves were arranged in descending order of aperture size and secured within the sieve shaker. The 500-gram sample was then evenly distributed across the top sieve. The sieve stack was subjected to mechanical shaking for approximately twenty minutes to facilitate effective separation of the aggregate particles according to size. After the shaking process, the material retained on each sieve was carefully weighed and recorded. These measurements were subsequently used to complete the grading chart, which served as the basis for calculating the fineness modulus of the fine aggregate sample. This procedure ensures a standardized and accurate assessment of particle size distribution critical for concrete mix design.

## Test results:

Table 3.3 Particle size distribution for Fine Aggregate

| Sieve size (mm) | Mass Retained (gm.) | Individual (%) Retained | Cumulative Coarser (%) | Cumulative Passing (%) | Percent passing (ES C.D3. 201) |
|-----------------|---------------------|-------------------------|------------------------|------------------------|--------------------------------|
| 9.5             | 0                   | 0                       | 0                      | <b>100</b>             | <b>100</b>                     |
| 4.75            | 40                  | 4                       | 4                      | <b>96</b>              | <b>95 – 100</b>                |
| 2.36            | 80                  | 8                       | 12                     | <b>88</b>              | <b>80 – 100</b>                |
| 1.18            | 150                 | 15                      | 27                     | <b>73</b>              | <b>50 – 85</b>                 |
| 0.6             | 300                 | 30                      | 57                     | <b>43</b>              | <b>25 – 60</b>                 |
| 0.3             | 300                 | 30                      | 87                     | <b>13</b>              | <b>10 – 30</b>                 |
| 0.15            | 130                 | 13                      | 100                    | <b>3.5</b>             | <b>2 – 10</b>                  |
|                 |                     | <b>Total</b>            | 287                    |                        |                                |

$$\text{Fineness Modulus} = \frac{\sum \text{Cumulative coarser}}{100} (\%) = \frac{287}{100} = 2.87$$

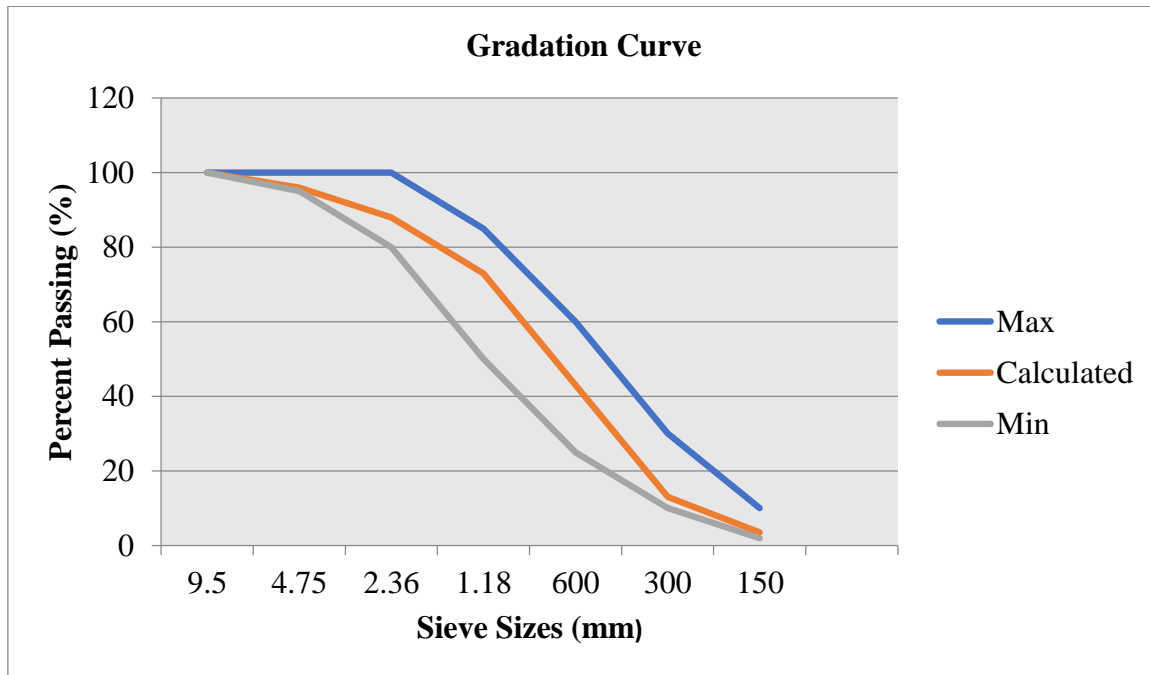


Figure 3.2 Gradation curve for fine aggregate

The fine aggregate gradation curve utilized in this study is presented in the accompanying figure, juxtaposed with the minimum and maximum fine aggregate quantities permitted by the Ethiopian Standard for various sieve sizes. Notably, the particle size distribution of the sand samples employed in this investigation conforms to the overarching requirements outlined by the Ethiopian standard.

### C. Specific gravity and Absorption capacity

#### Apparatus

The following apparatus were utilized for the fine aggregate testing procedure. A balance with a minimum capacity of 1 kilogram was employed to accurately weigh the aggregate samples. A pycnometer, serving as a suitable container, was used to facilitate the easy introduction and handling of the fine aggregate test sample during the testing process. For sample molding, a metal cone was utilized, featuring a top diameter of 38 mm, a bottom diameter of 89 mm, a height of 74 mm, and a minimum thickness of 0.9 mm. Additionally, a tamper was used to compact the sample within the mold; this tamper was constructed of metal, weighing  $340 \pm 15$  grams, and possessed a flat circular tamping face with a diameter of  $25 \pm 3$  mm. These apparatus ensured consistent sample preparation and accurate measurement of the physical properties of the fine aggregate.

### **Obtaining a Representative Test Sample of Fine Aggregate**

Employ a quartering device or sample divider to extract approximately 1000g of fine aggregate from the original sample. Next, dry the extracted material in a suitable container at a controlled temperature of  $110^{\circ}\text{C} \pm 5^{\circ}\text{C}$  until it reaches a consistent weight. Allow the sample to cool before submerging it in water and letting it soak for  $15 \text{ hours} \pm 4 \text{ hours}$ . Then, spread the sample out in an open area and stir it regularly to ensure uniform drying. Repeat this process until the test sample achieves a state of free-flowing consistency, indicating the absence of surface moisture. If the fine aggregate retains its molded shape, it still contains surface moisture. Continue drying the sample with steady stirring and intermittent testing until it exhibits a noticeable slump when removed from the mold, signifying surface dryness. Mechanical aids can facilitate this process.

#### **Procedure**

A 500-gram portion of the prepared fine aggregate sample was placed into the pycnometer, which was then filled with water to approximately 90% of its total capacity. The pycnometer was gently rolled, inverted, and shaken to eliminate any entrapped air bubbles within the aggregate and water mixture. If necessary, additional water was added to reach the recommended level, and the pycnometer was placed in a circulating water bath to stabilize its temperature at  $23 \pm 1.7^{\circ}\text{C}$ . Once thermal equilibrium was achieved, the combined weight of the pycnometer, water, and fine aggregate sample was recorded. The value of C was determined using the formula:  $C = 500 + W_f + 0.9976Va$

Following this, the fine aggregate sample was removed from the pycnometer, dried in an oven at  $105 \pm 5^{\circ}\text{C}$ , and then allowed to cool at ambient room temperature for a period of 30 to 90 minutes before being weighed again. Finally, the pycnometer was filled with water alone to its calibration mark, brought to a temperature of  $23 \pm 1.7^{\circ}\text{C}$ , and its weight was recorded. This procedure enabled the determination of specific gravity and water absorption characteristics of the fine aggregate.  $B = 0.9976V + W_f$

#### **Calculation**

##### **Bulk specific gravity:**

$$\text{Bulk sp. gr} = \frac{A}{B+500-C}$$

##### **Where**

A = weight of oven-dry sample in air, [g]

B = weight of pycnometer filled with water, [g] and

C = weight of pycnometer with sample and water to calibration mark, [g]

**Bulk sp gr (SSD basis):**

$$= \frac{500}{B+500-C}$$

**Apparent sp gr:**

$$= \frac{A}{B+A-C}$$

**Absorption (%):**

$$= \frac{500-A}{A} * 100$$

**Measured quantities: RS**

Weight of the sample = 500gm

W<sub>f</sub> (Mass of flask, gm.) = 320gm,

V (volume of pycnometer) = 975.39 ml

V<sub>a</sub> (volume of water [cm<sup>3</sup>]) = 769.80 ml,

A = 490 g,

**Calculation**

$$C = 0.9976V_a + 500 + W_f$$

$$= 1587.95g$$

$$B = 0.9976V + W_f$$

$$= 1293.05g$$

Table 3.4 Specific gravities and absorption capacity of fine aggregate

|                     | <b>Bulk specific gravity</b> | <b>Bulk specific gravity (SSD basis)</b> | <b>Apparent specific gravity</b> | <b>Absorption capacity</b> |
|---------------------|------------------------------|--|----------------------------------|----------------------------|
|                     | $\frac{A}{B + 500 - C}$      | $\frac{500}{B + 500 - C}$                | $\frac{A}{B + A - C}$            | $\frac{500 - A}{A} * 100$  |
| <b>Results (RS)</b> | 2.39                         | 2.44                                     | 2.51                             | 2.04%                      |

#### **D. Moisture content**

The methodology for determining the moisture content of coarse aggregates is outlined in the aforementioned techniques. In this particular study, the moisture content of fine aggregates was found to be 3.09 percent, a crucial factor in our investigation.

## Test results

### For RS

$$A = 500\text{g}$$

$$B = 485\text{g}$$

### Calculation

$$w(\%) = \frac{A-B}{B} * 100 \qquad w(\%) = \frac{500-485}{485} * 100 = 3.09 \%$$

### 3.4.3. Concrete Mix design

The concrete mix design for this study focuses on evaluating the combined effect of Portland Pozzolana Cement (PPC), as partial replacement for OPC, in combination with citric acid to enhance the performance of concrete in reinforced applications. This section outlines the design of concrete mixes, the selection of appropriate materials, and the targeted properties of the concrete mix.

Using the DOE mix proportioning technique, the optimal proportions of cement, river sand, coarse aggregate (grades 01 and 02), water, and citric acid were determined for a PPC-blended concrete mix design targeting the C-30 concrete grade. The resulting mix ratio table is presented below. “Design of Experiments (DOE) was adopted in previous concrete studies to effectively evaluate the influence of multiple interacting factors on concrete properties, such as workability, setting time, and strength (Bai & Wild, 2002; Kheder et al., 2003). Inspired by these approaches, this study used a structured test matrix to analyze the combined effects of PPC and citric acid.”

NB: the step-by-step DOE mix design procedure appeared on Appendix#2

Table3.5 DOE mix design concrete raw material Amounts

| Materials             | Weight per 1m <sup>3</sup> of concrete |
|-----------------------|--|
| Water                 | 190 kg                                 |
| Cement (OPC)          | 380kg                                  |
| Coarse aggregate (02) | 870.5 kg                               |
| Coarse aggregate (01) | 435 kg                                 |
| Fine aggregate (RS)   | 559.5 kg                               |

## Correction

In reality, the aggregate does not exist in a perfectly dry state. Consequently, the quantities of materials mentioned earlier need to be recalculated by taking into account the aggregate's inherent moisture content and its capacity to absorb water.

Table3.6 Moisture content and absorption capacity of the aggregates

| Materials             | Moisture Content | Absorption Capacity | Correction Factor  |
|-----------------------|------------------|---------------------|--------------------|
| River sand            | 3.09%            | 2.04%               | 1.05%, Moisture    |
| Coarse aggregate (02) | 2.41%            | 4.03%               | 1.62%, Absorption  |
| Coarse aggregate (01) | 3.13%            | 4.47%               | 1.34 %, Absorption |

Weight of coarse aggregate (02) =  $870.5 * (1 - 1.62/100) = 856.4$  kg

Weight of coarse aggregate (01) =  $435 * (1 - 1.34/100) = 429.2$  kg

Weight of River sand =  $559.5 * (1 + 1.05/100) = 565.4$  kg

Adjusted water content =  $190 + (870.5 * 1.62/100) + (435 * 1.34/100) - (559.5 * 1.05/100) = 204.1$  kg

Finally, the trial mix quantities per 1m<sup>3</sup> of concrete are displayed in Table 3.9.

Table3.7 Adjusted Concrete Raw Materials Quantity

| Materials             | Weight per 1m <sup>3</sup> of concrete | Weight per 0.1m <sup>3</sup> of concrete<br>(For Trial Mix Purpose) |
|-----------------------|--|---|
| Water                 | <b>204.1 kg</b>                        | <b>20.41 kg</b>   |
| Cement (OPC)          | <b>380 kg</b>                          | <b>38 kg</b>  |
| Coarse aggregate (02) | <b>856.4 kg</b>                        | <b>85.64 kg</b>   |
| Coarse aggregate (01) | <b>429.2 kg</b>                        | <b>42.92 kg</b>   |
| River sand            | <b>565.4 kg</b>                        | <b>56.54 kg</b>   |

Initially, compressive strength tests were conducted for three different binder combinations: 50% OPC + 50% PPC, 60% OPC + 40% PPC, and 70% OPC + 30% PPC. Among these, the mix containing 60% OPC and 40% PPC selected due to intermediate compressive strength and cost. In comparison to higher OPC proportions, this mix benefited from the economic advantage of PPC, which is generally less expensive than OPC. The increased OPC content in this mix contributed to higher compressive strength when compared to those with lower

OPC ratios. Therefore, the 60% OPC and 40% PPC mix was considered the most suitable base composition for further enhancement using citric acid, allowing for a focused evaluation of admixture effects without compromising the balance between strength and cost. Following the evaluation of compressive strength for the binder combinations, the mix that exhibited intermediate performance was further modified with varying dosages of citric acid (0.1%, 0.2%, 0.3%, and 0.4% by weight of PPC cement).

Table3.8 Designation of Concrete Mixes

| No. | Specimens Code | Concrete samples prepared from                |
|-----|----------------|---|
| 1.  | M <sub>O</sub> | OPC only = <i>Reference Mix</i>               |
| 2.  | M <sub>P</sub> | PPC only                                      |
| 3.  | O-50P-50       | 50% OPC + 50% PPC                             |
| 4.  | O-60P-40       | 60% OPC + 40% PPC                             |
| 5.  | O-70P-30       | 70% OPC + 30% PPC                             |
| 6.  | M <sub>1</sub> | 60% OPC + 40% PPC + 0.1%CA (by weight of PPC) |
| 7.  | M <sub>2</sub> | 60% OPC + 40% PPC + 0.2%CA (by weight of PPC) |
| 8.  | M <sub>3</sub> | 60% OPC + 40% PPC + 0.3%CA (by weight of PPC) |
| 9.  | M <sub>4</sub> | 60% OPC + 40% PPC + 0.4%CA (by weight of PPC) |

Table3.9 Quantities of concrete ingredients for each mix for 1m<sup>3</sup> of concrete

| ID. | Mix Code       | CA (%) | W/C ratio | FOR 1 m <sup>3</sup> OF CONCRETE |          |            |                 |             |            |         |
|-----|----------------|--------|-----------|----------------------------------|----------|------------|-----------------|-------------|------------|---------|
|     |                |        |           | OPC (kg)                         | PPC (kg) | Water (kg) | River sand (kg) | 02agg. (kg) | 01agg (kg) | CA (kg) |
| 1.  | M <sub>O</sub> | 0      | 0.5       | 380                              | 0        | 204.1      | 565.4           | 856.4       | 429.2      | 0       |
| 2.  | M <sub>P</sub> | 0      | 0.5       | 0                                | 380      | 204.1      | 565.4           | 856.4       | 429.2      | 0       |
| 3.  | O-50P-50       | 0      | 0.5       | 190                              | 190      | 204.1      | 565.4           | 856.4       | 429.2      | 0       |
| 4.  | O-60P-40       | 0      | 0.5       | 228                              | 152      | 204.1      | 565.4           | 856.4       | 429.2      | 0       |
| 5.  | O-70P-30       | 0      | 0.5       | 266                              | 114      | 204.1      | 565.4           | 856.4       | 429.2      | 0       |
| 6.  | M <sub>1</sub> | 0.1    | 0.5       | 228                              | 151.392  | 204.1      | 565.4           | 856.4       | 429.2      | 0.152   |
| 7.  | M <sub>2</sub> | 0.2    | 0.5       | 228                              | 151.544  | 204.1      | 565.4           | 856.4       | 429.2      | 0.304   |
| 8.  | M <sub>3</sub> | 0.3    | 0.5       | 228                              | 151.696  | 204.1      | 565.4           | 856.4       | 429.2      | 0.456   |
| 9.  | M <sub>4</sub> | 0.4    | 0.5       | 228                              | 151.848  | 204.1      | 565.4           | 856.4       | 429.2      | 0.608   |

Table3.10 Quantities of concrete ingredients for each mix for 0.1m<sup>3</sup> of concrete

| ID. | Mix Code       | CA (%) | W/C ratio | FOR 0.1 m <sup>3</sup> OF CONCRETE (for Trial Mix Purpose) |          |            |                 |             |            |         |
|-----|----------------|--------|-----------|--|----------|------------|-----------------|-------------|------------|---------|
|     |                |        |           | OPC (kg)   | PPC (kg) | Water (kg) | River sand (kg) | 02agg. (kg) | 01agg (kg) | CA (kg) |
| 1.  | M <sub>0</sub> | 0      | 0.5       | 38   | 0        | 20.41      | 56.54           | 85.64       | 42.92      | 0       |
| 2.  | M <sub>P</sub> | 0      | 0.5       | 0  | 38       | 20.41      | 56.54           | 85.64       | 42.92      | 0       |
| 3.  | O-50P-50       | 0      | 0.5       | 19   | 19       | 20.41      | 56.54           | 85.64       | 42.92      | 0       |
| 4.  | O-60P-40       | 0      | 0.5       | 22.8   | 15.2     | 20.41      | 56.54           | 85.64       | 42.92      | 0       |
| 5.  | O-70P-30       | 0      | 0.5       | 26.6   | 11.4     | 20.41      | 56.54           | 85.64       | 42.92      | 0       |
| 6.  | M <sub>1</sub> | 0.1    | 0.5       | 22.8   | 15.1848  | 20.41      | 56.54           | 85.64       | 42.92      | 0.0152  |
| 7.  | M <sub>2</sub> | 0.2    | 0.5       | 22.8   | 15.1696  | 20.41      | 56.54           | 85.64       | 42.92      | 0.0304  |
| 8.  | M <sub>3</sub> | 0.3    | 0.5       | 22.8   | 15.1544  | 20.41      | 56.54           | 85.64       | 42.92      | 0.0456  |
| 9.  | M <sub>4</sub> | 0.4    | 0.5       | 22.8   | 15.1392  | 20.41      | 56.54           | 85.64       | 42.92      | 0.0608  |

#### 3.4.4. Mixing and casting

The duration of mixing concrete shall commence once all solid materials are loaded into the mixer. To ensure efficient mixing, a portion of the water should enter the mixer before the addition of cement and aggregate, with all water fully incorporated within the first quarter of the designated mixing time. In the absence of mixer performance tests or established mixing speeds, a minimum mixing time of one minute is required for mixers with capacities of 1 cubic meter or less. For larger capacity mixers, an additional 15 seconds should be added for each cubic meter or fraction thereof of capacity.

This study utilizes a mechanical mixer with a maximum capacity of 1 cubic meter to combine the constituents of concrete. To rapidly assess the uniformity, workability of each mix, slump tests were conducted immediately following mixing.

In this study, only compressive strength, setting time, and workability tests were conducted, as these three parameters are fundamental indicators of the behavior of concrete throughout its mixing, placing, and hardening phases. Workability is essential for evaluating how easily concrete can be mixed, transported, and placed, particularly when incorporating admixtures such as citric acid that influence the mix's fluidity. Setting time provides insight into the duration concrete remains workable and the onset of strength gain, both of which are directly affected by the use of Portland Pozzolana Cement (PPC) and citric acid. Compressive

strength, being the most critical structural property of concrete, serves as the principal measure of its quality and long-term performance. Focusing on these key tests allows for a practical and effective evaluation of the combined effects of PPC and citric acid on reinforced concrete.

The primary target for the concrete mix was to achieve a compressive strength of 30 MPa. at 28 days of curing. Additionally, workability was maintained with a slump value of 50-100 mm for all mixes. The effect of citric acid on setting time was also monitored.

To evaluate compressive strength, cube molds measuring 100mm x 100mm x 100mm were employed. For each mix type, nine cube samples were collected, resulting in a total of 54 cubes prepared for compressive strength testing on the 7th, 28th, and 56th days.

The mix designs were subjected to standard tests to determine their setting time, workability (slump test), compressive strength at 7, 28 and 56 days of curing.

### **1. Setting time of cement mixed with citric acid**

#### **Objective**

The purpose of this test is to determine the initial and final setting times of cement with citric acid paste prepared with normal consistency.

#### **Theory**

When water is added to cement, it undergoes a chemical reaction known as hydration, which causes the cement to gradually harden and form a solid mass—this process is referred to as the setting of cement. The time it takes for the paste to begin and complete this transition is called its setting time. Since hydration is influenced by the water content, the setting time varies with the water-cement ratio. To maintain consistency and avoid confusion, the standard practice is to determine setting time using cement paste of normal consistency.

In laboratory conditions, two key setting times are measured: the **initial setting time** and the **final setting time**. The initial setting time is defined as the period required for the Vicat needle to penetrate the paste to a depth of 25 mm within 30 seconds of release. The final setting time is the moment when the Vicat needle no longer penetrates the paste.

The equipment required for conducting the setting time test includes the Vicat apparatus, which is essential for measuring the penetration of the needle into the cement paste. Additional apparatus used in the preparation and testing process includes standard weights for

calibration, a graduated cylinder for accurately measuring water, a mixing dish for preparing the cement paste, and a trowel for thorough mixing and placement of the paste into the Vicat mold.

The procedure for determining the setting time of cement begins with preparing a cement paste of normal consistency. The prepared paste is then placed into the larger end of a conical ring mold. Any excess paste at the larger end is removed using a single, smooth motion with a sharpened trowel. After that, the mold is inverted onto a glass plate, and the excess paste at the smaller end is sliced off with an oblique stroke of the trowel held at a slight angle. Care must be taken during this trimming process to avoid compressing the paste.

Immediately after molding, the specimen is placed in a moist room and kept there for the entire test period, except during the actual measurements. The specimen remains in the mold, supported by the glass plate throughout the test. After 30 minutes of undisturbed curing in the moist cabinet, the Vicat needle is lowered to rest on the surface of the specimen. The screw is tightened, and the indicator is set to the top of the scale or an initial reading is taken. The rod is then released quickly, and the needle is allowed to penetrate the paste for 30 seconds. Care should be taken to ensure that each penetration is made at least 10 mm away from any previous penetration and from the inside edge of the mold, as specified by ASTM C191.

The depth of penetration of the 1 mm diameter needle is recorded at this point and at 10-minute intervals thereafter until the penetration reaches 25 mm or less. All penetration measurements are recorded. The time corresponding to a 25 mm penetration, determined by interpolation if necessary, is taken as the **Initial Setting Time**. The **Final Setting Time** is the point at which the needle no longer visibly sinks into the paste.

## **2. Slump Test**

The most fundamental assessment of concrete's performance is the slump test, which evaluates its workability and consistency. This test yields three distinct outcomes: True Slump, Shear Slump, and Collapse Slump. The True Slump indicates a desirable combination of workability and consistency. On the other hand, the Shear Slump is typically associated with harsh mixes that lack cohesion, while the Collapse Slump is characteristic of overly wet mixes that are deficient in cohesiveness.

### **Apparatus**

The apparatus included a **slump cone** measuring **300 mm in height**, with a **base diameter of 200 mm** and a **top diameter of 100 mm**, conforming to standard geometrical specifications. The cone was placed on a **waterproof, non-absorbent base plate** measuring approximately **450 mm × 450 mm**, providing a stable and consistent surface during testing.

A **steel tamping rod** with a **diameter of 16 mm** and a **length of 600 mm**, having one end rounded to prevent damage to the concrete surface during compaction, was used for tamping the concrete in the cone. In addition, a **measuring tape or a ruler** was employed to measure the vertical slump of the concrete after the cone was lifted, ensuring accurate determination of workability.

### **Procedure**

Before commencing the test, the interior surface of the slump cone was ensured to be clean, dry, and free from any residual or hardened concrete. The cone was then placed centrally on a clean, level, and non-absorbent base plate. The footrests were properly secured to prevent movement during the test. Using a scoop, the cone was filled with fresh concrete in three equal layers, each approximately 100 mm in height. The first layer was filled to about one-third of the cone's height and compacted by rodding 25 times with a 16 mm diameter tamping rod. Subsequent layers were added in the same manner, with each layer also being rodded 25 times. The rod was allowed to penetrate into the layer below to ensure uniform compaction. After the top layer was rodded, a slight concrete surcharge was maintained above the cone. The excess concrete was then removed, and the top surface was leveled. While keeping both feet firmly on the footrests, the exterior surfaces of the cone and the base plate were cleaned. The cone was then lifted vertically in a steady motion and inverted before being placed beside the concrete specimen. As expected, the concrete slumped under its own weight. The slump was measured immediately by placing the tamping rod horizontally across the top of the upturned cone and using a measuring scale to determine the vertical distance from the underside of the rod to the highest point of the slumped concrete, to the nearest 5 mm.

### **3. Compressive strength of concrete**

Finding the concrete's load-carrying capacity is the aim of the test. Carrying loads is what concrete constructions are mostly used for. These loads may be in the form of dead, alive, wind, earthquake, snow, or any combination of these. Because of this, the concrete that is made cannot break under the pressure of any of these loads. A sample of new concrete is

placed in special cube molds and tested for failure in a specific machine to ascertain the strength of the concrete.

### **Apparatus**

The following equipment was utilized during the preparation and testing of concrete samples. A **mechanical mixer** was employed to ensure uniform mixing of the concrete constituents, facilitating consistency and reproducibility across all batches. A **scoop and trowel** were used for transferring and placing the fresh concrete into molds with precision. **Steel cubical molds** with internal dimensions of **100 mm × 100 mm × 100 mm** were used to cast specimens for compressive strength testing. A **tamping rod**, made of steel with a standard diameter of 16 mm and length of 600 mm, was used to compact the concrete within the molds in layers to eliminate air voids. After curing, the hardened concrete specimens were tested for compressive strength using a **compression testing machine**, which applied load gradually until failure, in accordance with relevant standards.

### **Procedures**

The concrete mix used for compressive strength testing was identical to that prepared and evaluated for workability to ensure consistency across tests. **Steel cube molds** with dimensions of either **100 mm × 100 mm × 100 mm** or **150 mm × 150 mm × 150 mm** were thoroughly cleaned and lightly oiled prior to casting to facilitate easy demolding. Freshly mixed concrete was placed into the molds in layers, and each specimen was subjected to vibration or tamping for approximately **30 seconds** to eliminate entrapped air and ensure compaction. The surface of each mold was leveled and any excess concrete was removed using a trowel. The **mix type, grade, and date of mixing** were clearly marked on the top surface of each specimen. After 24 hours of initial setting, the concrete cubes were carefully demolded and placed in a **curing tank containing water**, where they remained until the designated testing ages. Compressive strength tests were conducted at **7, 28, and 56 days**, during which the specimens were loaded to failure using a calibrated **compressive strength testing machine**. The maximum failure load was recorded, and the **compressive strength** of each specimen was calculated by dividing the failure load by the **cross-sectional area** of the specimen.

#### **i. Curing**

Following the casting process, the specimens were carefully removed from their molds and subjected to a controlled curing regimen. This crucial step is designed to regulate the moisture

levels within the concrete, thereby preventing excessive moisture loss and facilitating the development of optimal strength over time.

ii. Testing

In the realm of concrete testing, the compressive strength test stands out as the most vital, as it provides a comprehensive understanding of the material's properties. This crucial assessment is typically conducted using cube or cylinder specimens, with specific dimensions and uses governed by various standards. For instance, the American Standard Test Method recommends the use of 15 cm or 10 cm cubes, depending on the aggregate size. In this particular study, 10 cm x 10 cm x 10 cm cubes were chosen due to the 19 mm nominal maximum size of the boulder aggregate. The concrete cube specimens underwent automatic compressive testing at three distinct stages: 7, 28, and 56 days of curing. The load was incrementally applied at a rate of 140 kg/cm<sup>2</sup> per minute until failure occurred. Ultimately, the compressive strength of the concrete was calculated by dividing the maximum load at failure by the cross-sectional area of the specimen.

$$\text{compressive strength} = \frac{\text{Failure load}}{\text{Specimen's area}}$$

## CHAPTER FOUR

### RESULTS AND DISCUSSION

The objective was to assess the combined impact of PPC and citric acid on various properties of concrete, such as setting time, workability, and compressive strength. The discussion below focuses on interpreting the data, identifying trends, and comparing the experimental results with control.

#### **Compressive strength of binder compositions**

In this study, **setting time** and **workability tests** were not conducted for the three initial binder combinations (50% OPC + 50% PPC, 60% OPC + 40% PPC, and 70% OPC + 30% PPC). The primary objective of this phase was to **evaluate the influence of binder ratio on compressive strength**, which directly reflects the structural performance of concrete. Since PPC is not intended to fully replace OPC and is already known to delay setting time and affect workability due to its pozzolanic nature, the **comparative strength performance at 28 days** was prioritized to determine the most balanced mix for further experimental analysis.

Moreover, **workability and setting time were considered secondary parameters** for the selection of the optimum binder blend, as they are influenced by many factors such as temperature, humidity, and admixture use. These properties were instead **evaluated more precisely in the second phase** of the study, where citric acid was incorporated as a chemical admixture. In this phase, the **60% OPC + 40% PPC** combination—selected based on compressive strength and cost balance—was used to assess the effects of citric acid on workability and setting behavior.

Therefore, omitting workability and setting time tests in the initial stage allowed the study to maintain focus on strength optimization before introducing admixtures, ensuring a more controlled and targeted investigation.

To evaluate the influence of binder composition on the compressive strength of concrete, three different mix proportions were initially tested: **50% OPC + 50% PPC**, **60% OPC + 40% PPC**, and **70% OPC + 30% PPC**. These combinations were selected based on the understanding that **Portland Pozzolana Cement (PPC)**, while beneficial for long-term durability and sustainability, **cannot fully replace Ordinary Portland Cement (OPC)** due to its relatively lower early-age strength development. Compressive strength was chosen as

the primary performance indicator, as it is a fundamental property reflecting the structural capacity of concrete. The tests were conducted at **28 days of curing**, a standard age widely recognized for assessing the **ultimate compressive strength** of concrete. The results from these tests provided a basis for selecting the most suitable binder composition for further investigation involving the addition of citric acid. Neville, “Properties of Concrete”, 4th edition, suggests a conversion factor of 0.96 to translate 100mm cube strength to 150mm cube strength.

Table 4.1 28<sup>th</sup> day Compressive Strength Results of Binder composition

| Mix code             | Sample No.     | Failure load of 100 mm cubes (KN) | Compressive strength of 100mm cubes, (Mpa) | Compressive strength of 150mm cubes, (Mpa) |
|----------------------|----------------|-----------------------------------|--|--|
| <b>M<sub>O</sub></b> | <b>1</b>       | 347                               | 24.8                                       | 23.8                                       |
|                      | <b>2</b>       | 372                               | 26.3                                       | 25.2                                       |
|                      | <b>3</b>       | 342                               | 28.6                                       | 27.5                                       |
|                      | <b>Average</b> |                                   | <b>26.6</b>                                | <b>25.5</b>                                |
| <b>M<sub>P</sub></b> | <b>1</b>       | 269                               | 27.5                                       | 26.4                                       |
|                      | <b>2</b>       | 244                               | 28.8                                       | 27.6                                       |
|                      | <b>3</b>       | 235                               | 25.1                                       | 24.09                                      |
|                      | <b>Average</b> |                                   | <b>27.1</b>                                | <b>26.03</b>                               |
| <b>M<sub>I</sub></b> | <b>1</b>       | 269                               | 27.6                                       | 26.5                                       |
|                      | <b>2</b>       | 301                               | 30.5                                       | 29.3                                       |
|                      | <b>3</b>       | 257                               | 26.9                                       | 25.8                                       |
|                      | <b>Average</b> |                                   | <b>28.3</b>                                | <b>27.2</b>                                |

## Discussion

The compressive strength results at 28 days for the three binder combinations—**50% OPC + 50% PPC**, **60% OPC + 40% PPC**, and **70% OPC + 30% PPC**—yielded average values of **25.5 MPa**, **26.03 MPa**, and **27.2 MPa**, respectively. These results show a clear trend: increasing the proportion of OPC in the binder leads to an improvement in compressive strength. This is consistent with the known behavior of PPC, which typically contributes to long-term strength development through pozzolanic reactions but exhibits lower early- and medium-term strength compared to OPC due to its lower clinker content (Neville, 2011; Mehta & Monteiro, 2014).

The mix with **70% OPC and 30% PPC** demonstrated the highest compressive strength (27.2 MPa), as expected, due to the higher content of clinker, which accelerates hydration and

strength gain (ACI Committee 233, 2003). However, the marginal difference between this mix and the **60% OPC + 40% PPC** mix (only **1.17 MPa**) suggests that the latter provides a more favorable balance between strength and potential cost or environmental impact (Bijen, 1996). On the other hand, the **50% OPC + 50% PPC** combination showed the lowest strength (25.5 MPa), reinforcing the limitation of using high PPC proportions when early or design strength is a primary concern (Hewlett & Liska, 2019).

Overall, while all three mixes achieved satisfactory strength values for general structural applications, the **60% OPC + 40% PPC** mix was found to be an optimal compromise between mechanical performance and material efficiency, justifying its selection for subsequent experimental phases involving admixture modification.

#### 1.1.Setting time

The setting time of concrete is an essential property that affects the handling and placement of the mix. The setting time was determined by the Vicat apparatus, and the results are shown in Table 4.1.

First trial was made using dosage of citric acid 0.4% by weight of Portland Pozzolanic cement. It was found that the delay in the initial and final setting time relative to reference mix is not within ASTM-C494 specifications. Then many trials were made using dosages of citric acid 0.1%, 0.2% and 0.3% & 0.4% by weight of PPC cement until the optimum dosage was obtained. The initial and final setting time of concrete mix with different dosages of citric acid are shown in Table 4.1. It can be observed that the 0.1, 0.2 & 0.3% dosage of citric acid causes a delay in initial and final setting time within ASTM-C494 (2003) range. Table 4.1 shows also that the 0.4% dosage of citric acid cause a delay in initial and final setting time of 1hr 55 min and 3hr 50min respectively relative to reference mix. This result is not conform to ASTM-C494 (2003) requirements which specified that the delay in initial and final setting time must not be less than (1) hour and not more than (3:30) hours relative to reference mix, respectively.

Table4.2 Effect of citric acid on the initial & final setting time

| Mix code       | Mix Type  | Delay in setting time relative to reference mix (hrs. : min) |       |
|----------------|---|--|-------|
|                |   | Initial  | Final |
| M <sub>1</sub> | 60% OPC + 40% PPC + 0.1% CA<br>(by weight of PPC) | 1:30   | 2:40  |
| M <sub>2</sub> | 60% OPC + 40% PPC + 0.2% CA<br>(by weight of PPC) | 1:35   | 2:55  |
| M <sub>3</sub> | 60% OPC + 40% PPC + 0.3% CA<br>(by weight of PPC) | 1:50   | 3:10  |
| M <sub>4</sub> | 60% OPC + 40% PPC + 0.4% CA<br>(by weight of PPC) | 1:55   | 3:50  |

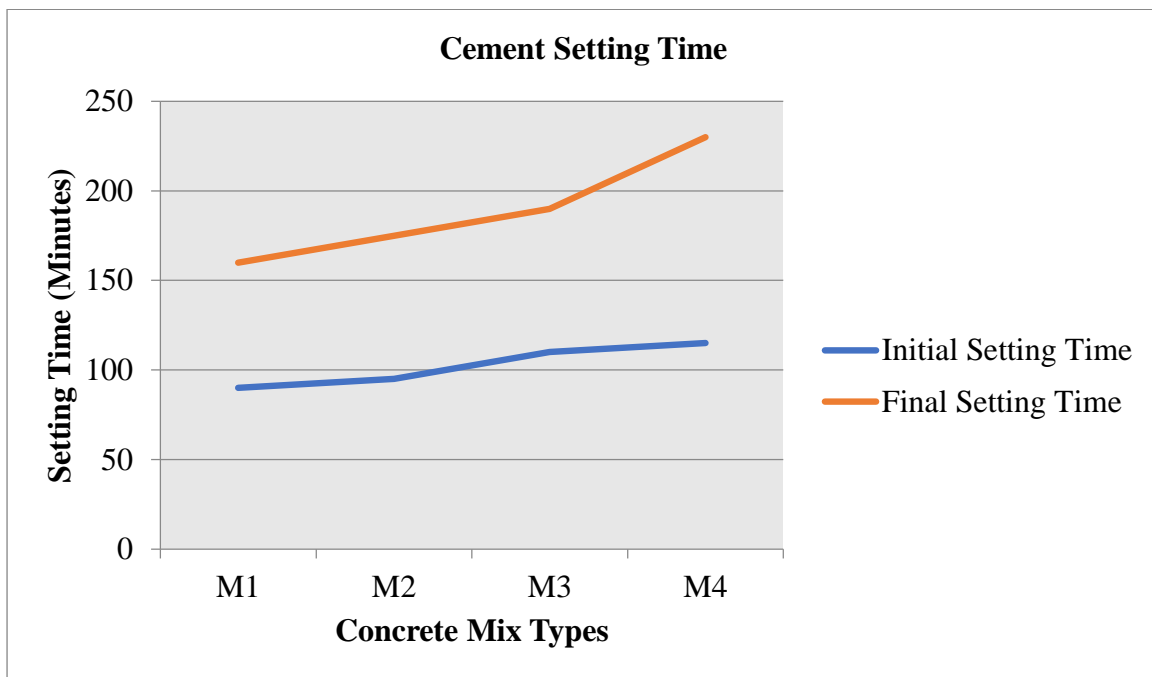


Figure4.1 Cement Setting Time

### Discussion

Citric acid is known to significantly retard the setting time of concrete by interfering with the hydration process of cement. This retarding effect occurs because citric acid chelates calcium ions in the mix, which slows down the hydration reactions of critical compounds such as tricalcium aluminate (C<sub>3</sub>A) and tricalcium silicate (C<sub>3</sub>S), thus extending the setting period

(Ramachandran, 1995; Taylor, 1997). The extent of this retardation is highly dosage-dependent. Research indicates that increasing the concentration of citric acid leads to progressive delays in both initial and final setting times (Dodson, 1990; Mindess et al., 2003). For example, the use of 0.4% citric acid by weight of PPC cement has been observed to significantly delay the initial setting time, while higher dosages can further extend this delay to levels unsuitable for practical use. In this study, the maximum dosage of citric acid was limited to 0.4% based on preliminary setting time tests, which revealed that dosages exceeding this threshold resulted in setting times that no longer complied with the acceptable limits defined by ASTM C494 for retarding admixtures (ASTM C494/C494M-19). As previously discussed, excessive retardation may not only hinder the work schedule but can also negatively affect the early and ultimate compressive strength by disrupting normal hydration kinetics and microstructure development (Neville, 2011). Therefore, 0.4% was selected as the maximum dosage in this experimental program to strike a balance between enhanced workability and acceptable setting and strength performance.

### 1.2. Workability

Workability, as measured by the slump test, is an essential property that determines how easily concrete can be mixed, placed, and compacted. The results of the slump tests for various mixes are shown in Table 4.2.

Following the ASTM C-143, “Standard Test Method for Slump of Hydraulic Cement Concrete”, a slump test was performed for each fresh concrete mix, comprising 0.1%, 0.2%, 0.3%, and 0.4% of addition of citric acid by weight of PPC. Table 4.2 displays the results, which are reported to the closest 5 mm. A 50 - 100 mm slump limit is necessary. The findings of the slump test fall within the necessary range as a result.

### **Discussion:**

The workability of the experimental mixes incorporating citric acid was observed to be slightly higher than that of the control mix (MO). This improvement in workability can be attributed to the plasticizing effect of citric acid, which likely reduces interparticle friction and enhances the dispersion of cement particles in the mix, resulting in better flowability (Ramachandran, 1995; Mindess et al., 2003). Citric acid, due to its carboxylic functional groups, has the ability to adsorb onto the surface of cement particles, effectively deflocculating them and increasing the free water available for lubrication (Taylor, 1997).

This mechanism is similar to that of conventional plasticizers or water-reducing admixtures, albeit citric acid is primarily known as a set retarder.

Furthermore, the observed trend of increasing workability with higher citric acid dosages supports the hypothesis that the synergistic use of Portland Pozzolana Cement (PPC) and citric acid can improve the fresh properties of concrete. PPC itself contributes to workability through its finer particles and pozzolanic content, which can act as internal lubricants (Mehta & Monteiro, 2014). When combined with citric acid, this effect may be amplified, particularly in mixes containing high levels of OPC, where workability is often a challenge. These findings are consistent with prior studies that report enhanced slump and ease of placement in concrete mixes modified with citric acid at appropriate dosages (Bentz et al., 2012). Thus, the combined use of PPC and citric acid presents a promising approach to improving the workability of OPC-based concrete without compromising its other key properties provided the dosage is carefully controlled.

Table4.3 Slump test results

| <b>Mix code</b>      | <b>Mix Type</b>             | <b>Slump length<br/>(mm)</b> |
|----------------------|-----------------------------|------------------------------|
| <b>M<sub>0</sub></b> | OPC Mix                     | 55                           |
| <b>M<sub>P</sub></b> | PPC Mix                     | 60                           |
| <b>M<sub>1</sub></b> | 60% OPC + 40% PPC + 0.1% CA | 65                           |
| <b>M<sub>2</sub></b> | 60% OPC + 40% PPC + 0.2% CA | 70                           |
| <b>M<sub>3</sub></b> | 60% OPC + 40% PPC + 0.3% CA | 85                           |
| <b>M<sub>4</sub></b> | 60% OPC + 40% PPC + 0.4% CA | 95                           |

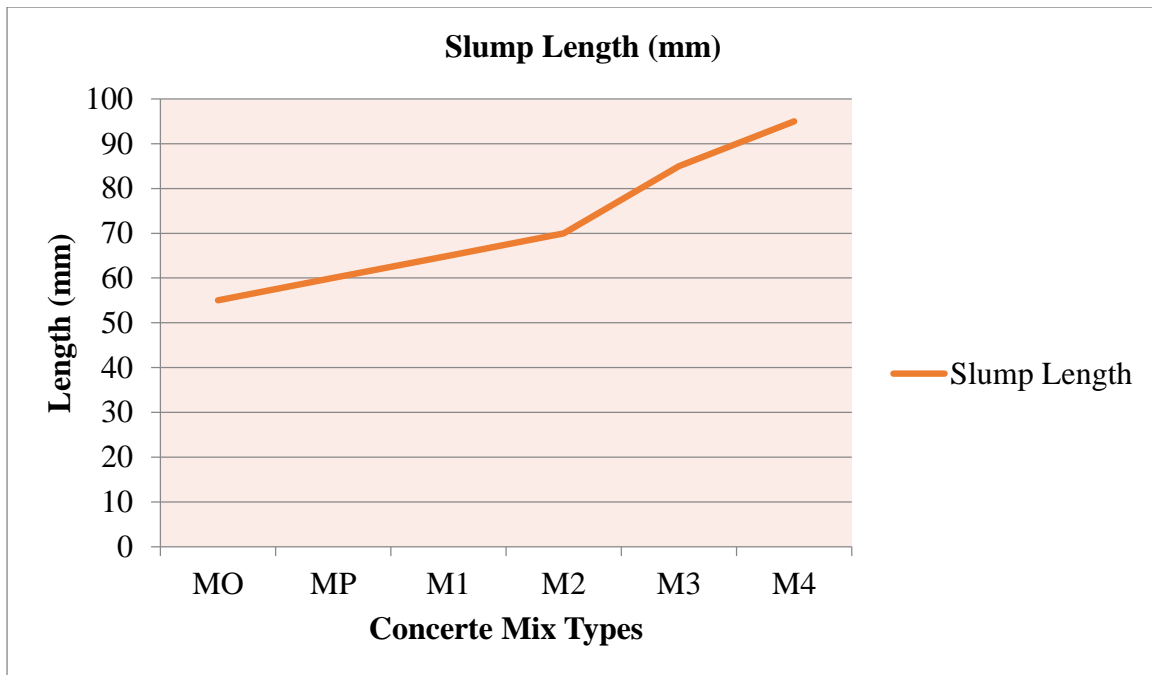


Figure 4.2. Slump Length

### 1.3. Compressive Strength Test Results

The compressive strength of concrete is one of the most critical factors in determining its suitability for reinforced concrete applications. Compressive strength was measured at 7, 28 and 56 days of curing. The 28<sup>th</sup> day results are presented in Table 4.3.

Compressive strength tests were done for the C-30 concrete class. Molds measuring 100 mm in cubes were used for the compressive strength tests. Neville, “Properties of Concrete”, 4th edition, suggests a conversion factor of 0.96 to translate 100mm cube strength to 150mm cube strength.

Prerequisites for the acceptance of concrete's compressive strength as specified in ACI 301, Specifications for Structural Concrete; “The strength level of concrete will be considered satisfactory when: the averages of all sets of three consecutive compressive strength test results molded and cured by the requirements of ASTM C-31M equal or exceed  $f_c'$  (specified strength), and no individual strength test falls below  $f_c'$  by more than 3.5MPa when  $f_c'$  is 35MPa or less, or by more than 0.1times  $f_c'$  when  $f_c'$  is more than 35 MPa”[36, page9]. The tables below display the average compressive strength test results for unique and reference concrete mixes. As demonstrated in Table 4.3, the average compressive strength result achieved by concrete manufactured with OPC is 33.9MPa for the C-30 concrete class, which is greater than the specified compressive strengths. As a result, the 28<sup>th</sup> day compressive

strength test results meet the requirements listed in ACI 301 in order for the compressive strength of concrete to be accepted.

Table 4.4 28<sup>th</sup> day Compressive strength test results

| Mix code             | Sample No.     | Failure load of 100 mm cubes (KN) | Compressive strength of 100mm cubes, (Mpa) | Compressive strength of 150mm cubes, (Mpa) |
|----------------------|----------------|-----------------------------------|--|--|
| <b>M<sub>O</sub></b> | <b>1</b>       | 347                               | 34.7                                       | 33.3                                       |
|                      | <b>2</b>       | 372                               | 37.2                                       | 35.7                                       |
|                      | <b>3</b>       | 342                               | 34.2                                       | 32.8                                       |
|                      | <b>Average</b> |                                   | <b>35.4</b>                                | <b>33.9</b>                                |
| <b>M<sub>P</sub></b> | <b>1</b>       | 269                               | 20.9                                       | 20.1                                       |
|                      | <b>2</b>       | 24.4                              | 21.4                                       | 20.5                                       |
|                      | <b>3</b>       | 235                               | 23.1                                       | 22.19                                      |
|                      | <b>Average</b> |                                   | <b>21.8</b>                                | <b>20.93</b>                               |
| <b>M<sub>1</sub></b> | <b>1</b>       | 269                               | 26.9                                       | 25.8                                       |
|                      | <b>2</b>       | 301                               | 30.1                                       | 28.9                                       |
|                      | <b>3</b>       | 257                               | 25.7                                       | 24.7                                       |
|                      | <b>Average</b> |                                   | <b>27.6</b>                                | <b>26.5</b>                                |
| <b>M<sub>2</sub></b> | <b>1</b>       | 277                               | 27.7                                       | 26.6                                       |
|                      | <b>2</b>       | 314                               | 31.4                                       | 30.1                                       |
|                      | <b>3</b>       | 292                               | 29.2                                       | 28.0                                       |
|                      | <b>Average</b> |                                   | <b>29.4</b>                                | <b>28.2</b>                                |
| <b>M<sub>3</sub></b> | <b>1</b>       | 321                               | 32.1                                       | 30.8                                       |
|                      | <b>2</b>       | 357                               | 35.7                                       | 34.3                                       |
|                      | <b>3</b>       | 334                               | 33.4                                       | 32.1                                       |
|                      | <b>Average</b> |                                   | <b>33.7</b>                                | <b>32.4</b>                                |
| <b>M<sub>4</sub></b> | <b>1</b>       | 293                               | 29.3                                       | 28.1                                       |
|                      | <b>2</b>       | 326                               | 32.6                                       | 31.3                                       |
|                      | <b>3</b>       | 321                               | 32.1                                       | 30.8                                       |
|                      | <b>Average</b> |                                   | <b>31.3</b>                                | <b>30.1</b>                                |

## Summary

Table 4.5. Summary of Compressive Strength Results

| No. | Mix Code       | 28 <sup>th</sup> day Average Compressive Strength Result (Mpa.) |
|-----|----------------|---|
| 1.  | M <sub>O</sub> | 33.9  |
| 2.  | M <sub>P</sub> | 20.9  |
| 3.  | M <sub>1</sub> | 26.5  |
| 4.  | M <sub>2</sub> | 28.2  |
| 5.  | M <sub>3</sub> | 32.4  |
| 6.  | M <sub>4</sub> | 30.1  |

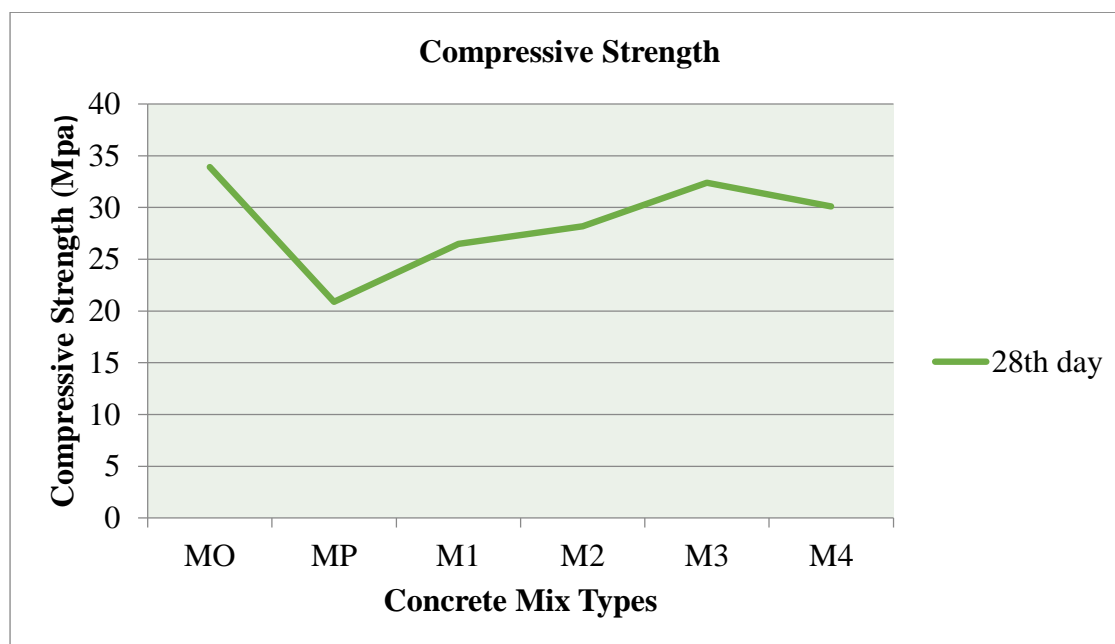


Figure 4.3. 28<sup>th</sup> day Compressive Strength

The concrete mixed with 40% PPC and 0.3% citric acid (by weight of PPC) has a compressive strength of 32.4 for C-30 at 28 days, which is comparable with OPC, based concrete. Therefore, the preconditions listed in ACI 301 for acceptance of compressive strength of concrete are likewise satisfied by the compressive strengths of concrete prepared with 40% PPC and 0.3% citric acid (by weight of PPC) at 28 days.

### Discussion:

The compressive strength results revealed that the mix containing 40% PPC in combination with 0.3% citric acid (by weight of PPC) produced strength values that were only slightly lower than those of the control mix (M<sub>O</sub>), suggesting a reasonably effective performance. This slight reduction can primarily be attributed to the dilution effect caused by the partial

replacement of OPC with PPC, which is known to exhibit lower early-age strength due to its slower pozzolanic reaction and lower clinker content (Neville, 2011; Mehta & Monteiro, 2014). Furthermore, while citric acid acted as a plasticizer and enhanced the workability of the mix, its influence on strength was more complex. Citric acid significantly retards the hydration process by chelating calcium ions and delaying the reactions of both tricalcium silicate ( $C_3S$ ) and tricalcium aluminate ( $C_3A$ ), which are primarily responsible for early strength development in OPC-based systems (Ramachandran, 1995; Taylor, 1997).

The interaction between citric acid and the pozzolanic components of PPC may also have influenced the overall hydration kinetics and the formation of strength-giving products like calcium silicate hydrate (C–S–H). While PPC contributes to strength development at later stages through secondary reactions with calcium hydroxide, excessive retardation caused by higher doses of citric acid may interfere with the timely formation of a robust cementitious matrix. The results of this study indicate that the combined use of PPC and citric acid can be beneficial for compressive strength up to an optimal dosage—specifically 0.3% citric acid—beyond which performance begins to decline due to over-retardation (Dodson, 1990; ASTM C494/C494M-19). A dosage limit of 0.4% was therefore adopted in this study to avoid setting time delays exceeding ASTM standards and to prevent significant adverse effects on compressive strength. This finding is consistent with previous studies that caution against excessive use of set-retarding admixtures, as they can impair the development of early and even long-term strength if not carefully controlled (Mindess et al., 2003).

#### 1.4. Cost Comparison

As indicated in Table 4.5, the cost comparison is done between the concrete mixes created with OPC, and the concrete mixes prepared with 40% PPC and 0.3% Citric acid. The cost of the concrete mix made with PPC and citric acid is 258.856 Ethiopian birr less per cubic meter for C-30 than the mix made with OPC. This indicates that cost savings can be obtained without affecting the required compressive strength by employing concrete mix prepared with PPC and citric acid.

**Note;** prices of cement were taken from yencomad construction Plc. (price including Vat & transportation cost) in May 2025.

Table4.6 Cost comparison between M<sub>0</sub> and M<sub>0.3</sub>

| Ingredients            | Unit | Price (birr / unit) | M <sub>0</sub><br>(OPC only) |                     | M <sub>0.3</sub><br>(60% OPC + 40% PPC = 0.3%CA) |                 |
|------------------------|------|---------------------|------------------------------|---------------------|--|-----------------|
|                        |      |                     | Quantity (Qt.)               | Cost (birr)         | Quantity (Qt.)                                   | Cost (birr)     |
| Cement (Dangote-PPC)   | Qt.  | 1300                |                              |                     | 1.51544  | 1970.072        |
| Cement (Dangote-OPC)   | Qt.  | 1650                | 3.8                          | 6270                | 2.28   | 3762            |
| Citric Acid            | Kg.  | 612                 |                              |                     | 0.456  | 279.072         |
|                        |      |                     |                              | <b>6270</b>         |  | <b>6011.144</b> |
| <b>Cost Difference</b> |      |                     |                              | <b>258.856 birr</b> |  |                 |

### Discussion

Concrete is one of the most widely used construction materials globally, particularly in infrastructure, housing, and large-scale public works projects. Due to the massive volume in which it is consumed, even modest reductions in the cost per cubic meter can result in substantial financial savings. For example, a reduction of 259 Ethiopian birr per cubic meter in a project requiring just 100 m<sup>3</sup> of concrete results in a direct saving of 25,900 birr. In large infrastructure developments or housing projects exceeding 1,000 m<sup>3</sup>, this translates into cumulative savings potentially reaching hundreds of thousands of birr, underscoring the critical importance of economically optimized mix designs (Mehta & Monteiro, 2014; Thomas & Jennings, 2019).

The cost-efficiency demonstrated by the experimental mix in this study is primarily attributed to two interrelated strategies. First, the partial replacement of Ordinary Portland Cement (OPC) with Portland Pozzolana Cement (PPC) significantly reduces material costs, as PPC is generally less expensive than OPC due to its lower clinker content and greater availability of natural pozzolanic materials (Habert et al., 2010). Second, the use of citric acid as an admixture enhances workability, potentially eliminating the need for more costly commercial admixtures such as high-range water reducers or set retarders (Ramachandran, 1995). This dual strategy not only delivers technical adequacy but also supports economic optimization, aligning with the overarching goals of sustainable and affordable construction.

Such material cost reductions are particularly critical in the context of low-cost housing schemes, rural road networks, and community infrastructure projects. Stakeholders including government agencies, NGOs, and private contractors operating under budgetary constraints can benefit significantly from mix designs that maintain performance while lowering material costs. The observed savings of 259 birr per cubic meter make the proposed mix highly suitable for such cost-sensitive applications.

Beyond financial advantages, this approach contributes to environmental sustainability. Replacing a portion of OPC with PPC reduces the embodied carbon of the concrete, as PPC production involves less energy-intensive clinker burning (Scrivener et al., 2018). Additionally, the use of citric acid, a biodegradable and less energy-intensive compound, supports environmentally responsible admixture practices. Together, these aspects promote broader adoption of resource-efficient, low-carbon construction technologies that address both environmental and economic sustainability imperatives.

#### **4.5 Environmental Significance of PPC and Citric Acid in Concrete**

In addition to the economic merits, the integration of Portland Pozzolana Cement (PPC) and citric acid into concrete mix design provides significant environmental advantages. These materials collectively contribute to sustainable construction practices by reducing greenhouse gas emissions, promoting industrial waste utilization, and minimizing the overall ecological footprint associated with cement and concrete production.

##### **4.5.1 Environmental Benefits of Portland Pozzolana Cement (PPC)**

###### **a) Reduction in CO<sub>2</sub> Emissions:**

The production of Ordinary Portland Cement (OPC) is one of the most carbon-intensive industrial processes, releasing approximately 850 to 900 kg of CO<sub>2</sub> per ton of clinker primarily due to the calcination of limestone and high-temperature kiln operations (Habert et al., 2010; Scrivener et al., 2018). PPC, which incorporates supplementary cementitious materials such as fly ash, significantly lowers clinker content. By partially substituting OPC with PPC, carbon emissions per unit of cement are reduced, supporting climate-friendly construction practices.

**b) Utilization of Industrial Waste:**

Fly ash, a pozzolanic by-product of coal combustion in power plants, is a key component of PPC. Its use in cement contributes to sustainable waste management by diverting potentially harmful industrial waste from landfills. Effective utilization of fly ash mitigates environmental hazards such as heavy metal leaching, groundwater contamination, and soil degradation (Malhotra & Mehta, 2005).

**c) Enhanced Durability and Lifecycle Extension:**

The pozzolanic reaction in PPC improves the microstructure of concrete by refining pore structure and reducing permeability. This results in enhanced resistance to chemical attack, sulfate exposure, and chloride penetration, thereby prolonging the service life of concrete structures. Longer service life leads to reduced demand for repair, replacement, and associated construction materials contributing to lower resource consumption and environmental impact over time (Mehta & Monteiro, 2014).

#### 4.5.2 Environmental Contributions of Citric Acid

**a) Biodegradable and Eco-Friendly Nature:**

Citric acid is a naturally occurring organic acid derived from citrus fruits and widely used in the food and pharmaceutical industries. Unlike synthetic admixtures, citric acid is biodegradable and non-toxic, making it an environmentally safe alternative for modifying concrete properties. It poses minimal environmental risks during concrete production and disposal (Ramachandran, 1995).

**b) Reduction in Petrochemical-Based Admixtures:**

As a natural set retarder and plasticizer, citric acid can reduce or replace petroleum-based admixtures such as lignosulfonates or synthetic polymers, which are often associated with toxicity and environmental persistence. This replacement contributes to a reduction in the use of non-renewable resources and harmful chemical compounds in construction materials (Matschei et al., 2007).

**c) Improved Workability and Reduced Water Demand:**

Citric acid enhances the workability of concrete by dispersing cement particles and reducing internal friction, which enables a lower water-to-cement ratio without compromising flowability. This reduction in water content can improve strength and durability while

minimizing cement usage—thereby indirectly reducing the energy consumption and CO<sub>2</sub> emissions tied to cement production (Zhang et al., 2015).

In conclusion, the combined use of PPC and citric acid aligns closely with green construction principles by lowering the environmental impact of concrete production. Their adoption supports more sustainable engineering practices through carbon reduction, waste valorization, and a shift toward biodegradable admixture systems. These strategies not only improve material performance but also contribute meaningfully to climate resilience and environmental stewardship in the construction sector.

## CHAPTER FIVE

### CONCLUSION

This study aimed to evaluate the combined effect of Portland Pozzolana Cement (PPC) as partial replacement of OPC and citric acid in enhancing the performance of concrete for reinforced concrete applications. The experimental investigation focused on assessing the key properties of concrete, including setting time, workability, and compressive strength, when incorporating PPC and citric acid as partial cement replacements and additives. The following conclusions can be drawn from the findings:

**Setting Time:** The inclusion of citric acid resulted in an increase in both initial and final setting times for all experimental mixes. This finding indicates that citric acid retards the hydration process in concrete, which is advantageous in specific applications where slower setting is required i.e. long distance travel, traffic jam, and hot temperature.

**Effect on Workability:** The addition of citric acid in the concrete mix, in combination with PPC, led to a slight improvement in workability compared to the control mix. This can be attributed to citric acid's potential role as a plasticizer, which reduces friction between particles and improves flow ability. PPC also enhances the workability of concrete due to the inclusion of pozzolanic materials, such as fly ash; in PPC enhances the cohesiveness and plasticity of the concrete mix, making it easier to work with and reducing the need for excessive water. The workability of the concrete mixes remained within acceptable limits, making the use of citric acid & PPC beneficial for achieving better consistency in the mix.

**Compressive Strength:** Initially, compressive strength tests were conducted for three different binder combinations: 60% OPC + 40% PPC, 50% OPC + 50% PPC, and 70% OPC + 30% PPC. Among these, the mix containing 60% OPC and 40% PPC was selected due to intermediate compressive strength and cost. This intermediate performance may be attributed to the balanced pozzolanic activity of PPC and the early strength contribution of OPC, resulting in enhanced overall strength development. Following the evaluation of compressive strength for the binder combinations, the mix that exhibited intermediate performance was further modified with varying dosages of citric acid (0.1%, 0.2%, 0.3%, and 0.4% by weight of PPC cement). Among these, the optimum compressive strength was achieved at a citric acid dosage of 0.3%. The mix with 40% PPC replacement and 0.3% citric acid exhibited the highest compressive strength, achieving 32.4 MPa at 28 days. However, beyond 0.3% citric acid replacement, the strength began to decrease, likely due to over retardation of hydration.

**Suitability for Reinforced Concrete Applications:** Based on the results, it is evident that the combination of PPC and citric acid can improve the performance of concrete in reinforced concrete applications. The use of PPC as a partial replacement for OPC is particularly beneficial in improving durability and sustainability, while citric acid enhances workability and retard hydration. The concrete mixes with up to 40% PPC and 0.3% citric acid exhibited promising results, making them suitable for applications where early strength are critical.

**Cost Analysis:** The cost analysis reveals that PPC-based concrete is more economical than OPC-based concrete, primarily due to the lower base price of PPC. Among the tested combinations, PPC with 0.3% citric acid provided the best balance between cost efficiency and performance, maintaining adequate strength while reducing material costs compared to OPC mixes. Thus, for sustainable and cost-effective construction, PPC modified with a controlled dosage of citric acid is a more favorable alternative to OPC.

### **Recommendations for Future Research**

Although this study has demonstrated the potential benefits of PPC and citric acid, further research is required to fully understand the long-term effects and mechanisms of citric acid in cement hydration. Future studies should explore the interaction of citric acid with other admixtures, and the effects on concrete performance under different environmental conditions. Additionally, investigating the influence of PPC and citric acid on the shrinkage, thermal behavior, and corrosion resistance of reinforced concrete would provide a more comprehensive understanding of their suitability for large-scale applications.

## REFERENCES

- [1] Meseret Simachew, “Study on Application of Portland Pozzolana Cement for Structural concrete,” Msc, Addis Ababa University, Addis Ababa, 2021.
- [2] I. (Itzhak) Soroka, “Portland cements paste and concrete” Macmillan, 1979. Accessed: Aug. 19, 2024. [Online]. Available: <https://cir.nii.ac.jp/crid/1130000797592185984.bib?lang=en>
- [3] Neville A.M and J.J Brooks, “Concrete Technology, 2nd ed. Pearson Education Limited, 2010.
- [4] Z. Li, “Advanced Concrete Technology” Wiley, 2011. doi: 10.1002/9780470950067.
- [5] M. Tokyay, “Cement and Concrete Mineral Admixtures”,CRC Press, 2016. doi: 10.1201/b20093.
- [6] ASTM International, “Standard Specification for Blended Hydraulic Cements,” 2003.
- [7] Gajanan M. Sabnis, “Green Building with Concrete, 2nd ed. CRC press, 2016.
- [8] Johanna Lehne and Felix Preston, Making Concrete Change Innovation in Low-carbon Cement and Concrete. Chatham House, 2018.
- [9] American Society for Testing and Materials, “Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete,” ASTM C-618, 2003.
- [10] Pierre Claude Aitcin, Binders for Durable and Sustainable Concrete. Taylor & Francis e- Library, 2008.
- [11] Addisu Fentaw, “Study on the Uses of Derba Ordinary Portland and Portland Pozzolana Cements for Structural Concrete Production,” MSc, Addis Ababa University, Addis Ababa, 2014.
- [12] Dhanya Sathyan, K B An, K M Mini, and Aparna S, “Optimization of Superplasticizer in Portland Pozzolana Cement Mortar and Concrete,” 2018.
- [13] Pierre Claude Aitcin and Sidney Mindess, “Sustainability of Concrete,” Taylor & Francis e- Library, p. 97, 2011.

- [14] Rasyiid Lathiif Amhudo, Tavio, and I Gusti Putu Raka, “Comparison of Compressive and Tensile Strengths of Dry-Cast Concrete with Ordinary Portland and Portland Pozzolana Cements,” *Civil Engineering Journal*, vol. 4, no. 8, 2018.
- [15] Costas Georgopoulos and Andrew Minson, “Sustainable Concrete Solutions,” Wiley Blackwell, John Wiley & Sons, pp. 22–23, 2014.
- [16] Ravindra K. Dhir, Michael J. Mc Carthy, and Moray D. Newlands, “Concrete for Extreme Conditions,” Thomas Telford Ltd, pp. 67–71, 2002.
- [17] Mengistu Aregaw, “Investigation of Calcite and Volcanic Ash for their Utilizations as Cement Filling and Additive Materials,” Msc, Addis Ababa University, Addis Ababa, 2010.
- [18] American Society for Testing and Materials, ASTM C33, Standard Specification for Concrete Aggregates. West Conshohocken: ASTM International, 2008.
- [19] Steven H. Kosmatka, Beatrix Kerkhoff, and William C. Panarese, *Design and Control of Concrete Mixtures*, 14th ed. Portland Cement Association, 2003.
- [20] Thomas Dyer, “Concrete Durability (2014),” Taylor & Francis Group, p. 23,.
- [21] Ethiopian Building Code Standard, EBCS-2 (1995). “Structural Use of Concrete” Addis Ababa: ministry of Works and Urban Development,
- 22 ASTM C494/C494M-19. (n.d.). Standard Specification for Chemical Admixtures for Concrete. . ASTM International.
- 23 Bentz, D. P., Jensen, & O. M. (2004). Mitigation strategies for autogenous shrinkage cracking. *Cement and Concrete Composites*.
- 24 Bijen, J. (1996). Benefits of slag and fly ash. *Construction and Building Materials*. 309–314.
- 25 Dodson, & v. H. (1990). *Concrete Admixtures*. . Van Nostrand Reinhold.
- 26 Habert, G., d’Espinoze, de Lacaillerie, J. B, & Roussel, N. (2010). An environmental evaluation of geo polymer based concrete production: Reviewing current research trends. . *Journal of Cleaner Production*.
- 27 Hewlett, P. C, Liska, & M. (2019). *Lea’s Chemistry of Cement and Concrete* (5th ed.). Butterworth-Heinemann.

28. Kodur, v. K. R, Phan, L., & T. (2007). Critical factors governing the fire performance of high strength concrete systems. *Fire Safety Journal*, 482–488.
29. Malhotra, v. M., Mehta, & P. K. (2005). *High-Performance, High-Volume Fly Ash Concrete: Materials, Mixture Proportioning, Properties, Construction Practice, and Case Histories*. . Supplementary Cementing Materials for Sustainable Development Inc.
30. Matschei, T., Lothenbach, B., Glasser, & F. P. (2007). The role of calcium sulfate in cement hydration. *Cement and Concrete Research*.
31. Mehta, P. K, Monteiro, & P. J. M. (2014). *Concrete: Microstructure, Properties, and Materials* (4th ed). McGraw-Hill Education.
32. Mindess, S., Young, F., Darwin, & D. (2003). *Concrete* (2nd ed). Pearson Education.
33. Neville, & A. M. (2011). *Properties of Concrete*. 5th ed.
34. Péra, J., Husson, S., Guilhot, & B. (1999). Influence of finely ground limestone on cement hydration. *Cement and Concrete Composites*.
35. Ramachandran, v. S., Feldman, R. F., Beaudoin, J. J., Sakai, & E. (1996). *Concrete Admixtures Handbook: Properties, Science and Technology* (2nd ed). Noyes Publications.
36. Scrivener, K. L., John, v. M., Gartner, & E. M. (2018). Eco-efficient cements: Potential economically viable solutions for a low-CO<sub>2</sub> cement-based materials industry. . *Cement and Concrete Research* .
37. Song, H.-W., & Saraswathy, V. (2007). Corrosion Monitoring of Reinforced Concrete Structures-A Review. In *Int. J. Electrochem. Sci* (Vol. 2). [www.electrochemsci.org](http://www.electrochemsci.org)
38. Taylor. (1997). *Cement Chemistry* (2nd ed). Thomas Telford.
39. Thomas, J. J, Jennings, & H. M. (2019). *Fundamentals of Concrete*. MIT Open Course Ware.
40. Zhang, T., Feng, N., Hao, & T. (2015). Effects of organic acids on the hydration and microstructure of cement pastes. *Construction and Building Materials*.

## APPENDIX- 1

### Completed Mix design using DOE Techniques

|                              |  |   |   |                               |                              |
|------------------------------|--|---|---|-------------------------------|------------------------------|
| <b>13</b>                    | <b>1.1</b> characteristic strength<br><br><b>1.2</b> standard deviation<br><b>1.3</b> margin<br><b>1.4</b> Target mean strength<br><b>1.5</b> Cement type<br><b>1.6</b> Aggregate type: coarse<br>Aggregate type: fine<br><b>1.7</b> free water/cement ratio<br><b>1.8</b> maximum free water/cement ratio | Specified<br><br>Fig 3<br>C1<br>C2<br>Specified<br><br>Table 2 Fig 4<br>Specified | $\frac{30}{\text{Proportion defective } 5 \text{ percent}}$ $\frac{\text{N/mm}^2}{\text{N/mm}^2} \text{ or no data } 8 \text{ N/mm}^2$ $(k=1.64) \quad 1.64 * 8 = 13.12 \text{ N/mm}^2$ $30 + 13.12 = 43.12 \text{ N/mm}^2$ <p><b>OPC / SRPC/RHPC</b><br/> <b>Crushed</b><br/> <b>Uncrushed &amp; crushed</b><br/> <b>0.5</b></p> <p>---- } use the lower value of <b>0.5</b></p> |                               |                              |
| <b>2</b>                     | <b>2.1</b> slump or vibe time<br><b>2.2</b> maximum aggregate size<br><b>2.3</b> free water content  | Specified<br>Specified<br>Table 3   | Slump <b>30-60</b> mm or vibe time <b>--</b> s<br>$\frac{19}{\text{mm}}$ $\frac{190}{\text{kg/m}^3}$  |                               |                              |
| <b>3</b>                     | <b>1.1</b> cement content<br><b>1.2</b> maximum cement content<br><b>1.3</b> minimum cement content<br><br><b>3.4</b> modified free water/cement ratio   | C3<br>Specified<br>Specified  | $\frac{190}{0.5} = 380 \text{ kg/m}^3$ $\text{----- kg/m}^3$ $\text{----- kg/m}^3$ <p>Use 3.1 if <math>\leq 3.2</math><br/>         Use 3.3 if <math>\leq 3.1</math></p> $\text{-----}$   |                               |                              |
| <b>4</b>                     | <b>4.1</b> relative density of aggregate (SSD)<br><b>4.2</b> concrete density<br><b>4.3</b> total aggregate content  | Fig 5<br>C4   | $\frac{2.8}{\text{known/assumed}}$ $\frac{2400}{\text{kg/m}^3}$ $2400 - 380 - 209 = 1811 \text{ kg/m}^3$  |                               |                              |
| <b>5</b>                     | <b>5.1</b> grading of fine aggregate<br><br><b>5.2</b> proportion of fine aggregate<br><b>5.3</b> fine aggregate content<br><b>5.4</b> Coarse aggregate content  | Percentage passing 600 $\mu\text{m}$ sieve<br>Fig 6<br><br>C5                     | $\frac{60}{\%}$ $\frac{30}{\%}$ $\frac{1811}{1811} * 0.3 = 543.3 \text{ kg/m}^3$ $\frac{1811}{1811} - 543.3 = 1267.7 \text{ kg/m}^3$  |                               |                              |
| Quantity                     | Cement (kg)  | water (kg/lt)   | River sand (kg)   | Coarse aggregate (kg)         |                              |
| Per m3 (to the nearest 5kg ) | <b>380</b>   | <b>209</b>  | <b>543.3</b>  | <b>10 mm</b><br><b>418.34</b> | <b>20mm</b><br><b>849.36</b> |
| Per trial mix of 0.1 m3      | <b>38</b>  | <b>20.9</b>   | <b>54.33</b>  | <b>41.834</b>                 | <b>84.936</b>                |

APPENDIX 2:

Compressive strength Test Results (7<sup>th</sup> & 56<sup>th</sup> day)

Mix code: M<sub>O</sub> (OPC Mix)

Table A2.1: 7<sup>th</sup> and 56<sup>th</sup> -day Compressive strength test results for M<sub>O</sub>

| S.N | Age (days) | Cube Size (m)  |     |     | Volume (m <sup>3</sup> ) | Load (N) | Comp. Strength (MPa)<br>For 10cm cube | Comp. Strength (MPa)<br>For 15cm cube |
|-----|------------|----------------|-----|-----|--------------------------|----------|---------------------------------------|---------------------------------------|
|     |            | L              | B   | D   |                          |          |                                       |                                       |
| 1.  | 7          | 0.1            | 0.1 | 0.1 | 0.001                    | 262      | 26.2                                  | 25.15                                 |
| 2.  |            | 0.1            | 0.1 | 0.1 | 0.001                    | 270      | 27                                    | 25.92                                 |
| 3.  |            | 0.1            | 0.1 | 0.1 | 0.001                    | 291      | 29.1                                  | 27.94                                 |
|     |            | <b>Average</b> |     |     |                          |          | <b>27.43</b>                          | <b>26.34</b>                          |
| 1.  | 56         | 0.1            | 0.1 | 0.1 | 0.001                    | 349.6    | 40.06                                 | 38.46                                 |
| 2.  |            | 0.1            | 0.1 | 0.1 | 0.001                    | 354.6    | 37.54                                 | 36.04                                 |
| 3.  |            | 0.1            | 0.1 | 0.1 | 0.001                    | 374.6    | 37.46                                 | 35.96                                 |
|     |            | <b>Average</b> |     |     |                          |          | <b>38.35</b>                          | <b>36.82</b>                          |

Mix code: M<sub>P</sub> (PPC Mix)

Table A2.2: 7<sup>th</sup> & 56<sup>th</sup> day's Compressive strength test results for M<sub>P</sub>

| S.N | Age (days) | Cube Size (m)  |     |     | Volume (m <sup>3</sup> ) | Load (N) | Comp. Strength (MPa)<br>For 10cm cube | Comp. Strength (MPa)<br>For 15cm cube |
|-----|------------|----------------|-----|-----|--------------------------|----------|---------------------------------------|---------------------------------------|
|     |            | L              | B   | D   |                          |          |                                       |                                       |
| 1.  | 7          | 0.1            | 0.1 | 0.1 | 0.001                    | 136      | 13.6                                  | 13.06                                 |
| 2.  |            | 0.1            | 0.1 | 0.1 | 0.001                    | 147      | 14.7                                  | 14.11                                 |
| 3.  |            | 0.1            | 0.1 | 0.1 | 0.001                    | 162      | 16.2                                  | 15.55                                 |
|     |            | <b>Average</b> |     |     |                          |          | <b>14.83</b>                          | <b>14.24</b>                          |
| 1.  | 56         | 0.1            | 0.1 | 0.1 | 0.001                    | 266.3    | 22.45                                 | 21.56                                 |
| 2.  |            | 0.1            | 0.1 | 0.1 | 0.001                    | 276.3    | 25.85                                 | 24.82                                 |
| 3.  |            | 0.1            | 0.1 | 0.1 | 0.001                    | 293.8    | 25.93                                 | 24.9                                  |
|     |            | <b>Average</b> |     |     |                          |          | <b>24.75</b>                          | <b>23.76</b>                          |

**Mix code: M<sub>1</sub> (60% OPC + 40%PPC + 0.1% CA)**

Table A2.3: 7<sup>th</sup> & 56<sup>th</sup> -day Compressive strength test results for M<sub>1</sub>

| S.N | Age (days) | Cube Size (m)  |     |     | Volume (m <sup>3</sup> ) | Load (N) | Comp. Strength (MPa)<br>For 10cm cube | Comp. Strength (MPa)<br>For 15cm cube |
|-----|------------|----------------|-----|-----|--------------------------|----------|---------------------------------------|---------------------------------------|
|     |            | L              | B   | D   |                          |          |                                       |                                       |
| 1.  | 7          | 0.1            | 0.1 | 0.1 | 0.001                    | 210      | 21                                    | 20.16                                 |
| 2.  |            | 0.1            | 0.1 | 0.1 | 0.001                    | 218      | 21.8                                  | 20.93                                 |
| 3.  |            | 0.1            | 0.1 | 0.1 | 0.001                    | 233      | 23.3                                  | 22.37                                 |
|     |            | <b>Average</b> |     |     |                          |          | <b>22.03</b>                          | <b>21.15</b>                          |
| 1.  | 56         | 0.1            | 0.1 | 0.1 | 0.001                    | 370.4    | 32.67                                 | 31.36                                 |
| 2.  |            | 0.1            | 0.1 | 0.1 | 0.001                    | 380.4    | 31.83                                 | 30.56                                 |
| 3.  |            | 0.1            | 0.1 | 0.1 | 0.001                    | 390.4    | 34.88                                 | 33.48                                 |
|     |            | <b>Average</b> |     |     |                          |          | <b>33.13</b>                          | <b>31.8</b>                           |

**Mix code: M<sub>2</sub> (60% OPC + 40%PPC + 0.2% CA)**

Table A2.4: 7<sup>th</sup> & 56<sup>th</sup> day Compressive strength test results for M<sub>2</sub>

| S.N | Age (days) | Cube Size (m)  |     |     | Volume (m <sup>3</sup> ) | Load (N) | Comp. Strength (MPa)<br>For 10cm cube | Comp. Strength (MPa)<br>For 15cm cube |
|-----|------------|----------------|-----|-----|--------------------------|----------|---------------------------------------|---------------------------------------|
|     |            | L              | B   | D   |                          |          |                                       |                                       |
| 1.  | 7          | 0.1            | 0.1 | 0.1 | 0.001                    | 219.4    | 21.94                                 | 21.06                                 |
| 2.  |            | 0.1            | 0.1 | 0.1 | 0.001                    | 229.4    | 22.94                                 | 22.02                                 |
| 3.  |            | 0.1            | 0.1 | 0.1 | 0.001                    | 242.4    | 24.24                                 | 23.27                                 |
|     |            | <b>Average</b> |     |     |                          |          | <b>23.04</b>                          | <b>22.12</b>                          |
| 1.  | 56         | 0.1            | 0.1 | 0.1 | 0.001                    | 380.8    | 38.08                                 | 36.56                                 |
| 2.  |            | 0.1            | 0.1 | 0.1 | 0.001                    | 390.8    | 35.33                                 | 33.92                                 |
| 3.  |            | 0.1            | 0.1 | 0.1 | 0.001                    | 400.8    | 36.74                                 | 35.27                                 |
|     |            | <b>Average</b> |     |     |                          |          | <b>36.72</b>                          | <b>35.25</b>                          |

**Mix code: M<sub>3</sub> (60% OPC + 40%PPC + 0.3% CA)**

Table A2.5: 7<sup>th</sup> & 56<sup>th</sup> day Compressive strength test results for M<sub>3</sub>

| S.N | Age (days) | Cube Size (m)  |     |     | Volume (m <sup>3</sup> ) | Load (N) | Comp. Strength (MPa)<br>For 10cm cube | Comp. Strength (MPa)<br>For 15cm cube |
|-----|------------|----------------|-----|-----|--------------------------|----------|---------------------------------------|---------------------------------------|
|     |            | L              | B   | D   |                          |          |                                       |                                       |
| 1.  | 7          | 0.1            | 0.1 | 0.1 | 0.001                    | 230      | 23                                    | 22.08                                 |
| 2.  |            | 0.1            | 0.1 | 0.1 | 0.001                    | 237.3    | 23.73                                 | 22.78                                 |
| 3.  |            | 0.1            | 0.1 | 0.1 | 0.001                    | 252.3    | 25.23                                 | 24.22                                 |
|     |            | <b>Average</b> |     |     |                          |          | <b>23.99</b>                          | <b>23.03</b>                          |
| 1.  | 56         | 0.1            | 0.1 | 0.1 | 0.001                    | 391.3    | 39.13                                 | 37.56                                 |
| 2.  |            | 0.1            | 0.1 | 0.1 | 0.001                    | 401.3    | 40.13                                 | 38.52                                 |
| 3.  |            | 0.1            | 0.1 | 0.1 | 0.001                    | 416.3    | 41.63                                 | 39.96                                 |
|     |            | <b>Average</b> |     |     |                          |          | <b>40.3</b>                           | <b>38.68</b>                          |

**Mix code: M<sub>4</sub> (60% OPC + 40%PPC + 0.4% CA)**

Table A2.6: 7<sup>th</sup> & 56<sup>th</sup> day Compressive strength test results for M<sub>4</sub>

| S.N | Age (days) | Cube Size (m)  |     |     | Volume (m <sup>3</sup> ) | Load (N) | Comp. Strength (MPa)<br>For 10cm cube | Comp. Strength (MPa)<br>For 15cm cube |
|-----|------------|----------------|-----|-----|--------------------------|----------|---------------------------------------|---------------------------------------|
|     |            | L              | B   | D   |                          |          |                                       |                                       |
| 1.  | 7          | 0.1            | 0.1 | 0.1 | 0.001                    | 191.3    | 23.17                                 | 22.24                                 |
| 2.  |            | 0.1            | 0.1 | 0.1 | 0.001                    | 200.8    | 24.84                                 | 23.85                                 |
| 3.  |            | 0.1            | 0.1 | 0.1 | 0.001                    | 221.3    | 23.55                                 | 22.61                                 |
|     |            | <b>Average</b> |     |     |                          |          | <b>23.85</b>                          | <b>22.90</b>                          |
| 1.  | 56         | 0.1            | 0.1 | 0.1 | 0.001                    | 334      | 36.4                                  | 34.94                                 |
| 2.  |            | 0.1            | 0.1 | 0.1 | 0.001                    | 345      | 36.58                                 | 35.12                                 |
| 3.  |            | 0.1            | 0.1 | 0.1 | 0.001                    | 364      | 39.58                                 | 38                                    |
|     |            | <b>Average</b> |     |     |                          |          | <b>37.52</b>                          | <b>36.02</b>                          |

APPENDEX-3

Gallery

2.1. Materials used



Photo: Dangote cement



Photo: 02 coarse aggregate



Photo: 01 coarse aggregate



Photo: River sand



Photo: Citric Acid



Image: Tap water



Photo: **Weighting balance**



Photo: **Mechanical mixer**



Photo: **Slump Cone apparatus**



Photo: **Cube Mold**