CHEMICAL ACCELERATING ADMIXTURE DOSAGE OPTIMIZATION AND EFFECT ON CONCRETE PROPERTIES WITH DIFFERENT CEMENT BRANDS

Bikila Negash Tabor

A Thesis Submitted to Department of Civil Engineering

School of Civil Engineering and Architecture

Presented In Partial Fulfillment of The Requirements of Masters of Science in Civil Engineering (Specialization in Construction Engineering and Management)

Office Of Graduate Studies

Adama Science and Technology University

June, 2023

Adama, Ethiopia

CHEMICAL ACCELERATING ADMIXTURE DOSAGE OPTIMIZATION AND EFFECT ON CONCRETE PROPERTIES WITH DIFFERENT CEMENT BRANDS

Bikila Negash Tabor

Advisor: Fikreyesus Demeke Cherkos (Ph.D.)

A Thesis Submitted to Department of Civil Engineering

School of Civil Engineering and Architecture

Presented In Partial Fulfillment of The Requirements of Masters of Science in Civil Engineering (Specialization in Construction Engineering and Management)

Office Of Graduate Studies

Adama Science and Technology University

June, 2023

Adama, Ethiopia

DECLARATION

I declare that this thesis entitled "**Chemical Accelerating Admixture Dosage Optimization and Effect on Concrete Properties with Different Cement Brands"** is my own work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation. It is being submitted for the partial fulfilment for the award of the degree of Master of Science in Civil Engineering (Construction Engineering and Management) at Adama Science and Technology University School of School of Civil Engineering and Architecture.

Bikila Negash Tabor	____________	______________
Name of student	Signature	Date

RECOMMENDATION OF ADVISOR

I hereby certify that I have read and evaluated this thesis entitled **"Chemical Accelerating Admixture Dosage Optimization and Effect on Concrete Properties with Different Cement Brands"** prepared under my guidance by **Bikila Negash Tabor** submitted in partial fulfillment of the requirements for the degree of Maters of Science in Civil Engineering (Construction Engineering and Management). Therefore, I recommend that the candidate has fulfilled the requirements and hence he/she can submit the thesis to the department.

Fikreyesus Demeke (PhD)	________________________	________________
(Major Advisor/Supervisor)	Signature	Date

APPROVAL SHEET

I hereby certify that all the correction and recommendation suggested by the board of examiners are incorporated into the final thesis entitled **“Chemical Accelerating Admixture Dosage Optimization and Effect on Concrete Properties with Different Cement Brands”** by **Bikila Negash Tabor**.

______________________	______________________	______________
Major Advisor/Supervisor	Signature	Date
______________________	______________________	______________
Co-advisor/ Co-supervisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis open defense **Bikila Negash Tabor** have read and evaluated his final entitled **“Chemical Accelerating Admixture Dosage Optimization and Effect on Concrete Properties with Different Cement Brands”** and examined the candidate. This is, therefore, to certify that the final thesis has been accepted in partial fulfillment of the requirement of the degree of Master of Science in Civil Engineering (Construction Engineering and Management).

______________________	______________________	______________
Chairperson	Signature	Date
______________________	______________________	______________
Internal Examiner	Signature	Date
______________________	______________________	______________
External Examiner	Signature	Date

Finally approved and acceptance of the final thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the candidate´s Department Graduate Council (DGC) and School Graduate Committee (SGC).

______________________	______________________	______________
Department Head	Signature	Date
______________________	______________________	______________
School Dean	Signature	Date
______________________	______________________	______________
Office of Postgraduate Studies, Dean	Signature	Date

ACKNOWLEDGEMENTS

First, I would like to express my deep gratitude to my advisor **Fikreyesus Demeke (Ph.D)** for his continuous support and direction throughout the writing of my thesis. want to express my sincere gratitude to the Civil Engineering Department staff members that assisted me in fin ishing this thesis.

I want to express my profound gratitude to my family and friends for their support, understanding, and encouragement during my study years as well as for their assistance in writing this thesis. I owe a great deal of thanks to the several authors and researchers whose work I referenced or quoted in my thesis.

Last but not least, I would like to give my deepest gratitude to **Beza Bekele**, for her unwavering support throughout this entire research. Her encouragement and unwavering support have been my greatest source of strength.

ABSTRACT

Concrete is the most common building material that is used prominently in the construction industry. To achieve high early strength, the use of chemical accelerating admixtures is a valuable choice in concrete production. However, there is a lack of studies that provide the optimum dosage of accelerating admixture to produce desirable properties in concrete. Due to the lack of optimum dosage of accelerating admixture there are incompatibility problems between admixture and different brands of cement. In this regard, this study aims to determine the optimum dosage of chemical accelerating admixture and its effects on the properties of fresh and hardened concrete with different brands of cement. This experimental study was performed on C40 concrete made with Derba, Dangote, and National Ordinary Portland Cements and variable dosage range of 0.5% to 3% of ASTM Type E high-range water-reducing and accelerating admixture (HRWRAA) with variable water to cement ratios. Based on the experimental results, the physical properties of cements vary with cement brands, with Dangote cement having a higher fineness (96.29%) than Derba cement (93.39%) and National cement (95.09%). National cement has a faster initial (172.9min) and final (250min) setting time than Dangote and Derba cements. The optimum dosage of HRWRAA for Derba, Dangote, and National cements was 1.5%, 2%, and 1.5%, respectively. As Dangote cement is finer, it needs more HRWRAA to achieve the optimum values. At optimum dosage of HRWRAA, the slump value was achieved 135mm,175mm and 125mm for Derba, Dangote, and National cements, respectively. At optimum dosage of HRWRAA, Concrete mixes with Derba, Dangote, and National cements have achieved 7days compressive strength of 48.89Mpa, 50.67Mpa and 48.48Mpa respectively. At optimum dosage, 7 days tensile strength of control mix was improved by 68.05%, 64.52% and 51.95% for Derba, Dangote, and National cements, respectively. Similarly, at the age of 28 days, the flexural strength of control mix was improved by 12.23%, 11.57%, 10.32% and permeability of the control mix concrete was improved by 39.6%, 34.6% and 31.6% for Derba, Dangote, and National cements, respectively. However, the application of HRWRAA has shown an increase in the cost of concrete mix, with National Cement demanding a higher cost to produce 1m3 of concrete than Derba and Dangote Cements. Generally, HRWRAA plays a vital role in improving the physical properties, mechanical properties, and durability of concrete. However, overdoses of HRWRAA were found to reduce the strength of concrete by developing higher porosity due to bleeding and segregation occurrences.

Key words: *Accelerator, Dosage, Cement, Concrete Strength, Admixture*

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS AND ABBREVATIONS

ACI	American Concrete Institute
ASTM	American Society for Testing and Material
HRWRA	High Range Water Reducing Admixture
HRWRAA	High Range Water Reducing and Accelerating Admixture
SNF	Sulphonate Naphthalene Formaldehyde
SP	Superplasticizer
w/c	Water to Cement Ratio
GGBS	Ground Granulated Blast-furnace Slag
AASHTO	American Association of State and Highway Transportation Officials
ASTM	American Society for Testing and Materials
CA	Coarse Aggregate
FA	Fine Aggregate
MPa	Mega Pascal
C-S-H	Calcium Silicate Hydrate
C-40	Compressive strength of 40 MPa
OPC	Ordinary Portland cement
LOI	Loss of Ignition

LIST OF CHEMICAL FORMULAS

Al_2O_3	Aluminium Oxide
$Ca(OH)_2$	Calcium Hydro Oxide
$CaCO_3$	Calcium Carbonate
CaO	Calcium Oxide
Fe_2O_3	Iron Oxide
$MgSO_4$	Magnesium Sulfate
Na_2SO_4	Sodium Sulfate
K_2O	Potassium Oxide
MgO	Magnesium Oxide
Na_2O	Sodium Oxide
P_2O_5	Phosphate Oxide
SiO_2	Silica Oxide
SO_3	Sulfur tri Oxide
$3CaO.SiO_2$	Tricalcium silicate
$2CaO.SiO_2$	Tricalcium silicate
$3CaO.Al_2O_3$	Tricalcium aluminate
$4CaO.Al_2O_3.Al_2O_3$	Tetracalcium Aluminoferrite

CHAPTER ONE

1. INTRODUCTION

1.1 Background of the Study

Concrete admixtures are substances introduced into a batch of concrete in order to alter or improve the properties of the fresh or hardened concrete or both. According to (Raheem et al., 2010), numerous benefits are available through the use of admixtures such as: improved quality, acceleration or retardation of setting time, coloring, greater concrete strength, increased flow for the same water-to-cement ratio, enhanced frost and sulfate resistance, and improved fire resistance and improved workability. The specific effects of an admixture generally vary with the type of cement, mix proportion and dosage amount used (Kett, 2014). The effects of various admixtures on concrete can varied, and sometimes have an adverse effect on desired qualities. To get the intended results, it is necessary to carefully consider the quantity and type of admixture used. Adjusting the proportion of the concrete mixture to maintain the required qualities may be essential to maximize the use of certain admixtures (Li, 2011).

In modern periods, the need for optimum and rapid construction has given rise to the use of chemical admixtures. In the construction industry, a lot of admixtures are used for different purposes to improve different properties of concrete. Accelerating admixtures are one of these admixtures that have a significant impact on the workability, setting time, early strength, durability, and sustainability of concrete constructions (Naqash, 2014a). However, it is necessary to investigate the optimum dosage and how an admixture might be used to enhance a certain concrete mix using different cement brands (Sountharararajan & Sivakumar, 2012).

Accelerating admixture is added to concrete for the purpose of shortening setting time and increasing early strength development. Different accelerating admixtures can be found on the market; from those admixtures, high-range water-reducing accelerating admixtures, also known as ASTM Type E is the main types of admixtures that provide a lot of improvement for the properties of concrete. However, in Ethiopia, studies and research on the dosage optimization of accelerating admixtures and their impact on the characteristics of concrete have not been conducted well. Numerous factors, including the amount of accelerator used, the water-to-cement ratio, the grading of fine aggregate, the form and surface characteristics of the aggregate, and the volume of aggregate, influence the properties of concrete (Kett, 2014). Determining the dosage of accelerating admixture with different cement brands is therefore important in reducing quality related problems, total personnel and material resources as well as trial time for the development of the desired quality of concrete (James & Mattew, 2016). As a result, the primary goal of this thesis is to determine the optimum dosage of accelerating admixture with different cement brands in order to avoid cement-admixture incompatibility and to produce workable, early hardened, and strengthened and durable concrete in situations where early removal of formwork is needed, quick maintenance is required and at cold weather condition.

1.2 Statement of the problem

Concrete should be workable, strong, durable, watertight, and wear resistant. These qualities can often be obtained easily and economically by the proper usage of admixtures with optimum dosage (Tao et al., 2021). Even if there are various types of admixtures, chemical accelerating admixtures have become widely used due to their effectiveness in achieving high early strength concrete, which helps for early formwork striking and demolding; early removal of formwork is needed, quick maintenance is required and for areas with cold weather condition. However, the effectiveness of the Accelerating admixture can be affected by different factors such as water to cement ratio, cement brand, ambient temperature, time of addition, dosage of admixture added and mixing time (Kett, 2014).

There can also be an incompatibility between cementing materials and admixtures. Some incompatibility problems reported between cement and admixtures are: Slump loss, Low strength gain rate, Early stiffening of concrete, Segregation of concrete, shrinkage and Cracking(James & Mattew, 2016). As the effectiveness of chemical accelerating admixtures depends on different parameters, to avoid incompatibility problems and by maximizing the effectiveness, concrete trial mixtures should be made with the admixture and different cement brands to meet applicable specifications. The hydration reaction of cement and admixture has variations in performance when using different cement brands, even if they are of the same grade (Plank et al., 2015). This variation arises due to differences in the physical and chemical properties of the cement brands.

Hence, the compatibility of the accelerating admixture with other admixtures and job materials, as well as the effects of the accelerating admixture on the properties of fresh and hardened concrete with different cement brands, should be studied. Therefore, the amount of admixture recommended by the manufacturer should be verified and adapted with different cement brands (Shrivastava & Kumar, 2016). In this regard, the present study tried to provide optimum dosage of chemical accelerating admixture with different cement brands to increase the performance of accelerating admixtures with different cement brands and to enhance desirable quality of fresh and hardened concrete.

1.3 Objective

1.3.1 General Objective

The general objective of the study was to determine optimum dosage of chemical Accelerating admixture and investigating the effects on concrete properties with different cement brands.

1.3.2 Specific Objectives

The specific objectives of this particular research were

- ✓ To characterize physical properties of different cement brands.
- ✓ To study the effects of Accelerating admixture on physio-mechanical properties of concrete with different cement brands.
- ✓ To study the effect of Accelerating admixture on permeability of concrete with different cement brands.
- ✓ To compare cost impact of applying accelerating admixture on concrete mix with different cement brands.

1.3.3 Research Questions

The research questions that are expected this research would answer were:

- ✓ What is the character of physical properties of different cement brands?
- ✓ What is the effect of Accelerating admixture on physio-mechanical properties of concrete with different cement brands?
- ✓ What is the effect of Accelerating admixture on permeability of concrete with different cement brands?
- ✓ What is cost impact of applying accelerating admixture on concrete mix with different cement brands?

1.4 Significance of the Study

The main focus of this research is to study the dosage optimization and effects of high-range water-reducing and accelerating admixtures on concrete properties. The study provides a guide for construction stakeholders on the application of accelerating admixture for cost-effective production of high-quality concrete. The study is significant for contractors, ready-mix concrete suppliers, Construction Material Manufacturers, and project owners to look for the optimum dosage of accelerating admixture to achieve desired plastic or hardened concrete properties such as workability, setting time, early strength, and durability of concrete in an economical and efficient way. It also emphasizes the need for compatibility testing of cement and admixture and further research to ensure the effectiveness of the accelerating admixtures.

1.5 Scope and Limitations of the Study

The research conducted aimed to study the effect of an accelerating admixture, specifically the ASTM Type E Polymeric Sulphonate Naphthalene-based HRWRAA, on the fresh and hardened properties of concrete. The study focused on three commonly used ordinary Portland cement brands in Ethiopia, namely, Derba Cement, Dangote Cement, and National Cement. However, there were certain limitations. Firstly, the research did not consider other potential factors that could influence concrete performance, such as varying environmental conditions. Additionally, the study only examined the physical properties of the cement brands and did not have access to information regarding the relative proportions of ingredients from the manufacturing companies. Furthermore, the cost comparison analysis only examined the application of HRWRAA with three cement brands.

1.6 Research Organization

This thesis is organized into five chapters, namely introduction; literature review; materials and methods; results and discussion; conclusions and recommendation as stated below. Chapter one an introduction part that deals with the background of the study, mainly introduces statement of the problem, the general and specific objectives of the study, the research question that are tried to answer at the end of the research, significance of the study and scope and limitation of the study. The second chapter consists of the fundamentals of concrete and its constituent properties including the classification, production and requirement of cement and aggregate through referring and reviewing different literatures thoroughly. Further, general feature of concrete and chemical admixture was explained. In addition, the gaps that are facing during using of accelerating admixture in construction works were demonstrated. Chapter three was discussed about layout of the research, material properties; and method and mix proportion of cement slurry and concrete mixtures; and specimen preparation for this experimental research. Chapter four deals with test results that were observed from the experimental study and brief discussion focused on the findings. It also demonstrating the significance and implication of test result concisely. Chapter five was discussed the conclusions and the recommendations that were derived from the research. Finally, list of reference material that are used to support this research were listed, annexes showing mix design, test procedures, test results and photographs are attached at the end.

1.7 Summary

In this chapter, the background and statement of the problem have been presented. Further, the study aims, associated objectives, scope of the study, significance of the study and the organization of the thesis to achieve these objectives have briefly been presented. In the next chapter, the literature review and the gaps in the prior research will be presented.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Introduction

In recent years a considerable increase in use of chemical admixtures for concrete production has led to growth in scientific studies of their influence on thermal and physical characteristics of various types of concrete (Neville & Brooks, 2010). In maintaining and delivering the desired amount and quality of concrete, admixtures have a major role in concrete manufacturing industry. Admixtures have long been recognized as important components of concrete used to improve concrete performance. The original use of admixtures history in cementitious mixtures is not well documented. Concrete admixtures are defined as materials other than water, aggregates, cementitious materials, and fiber reinforcement, used as an ingredient of a cementitious mixture to modify its freshly mixed, setting, or hardened properties and that is added to the batch before or during its mixing (Plank et al., 2015).

Water-reducing and accelerating admixtures are used to reduce the quantity of mixing water required to produce concrete of a certain slump, reduce water-cement ratio, reduce cement content, or increase slump, reduce setting time and increase early strength of concrete. It can reduce the water content by approximately 12% to 35% (ACI, 2009). An increase in strength is generally obtained with water-reducing admixtures as the water-cement ratio is reduced concrete strength is increase. A reduction of water can result in finishing difficulties on flat surfaces when rapid drying conditions are present. Water reducers can be modified to give varying degrees of retardation while others do not significantly affect the setting time. According to ASTM C 494 (ASTM C 494/C 494M, 2001) Type A water reducers can have a little effect on setting, while Type D admixtures provide water reduction with retardation, and Type E admixtures provide water reduction with accelerated setting time and early strength.

High range water reducing and Accelerating admixture provides the ability to shorten the time of setting to meet the desired early strength of concrete. Since Type E admixture has water reduction, the strength improvement resulting from water-reducing admixtures is primarily a result of reducing the *w/cm* and increasing cement efficiency. For a given air content, concrete strength is inversely proportional to the *w/cm* and, therefore, the reduction in water needed to achieve the desired slump and workability when a water-reducing agent is used will result in an increase in strength(Shrivastava & Kumar, 2016). Therefore, the main discussion of this chapter is reviewing different literatures which focused on chemical admixture, particularly on the effects of high range water reducing and Accelerating (Type E) admixture on the concrete property. It dealt with the general features of those components and the effects of admixtures on the properties of plastic and hardened concrete. Even though, no sufficient research has been carried out on accelerating Admixtures with different cement brands in Ethiopia's context, empirical and theoretical literature relating to the topic has been reviewed.

2.2 Concrete Materials

Concrete is the most widely used strongest construction material that forms the basis of our modern life. It is produced by mixing fine and coarse aggregates, cement, water and additives in a certain given proportion (Li, 2011). basically, it's a mixture of two components: aggregates and paste. The paste, comprised of Portland cement and water, binds the aggregates into a strong mass as the paste hardens because of the chemical reaction of the cement and water. Additional cementitious materials and chemical admixtures may also be included in the paste to modify the properties of fresh and hardened concrete (H.Kosmatka et al., 2008).

Admixtures are ingredients other than water, aggregates, hydraulic cement, and fibers that are added to the concrete batch immediately before or during mixing (Duggal, 2017). When used properly, admixtures can accelerate or delay the setting time of concrete, improve workability, increase strength development, increase concrete durability, and improve finishibility. Basically, two categories of admixtures are available: mineral and chemical admixture (ACI, 2009). The specific effect of an admixture is dependent on a number of variables, such as the type and amount of admixture, the compound composition, kind, brand, amount of cement and so on. Therefore, an admixture should be employed only after appropriate evaluation of its effects, if necessary, by use with the particular concrete and under the conditions of use intended. The admixture quantities used are, with few exceptions, very small; nevertheless, they can impart certain desirable properties to the concrete (Collepardi, 1998). The main objective of this section is briefing concrete- making materials, exclusively cement, aggregates and admixtures.

2.2.1 Cement

Ethiopian Standard defines cement as a hydraulic binder, i.e. finely ground inorganic material which, when mixed with water, forms a paste which sets and hardens by hydration reaction processes and which, after hardening, retains its strength and stability even underwater. cement is a material with adhesive and cohesive properties that make it capable of bonding mineral fragments into a compact whole. For constructional purposes, the meaning of the term 'cement' is restricted to the bonding materials used with stones, sand, bricks, and building blocks (Neville, 1995). Generally, cementing materials are two types: non-hydraulic cements which either not able to set and harden in water (E.g. Non-hydraulic lime) or which are not stable in water (e.g. gypsum plasters) and Hydraulic cements which are cements able to set and harden in water, and give a solid mass which does not disintegrate, which is remain stable in water (ACI, 2009). E.g Portland cement.

2.2.1.1 Portland cement

Portland cement is a type of hydraulic cement that is commonly used in construction. It is made from a mixture of limestone, clay, and other materials, which are heated in a kiln at high temperatures(ACI, 2009). Portland cement is the most widely used type of cement and is used as a binding agent in concrete, mortar, and grout. It has excellent strength and durability properties, making it suitable for various construction applications. Additionally, it can harden and set even underwater, making it ideal for projects like bridges and dams. Portland cement is made by heating a mixture of limestone and clay or other materials of similar bulk composition and sufficient reactivity, ultimately to a temperature of about 1450C (Li, 2011). The raw materials required for manufacture of Portland cement are calcareous materials, such as limestone or chalk, and argillaceous material such as shale or clay. The process of manufacture of cement consists of grinding the raw materials, mixing them intimately in certain proportions depending upon their purity and composition and burning them in a kiln at a temperature of about 1300 to 1500°C, at which temperature, the material sinters and partially fuses to form nodular shaped clinker (Biernacki et al., 2017). The clinker is cooled and ground to fine powder with addition of about 3 to 5% of gypsum. The Ethiopian standard ESC.DS.201 classifies Portland cement into five categories (CEM I, CEM II, CEM III, CEM IV and CEM V).

Table 2-1 Classification of cement according to Ethiopian standard

Designation	Description
CEM I	**Portland cement:** clinker with up to 5% of minor additional constituents
CEM II	Clinker with up to 35% of other constitutes (slag, silica fume, pozzolans, fly ash, burnt shale, and limestone) with 5% minor constituents: • Portland slag cement Portland silica fume cement • Portland pozzolana cement • Portland fly ash cement • Portland burnt shale cement • Portland limestone cement • Portland composite cement
CEM III	**Blast furnace cement:** Clinker with more than 35% blast furnace slag with 5% minor constituents.
CEM IV	**Pozzolanic cement:** Clinker with up to 55% of a composite of other constitutes (silica fume, pozzolana and fly ash) with 5% minor constituents.
CEM V	**Composite Cement:** Clinker with up to 49% pozzolana or fly ash with 5% minor constituents.

Ordinary Portland cement is a type of cement categorized under CEM I Portland cement and contains clinker with up to 5% of other constituents. OPC Cement is the most common type of cement and classified into three grades, namely 32.5 grade, 42.5 grade and 52.5 grade depending upon the strength of the cement at 28 days (Taylor, 1997). One of the most important benefits of OPC is the faster rate of development of strength. Ordinary Portland (CEM I) cement is suitable for general concrete construction when there is no exposure to sulphates in the soil. The standard requires that it is made from 95 to 100 percent of Portland cement clinker and 0 to 5 percent of minor additional constituents. Minor additional constituents are one or more of the other cementitious materials or filler. Filler is defined as any natural or inorganic mineral material other than a cementitious material (Mehta & Monteiro, 2005).

2.2.1.2 Manufacturing process of Portland cement

There are two basic methods called Dry process and Wet process used in Portland cement production, depending on the water content of the material feedstock. In Dry process Dry materials are proportioned, ground to a powder, blended and fed into the kiln. The process is avoiding the use of slurry material and as a result is far less energy intensive. Modern day kilns are much more efficient than the kilns of old (Simmons, 2011). Wet process Involves adding water to the proportioned raw materials then grinding, blending operations in slurry form. The wet process was the original rotary kiln process developed at a time when material handling of slurries was more developed than those of dry powders. However, it has much higher energy requirements due to the amount of slurry water that must be evaporated before calcinations can take place (Biernacki et al., 2017).

The following reaction take place during cement production below 1300 °C. first Water is completely driven off at a very initial stage of burning at temperatures as low as 400°C, then carbonates of calcium are completely detached to calcium oxide and carbon dioxide at temperature between 800-900oC, thirdly Decomposition of clay minerals takes place and finally he reaction of lime with quartz and clay mineral decomposition products to give belite (impure C_2S), aluminate (impure C_3A), and ferrite (impure C_4AF). at 1300-1450 °C Melt is formed mainly from the aluminate and ferrite, then 20-30% of the mix became a liquid. Much of the belite and nearly all lime reacts in the presence of melt to give alite (impure C_3S) and finally the materials nodulize to form clinker. At the end of the production process, Cooling and crystallization of the various mineral phases formed in the kiln (Taylor, 1997).

The raw materials used for the manufacture of cement consist mainly of lime, silica, alumina and iron oxide. The relative proportions, rate of cooling and fineness of grinding of these oxide compositions are responsible for influencing the various properties of cement (Aggarwal et al., 2015). About 95% of Portland cement clinker is made of combinations of four oxides. These are: lime (CaO), silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3). Other, so-called minor constituents or impurities include, among others, Magnesia, Sodium, and Potassium Oxides (the alkalies), Titanium, Phosphorous and Manganese Oxides (ACI, 2009).

2.2.1.3 The Physical Properties of Ordinary Portland cement

Ordinary Portland cement is a widely used construction material with various physical properties that make it a preferred choice in the construction industry. It is a fine powder that consists mainly of calcium silicates and aluminates, which are responsible for its binding and strength-giving properties (Uzoegbo, 2020). The physical properties of Ordinary Portland Cement include:

Fineness

The measurement of cement fineness is the size of the cement particle. It is often stated in square meters per kilogram (m^2/kg), which is the specific surface area of cement. The development of concrete's strength is significantly influenced by the cement's fineness. The surface area, hydration, and bonding with water and aggregates are all improved with finer cement particle size (Ferraris et al., 2018). Higher early strength of the concrete mix is produced by finer cement. OPC is a fine powder that has a specific surface area of between 225 and 450 m^2/kg. It is strongly reactive with water and promotes a quicker increase in strength.

Setting time

Cement setting time refers to the time it takes for a cement paste or mortar to harden and develop its full strength. There are two types of setting time for cement, initial setting time and Final setting time (Biernacki et al., 2017). initial setting time is the time taken by cement to harden sufficiently and to resist a certain amount of pressure. Final setting time is the time taken by cement to harden completely and attain its full strength. the final setting time of cement is around 10 hours. The setting time of cement can be affected by various factors such as the type of cement, water content, temperature, and humidity.

Compressive Strength

The compressive strength of cement is the capacity of cement to withstand crushing forces when subjected to an applied load. It is an important property of cement as it determines its overall strength and durability. The compressive strength of cement is typically measured in pounds per square inch (psi) or megapascals (MPa). the standard compressive strength test for cement is done by preparing mortar cubes of standard dimensions and allowing them to cure for a specific period. The cubes are then subjected to a compressive load until they fracture. The maximum load that the cube can bear before fracturing is recorded as the compressive strength of the cement. However, the strength may vary depending on the type of cement, water-cement ratio, and curing conditions (ACI, 2009).

Soundness

The soundness of cement refers to the ability of the hardened cement paste to retain its volume after setting. The soundness of cement is an important property and is determined by the Le Chatelier method or the Autoclave method according to ASTM C151. The Le Chatelier method determines the soundness by measuring the increase in length of a cement pat when immersed in water. The Autoclave method determines the soundness by subjecting the cement to high temperature and pressure in an autoclave. According to the ASTM C150 specification for Portland cement, the maximum amount of expansion for both methods should not exceed 0.8% for normal cement and 0.5% for rapid-hardening cement (Biernacki et al., 2017).

Heat of hydration

Heat of hydration is the amount of heat that is either released or absorbed when a substance is hydrated. When considering cement chemistry, it's used to describe the heat produced when cement and water are combined. This process is highly exothermic and can lead to temperature increases, which can have major implications for the strength and durability of concrete structures (Neville & Brooks, 2010). the heat of hydration of cement is influenced by a range of factors, including the chemical composition of the cement, the water-to-cement ratio, and the curing temperature. The higher levels of alite (C_3S) and belite (C_2S) in the cement result in higher heat of hydration, while the presence of supplementary cementitious materials such as fly ash or slag can reduce the heat of hydration.

Loss on Ignition

Loss on ignition (LOI) of cement refers to the mass of cement that is lost when it is heated to a specific temperature. When cement is heated at a temperature of around 1000 °C, the organic materials present in the cement, such as carbonates, sulfates, and hydroxides, are decomposed and converted to their oxide forms. This leads to a reduction in the mass of the cement, which is referred to as the LOI (Taylor, 1997). The LOI of cement is an important parameter as it indicates the amount of organic material present in the cement, which can affect its properties and performance of cement. A high LOI can lead to reduced strength, increased setting time, and reduced durability of the cement. Hence, the LOI of cement is an important factor that is monitored during the production and testing of cement. Higher LOI leads to lower cement strength and durability (Mehta & Monteiro, 2005).

2.2.1.4 Chemical composition of Portland Cement

Portland cement is composed of four main oxides, namely: lime (CaO) 60%-70%, Silica (SiO_2) 17%-25%, Alumina (Al2O3) 3%-8% and Iron Oxide (Fe_2O_3) 0.5%-6%. Additionally, magnesium oxide (MgO) 0.5%-4%, alkalis 0.3%-1.2% and SO_3 2%-3.5% (ACI, 2009). However, the principal compounds, in Portland cement exist not in the form of simple oxides but as minerals of more complex molecular structure. Portland cement is a hydraulic cement that is primarily composed of four main compounds namely tricalcium silicate ($3CaO.SiO_2$), dicalcium silicate ($2CaO.SiO_2$), tricalcium aluminate ($3CaO.Al_2O_3$) and tetracalcium aluminoferrite ($4CaO.Al_2O_3.Fe_2O_3$). As shown in the Table 2.2 ,These compounds are present in varying proportions and their amounts determine the properties of the cement (Taylor, 1997).

Table 2-2 Main compounds of Portland cement

Compound	Chemical Formula	Usual Range, Weight(%)	Properties
Tricalcium silicate	**3CaO .SiO2**	**45 – 60**	Harden rapidly. Provides early strength, High heat generation.
Dicalcium silicate	**$2CaO .SiO_2$**	**15 – 30**	Reacts & harden slowly, provide later strength,
Tricalcium aluminate	**3CaO.Al2O3**	**6 – 12**	First compound to hydrate, highest heat of generation, responsible for initial setting of cement,
Tetra calcium alumino ferrite	**4CaO.Al2O3.Fe $2O_3$**	**6 – 8**	Does not affect the behavior of cement. (No contribution to strength).
Gypsum	**$CaSO_4.2H_2O$**	**5**	Slow down setting time.

Tricalcium silicate (C_3S) is the most abundant compound in Portland cement, that comprising about 45% to 60% of the total mass. It reacts with water to form calcium silicate hydrate (C-S-H) gel, which is responsible for the strength and durability of the cement. Dicalcium silicate (C_2S) makes up about 15% to 30% of the cement and also contributes to strength development. Tricalcium aluminate (C_3A) makes up about 5% to 15% of the cement and reacts rapidly with water to form hydrated calcium aluminate compounds, which contribute to early strength development (Neville & Brooks, 2010). The presence of C_3A also affects the setting time and workability of the cement. Tetracalcium aluminoferrite (C_4AF) makes up about 5% to 10% of the cement and contributes to the color of the cement as well as its resistance to sulfate attack. In addition to these four main compounds, Portland cement may contain other minor constituents such as gypsum ($CaSO_4.2H_2O$), which regulates the setting time of the cement, and various admixtures that can improve the workability, strength, durability, and other properties of the cement (Fohrer et al., 2007).

The relative amounts of these four chemicals in the final product of the cement will depend on the desired properties of the cement. For example, if a high rate of hydration (hardening) is desired, a higher proportion of C_3S may be used. If high early strength is a priority, a combination of C_3S and C_3A may be used. For ultimate strength, a higher proportion of C_2S may be included. The amount of heat given off during the hydration process can also be controlled by adjusting the levels of C_3A and sulfate content (Li, 2011). Furthermore, resistance to chemical attack can be enhanced by replacing some of the C_3S with C_2S, and by reducing the amount of C_3A in the cement. Therefore, the proportions of these chemicals can be adjusted to produce cement with a wide range of properties to suit specific construction.

2.2.1.5 Hydration Reaction of cement

primary function of cement in concrete is to bind the aggregate particles to create concrete that is both tough and durable. The hydration of the cement, which is influenced by the composition and fineness of the cement, is likely the one component that has the most impact on these qualities. When Portland cement comes into contact with water, a chemical reaction known as hydration takes place (Dams et al., 2023). However, Portland cement hydration is a far more complicated phenomenon. This is true because Portland cement is a complicated heterogeneous mixture of several chemical components.

The reaction of cement with water is a reaction of individual compounds. the hydration reaction of cement compounds is a complex process that involves the reaction of tricalcium silicate, dicalcium silicate tricalcium aluminate and Tetracalcium aluminoferrite with water to produce various hydrated compounds. These compounds contribute to the strength, durability, and setting properties of concrete (Taylor, 1997).

Table 2-3 Characteristics of hydration of cement compounds

Compounds	Reaction rate	Amount of heat liberated	Contribution to cement	
			Strength	Heat liberation
C_3S	Moderate	Moderate	High	High
C_2S	Slow	Low	Low initially, high later	Low
C_3A	Fast	Very high	Low	Very High
C_4AF	Moderate	Moderate	Low	Moderate

2.2.2 Aggregates

Concrete contains about 70-75% aggregates and its strength and durability is greatly influenced by the properties of aggregates used in concrete production. Concrete aggregate is a more or less inert, granular, usually inorganic material consisting normally of stone(s) or stone like solid(s). Typical examples are sand, gravel, crushed stone, and crushed slag. The use of aggregate in concrete is greatly reduces amount of cement that needed, which is important both from technical and economical standpoints (Rendon Diaz Miron & Koleva, 2017).

Aggregates can be classified in several different ways. One of the most frequently used classifications is according to the sizes of their grains or particles. the fine and coarse aggregates generally occupy 60% to 75% of the concrete volume and strongly influence the concrete's freshly mixed and hardened properties, mixture proportions, and economy (Neville, 1995). Fine aggregates generally consist of natural sand or crushed stone with most particles smaller than 5 mm. Coarse aggregates consist of one or a combination of gravels or crushed stone with particles predominantly larger than 5 mm and generally between 9.5 mm and 37.5 mm.

Aggregate's shape, texture and grading have a significant effect on the performance of concrete. Aggregate blends with well-shaped, rounded, and smooth particles require less paste for a given slump than blends with flat, elongated, angular, and rough particles. At the same time, uniform grading with proper amounts of each size result in aggregate blends with high packing and low water demand. Optimized aggregate blends have high packing, requiring low amounts of paste. As a result, they are less expensive and have less durability problems caused by the paste such as heat generation, porosity, and drying shrinkage (H.Kosmatka et al., 2008).

2.2.3 Classification of Aggregates

Aggregates are classified based on their geological origin, size, and shape. According to ASTM C33 Standard Specification for Concrete Aggregates, there are four major classifications of aggregates: Coarse aggregates are aggregates that are retained on a 4.75 mm (No. 4) sieve. They are generally round, angular, or irregular in shape and are sourced from natural or artificial sources. Fine aggregates are aggregates that pass through a 4.75 mm (No. 4) sieve but are retained on a 0.075 mm (No. 200) sieve. They are generally angular or rounded and sourced from natural or artificial sources. Lightweight aggregates are aggregates that have a low specific gravity due to the presence of natural or artificial pores. They are generally sourced from volcanic rocks or artificial materials such as expanded shale or clay. Heavyweight aggregates These are aggregates that have a high specific gravity due to the presence of heavy minerals such as magnetite or barite. They are generally sourced from natural or artificial sources ASTM C33 Standard Specification for Concrete Aggregates.

2.2.4 Properties of Aggregates

Particle size distribution

The particle size distribution of aggregates is called grading. Grading determines the paste requirement for a workable concrete since the voids among aggregate particles requires the same amount of cement paste to fill out in the concrete mixture (Siegel et al., 2013). To obtain a grading curve for an aggregate, sieve analysis has to be conducted Five size distributions are generally recognized: dense, gap graded, well-graded, uniform graded, and open graded. The dense and well-graded types are essentially the wide size ranges with smooth distribution. The dense graded is for coarse aggregate and well-graded for fine aggregate. Gap grading is a kind of grading that lacks one or more intermediate size. For uniform grading, only a few sizes dominate the bulk materials. Open grading is defined as being under compact conditions, the voids among the aggregate are still comparatively large. Also, the smaller size of aggregate usually dominates the bulk and can be easily disturbed by small cavity (Li, 2011). According to ASTM C33 (Standard Specification for Concrete Aggregates), aggregates for concrete should have a maximum size of 1.5 inches and a maximum percentage of passing the No. 4 sieve.

Shape and texture

The shape of aggregate is an important characteristic since it affects the workability of concrete. Not only will the characteristic of the parent rock, but also the type of crusher used influence the shape of aggregates. From the standpoint of economy in cement for a given w/c ratio, rounded aggregates are preferable to angular aggregates. Angular aggregates give higher strength and sometimes greater durability as a result of interlocking texture in the hardened concrete. Flat particles in concrete aggregates will have particularly objectionable influence on the workability, cement requirement, strength and durability. In general, excessively flat aggregates make very poor concrete (Chatveera & Lertwattanaruk, 2009).

Density and porosity

The qualities of the concrete can be significantly influenced by the density of the aggregates used in the concrete mix. Lightweight aggregates like expanded clay, shale, or perlite can be used to reduce the weight of concrete while dense aggregates like granite or basalt can increase the unit weight of concrete. The permeability and durability of the concrete can also be affected by the aggregate' porosity (Akinkurolere, 2021). Using porous aggregates may cause the concrete's strength and durability to degrade due to higher water absorption. To ensure that the final concrete has the desired qualities and performance, it is crucial to take aggregate properties into account when designing a concrete mix (Neville & Brooks, 2010).

Specific Gravity

The ratio of an aggregate's weight to the weight of an equivalent volume of water at a certain t emperature is known as the specific gravity of the aggregate. However, a higher specific gravity of the aggregate does not necessarily indicate higher strength and durability of concrete. A higher specific gravity typically indicates that the aggregate has higher density and is more compact, which can lead to better workability and increased resistance to wear and tear (Duggal, 2017). However, the strength and durability of concrete also depend on other factors such as the quality of cement, water-cement ratio, and curing methods.

Fineness Modulus

Fineness modulus, according to ASTM 125, is a single parameter that describes the average size of the particles in a aggregate sample and is calculated by adding the cumulative percentages by mass of aggregate retained on specified sieves and dividing the sum by 100. To characterize the overall coarseness or fineness of an aggregate, the concept of a fineness modulus is developed. FM is an index of the fineness of an aggregate the higher the FM, the coarser the aggregate. Different aggregate grading may have the same FM. It is useful in estimating proportions of fine and coarse aggregates in concrete mixtures.

2.2.5 Chemical Properties of Aggregates

A mineral is a naturally occurring solid substance with an orderly internal structure and a chemical composition that ranges within narrow limits. Mineral aggregates are chemically inactive in concrete, but they may commonly contain reactive substances that are harmful to concrete if present in excess quantities. Such substances are called deleterious materials. Three broad categories of deleterious substances that may be found in aggregates such as impurities which interfere with the processes of hydration of cement, coatings preventing the development of good bond between aggregate and the hydrated cement paste and certain individual particles which are weak or unsound in themselves (ACI, 2009).

2.2.6 Mechanical Properties of Aggregates

Aggregate characteristics that are shape, texture, and grading influence workability, finishability, pumpability, strength, shrinkage, creep, density, permeability, and durability of concrete. Construction and durability problems have been reported due to poor mixture proportioning and variation on grading (Kett, 2014). If aggregate voids are minimized, the amount of paste required for filling these voids is also minimized to maintain workability and strength. Consequently, optimal mixture proportioning will produce good-quality concrete with a minimum amount of cement. Within limits, the less paste at a constant water-cement ratio, the more durable the concrete (Li, 2011).

Generally, flexural strength is more affected than compressive strength. Rougher texture results in a greater adhesion or bond between the particles and cement matrix. The water requirement of round and/or smooth particles is less than that of angular and/or rough particles, especially for fine aggregates; On the other hand, coarse aggregate roughness increases the tensile and flexural strengths of the concrete.

It is generally understood that the compressive strength of concrete cannot significantly exceed the major part of the aggregate contained therein, although it is not easy to determine the crushing strength of the aggregate itself. The required information about the aggregate particles has to be obtained from indirect tests, such as crushing strength of prepared rock samples, crushing value of bulk aggregate, and performance of aggregate in concrete. The aggregate crushing value (ACV) test is prescribed by different standards, and is a useful guide when dea1ing with aggregates of unknown performance (Mehta & Monteiro, 2005).

2.3 Concrete Admixtures

Nowadays, ordinary concrete may not be able to achieve the required level of quality performance or durability when used for a number of purposes under a variety of situations. Admixture is used to modify the qualities of conventional concrete to make it suitable for any purpose. Admixtures are unique chemicals that are added to the batch before or during the mixing of concrete (Collepardi, 1998). An admixture is a material other than water, aggregates, hydraulic cement, and fiber reinforcement used as an ingredient in the cementitious mixture to modify its freshly mixed and hardened properties" (ASTM C125-68). Admixture can be a single chemical or a mixture of multiple chemicals and is available as powders, although most are aqueous solutions since, they are easier to dispense into the concrete and then spread (Tkaczewska, 2014).

2.3.1 Classification of Admixtures

Admixtures mainly grouped in to two mineral and chemical admixture (ACI, 2009). Mineral Admixtures are insoluble siliceous or aluminous materials, used at relatively large amounts. Since they are fine particle size of siliceous material can slowly react with calcium hydroxide at normal temperature to form cementitious products. They can be divided into two broad categories: pozzolanic and non-pozzolanic (Dodson, 1990).

The pozzolanic materials are essentially siliceous or aluminous materials which possessing cementitious properties and react with calcium hydroxide, in the presence of water, liberated in the hydration process to form compounds possessing cementitious properties. The pozzolana can be replaced with cement by 10 to 35 % (Tkaczewska, 2014). The substitution produces cement that is more impermeable and more resistant to the action of salt, sulphates, or acid water. But its strength gain is usually slower than normal concrete. Pozzolanic mineral admixtures, such as fly ash, silica fume, metakoline, Clay, Shale and rice husk ash, react with calcium hydroxide in the presence of water to form cementitious compounds. They increase the strength and durability of the concrete, reduce its permeability, and enhance its workability (Plank et al., 2015).

Non-pozzolanic admixtures, such as ground granulated blast furnace slag (GGBS), reduce the heat of hydration, improve the workability of the concrete, and increase its resistance to sulphate attack and alkali-silica reaction. Overall, mineral admixtures offer several advantages in the production of concrete, including improved performance, reduced cost, and environmental benefits. Due to numerous benefits associated with their use, they are also known as supplementary cementing materials (Dodson, 1990) .

Chemical admixtures are additives designed to enhance the properties of concrete in the plastic and hardened states, increase efficiency of ingredients and improve the economy of the concrete mixture (ACI, 2009). Chemical admixtures are used to modify the properties of fresh concrete, like increase workability without increasing water content, or decrease the water content without changing the workability, retard or accelerate the time of initial setting, reduce segregation, improve pumpability and reduce the rate of slump loss (Siegel et al., 2013). Also admixture are used to modify properties of hardened concrete, such as: reduce the rate of heat evolution during early cement hydration, accelerate the rate of strength development at early ages, increase strength (compressive, tensile, or flexural), increase resistance to freezing and thawing, decrease permeability, reduce expansion caused by alkali aggregate reaction, increase bond to steel reinforcement and between existing and new concrete, improve impact resistance and abrasion resistance, inhibit corrosion of embedded metal, produce colored concrete or mortar and reduce drying shrinkage (Ramachandran, 1996).

Concrete admixtures should only be used when the required modification cannot be made by varying the composition and proportions of the basic constituents' materials, or when the admixtures can produce the required effect more economically. The specific effects of an admixture generally vary with type of cement, cement-water ratio, ambient conditions (particularly temperature) and its dosage. The admixture is generally added in relatively small quantity ranging from 0.05% to 3% by weight of cement (Yuan et al., 2018). Over-use of admixture has negative effects on the properties of concrete. The major reasons for using admixtures are: to reduce the cost of concrete construction, to achieve certain properties in concrete more effectively than by other means, to maintain the quality of concrete during the stages of mixing, transporting, placing, and curing in adverse weather conditions and to overcome certain emergencies during concreting operations (H.Kosmatka et al., 2008).

The effectiveness of an admixture depends on several factors including: type and amount of cement, water to cement ratio, mixing time, slump, and temperatures of the concrete. Sometimes, effects similar to those achieved through the addition of admixtures can be achieved by altering the concrete mixture-reducing the water-cement ratio, adding additional cement, using a different type of cement, or changing the aggregate and aggregate gradation (H.Kosmatka et al., 2008). Trial mixtures should be made with the admixture and the job materials at temperature and humidity anticipated on the job. In this way the compatibility of the admixture with other admixtures and job materials, as well as the effects of the admixture on the properties of the fresh and hardened concrete, can be observed. The amount of admixture recommended by the manufacturer or the optimum amount determined by laboratory tests should be used. Generally, with respect to their characteristics chemical admixtures are classified into five, air-entraining, accelerating, water-reducing and set-controlling, admixtures for flowing concrete, and miscellaneous (ACI, 2009).

2.3.1.1 Air-Entraining Admixtures

Air-entraining admixtures are chemicals added to concrete or mortar mixes to increase the air content in the mix. Air-entraining admixtures, which are used in concrete to increase workability and improve freeze-thaw resistance. the use of air-entraining admixtures can reduce the compressive strength of concrete by 5-10%. This is because the air bubbles in the concrete reduce the density and increase the porosity, which can cause cracking and reduce the strength

(Portland Cement Association. Accessed 23 Nov. 2021). Air-entrained concrete is produced using air-entraining Portland cement, or by the introduction of air-entraining agents, under careful engineering supervision, as the concrete is mixed on the job. The amount of entrained air is usually between four and seven percent of the volume of the concrete, but may be varied as required by special conditions.

2.3.1.2 Accelerating Admixture

An accelerating admixture is a type of admixture used in concrete to increase the rate of early strength development. When an admixture is added to concrete, mortar, or grout, it speeds up the hydraulic cement's hydration, reduces the time required to set, or speeds up setting or early hardening, or both (ASTM C 494-86, Type C and Type E). This type of admixture is typically used in cold weather conditions to allow for earlier removal of formwork or to speed up construction schedules. According to the National Ready Mixed Concrete Association (NRMCA 2021) Accelerating admixtures can also improve the durability and workability of the concrete mix. Common materials used as accelerating admixtures include calcium chloride, sodium nitrate, and sodium chloride. However, it's important to follow proper dosage requirements and consult with a professional to ensure proper application and safety.

2.3.1.3 Water Reducing Admixture

Water reducing admixture is a type of chemical additive that is added to the mixture of concrete in construction to reduce the amount of water needed for the same consistency and workability(ACI, 2009). Water-reducing admixtures usually reduce the required water content for a concrete mixture by about 5 to 10 percent. Consequently, concrete containing a water-reducing admixture needs less water to reach a required slump than untreated concrete. This admixture helps in making the concrete more workable and easier to handle without compromising strength, durability, and other properties of the concrete. The use of water-reducing admixtures also reduces the drying time of concrete, making the construction process more efficient. With water-reducing admixtures, concrete manufacturers can achieve higher quality concrete with less water content, saving both time and cost (Shrivastava & Kumar, 2016).

2.3.1.4 Retarding Admixture

Retarding admixtures are used to slow down concrete's setting time and prevent the delaying effect of warm weather on concrete setting. High temperatures often cause an increased rate of hardening which makes placing and finishing difficult. Retarders keep concrete workable during placement and delay the initial set of concrete (Azmee & Shafiq, 2018). Most retarders also function as water reducers and may entrain some air in concrete. The dosage of a retarding admixture for concrete depends on several factors, including the type of admixture, the temperature and humidity of the environment, and the desired setting time. The dosage rate of retarding admixture can vary depending on the brand and type of admixture, and the manufacturer's recommendations should always be followed. It is important to note that the use of a retarding admixture can also affect the strength development and workability of the concrete, so care should be taken to ensure that the proper dosage is used to achieve the desired results. It is also important to check compatibility with other additives, like plasticizer and accelerator, if they are used in the mix (Duggal, 2017).

2.3.1.5 Super-plasticizing Admixtures

Super plasticizing admixtures, also known as high-range water reducers are chemical compounds added to concrete mixtures to increase their flowability without sacrificing strength or durability. superplasticizers reduce water content by 12 to 35 percent and can be added to concrete with a low-to-normal slump and water-cement ratio to make high-slump flowing concrete (ACI, 2009). Flowing concrete is a highly fluid but workable concrete that can be placed with little or no vibration or compaction. The effect of superplasticizers lasts only 30 to 60 minutes, depending on the brand and dosage rate, and is followed by a rapid loss in workability (Tkaczewska, 2014). These admixtures are typically used in high-strength concrete mixes, such as those used in high-rise buildings, tunnels, or bridges, where the concrete needs to flow easily to fill complex forms or reinforced sections. Superplasticizers work by dispersing the cement particles in the mixtures more effectively, reducing the surface tension of the water in the concrete mixture, and allowing the concrete to flow more easily while maintaining strength and durability. This can result in significant improvements in workability, early strength development, and long-term durability in the finished concrete structure (Plank et al., 2015).

2.3.2 Accelerating Admixture

The rates of chemical reactions between clinker materials in cements and water may be altered by adding small amounts of chemical substances to the cement-water mix. Substances affecting these rates to give an overall increase in the hydration rate is called accelerators(Azmee & Shafiq, 2018). Hence, an accelerator is added to concrete for the purpose of shortening setting time and increasing early strength development. Some accelerators affect either setting or hardening, while several accelerate both setting and hardening. There are different types of concrete accelerators such as Sodium Nitrate, Triethanolamine, Calcium Formate, Aluminum Sulfate and Potassium Nitrate (Tao et al., 2021) .The most widely used accelerating material is calcium chloride, which has been used since 1885 and finds application mainly in cold weather, when it allows the early strength gain to approach that of concrete cured under normal curing temperatures and, probably more importantly, reduces the setting time so that finishing operations can proceed without unnecessary delay. In this way, mold stripping, lifting and handling of precast items and finishing of flatwork can proceed normally. In addition, the concrete is less liable to damage by early age freezing (Naqash, 2014).

There has been controversy over the use of calcium chloride in concrete containing embedded metal in view of the possibility of corrosion, particularly where the concrete is of a porous nature. Many countries have made provision in the relevant codes of practice to prevent or limit its use where steel reinforcement is present This has renewed interest in 'chloride-free' accelerators as replacements for calcium chloride in reinforced concrete (Dorn et al., 2022).

2.3.3 Classification of Accelerators

The American Society for Testing and Materials (ASTM) C494 is a standard that classifies accelerators for concrete based on their chemical composition and intended use. There are two main categories of accelerators according to this standard.

2.3.3.1 Accelerating admixture Type C

According to ASTM C494, accelerating admixture Type C is a type of concrete admixture which is used to accelerate the setting time of concrete. This type of admixture is made up of chemicals that help in speeding up the hydration process of the cement. As a result, the concrete gains strength at a faster rate than normal concrete. Accelerating admixture Type C is commonly used in cold weather conditions, where the low temperatures can significantly slow down the setting and curing of concrete (ACI, 2009).This category of admixture is based mainly on the major raw materials, calcium chloride, calcium nitrate, calcium formate and calcium thiocyanate, with minor amounts of other materials occasionally being included in the formulations, such as calcium thiosulfate and triethanolamine. triethanolamine is not normally used alone but because it is sometimes used in other categories of admixture to compensate for retarding influences (Sounthararajan & Sivakumar, 2012).

Accelerating admixture type C is used in cases where the construction needs to be completed quickly or where low temperatures are preventing the concrete from setting properly. It can also be used in precast concrete applications where a faster setting time is desirable (Li 2018). One of the advantages of using accelerating admixture type C is that it reduces the time required for concrete curing, which allows for earlier removal of formworks and faster construction cycle times. However, it should be noted that excessive use of this admixture can result in cracking of the concrete due to the higher heat of hydration generated during the setting process. Overall, accelerating admixture type C is a useful in construction projects that require faster setting times for concrete (Yaphary et al., 2017).

2.3.3.2 Water Reducing and Accelerating ASTM Type E

According to ASTM C494, Type E admixture is a type of concrete admixture that can be used to accelerate setting time and increase early strength of concrete. This type of accelerating admixture accelerates the setting and early strength development of concrete, but is also effective at reducing the amount of water needed in the mix. Type E admixtures are recommended for use in situations where a higher strength concrete is required, or where the use of water-reducing admixtures is desirable.

The main compounds used in water reducing and accelerating admixture may vary depending on the manufacturer and specific product. However, the main compounds used in water reducing and accelerating admixtures are lignosulfonates, sulfonated naphthalene-formaldehyde condensates, and polycarboxylates (James & Mattew, 2016). It produced by using a combination of chemicals such mixed in specific proportions with other components like dispersants and air entraining agents to produce admixtures that can improve the workability of concrete and accelerate its setting time. Lignosulfonates are derived from wood and are the oldest and most widely used type of water-reducing admixture. Sulfonated naphthalene-formaldehyde condensates are synthetic and provide faster setting times than lignosulfonates (Ramachandran, 1996). Polycarboxylates are the newest type of admixture and are the most efficient at water reduction, with a lower dosage required to achieve the same effect as lignosulfonates or sulfonated naphthalene-formaldehyde condensates. According to an article published in the Journal of Adhesion Science and Technology, water-reducing agents such as lignosulfonates, sulfonated naphthalene formaldehyde, and sulfonated melamine formaldehyde, act as dispersants that prevent the aggregation of cement particles and increase the fluidity of the concrete mix, allowing a reduction of water content without compromising slump. In contrast, accelerating admixtures like calcium chloride and triethanolamine work by dissolving into the mixing water and increasing the ion concentration, which speeds up the chemical reactions between cement and water which leading to a faster strength gain (Naqash, 2014).

Water-reducing and accelerating admixtures can reduce the amount of water required up to 35% to improve the workability of the mix and reduce the setting time of the concrete and increase its early strength development. This, in turn, can result in a denser and stronger concrete and improve the flow of concrete and reduce the segregation and bleeding of mixtures (Portland cement association 2021). High range water reducing and accelerating admixture is widely used high-strength concrete in emergency or repairing construction. Concrete with this product can achieve 50% designed strength in one day under normal temperature (20 ±3). In the construction using sliding form, the concrete with this product can reach the strength to remove the form in 10 hours; in the large-form construction, the concrete with this product can reach the strength of removing the form in one day; if the curing temperature is 50°C, it can achieve 75% of designed strength in 12 hours. This product is designed for the constructions requiring hardening accelerating for normal concrete, steel-reinforced concrete, and pre-stress concrete under normal temperature, low temperature and negative temperature (Kosmatka et al., 2011).

2.3.4 Water Reduction Mechanism of Superplasticizer Admixture

Superplasticizer admixtures are commonly used in concrete to enhance its workability and reduce the water-cement ratio without compromising its strength and durability. The water reduction mechanism of superplasticizer admixtures occurs due to their ability to disperse and separate cement particles, which reduces the interparticle forces and allows water to penetrate the cement particles effectively. This mechanism leads to an increase in the workability of concrete with a reduced water-cement ratio, resulting in better flow and minimized voids.According to a study conducted by (Tkaczewska, 2014), superplasticizer admixtures mainly function by reducing the surface tension of water and increasing its fluidity, which helps to disperse cement powders and reduce particle interactions. The study also revealed that the mechanism works due to a combination of electrostatic and steric repulsion phenomena, which work together to disperse the cement particles in the concrete mixture. In addition, according to Banthia et al. (1999), superplasticizer admixtures contain a high amount of negatively charged sulfonic acid-based polymers that repel the negatively charged cement particles, which further reduces particle interactions and enhances the workability of concrete. Other factors that contribute to the water reduction mechanism of superplasticizer admixtures are their ability to improve cement hydration rate and reduce cement fineness.

2.3.5 Accelerating Mechanism of Accelerator

Accelerator admixtures are commonly used in concrete to speed up the setting and hardening process of the material. These admixtures accelerate the hydration of cement particles, thereby reducing the time required for the concrete to reach its desired strength. This can be achieved through a variety of mechanisms, such as increasing the temperature of the mix or providing additional ions that facilitate the chemical reactions that occur during cement hydration (Sounthararajan & Sivakumar, 2012). One of the mechanisms by which accelerator admixtures work is through the formation of calcium silicate hydrate (C-S-H) gel. The C-S-H gel is a product of the hydration of cement particles, and it gives concrete its strength and durability. Accelerator admixtures provide additional calcium ions to the mix, which react with the silicate ions to form C-S-H gel at a faster pace, leading to faster hardening and setting of the concrete. According to (Y. Cai et al. (2013), another accelerating mechanism of accelerator admixture involves the nucleation of calcium aluminate hydrate (C-A-H) gel.

2.3.6 Interaction of Water Reducing and Accelerating Admixture with Cement

Cement is a key material in concrete production, which provides the basic foundation and infrastructure for construction projects. However, the quality of concrete can be improved by using certain admixtures, such as HRWRAA (Collepardi, 1998). While cement helps provide the strength in concrete, HRWRAA improve the workability and early strength of concrete, and allow for the reduction of the water-cement ratio. The interaction between cement and HRWRAA occurs on the surface of cement particles. The HRWRAAs specifically adsorb to the surface of the cement particles, covering the negatively charged hydroxyl groups and neutralizing the surface charge. This allows for cement particles to disperse more evenly throughout the mix, and reduces the attractive forces between particles. Several studies have investigated the interaction between cement and HRWRAAs. For instance, a study by (Lee et al., 2019), found that HRWRAA molecules could react with calcium ions in the cement, forming a coordination bond. This interaction caused the HRWRAA to become partially embedded in the cement particles, leading to an increase in the workability of the concrete mix. Another study by (Dams et al., 2023) investigated the effects of HRWRAA on the microstructure of cement paste. The researchers found that HRWRAA could improve the dispersion of cement particles and reduce the water-cement ratio, leading to an enhancement in the mechanical and durability properties of the concrete.

2.3.7 Major Cement Properties Affecting Effectiveness of Water Reducing and Accelerating Admixture

2.3.7.1 Chemical composition

According to (Akanni et al., 2014), as shown in Table 2.4. Depend on source of raw materials, the manufacturing process, and the brand's quality control criteria all have an impact on cement quality in which different brands of cement with the same grade can differ in their chemical composition. The main components of most types of cement are calcium oxide, silicon dioxide, aluminum oxide, and iron oxide. However, different companies might utilize various source and processing methods. These changes in chemical composition may have an effect on the hydration reaction. For example, Portland cement, containing a mixture of limestone and clay, can have variations in the amount of calcium, iron, and aluminum oxides. (Rafi & Murtaza

Nasir, 2014) found that several cement brands had varying chemical compositions, leading to different heat release rates and strength development during hydration These variations can impact the rate and strength of the hydration reaction, affecting the overall quality and durability of structures built with various brands of cement (Omoniyi & Okunola, 2016).

Table 2-4 Oxide Composition with Cement Brands in Ghana (Akanni et al., 2014)

Cement	Dangote	Diamond	Elephant	Purechem
CaO (%)	64	66.3	62	67.1
SiO (%)	22	18	16	24
Fe_2O_3 (%)	5.2	3.4	3.2	3
AL_2O_3 (%)	5.6	4.4	5.2	5.8
SO_3 (%)	1.59	1.89	1.34	2.27
MgO (%)	0.58	2.14	1.48	2.38
LOI (%)	2.49	1.22	1.49	2.04

Table 2-5 Oxide Composition with Cement Brands in Nigeria (Omoniyi & Okunola, 2016)

Cement sample code	Percentage composition			
	CaO	**SiO_2**	**A12O3**	**Fe_2O_3**
As	58.92	20.47	3.83	2.31
Br	56.17	19.68	5.30	2.13
De	63.48	16.56	4.78	2.86
Sk	62.14	19.08	4.69	2.39
ASTM C150-07 SPECIFICATION	61–67	19–23	2.5–6.0	0–6.0

2.3.7.2 Cement mineralogy

Cement mineralogy can have a significant effect on the effectiveness chemical admixtures. Different types of cement have varying mineralogical compositions, which can impact the chemical reactions that take place between the admixtures and cement by (James & Mattew, 2016). Changing cement brands can have a significant impact on the rate of strength development of concrete HRWRAA. This is primarily due to the differences in the chemical composition of different cement brands, which can affect the interactions between the cement, the admixture, and the water. According to a study conducted by (Biernacki et al., 2017), changing cement brands can affect the setting time, strength development, shrinkage, and durability of the concrete.

The main components of cement that impact the performance of these admixtures are C_3S, C_2S, C_3A, and C_4AF. The presence of C3S (tricalcium silicate) in cement leads to better compatibility HRWRAA (Mehta & Monteiro, 2005). C_3S reacts with the admixture, which enhances its dispersing properties, leading to better workability and improved strength development.C_2S (dicalcium silicate) in cement does not have as significant an effect on HRWRAA as C3S. One study conducted by (Xie et al., 2020), investigated the effect of the chemical composition of cement on the strength development of concrete with HRWRAA. The study found that the presence of C3S in cement had a significant positive impact on the strength development of concrete with HRWRAA. cements with higher C_3A, such as calcium aluminate cement, exhibited greater effectiveness of HRWRAA. This is due to the fact that the aluminate mineral reacts more readily with the admixture, leading to greater improvement in workability and early strength gain

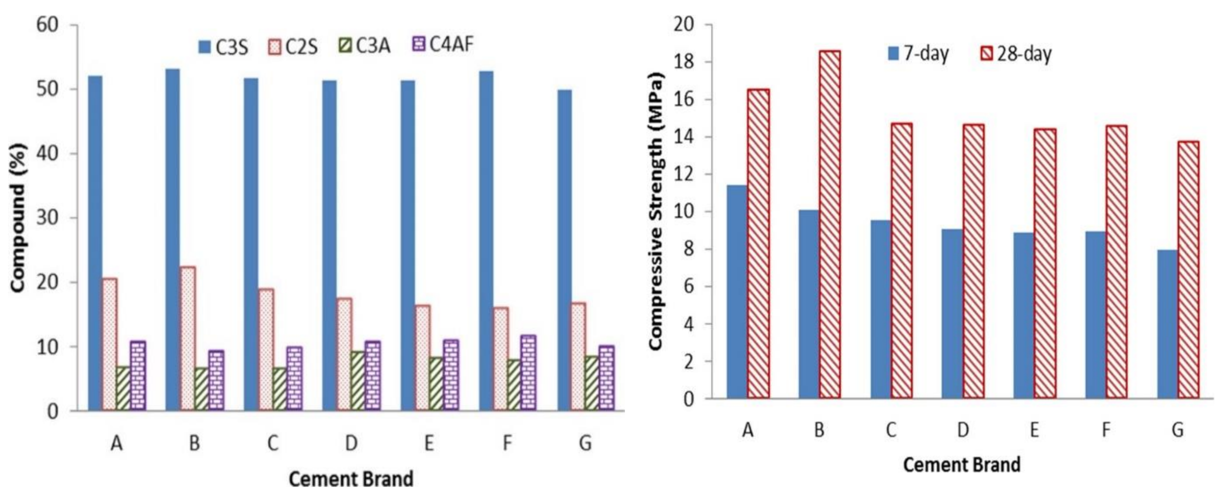
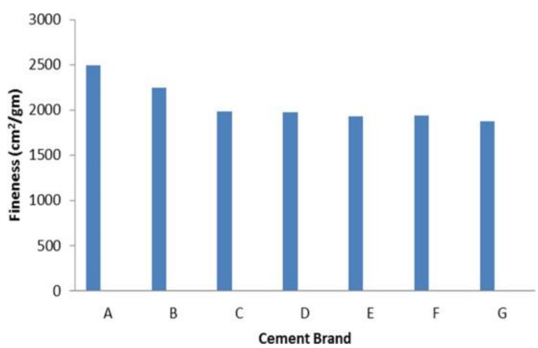


Figure 2-1 variation in Cement mineralogy and its effect on strength development with different cement Brands in Pakistan (Rafi & Murtaza Nasir, 2014)

2.3.7.3 Fineness

The fineness of cement can have a significant effect on the effectiveness of high-range water-reducing and accelerating admixtures. According to Li et al. (2016), the reduction in water demand achieved by admixtures is closely related to the particle size distribution and specific surface area of cement. Finer cement with a larger surface area can provide more reactive sites for the admixture to work, resulting in a higher degree of dispersion and better water reduction effect. However, if the cement is too fine, it can cause an increase in adsorption of the admixture on the surface of cement particles, which leads to a decrease in the effectiveness of the admixture. Furthermore, the workability of cement paste is also affected by the fineness of cement. The finer the cement, the greater the paste surface area, leading to increased water demand and slower setting. This counteract the effect of the admixture that aims to reduce the water demand and accelerate the setting (Shrivastava & Kumar, 2016).



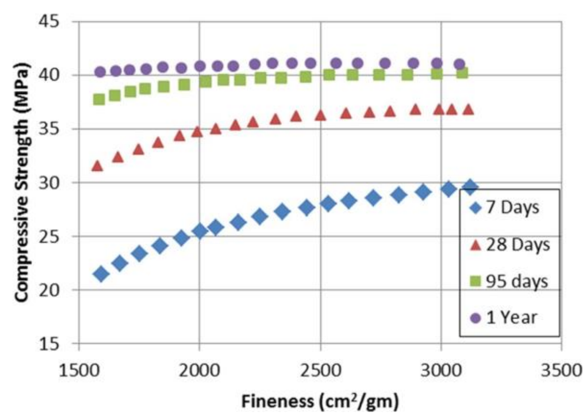


Figure 2-2 variation of fineness with cement brand and its effect on compressive strength in Pakistan (Rafi & Murtaza Nasir, 2014)

2.3.7.4 Setting time

Setting time of cement has a significant effect on the effectiveness of dosage of high range water reducing and accelerating admixtures. These admixtures are widely used in the construction industry to enhance the workability and strength of concrete. The effectiveness of these admixtures primarily depends on the setting time of cement. According to a study conducted by (Sounthararajan & Sivakumar, 2012), the setting time of cement affects the performance of high range water reducing admixture (HRWRAA). The study found that the dosage of HRWRAA required decreased as the setting time of cement increased. This is because a slower setting time allows more time for the HRWRAA to disperse and improve the workability of the concrete. Similarly, the setting time of cement also affects the performance of accelerating admixtures. According to a study by (Tkaczewska, 2014), a longer setting time of cement can significantly reduce the effectiveness of accelerating admixtures. admixtures

Table 2-6 setting time and soundness with cement Brands (Omoniyi & Okunola, 2016)

Cement sample	Initial setting time (Min.)	Final setting time (Min.)	Expansion (Soundness in mm)
As	191	236	3.43
Br	187	284	1.00
De	198	253	3.00
Sk	178	238	1.00
ASTM C150-07 SPECIFICATION	30 and above	Not more than 600	-

2.3.7.5 water-to-cement ratio

The water-to-cement ratio (w/c) is an important factor that affects the concrete mixture's workability, strength, and durability. Admixtures like high range water reducing and accelerating admixtures are commonly used to enhance the performance of concrete mixtures. These admixtures can help achieve high strength and durability with a reduced amount of water. Proper dosage of high range water reducing and accelerating admixtures is also essential for achieving the desired properties. The effectiveness of these admixtures may vary with different w/c ratios. Several studies have investigated the effect of w/c ratio on the performance of concrete mixtures containing these admixtures. According to a study by (Chu, 2019), the effectiveness of high range water reducing admixtures decreases with increasing w/c ratio. They found that for a given admixture dosage, the slump flow and compressive strength decreased as w/c ratio increased.

2.3.8 High Range Water Reducing and Accelerating Admixture Dosage optimization.

In order to determine the optimum dosage for the admixture with different cement brands, an experimental investigation should be carried (Aswed et al., 2022). The optimum dosage of accelerating admixtures different based on the specific cement brand's chemical composition. The optimum dosage required to achieve the desired performance depend on the cement's chemical composition. Changing cement brands can have a significant impact on the rate of strength development of concrete with accelerating admixture.

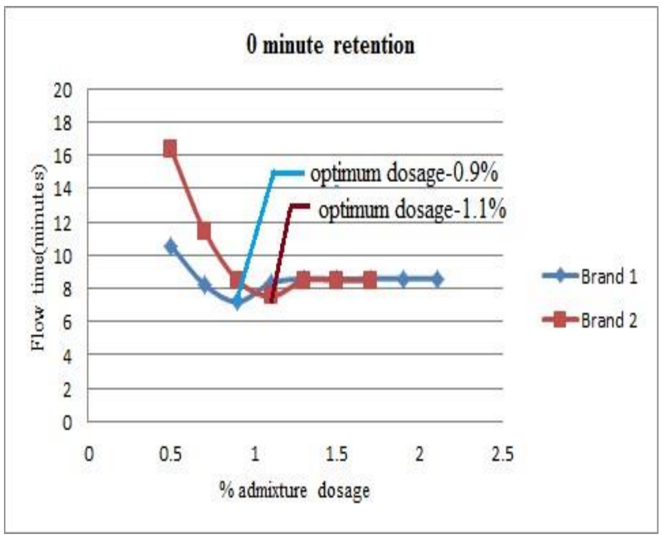


Figure 2-3 optimum dosage variation with cement brands (Antoni et al., 2017)

2.3.9 Effect Of High Range Water Reducing and Accelerating on Properties of Fresh Concrete

Workability

Workability of concrete is improved when HRWRAA admixtures are incorporated in the mixture at given water content (Lee et al., 2019). The ability of water reducing and accelelerating is to increase the slump of concrete depends on the type, dosage, w/c ratio, nature and amount of cement, aggregate, temperature, etc. (Sounthararajan & Sivakumar, 2012) investigated the properties of fresh concrete incorporating different dosages of HRWRAA, and the results showed that increasing the dosage of HRWRAA could significantly improve the workability of fresh concrete while maintaining a similar level of water content. HRWRAA are a type of superplasticizer that significantly reduces the amount of water required in concrete mixtures while maintaining workability, making the concrete much more cohesive and easier to handle. Accelerating admixtures can also be added to concrete to speed up the setting and hardening process. According to the study conducted (Naqash, 2014b). the use of can significantly improve the workability of concrete. The research found that the use of a specific type of HRWRAA, polycarboxylate ether-based superplasticizer, in combination with calcium nitrate accelerating admixture, increased workability without affecting compressive strength and other properties of concrete. The study also reported that the use of HRWRAA had effects on the properties of concrete (Plank et al., 2015).

Rate of slump loss

HRWRAA, are commonly used in concrete to increase the workability and reduce water content, which ultimately leads to higher strengths. However, these admixtures can also have an impact on the rate of slump loss of concrete, which refers to the loss of concrete workability over time (Tkaczewska, 2014). the use of HRWRAA can significantly increase the initial slump of concrete, but can also lead to a rapid rate of slump loss if not properly controlled. This is due to the fact that water reducing and accelerating admixtures contain molecules that are highly sensitive to adsorption on the surface of cement particles. As a result, if the dosage of HRWRAA is too high or if there is a delay in the casting process, the molecules can become permanently adsorbed on the surface of the cement particles, reducing the workability of the concrete (Ren et al., 2021).

the impact of HRWRAA on slump loss is highly dependent on other factors such as cement type, curing conditions, and temperature (Sounthararajan & Sivakumar, 2012).The study found that under hot conditions, there was a more rapid rate of slump loss in concretes containing superplasticizers compared to those without. In conclusion, HRWRAA can be effective in enhancing the workability and strength of concrete. However, their use can also lead to a rapid rate of slump loss if not properly controlled. Factors such as dosage, cement type, curing conditions, and temperature can all have an impact on the rate of slump loss (Dorn et al., 2022). It is, therefore, important to carefully consider these factors when using such admixtures in concrete production.

Bleeding and Segregation

Bleeding is the process where water rises to the surface of freshly laid concrete due to the settlement of solid particles. This can result in an excess of water on the surface of the concrete, which can cause surface defects and a reduction in durability (Sours, 2015). Segregation is the separation of course and fine particles in freshly mixed concrete, which can lead to an inconsistent mix and a reduction in strength. the use of HRWRAA in concrete production can have both positive and negative effects. While HRWRAA can improve workability and reduce water content, they can also increase the risk of bleeding and segregation (Delgado et al., 1996). Using improper dosage of HRWRAA reduces the surface tension of the water in the mix, making it easier for it to rise to the surface. In addition, HRWRAA can cause a faster setting time, which increases the risk of segregation. However, the effect of HRWRAA on bleeding and segregation can be minimized by various measures. One method is to use a suitable dosage of HRWRAA, which takes into account the specific mix design and environmental conditions. The addition of a suitable air-entraining agent can also help to reduce bleeding and prevent segregation.

Setting Time

the addition of high-range water reducing and accelerating admixtures decrease in the setting time of concrete. This is due to the fact that these admixtures accelerate the hydration reaction, resulting in faster setting and hardening of the concrete. the setting time of concrete decreased with increasing HRWRAA dosage, indicating the acceleration effect of HRWRAA on concrete setting (Raheem et al., 2010). Moreover, the study found that the early-age strength development of concrete increased with increasing HRWRAA dosage. These admixtures work by reducing the amount of water needed in the mix while increasing the rate at which the concrete hydrates and sets. However, it is important to note that while high range water reducing and accelerating admixtures can improve the speed of setting, they can also affect other properties of the concrete such as workability, strength, and durability. It is important to carefully consider the specific needs of a project before using these admixtures (Aggarwal et al., 2015).

2.3.10 Effect of High Range Water Reducing and Accelerating on Properties of Hardened Concrete

The properties of fresh concrete are important only in the first few hours of its history whereas the properties of harden concrete assume an important which is retained the remainder of the life of concrete. HRWRAA are concrete admixtures that can greatly affect the properties of hardened concrete. HRWRAAs are chemical admixtures that reduce the water content required for a given workability and reduce setting time and increase early strength, leading to improved strength and durability of the hardened concrete (Plank et al., 2015). Accelerators in this admixture, speed up the rate of hydration of cement, resulting in higher early strength and shorter setting time.

Compressive Strength

The use of HRWRAA in concrete significantly improved its compressive strength and durability properties. the compressive strength of concrete increased with increasing dosage of HRWRAA up to a certain point, after which the strength started to decline. The optimum dosage of HRWRAA could significantly improve the compressive strength of concrete (Gooi et al., 2020). The study found that the inclusion of HRWRAA in concrete reduced its water-cement ratio, resulting in improved compressive strength and workability and reduce setting time and increase early strength of concrete. Accelerators increased the early age strength development of concrete, allowing for earlier removal of formwork. the use of HRWRAA and acceleration admixtures significantly increased the early-age compressive strength of concrete and the increased strength was likely due to the improved workability and reduced water content of the mixture and increase temperature, which allowed for denser, strong and more homogeneous concrete(Tao et al., 2021). Overdosing of high range water reducing and accelerating admixtures can have significant negative effects on the properties of hardened concrete. These admixtures, when used in excessive amounts, can cause the concrete to lose its strength and durability over time (Yuan et al., 2018).

Tensile Strength of Concrete

The addition of HRWRAA to concrete significantly increased the split tensile strength compared to the control mix (Farokhzad et al., 2016). this increase is due to the reduction in the water-cement ratio and the acceleration of cement hydration. these studies suggest that the addition of HRWRAA to concrete can improve its split tensile strength. According to a study conducted by (Sounthararajan & Sivakumar, 2012), the addition of high-range water-reducing and accelerating admixture (HRWRA) to concrete can increase its tensile strength by up to 35%. However, the actual degree of increase is dependent on many factors such as the type and dosage of the admixture, the properties of the concrete, and the curing conditions. However, it is important to note that the effects of admixtures on concrete strength can be influenced by several factors, such as mix design, curing conditions, and the type and dosage of admixture used. Therefore, it is advisable to conduct site-specific tests before application of admixture in concrete. an excessive addition of up to 12% by weight of cement of such admixtures resulted in a reduction of splitting tensile strength of about 12-23% (Dorn et al., 2022).

Flexural Strength

The use of high-range water-reducing and accelerating admixtures in concrete has been shown to generally improve its flexural strength. an optimal dosage of HRWRAA can improve the flexural strength of concrete, but excessive dosage can result in a decrease in strength the use of HRWRAA resulted in an increase in the flexural strength of concrete by up to 11% for PCE-based admixture and up to 9% for NF-based admixture (Lee et al., 2019).

Permeability

HRWRAA are often used in the concrete industry to improve workability, achieve higher strengths, and reduce curing time. However, the effects of HRWRAA on the permeability of concrete, especially at high dosages, are not well understood. Several studies have been conducted to investigate the impact of HRWRAAs on the permeability of concrete, and the results are summarized below. the permeability of concrete decreased with an increase in the dosage of HRWRAAs, at a higher dosage of HRWRAA (1.5% of the cement weight) in concrete reduced its permeability by 22% compared to the control mix (Rendon Diaz Miron & Koleva, 2017). the accelerating effect of the admixture did not have a significant impact on the permeability of concrete. the permeability of the concrete was reduced with an increase in the dosage of HRWRAAs up to a certain level. However, at higher dosages, the permeability of the concrete increased significantly, indicating that the HRWRAA was not effective in reducing the permeability of concrete at high dosages (Azmee & Shafiq, 2018) Furthermore, the use of HRWRAAs significantly decreased the chloride ion penetration and increased the resistance of concrete against chloride ion penetration (Akinkurolere, 2021). overdosing of HRWRAA admixtures can result in higher chloride ion penetration and carbonation rates, leading to the corrosion of steel reinforcement in concrete, reducing its durability.

2.4 Research Gap

The research gap in chemical accelerating admixture dosage optimization and its effect on concrete properties with different cement brands lies in the lack of full studies that investigate the optimal dosage of chemical accelerating admixtures to improve concrete qualities with different cement brands. Although previous studies in Ethiopia have explored the effect of chemical admixtures on concrete properties, the effect of accelerating admixtures on the physical, mechanical and durability of concrete with different remains poorly understood. More research is needed to understand the mechanisms behind the interactions between cement, chemical accelerating admixtures, and other concrete ingredients. By conducting a thorough review of existing literature and identifying clear research gaps, a study on chemical accelerating admixture dosage optimization and its effect on concrete properties with different cement brands could make valuable contributions to the field. Due to variation of chemical and physical properties of cement, even with cement of the same grade with different brands, Chemical Accelerating admixture has not shown the same extent of rate of strength development. There is nothing wrong with either the Accelerating admixture or that of cement. The fact is that they are just not compatible to show maximum strength. However, practically not common to conduct further study to determine the optimum dosage of Accelerator that is effective in strength development of cement paste, rather uses the manufacturer's instructions directly. As a result, the primary goal of this thesis is to determine the optimum dosage of accelerating admixture with different cement brands in order to avoid cement-admixture incompatibility and to produce workable, early hardened, and strengthened and durable concrete in situations where early removal of formwork is needed, quick maintenance is required and at cold weather condition.

CHAPTER THREE

3 MATERIALS AND METHODS

3.1 Introduction

The literature review in the previous chapter discussed various past studies and research gaps in relation to high-range water-reducing and accelerating admixtures and their effects on concrete properties with different cement brands. Based on the identified research gaps, Chapter 1 outlines the research objectives set for this study. This chapter clarifies the methodology adopted to accomplish the study's objectives. This chapter reviews the materials and methods used in this study. The first section designates the overall research design, materials used, test parameters, and specimen preparation, and then finally the experimental work to accomplish the research objectives.

3.2 Research Approach and Design

This specific research is designed as experimental type of research. The purpose of these experimental designs was to determine the optimal dosage of accelerating admixtures with different brands of cement with C-40 grade of concrete and observe the effects of accelerating admixtures on the workability of fresh concrete, the compressive strength of concrete, flexural strength, the tensile strength and permeability of concrete. To determine the effect accelerating admixtures on concrete behavior, the following are selected as fixed parameters and variable parameters in this study. Cement types, dosage of accelerating admixture and amount of water were selected as variable parameters. As Fixed Parameters, the fine aggregate and coarse aggregates sizes determined and quantity of cement.

3.3 Sources of Data and Sampling

Experimental data were used in this study as main data, and they were collected by observation while experiments were being conducted. The observation was carried out in accordance with clear, predetermined plans that included in experimental methods and procedures. In order to get the necessary facts, published books, standards, and journals were regarded as secondary data as substantiation. Due to their dominance in the current state of the building industry three types of cement and a water reducing and accelerating admixture are selected.

3.4 Research Methodology Framework

As shown in Figure 3.1, the flow chart is demonstrated what kind of study was being planned, how the study was carried and methodology to answer the kind of results for such research work and how to address the research problems adequately.

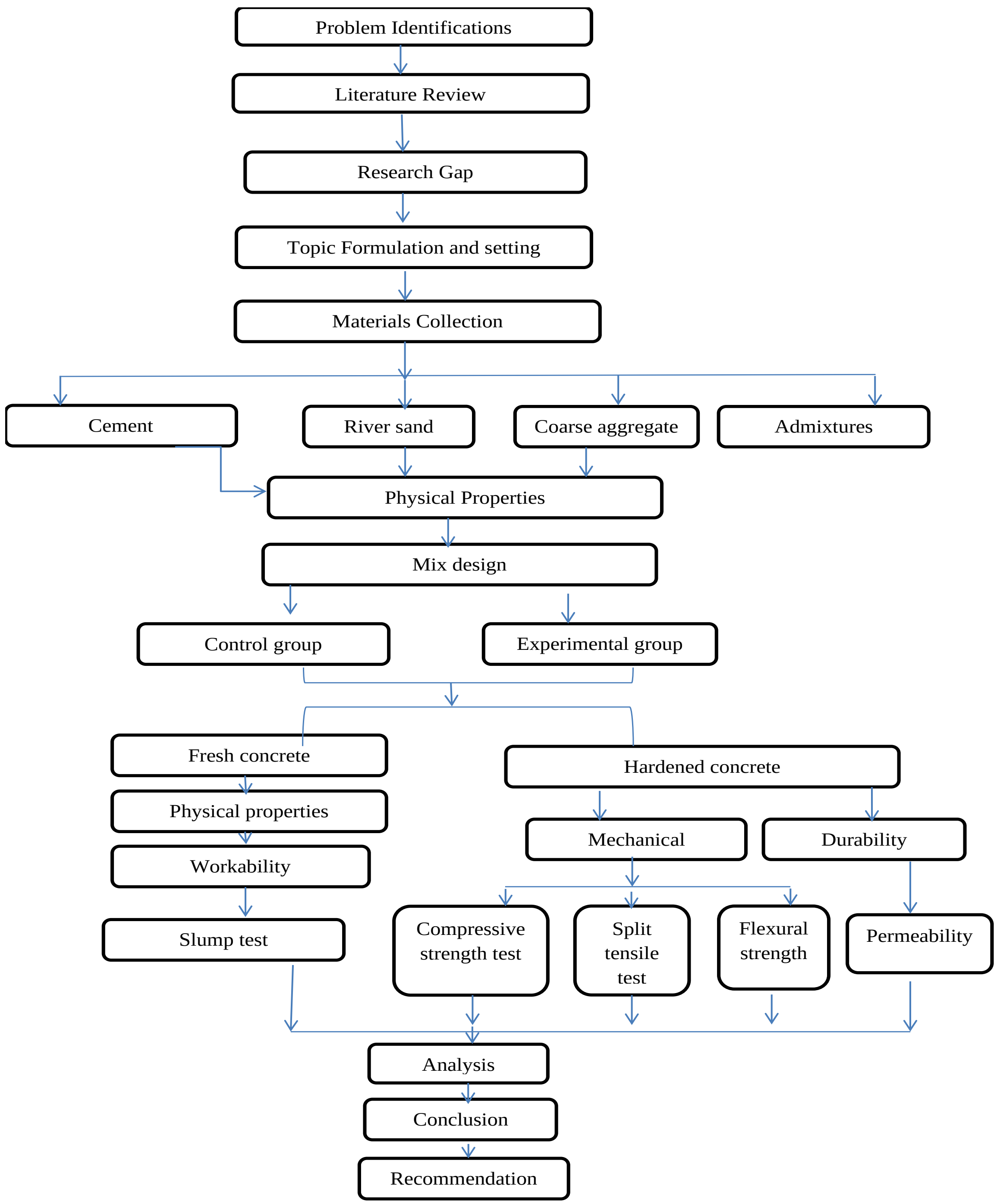


Figure 3-1 Research Methodology Framework

3.5 Materials for the Experiment

3.5.1 Cement

The cement used throughout the entire study was of the ordinary Portland (Type-I) Cement, namely Derba cement, Dangote cement and National cement, which are produced in Ethiopia. Type-I Cement is suitable for general concrete construction when there is no exposure to sulfates in the soil. Type-I cement complies with ASTM C-150 and has been used as a binding material for all mix proportions. Dangote, Derba and National Cement were used throughout this experiment due to the predominance use of such cements in the current Ethiopian construction industry. To determine the physical properties of cement, normal consistency, initial setting time, final setting time and fineness of cement test was conducted for all cement brands in section 3.6.

Dangote Cement is the largest cement plant in Ethiopia and capable of producing 32.5 and 42.5-grade cements to meet market needs. The location of the plant is in Oromia National Regional Government, West Shewa Zone, Ada Berga District, and Mugher Town (85 KM out of Addis Ababa). Dangote Ordinary Portland Cement 42.5N product was used in the experiment.

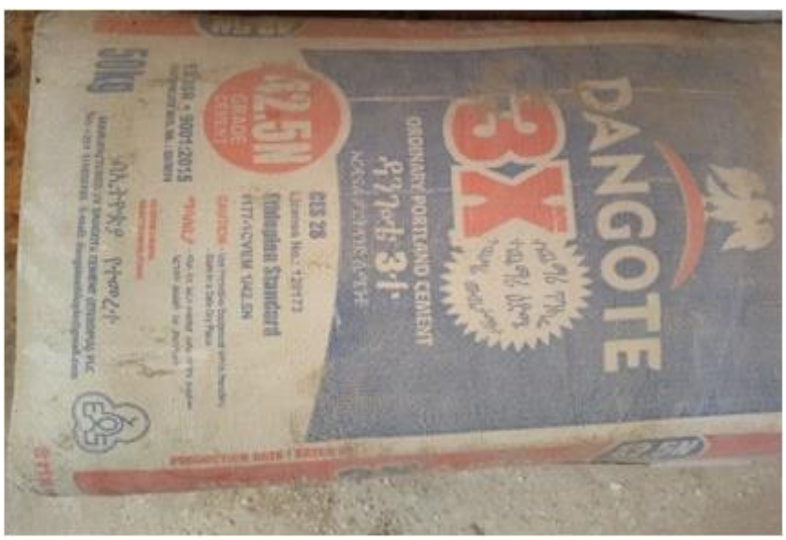


Figure 3-2 Dangote Cement Ordinary Portland cement

Derba Cement is a subsidiary company of the Midroc Group which is a private investment group based in Ethiopia. Derba Cement was established in 2006 with the aim of producing cement in the country to meet the demand for construction materials. Its plant is located in the Derba-Muger valley, about 70 km northwest of Addis Ababa. The company's plant has the capacity to produce

2.5 million tons of cement annually and it is one of the largest cement plants in Ethiopia. Derba Ordinary Portland cement (OPC) which is produced as per CEM-I was used throughout the experiment.

Figure 3-3 Derba Cement Ordinary Portland cement

National Cement Share Company is located in the Eastern part of Ethiopia, right at the entrance of Diredawa city at 515 km away from the capital city of Addis Ababa. The establishment of the current National Cement Share Company (NCSC), the former Dire dawa Cement & Limestone Factory, dates back to 1936 G.C. National Ordinary Portland cement (OPC) which is produced as per CEM-I was used throughout the experiment.

Figure 3-4 National cement Ordinary Portland cement

3.5.1 Aggregates

Aggregates are materials basically used as filler with binding material in the production of concrete. Aggregates form the body of the concrete, reduce the shrinkage and affect economy. Therefore, it is significantly important to obtain right type and quality of aggregates in production of concrete. They should be clean, Aggregates should be hard, strong, free of undesirable impurities, and chemically stable. It should also be free from impurities: silt, clay, dirt or organic matter (Li, 2011). Therefore, to judge the quality of the aggregate physical characteristic's tests have to be conducted. for this specific experiment for both fine and coarse aggregate the relevant tests were made to identify the properties of the aggregates that are used in this experimental works are suitable.

3.5.2 Fine Aggregate

River sand named as Alage sand, which is extracted from Alage area which is found in Oromia region about 150km from Addis Ababa was used to prepare the concrete samples. all fine aggregate which retains on 9.5mm sieve size were no longer relevant, and all the passing fine aggregate were used for experimentation. In order to investigate the properties of such natural sand properties, sieve analysis, fineness modules, specific gravity, water absorption capacity, moisture content, silt content and unit weight tests were carried out according to ASTM standards. Since these properties of the aggregates are significantly affecting the property of the concrete.

Figure 3-5 River Sand for the experiment

3.5.3 Coarse Aggregate

Coarse aggregate is a material commonly produced by crushing larger rock, separating the crushed portion according to size, and recombined in a carefully controlled manner. The coarse aggregate used in the experimental investigation was crushed rock from Bole sub-city, Addis Ababa, it is locally called “koye fache. The size of coarse aggregate used for the study was nominal aggregate sizes of 25mm. To evaluate the properties of coarse aggregate the following experimental test were conducted. specific gravity, unit weight, water Absorption and moisture content tests was conducted according to ASTM standard.

Figure 3-6 Coarse aggregate

3.5.4 Water

Water is an important ingredient of concrete. Part of mixing water is utilized in the hydration of cement and the balanced water is required for imparting workability to concrete. Thus, the quantity and quality of water is required to be looked into very carefully. The strength and durability of concrete is reduced due to the presence of chemical impurities in water. hence, the mixing water that used in this research were potable water supplied by Addis Ababa Water and Sewerage Authority found in the laboratory area.

3.5.5 Admixture

Different chemical admixtures are available in the local market which are import from abroad countries, like: India, USA etc, and there is also admixture produced in our country. For this particular research MC bauchemie high range water reducer and accelerator, muraplast SP103 (chloride free, Accelerating and super plasticizing admixture based on selected sulphonated naphthalene polymers) was used. The chemical admixture used in this study was muraplast SP103 highly effective Accelerating and high-range reducing superplasticizer and an extremely powerful deflocculating agent on soluble salt of polymeric naphthalene sulphonate, type E complying with ASTM C494. The recommended dosage is 0.5%-3% by weight of cementitious material. according to the manufacturer data this admixture has a shelf life of 12 months when stored under warehouse condition. Table 3.7 below shows the typical properties of mega flow sp103, type E admixture at 25°C described by the supplier.

Sulfonated naphthalene formaldehyde-based superplasticizers, are produced from a combination of raw materials. The main raw materials used in their production include naphthalene, formaldehyde, and sodium sulfonate. Naphthalene is a hydrocarbon compound derived from coal, tar or petroleum. It acts as the primary source for the sulfonated naphthalene portion of the superplasticizer. Formaldehyde, which can be produced from various sources like methanol, is used as a reactant to modify and sulfonate the naphthalene. sulfonating agents, such as sulfuric acid or sulfonic acid, are used to introduce sulfonic groups into the naphthalene formaldehyde polymer structure. These raw materials are combined through a series of chemical reactions to synthesize the superplasticizer.

Figure 3-7 Type E admixture

Table 3-1 properties of type E admixture at 25°C

Properties	Test method	Value
Specific gravity	ASTM C494	1.21 +/- 0.02
Component	-	Single
Form	-	Liquid
Color	BSEN 480-10	Brown
Air entrainment	ASTM C231	Up to 1%over control mix
Chloride content	BSEN 480-10	Nil to BSEN 934-2
PH	ASTM C494	7-9

3.6 Research Methods

Research method is a logical, well-thought-out plan for conducting experimental studies an describes the process that are considered before, during and after the laboratory experiment undertaken. It gave emphasis on how the experiments were carried to meet the need. To determine the effect accelerating admixtures on concrete behavior, the following are selected as fixed parameters and variable parameters in this study. Cement brands, dosage of accelerating admixture and amount of water were selected as variable parameters. As Fixed Parameters, the fine aggregate and coarse aggregates sizes determined and quantity of cement. first, Slump cone were carried out according to ASTM C 143 test for slump of Portland cement concrete on fresh concrete. And then, the experiments were further performed by production of concrete specimens on the basis of standard requirements to make valid the investigation. Hence, cubes, cylinders and beam specimens were prepared in pre-determined proportion and then after curing ages of 7 days' and 28 days' ASTM C39 for compressive strength of cubes, ASTM C 496 for splitting tensile strength, ASTM C293 test for flexural strength of concrete.

3.6.1 Physical property tests on cement

Normal consistency and setting time of cement

The normal consistency of hydraulic cement was checked to determine the amount of water required to make a neat paste of satisfactory workability. The setting time of cement refers to the time taken by cement paste to harden. There are two types of setting times: the initial setting time, during which the cement paste hardens to the point where a 25 mm needle could penetrate it, and the final setting period, during which the cement paste hardens to the point where the needle cannot penetrate it at all. According to ASTM C187 Standard Test Method for Amount of Water Required for Normal Consistency of Hydraulic Cement Paste, it was conducted by using the Vicat apparatus and the detail is calculation on appendix 1.1.


Figure 3-8 Normal consistency and Setting time test by using Vicat apparatus

Fineness of cement

Fineness is an important property of cement that relates to its grinding quality and particle size distribution. It is the ability of cement to be ground finely enough to pass through a certain sieve size. The fineness of cement affects its setting time, strength development, and workability. For this experimental research, The fineness of cement is typically measured by the No. 200 sieve method, which is a test method specified by ASTM Standards C204**.** The standard specifies that the sample should be dry and weighed before sieving, and the sieve should be shaken for a fixed period of time. The residue retained on the sieve is weighed, and the percentage by weight of the residue is calculated.

Figure 3-9 fineness of cement

3.6.2 Physical property tests on fine Aggregate

Silt Content

Good-quality sand should be clean, free from clay, silt, and other organic material, and should have a consistent particle size distribution. If the sand used in the concrete mix has a high silt or clay content, it will significantly reduce the strength of the concrete. Impurities can be classified as solid materials or soluble substances. Solid materials are generally present in a very finely divided state, passing the 75-μm sieve. The material in fine aggregates which is finer than 75μm is generally regarded as silt. As shown on figure 3.10, For this specific experimental research silt content test was performed according to ASTM C117 and the result was obtained 2.52% detail is calculation on appendix 1.2. ASTM C33-18 Standard Specification for Concrete Aggregates states that the maximum amount of silt allowed in fine aggregate used in concrete is 3% by weight, which the fine aggregate used is satisfied with.

Figure 3-10 fine Aggregate silt content Test

Gradation of fine aggregates

Sieve analysis is a method used to determine the particle size distribution of a material. It involves passing a sample of the material through a series of mesh sieves of decreasing size. The grading requirement for fine aggregate is according to ASTM C 33. The sieves are stacked in order, with the largest mesh size on top and the smallest at the bottom. The sample is then shaken for a fixed period of time and the amount of material that remains on each sieve is measured.

Figure 3-11 Sieve analysis of fine Aggregate

Table 3-2 Sieve analysis results of fine aggregate

Weight of sample taken = 500gm					
Sieve Size	Weight	Weight	Cumulative	Cumulative	ASTM Requirement
	Retain(gm.)	Retained (%)	Retained (%)	Passing (%)	Cumulative Passing (%)
9.5mm	0	0	0	**100%**	100
4.75mm	12	2.4	2.4	**98%**	95-100
2.36mm	63	12.6	15	**85%**	80-100
1.18mm	87	17.4	32.4	**68%**	50-85
600μm	125	25	57.4	**43%**	25-60
300μm	99	19.8	77.2	**23%**	10-30
150μm	93	18.6	95.8	**4%**	2-10
Pan	21	-	-	-	-
Total	**500**		**280.2**	-	-
			FM = 2.80		

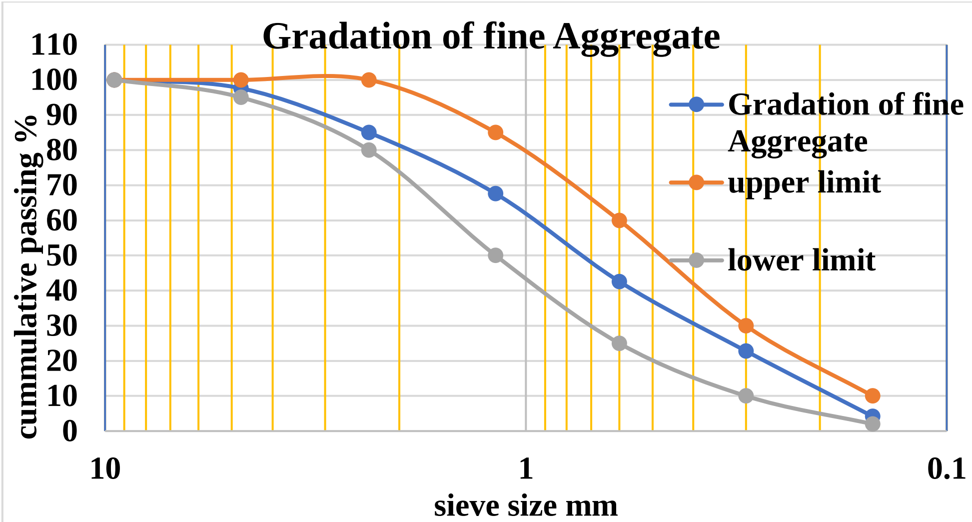


Figure 3-12 Gradation of fine Aggregate

According to the ASTM standard, the strength of concrete is directly related to the amount and quality of fine aggregate used in the mix. If sand particles are of varying sizes and do not have a consistent distribution, it can lead to inconsistencies in the concrete mix, which can cause issues in achieving the required strength. Table 3.4 and Figure 3.12 is illustrated the gradation of fine aggregate. The results are typically presented as the percentage of material that passes through each sieve versus the size of the sieve's mesh opening. The gradation result is satisfied the ASTM 33 standard requirement of gradation of fine aggregate.

Specific gravity and water absorption

Since aggregates generally contain pores, both permeable and impermeable, the meaning of the term specific gravity has to be carefully defined, and there are indeed different types of specific gravity, like: apparent specific gravity and bulk specific gravity. Bulk specific gravity refers to total volume of the solid including pores of the aggregate, and Apparent specific gravity refers to the volume of the solid is consider to include the impermeable pores but not the capillary ones. ASTM C128 standard for specific gravity and water absorption of fine aggregate specifies that the specific gravity of fine aggregates shall fall between 2.5 and 2.7 and that the water absorption for concrete aggregate shall not exceed 3%. As shown in table 3.5, the fine aggregate utilized in this experiment meet the ASTM standard's requirements for specific gravity, and water absorption.

Natural Moisture content

The strength and workability of a concrete are influenced by the water to cement ratio. The strength of the concrete decreases and workability rises as the water to cement ratio increases. Concrete aggregates are considered to be inert substances. However, the majority of the aggregates fail to respond to this expectation by either releasing water into the mix (wet aggregates) or absorbing it (dry aggregates). As a result, the property of the aggregates affects how the mix's water to cement ratio is designed. Therefore, it is crucial to determine the aggregate's moisture content as well as its absorption capacity. The moisture content of fine aggregates was determined by oven drying a sample of fine aggregate (500gm) in an oven at a temperature of 110+5 0c for 24 hrs and dividing the weight difference by the oven dry weight. For this experiment the natural moisture content was 6.6%.

Unit weight

Unit weight can be defined as the weight of a given volume of graded aggregate. It is thus a density measurement and is also known as bulk density. But this alternative term is similar to bulk specific gravity, which is quite a different quantity, and perhaps is not a good choice. The unit weight effectively measures the volume that the graded aggregate will occupy in concrete and includes both the solid aggregate particles and the voids between them. The unit weight is simply measured by filling a container of known volume and weighing it. Clearly, however, the degree of compaction will change the amount of void space, and hence the value of the unit weight variable. Since the weight of the aggregate is dependent on the moisture content of the aggregate and constant moisture content is required.

For this experiment unit weight test for aggregate was conducted According to ASTM C29/C29M Standard Test Method for Bulk Density (“Unit Weight”) and Voids in Aggregate detail is calculation on appendix 1.2. As shown on Table 3.5, The minimum unit weight of Fine Aggregates must be 1420 kg/m3 in accordance with ASTM C29 Standard Test Method for Bulk Density "Unit Weight" and Voids in Aggregate. As shown in the table 3.4 below the unit weight value was 1530 kg/m^3, hence, the fine aggregate utilized in this experiment and the results shown above meet the ASTM standard's requirements for unit weight.

Figure 3-13 Unit weights of Fine Aggregates

Table 3-3 Summary of test results for fine aggregate

No	Test Description		Test Result
1	Silt Content		2.51%
2	Moisture Content		6.6%
3	Unit weight	compacted	1530 kg/m^3
		loose	1380kg/m^3
4	Absorption Capacity		2.32%
5	Specific gravity	Bulk	2.57
		Bulk (SSD)	2.63

3.6.3 Physical Property Tests on Corse Aggregate

Gradation of coarse Aggregate

For this specific experiment, physical properties of coarse aggregate were performed accordingly to check that the aggregate properties are within standard to use for concrete. the aim of this test is to determine the gradation of coarse aggregate according to ASTM C33. 25 mm nominal maximum aggregate size was taken to conduct this study. The coarse aggregate gradation chart described in the figure 3.14 and Table 3.6 The gradation result is satisfied the ASTM 33 standard requirement of gradation of coarse aggregate.

Table 3-4 Sieve analysis for coarse aggregate

Sieve size(mm)	Weight Retain(gm.)	Weight Retained (%)	Cumulative Retained (%)	Cumulative Passing (%)	Cumulative passing (%)
37mm	0.0	0.0	0.0	**100.0**	100
25 mm	43.3	2.165	2.2	**97.8**	90-100
19 mm	613.2	30.7	32.8	**67.2**	40-85
12.5 mm	820.3	41.0	73.8	**26.2**	10-40
9.5 mm	326.4	16.3	90.2	**9.8**	0-15
4.75 mm	173.8	8.7	98.8	**1.2**	0-5
Pan	23.0	1.2			
total	**2000**				

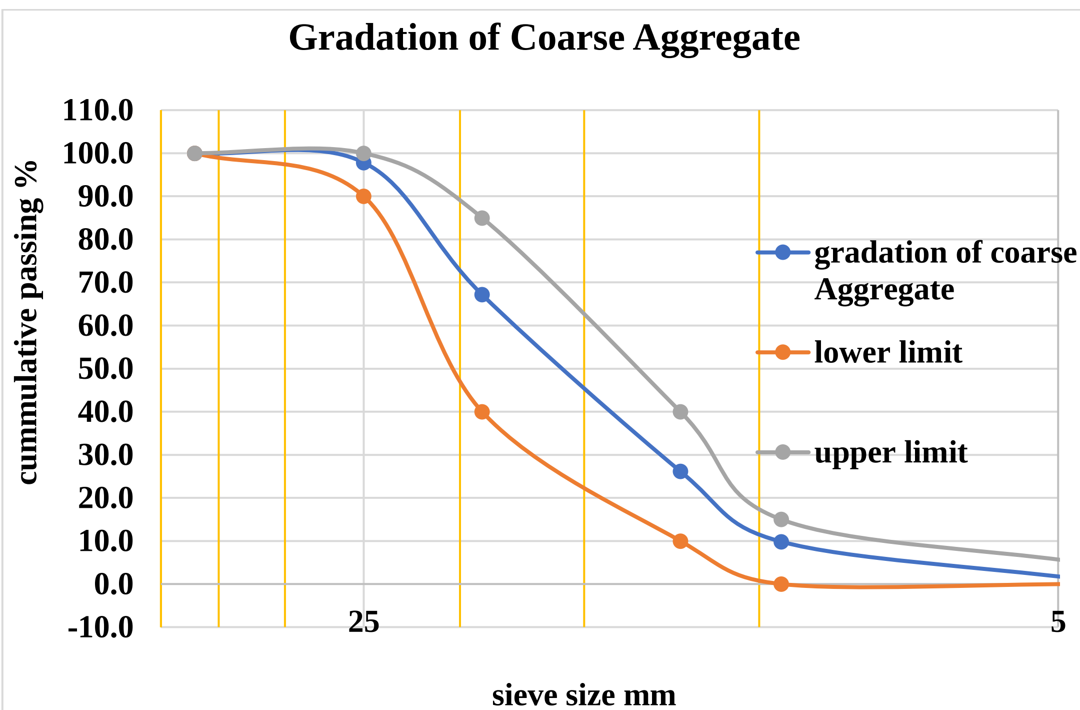


Figure 3-14 Gradation of Coarse Aggregate

Unit Weight, Specific Gravity, and Water Absorption of Coarse aggregate

Unit weight test for coarse aggregate was conducted According to ASTM C2 Standard Test Method for Bulk Density and ASTM C127 standard was use for specific gravity and water absorption of coarse aggregate. The test results for unit weight, specific Gravity, water absorption and moisture content is summarized in Table 3.7 and the detail calculation and procedure is attached on appendix 1.3.

Table 3-5 Summarized test results for coarse aggregate

No	Physical test for coarse aggregate		Results
1	Unit weight	Compacted unit weight	1608 kg/m^3
		Loose unit weight	1403 kg/m^3
2	Specific gravity	Bulk specific gravity	2.63
		Bulk specific gravity (SSD)	2.67
3	Absorption capacity		1.52 %
4	Moisture content		2.01%

According to ASTM C29/C29M-17a Standard Test Method for Bulk Density "Unit Weight" and Voids in Aggregate, for nominal sizes between 9.5 mm and 25 mm, the minimum unit weight shall be 1440 kg/m3. Similarly, in the ASTM standard for specific gravity and water absorption of coarse aggregate, ASTM C127/C127M-15a, the standard requirement for the specific gravity of coarse aggregates shall be within the range of 2.5 to 3.0 and 5% for water absorption for concrete aggregate. So, the above results conducted for aggregate, which is used in these experiments, satisfy the requirements for unit weight, specific gravity, and water absorption of the ASTM standard.

3.6.4 Concrete Mix Design and material proportioning

Concrete mix design is the process of choosing appropriate ingredients and find the most effective proportions of those ingredients to create a concrete mix with the desired properties, including strength, durability, workability, and other characteristics. Analyzing the project's particular requirements as considering factors like the environment, exposure factors, and desired performance are all part of a process. On the other hand, mix proportioning is the process of determining out how much of each ingredient to add to the concrete in order to get the desired results for the concrete. A correctly balanced concrete mix should be both durable, strong, and have a consistent appearance after it has hardened, as well as being affordable. Therefore, the key for producing a strong, durable and economical concrete rests on the careful proportioning and mixing of the ingredients. ACI 301-99, 1999 concrete mix design procedure was used to design a concrete that can achieve a desired workability and provides an average compressive strength. The required average compressive strength f'_{cr} was calculated for the specified class of concrete in accordance with one of the following

$f^icr = f^ic+1.34ks$ …………………………………………………….... Equation 3.1

$f^icr = f^ic + 2.33ks – 500$ ……………………………………………….Equation 3.2

Where: f^i_{cr} = required average compressive strength (Mpa)

f^i_c= specified strength (Mpa)

k = constant factor

s = standard deviation

ACI 301-99, 1999 concrete mix design manual was used to design for C-40 concrete grade. When field test records are not available to establish a standard deviation, the required average compressive strength can be selected from the following equations (ACI 301-99, 1999).

$f^i_{cr} = f^i_c + 7$ MPa when specified compressive strength is less than 21 Mpa,.

$f^i_{cr} = f^i_c + 8.5$MPa when specified compressive strength is between 21 to 35Mpa and

$f^i_{cr} = 1.1f^i_c + 5$ MPa when specified compressive strength is greater than 35 Mp.

So, Target mean strength for C-40 grade concrete is 49 N/mm^2. The left procedures of mix design are listed in Appendix 2. Table 3.7 present the quantities of mix proportion for 1m^3 of concrete for C-40 control concrete mix for all cement brands in the experiment.

Table 3-6 Concrete Mix design for 1m^3 C-40 Concrete as control mix (W/C 0.41)

Concrete Ingredients	Amount per 1m^3 (Kg)
Cement	**471**
Water	**160**
Fine aggregate	**666**
Coarse aggregate	**1083**

For a concrete mix with different dosages HRWRAA, the mix design for the control mix was revised by reducing the amount of water for mixing, and the dosage of accelerating admixture was calculated by percentage of cement weight. In all mixes with different cement brands, the same mix design was used. The quantity of cement used in the mix with HRWRAA was constant at every dosage of accelerating admixture. The dosage range of HRWRAA recommended by the manufacturer is 0.5% to 3% by weight of cement used. However, for this study, the dosage interval was set at 0.5%. Since the accelerating admixture used in the experiment was HRWRAA and has a high tendency for water reduction. for 0.5%, 1%, 1.5%, 2%, 2.5%, and 3% dosages of HRWRAA, 20%, 23%, 25%, 28%, 30%, and 33% water were reduced, respectively for concrete made with all cement brands and the proportion for $1m^3$ of concrete is shown in Table 3.9. with the following ratio 324 samples were prepared for compressive strength, tensile strength, flexural strength and permeability tests. W/c for control mix was 0.41.

Table 3-7 Quantity of materials in kg for mix in $1m^3$ C-40 concrete with HRWRAA

Mix Code	water reduction %	water after reduction (kg)	Cement (Kg/m^3)	FA (Kg/m^3)	CA (Kg/m^3)	HRWRAA (kg)
HRWRAA - 0.0%	0%	160	471	666	1083	0.0
HRWRAA - 0.5%	20%	128	471	698	1083	2.4
HRWRAA - 1.0%	23%	123	471	703	1083	4.7
HRWRAA - 1.5%	25%	120	471	706	1083	7.1
HRWRAA - 2.0%	28%	115	471	711	1083	9.4
HRWRAA - 2.5%	30%	112	471	718	1083	11.8
HRWRAA - 3.0%	33%	107	471	723	1083	14.1

Table 3-8 Total Number of Samples for Derba, Dangote and National cements

dosage	**Compressive strength(cube)**			**Tensile strength (cylinder)**			**flexural strength (beam)**	**Permeability (cube)**
	3days	7days	28days	3days	7days	28days	28days	28days
0.0%	9	9	9	9	9	9	9	9
0.5%	9	9		9	9			
1.0%	9	9		9	9			
1.5%	9	9	9	9	9	6	6	6
2.0%	9	9		9	9	3	3	3
2.5%	9	9		9	9			
3.0%	9	9		9	9			

3.6.5 Batching, Casting and curing of concrete specimens' preparation

The concrete ingredients cement, fine aggregate (sand), coarse aggregate, mixing water and admixture were measured by weight balance. After measuring the ingredients, weighted coarse aggregate was first added to the mixer and the cement was added after the coarse aggregate and then the fine aggregate was added next to cement and dry mixed for a minute. Then, water and admixture were added to the dry mixed concrete ingredients mixture and thoroughly mixed for two more minute. Full blending of the admixture and the concrete was ensuring by mixing for the period. The mixed concrete was checked for workability by filling the standard slump cone with three layers by rodding each layer with 25 times. In order to make concrete cubes, specified mold of size 15cm×15cm×15cm for Compressive Strength and concrete permeability according to ASTM 192, cylinder of diameter 15cm with 30cm height for Split Tensile Strength were prepared to produce the specimen's accordance to ASTM C 39 and beam mold with size of 10cm*10cm*50cm used for Flexural Strength test of concrete according to ASTM 192. Excess concrete was removed with trowel after proper compaction and top surface was smoothened. After casting, the specimens were stored in the laboratory with room temperature for 24 hours. After this period, the specimens were removed from the molds, immediately submerged in the clean and fresh water tank. The specimens were cured until testing days.

Figure 3-15 concrete sample preparation and curing

3.6.6 Fresh concrete test

Workability test

Concrete workability was evaluated by performing a slump test according to ASTM C 143 for slump of Portland cement concrete on fresh concrete with HRWRAA dosages of 0%, 0.5%, 1%, , 2%, 2.5%, and 3% high range water reducing and accelerating admixture dosage and reduction of water by 20%, 23%, 25%, 28%, 30% and 33% respectively. The slump result was conducted by using the slump test (cone dimensions: height = 300 mm, bottom diameter = 200 mm, top diameter = 100 mm). The first slump cone was filled with freshly mixed concrete, and a tamping rod was inserted into the slump cone and lifted straight up and down 25 times for each of three layers. any excess concrete from the top of the cone was removed with a shovel and Then the slump cone was pulled away from the concrete. The difference between the height of the cone before it was filled with concrete and the height of the concrete after it had been compacted was measured. slump measurement as the difference between the two heights was recorded.

Figure 3-16 slump test for workability

3.6.7 Hardened Concrete Tests

Compressive strength

And then, compressive strength test was conducted to identify the optimum dosage of high range water reducing and accelerating admixture that give maximum early strength for all cement brands. For C-40 concrete grade by 20%, 23%, 25%,28%, 30% and 33% water reduction in 0.5%, 1%,1.5%, 2%, 2.5% and 3% high range water reducing and accelerating admixture dosage added respectively. concrete sample were prepared for 3th, 7th and 28th days to find the optimum dosage of high range water reducing and accelerating admixture that can achieve maximum early compressive strength. the experiments were performed by production of specimens on the basis of standard requirements to make valid the investigation. concrete specimen of 15cm*15cm*cm15cm size was prepared to enable the full cross-section to be tested. Specimens was prepared according to ASTM C192/C192M-00 Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory. After the test specimens are made, their locations for identification were marked, and stored them in a laboratory environment for a day in accordance with ASTM C39/C39M-09 Standard Test Method for Compressive Strength of Cubic Concrete Specimens. As the admixture is accelerating admixture, 3day, 7day and 28daya test was performed. At testing day by using compression machine, compressive stress was applied at the rate of 0.3Mpa/sec until the specimen fails, and record the maximum load attained. compressive strength was calculated by dividing the maximum load attained by the cross-sectional area of the specimen. Finally, compressive strength results were reported according to ASTM C39/C39M-09.

Figure 3-17 compressive strength Test

Tensile strength

Tensile split strength test was done According to ASTM C496 standard for concrete tensile split testing. The procedure involves the following steps, cylindrical concrete specimen with a diameter of (150 mm) and a height of (300 mm) was used for sampling the specimen. Tensile splitting strength also was conducted for the average 3,7 and 28 days' using the same machine with compressive strength. The concrete was surface dried for two hours to be tested in the moist condition according to ASTM C39 The cylindrical specimen was Placed under a compression testing machine with a loading rate of 0.3Mpa/sec and capacity of 3000KN, with the axis of the cylinder parallel to the direction of the applied load. tensile load was applied to the specimen at a constant rate of deformation until the specimen fails. the maximum load applied to the specimen was recorded, and the splitting tensile strength of the concrete was calculate by using the following formula.

$$\text{Splitting Tensile Strength} = \frac{2P}{\pi D * h} \text{.............................Equation 3.3}$$

Where P maximum load in (KN)

D diameter of cylinder (mm)

H height of the cylinder (mm)

Figure 3-18 concrete split tensile strength test

Flexural strength

The flexural strength test was performed as per the ASTM C293 standard. To carry out this test, firstly, the concrete specimen was prepared, which should be a standard size of 100mm x 100mm x 500mm, as per the metric system. first, the specimen was placed on two supporting rollers. A load was then applied at the midpoint of the specimen, which was gradually increased until the specimen cracks or bends to a fixed limit. The load applied on the specimen was recorded continuously until the fracture during the test. Once the specimen has cracked or bent to a fixed limit, the machine was turned off, and the maximum load applied was recorded. The flexural strength of the specimen was calculated using the formula specified in the ASTM C293.

$$fb = \frac{3PL}{2bd^2}$$ ……………………………………………Equation 3.4

where: fb = flexural strength Mpa

L = the distance between the lower supporting rollers mm

P= maximum applied load N

b =width of the beam mm

d = depth of the beam mm

Figure 3-19 Flexural Strength Test

Permeability test

The depth of penetration of water under pressure is an important factor to consider when testing the durability and quality of hardened concrete. This test, often referred to as the water penetration or permeability test, measures the ability of water to penetrate into the concrete under pressure. It is an important test to determine the durability and quality of concrete structures. In this research, a non-steady-state water permeability test was selected to study the effect of HRWRAA admixtures on concrete permeability. The test was conducted according to ASTM C1202, on 15-cm-thick concrete cubes that had been cured for 28 days and surface dried on air. Before directly starting the laboratory test, the top surface of the cubes was cleaned and smoothed. Then, the cleaned and smoothed concrete was placed on the permeability testing device, and the bolts were tightened at the top of the sample to prevent any leakage of water when pressure is applied.

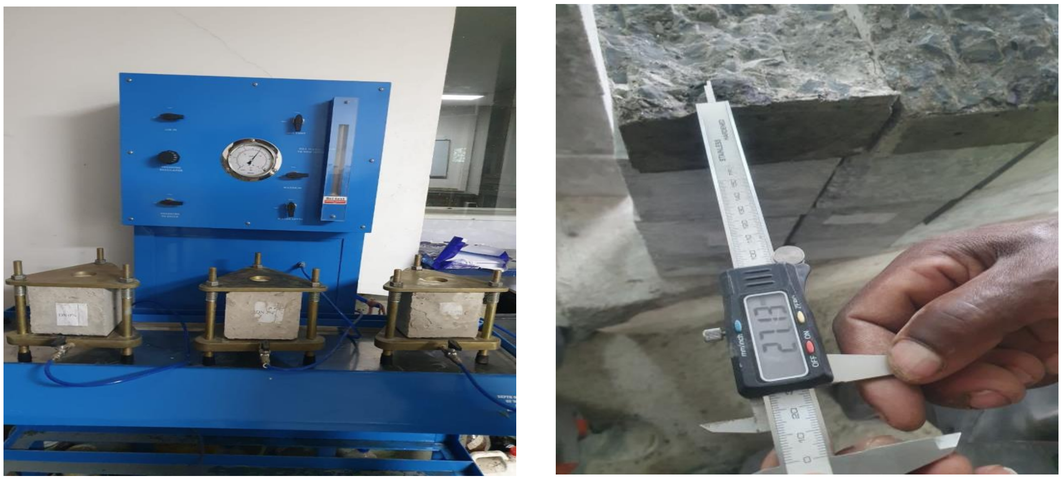


Figure 3-20 permeability test

3.6.8 Method of Data Analysis

The data were collected from laboratory results and analyzed based on a descriptive and quantitative approach. During the experiment, one group is exposed to the usual condition (the control group), and the others are the experimental group'. The process involved examining the truth of a statistical hypothesis relating to the stated research problem using a comparative experiment. The experiment was conducted before and after the introduction of treatments and recorded to compare the effects of such an independent variable on the fresh and hardened properties concrete specimens. The effect of the treatment was equal to the level of the phenomenon after the treatment minus the level of the phenomenon before the treatment. The design can be represented thusly: Graphical description and MS Excel program techniques were used for data collection and analysis of the recorded data; it helped to consider systematically illustrating recording information and manipulating it easily.

3.7 Summary

This chapter focuses on the materials and procedures followed in carrying out experimental research. The procedures used were developed with the intent of ensuring the validity and reliability of the study results. A comprehensive explanation of the research materials is provided in the chapter's preface. These included a variety of equipment, tools, and materials needed for collecting and analyzing data. Along with the steps taken to assure data accuracy and quality, the sources of the data were clearly described. The results will be thoroughly presented and discussed in the subsequent chapter.

CHAPTER FOUR

4 RESULTS AND DISCUSSION

4.1 General

The previous chapter discussed the research methodology adopted in this study. In this chapter, details of the experimental results are presented and discussed. First, the experimental results that were conducted on the physical properties of different brands of cement used in this experiment are presented. Subsequently, the effects of high-range water-reducing and accelerating admixtures on fresh and hardened C-40 concrete properties with various types of cement brands were examined using laboratory investigation. The first stage was examining the workability of concrete at different HRWRAA dosage ranges for the C-40 concrete mix design. The second stage was obtaining the maximum dosage of high-range water-reducing and accelerating admixture for highest early compressive. At the third stage, effects of the addition of high-range water-reducing and accelerating effects on concrete tensile split strength, flexural strength, and permeability were examined. Finally, the cost impact of applying HRWRAA with different cement brands were compared.

4.1.1 Physical property tests on cement

Normal consistency and setting time of cement

The normal consistency of hydraulic cement was checked to determine the amount of water required to make a neat paste of satisfactory workability. Setting time refers to the time it takes for concrete to harden and gain strength, and setting time is conducted by using a consistent amount of water. The consistency and setting time results are shown in Table 4.1.

Table 4-1 Normal Consistency and Setting Time of Cement Paste

Cement Brands	Normal consistency %	Initial setting time(min)	Final setting time(min)
Derba	27	197.5	290
Dangote	29	180	270
National	32	172.9	250

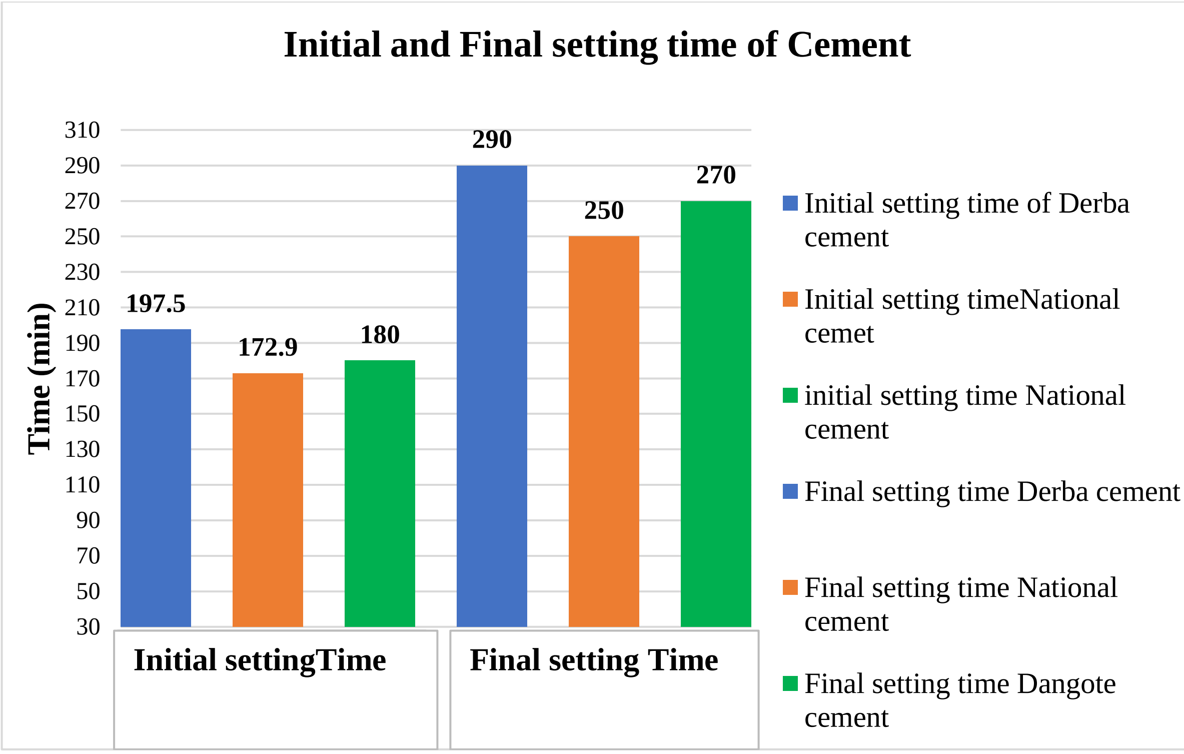


Figure 4-1 Initial and Final setting time of Cement

As shown in Table 4.1, the normal consistency test result of the ordinary Portland cement used for the experiment was 27%, 29%, and 32% for Derba, Dangote, and National cements, respectively. The consistency result of all cements is in the recommended range of 26% to 33% as per ASTM C187. However, the normal consistency of three cement brands has a variation due to the brands' relative proportions, sources of raw materials, production methods, and quality control. Due to the difference in normal consistency between cement brands, the amount of water needed for satisfactory workability will vary. So, the variation in normal consistency can affect the workability of concrete, in which the mix with three cement brands might have different slump values with the same amount of water.

The initial and final setting times are presented in summary in Table 4.1 and graphically in Figure 4.1. The initial setting times were 172.9 minutes, 180 minutes, and 197.5 minutes, and the final setting times were 250 minutes, 270 minutes, and 290 minutes, respectively, for Derba, Dangote, and National cements. The results show that the initial and final setting times for all cements are within the recommended range of the ASTM standard, which is initial setting time (not less than 45 minutes) and final setting time (not more than 10 hours). However, due to their chemical composition and brands' relative proportions, the initial and final setting for three cement brands is different. From the results, National Cement has shown a faster initial and final setting time, and Derba Cement has shown a slower initial and final setting time. Due to variations in setting time between cement brands, the hydration reaction of concrete, workability, setting time of concrete, dosage of HRWRAA, and rate of strength development can vary between cement brands. Additionally, the setting time of cement can affect the dosage of admixture needed to achieve the desired quality of concrete. When the setting time of cement is longer, the initial hydration and binding processes take more time to occur, and the concrete mixture may require a higher dosage of HRWRAA to maintain its desired workability and early strength. Conversely, if the setting time of cement is shorter, the initial hydration and binding processes occur more rapidly. In such situations, a lower dosage of HRWRAA is needed to achieve the desired workability and early strength (Shrivastava & Kumar, 2016).

Fineness of cement

Fineness is an important property of cement that relates to its grinding quality and particle size distribution. It is the ability of cement to be ground finely enough to pass through a certain sieve size. The fineness of cement affects its setting time, strength development, and workability. For this experimental research, the test for fineness of cement was conducted for Derba, Dangote and National cements and the result is summarized on Table 4.2 bellow.

Table 4-2 Fineness of Derba, Dangote and National OPC cements

Cement Brands	Sample	Cement (gm.)	Sieve size (mµ)	Residue (gm.)	% finer	Average % finer	Remark
Derba	1	50	75	3.2	93.16	**93.39**	**Recommended**
	2	50	75	2.98	93.66		
	3	50	75	3.12	93.34		
Dangote	1	50	75	1.56	96.78	**96.29**	**Recommended**
	2	50	75	1.75	96.37		
	3	50	75	2.05	95.72		
National	1	50	75	2.1	95.62	**95.09**	**Recommended**
	2	50	75	2.23	95.33		
	3	50	75	2.68	94.34		

As shown in the Table 4.2 the fineness results were 93.39%, 96.29 and 95.09% for Derba, Dangote and National cements respectively. The results show that, the fineness result of three of cement brands is in the range of ASTM recommendation. The standard requires that the residue retained on the 75-micrometer sieve should not exceed 8% by mass. However, the values of fineness of three cement brand have a difference in which Dangote cement is finer than Derba and National cement. The fineness of cement can vary within different brands due to several factors such as the difference in manufacturing processes and equipment used by each brand, grinding technique, duration, type of equipment and quality control standard (Biernacki et al., 2017).

The fineness of cement can have implications for concrete properties and the dosage of HRWRAA. Finer cement particles tend to hydrate faster, which can accelerate the initial setting time of concrete, contribute to higher early-age strength, require more water for the hydration reaction, and reduce the workability of the concrete mixture (Taylor, 1997). Additionally Finer cement particles have a larger overall surface area compared to coarser cement particles. This increased surface area means that more water is required to properly hydrate and react with the cement particles. As a result, finer cement requires a higher dosage of HRWRAA to achieve the desired workability and early strength due to increased surface area and water demand.

4.2 Effects of High range water reducer and accelerating admixture Dosage on workability.

The slump test results were conducted to evaluate the impact of HRWRAA admixture dosage on the workability of concrete with different cement brands. The use of high range water reducer and accelerating admixtures can have several effects on the physical properties of fresh concrete. The dosage of high range water reducer and accelerating admixtures plays a crucial role in determining the physical properties of fresh concrete (Naqash, 2014). A slump test was carried out on fresh concrete without and with HRWRAA with variable water amount reduction. Hence, the slump test was performed in accordance with the requirements of ASTM C 143. The slump results with or without HRWRAA are shown in Tables 4.3, 4.4, and 4.5 for Derba, Dangote, and National Cement, respectively. Percentages of HRWRAA and slump values were recorded and demonstrated in Figures 4.2, 4.3, and 4.4, as shown on the figure.

Table 4-3 Slump Test on Derba Cement with HRWRAA

HWRAA Admixture Dosage Rate (%)	Slump Height (mm)					
	Initial Slump	After 20 Minutes	After 30 Minutes	After 40 Minutes	After 50 Minutes	After 60 Minutes
0%	**45**	35	20	10	0	0
0.5%	**60**	45	25	10	0	0
1.0%	**110**	85	50	20	0	0
1.5%	**135**	95	55	30	10	0
2.0%	**195**	105	70	40	15	0
2.5%	**215**	125	85	45	20	10
3.0%	**240**	175	105	50	30	15

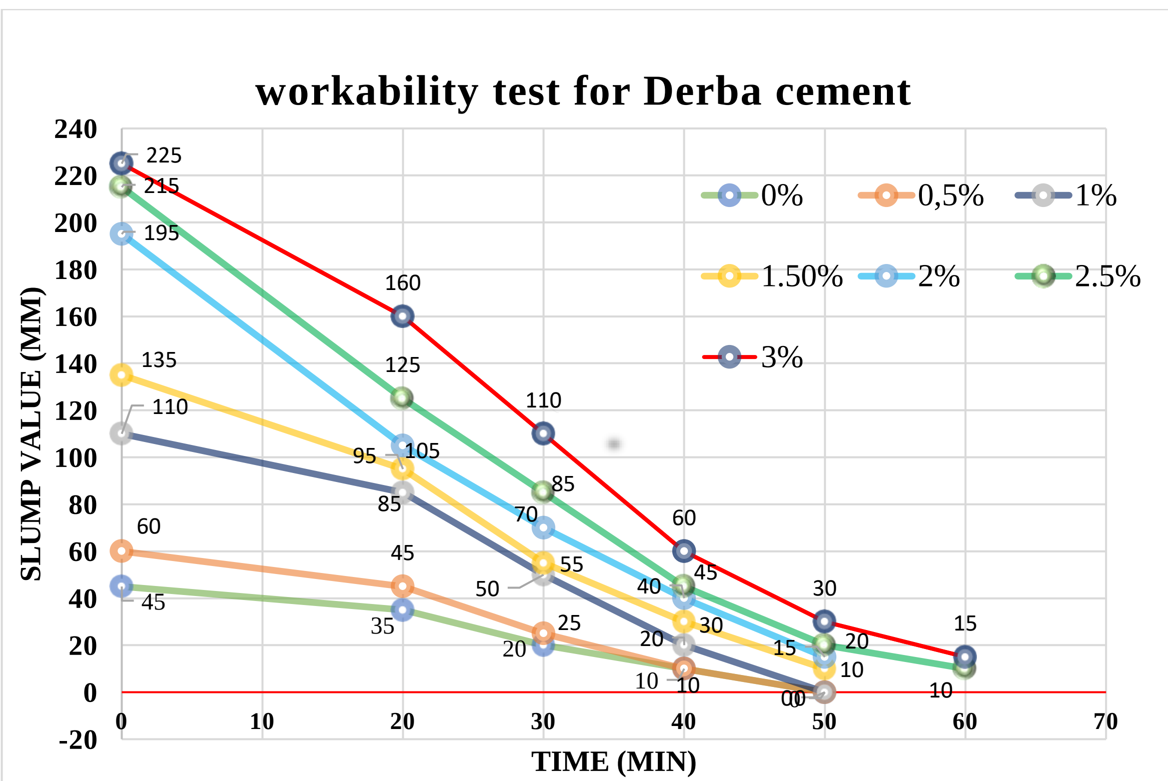


Figure 4-2 Effect of HRWRAA dosage on slump for Derba cement

Table 4-4 Slump Test on Dangote Cement with HRWRAA

HWRAA Admixture Dosage Rate (%)	Slump Height (mm)					
	Initial Slump	After 20 Minutes	After 30 Minutes	After 40 Minutes	After 50 Minutes	After 60 Minutes
0%	**30**	20	5	0	0	0
0.5%	**45**	25	15	0	0	0
1.0%	**90**	55	30	15	0	0
1.5%	**120**	80	45	25	15	0
2.0%	**175**	110	60	35	15	0
2.5%	**205**	145	95	50	30	5
3.0%	**225**	160	110	60	30	15

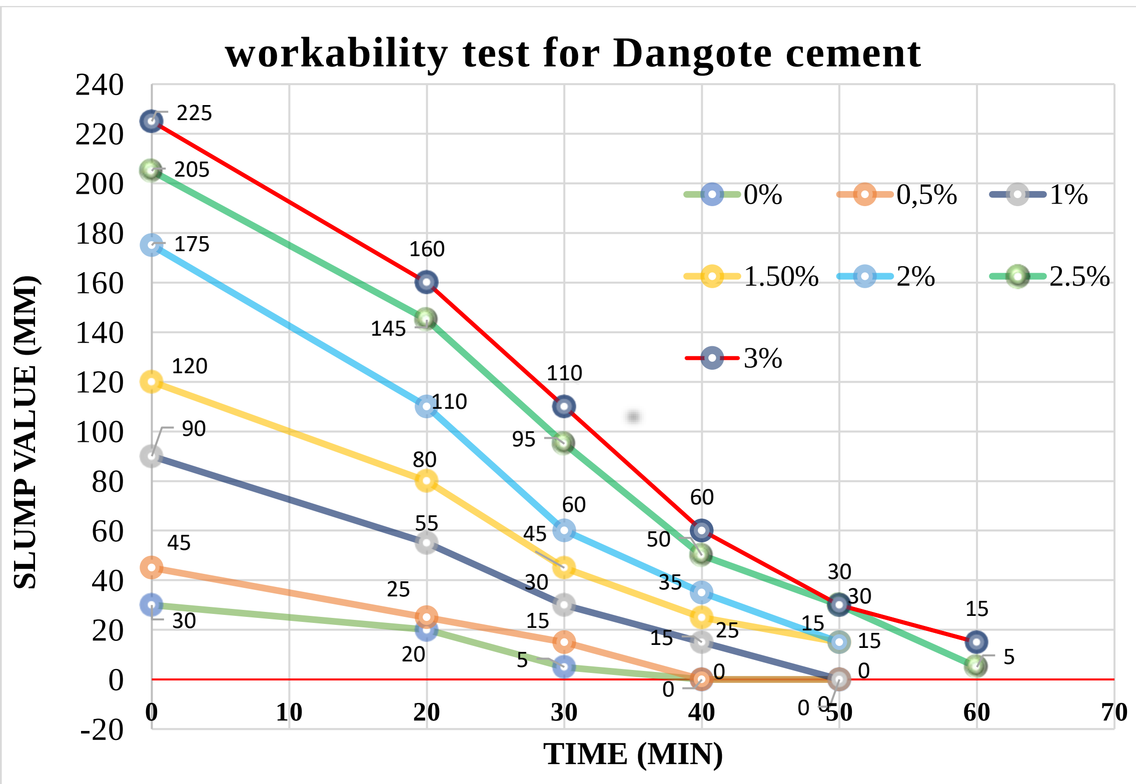


Figure 4-3 Effect of HRWRAA dosage on slump for Dangote cement

Table 4-5 Slump Test on National Cement with HRWRAA

HWRAA Admixture Dosage Rate (%)	Slump Height (mm)					
	Initial Slump	After 20 Minutes	After 30 Minutes	After 40 Minutes	After 50 Minutes	After 60 Minutes
0%	**10**	0	0	0	0	0
0.5%	**25**	15	5	0	0	0
1.0%	**60**	45	20	0	0	0
1.5%	**125**	65	40	10	0	0
2.0%	**170**	100	55	20	0	0
2.5%	**205**	115	85	50	25	10
3.0%	**235**	165	105	65	30	10

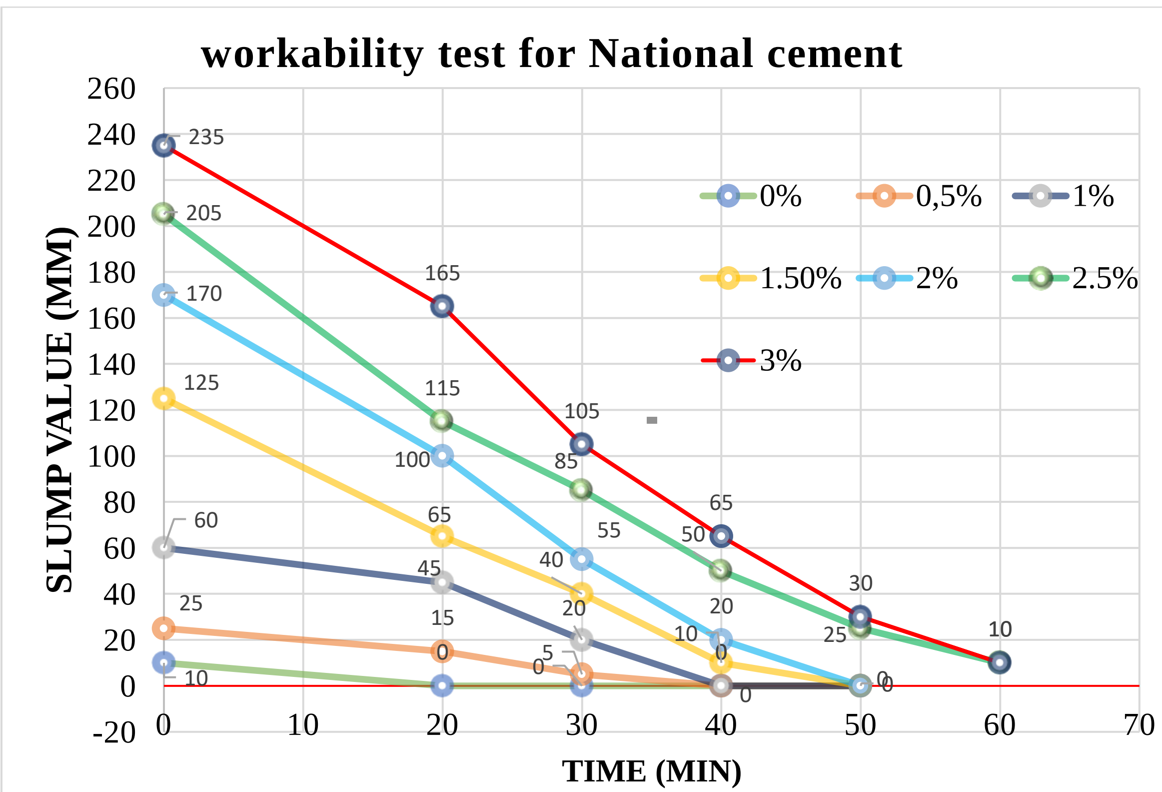


Figure 4-4 Effect of HRWRAA dosage on slump National cement

The above Figures 4.2, 4.3, and 4.4 show a slump in mm against changes in specific dosages of HRWRAA. During the increment in HRWRAA percentage, the slump value increased, as shown in the figure. The bar chart is plotted to observe the slump height condition, where six specimens, including the controlling specimen without HRWRAA and HRWRAA, are in a dosage of 0.5%, 1.5%, 2.0%, 2.5%, and 3.0% to represent the admixture dosage per 100 kg of cement.

Based on the observed slump measurements, at the initial time the concrete mix produced without HRWRAA had a slump of 45 mm, as observed with Derba Cement. As shown in Figure 4.3, with the addition of HRWRAA, the slump value increased to 60 mm, 110 mm, 135 mm, 195 mm, 215 mm, and 240 mm as the HRWRAA dose increased by 0.5%, 1%, 1.5%, 2%, 2.5%, and 3%, respectively. However, the initial slump values have been reducing through time. Mix with HRWRAA dose of 0%, 0.5% and 1% was reduced to zero slump after 50 minutes, 1.5% and 2% reduced to zero slump after 60 min. But, 2.5% and 3% workable for more than 60 min.

For Dangote cement, a slump of 30 mm was observed for the control mix, and with the addition of HRWRAA, the slump value increased to 45 mm, 90 mm, 120 mm, 175 mm, 205 mm, and 225 mm as the HRWRAA dose increased by 0.5%, 1%, 1.5%, 2%, 2.5%, and 3%, respectively. But the initial slump values have been reducing through time. Mix with HRWRAA dose of 0% and 0.5% was reduced to zero slump after 40 minutes, 1% reduced to zero slump after 50 minutes, 1.5% and 2% was after 60 min and 2.5% and 3% workable for more than 60 min.

As shown in Figure 4.4, the slump value for the control mix of National cement was 10 mm, and as the HRWRAA dose increased by 0.5%, 1%, 1.5%, 2%, 2.5%, and 3%, the slump value increased by 25 mm, 60 mm, 125 mm, 170 mm, 205 mm, and 235 mm, respectively. But the initial slump values have been reducing through time. Mix with HRWRAA dose of 0% was reduced to zero slump after 20 minutes, 0.5% and1% reduced to zero slump after 30 minutes, 1.5% and 2% was after 40 minutes and 2.5% and 3% after 50 minutes.

Workability of concrete is improved when HRWRAA admixtures are incorporated in the mixture at given water content (Lee et al., 2019). Similar to this, it is observed that as the dosage of HRWRAA increases, the initial slump value also increases, however, the slump values vary with different cement brands. The value of initial slump without HRWRAA concrete mix using Derba cement has shown better workability than Dangote and National Cement as illustrated in

Table 4.3, 4.4 and 4.5, respectively. Comparatively, National cement has shown low degree of workability than Dangote Cement without HRWRAA concrete mix. When adding 0.5% of HRWRAA on concrete mix using such brand of cement, even though low workability it is clearly shown that HRWRAA has effect on workability as demonstrated in Table 4.3, 4.4 and 4.5 respectively. Also, when adding 1% of HRWRAA, the degree of workability became significant even all brand of cement has medium workability Based on the recommendations of ASTM C143.

During addition of 1.5% of HRWRAA, Derba and Dangote cement have shown medium workability but National cement has shown high degree of workability. Likewise, during addition of 2% of HRWRAA, even all cement brands has shown high workability, when compared to each other Derba cement has shown workability than both Dangote and National cement. But both Dangote and National cement has shown nearly the same high workability. However, at addition of 2.5% of HRWRAA, concrete with all cement brands has shown highly workable properties with collapsed type of slump. Finally. At addition of 3% of HRWRAA, all Derba, Dangote and National cements has shown very highly flowable properties with collapse slump and segregated concrete.

the impact of HRWRAA on slump loss is highly dependent on other factors such as cement type, curing conditions, and temperature (Sounthararajan & Sivakumar, 2012). As shown on the above results, the initial slump values have been reducing through time, and it takes different dosages of HRWRAA for the slump to be zero. From the above results, at doses of 0%, 0.5%, and 1%, Derba cement was workable for 50 minutes; at 1.5% and 2%, Derba and Dangote cement were workable for 60 minutes; and at 2.5% and 3%, Derba, Dangote, and National cement were workable for more than 60 minutes.

The cement brands had varied slump values even at the same dosage of HRWRAA, with Derba cement showing better initial slump results than Dangote and National cement at a specific dosage of HRWRAA. This is due to the fact that Derba cement has a lower value of normal consistency and a slower setting time, which allows it to achieve higher workability. Relatively, because of the faster setting time and higher amount of normal consistency, Dangote and National Cement had nearly the same slump values with the same dosage of HRWRAA. This indicates that Derba cement has better workability in the concrete mixture than Dangote and

National cement at the same percentage of dose. Additionally, through time, the initial slump was reduced to a zero slump within different time periods for various dosages of HRWRAA. For the doses of 0%, 0.5%, and 1%, Derba cement has been workable for 50 minutes, which is longer than Dangote and National cements. At 1% and 1.5% dosages, Derba and Dangote cements have been workable for 60 minutes, and at 2.5% and 3% dosages, Derba, Dangote, and National cements have been workable for more than 60 minutes. The results show that the use of HRWRAA with different cement brands has shown different workability.

the choice of cement brand and HRWRAA dosage is crucial in achieving optimal slump values and desirable workability during concrete mixing. One of the ways to enhance the workability of concrete is by using HRWRAA. The amount of HRWRAA added to the mix is directly proportional to the workability of the concrete until the optimal dosage is reached. At this point, the concrete attains the desired workability and can be easily molded. In addition, duration of time for which the concrete is workable varies with the dosage HRWRAA for different cement brands. However, the use of excess HRWRAA can lead to bleeding and segregation, thereby reducing the cohesiveness and uniformity of the concrete. This negatively impacts the compressive strength of the concrete as well.

4.3 Effect of High range water reducer and accelerating admixture on Properties of Hardened Concrete Strength

Concrete will change from a fluid to a plastic state and finally to a solid, hardened state with the development of hydration. The intense effect of HRWRAA on the properties of hardened concrete has also been studied, and the properties of concrete inspected are compressive strength, tensile strength, flexural strength, and permeability. Let's discuss the effects of HRWRAA on hardened concrete based on the results of an experiment with values for control specimens. Compressive strength, Tensile strength and Flexural Strength of concrete with different dosage of HRWRAA and cement brands are shown in Table 4.6, Table 4.7 and Table 4.8. These tests were performed on 3 days, 7days and 28 days. The values of HRWRAA dosage. Compressive strength, Tensile strength and Flexural Strength at different specific dosage of HRWRAA also demonstrated in figure below.

Table 4-6 Compressive, Tensile and Flexural Strength of concrete using Derba Cement

Mix -Code and dosage	Slump Value mm	water reduction %	Compressive Strength			Splitting Tensile Strength			Flexural Strength
			3 days	7 days	28 days	3 days	7 days	28 days	28 days
DR-HRWRAA-0%	45mm	0%	19.56	31.11	46.22	2.23	3.13	5.27	**5.56**
DR-HRWRAA-0.5%	60mm	20%	21.33	32.89		2.69	3.55		
DR-HRWRAA-1%	110mm	23%	24.89	37.78		3.15	4.19		
DR HRWRAA-1.5%	135mm	25%	**28.44**	**48.89**	**55.11**	**3.52**	**5.26**	**6.28**	**6.24**
DR HRWRAA-2%	195mm	28%	26.22	42.07		3.06	4.66		
DR-HRWRAA-2.5%	215mm	30%	22.22	39.70		2.72	4.22		
DR-HRWRAA-3%	240mm	33%	13.56	23.78		1.66	2.88		

Table 4-7 Compressive, Tensile and Flexural Strength of concrete using Dangote Cement

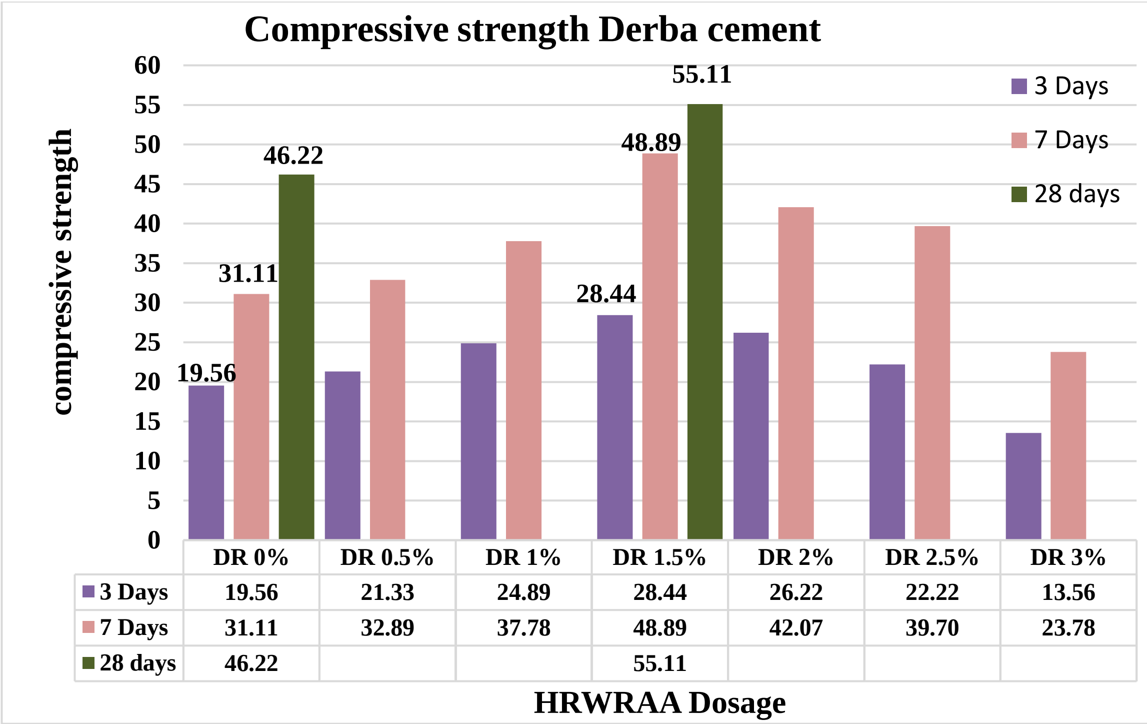
Mix -Code and dosage	Slump Value mm	water reduction %	Compressive Strength			Splitting Tensile Strength			Flexural Strength
			3 days	7 days	28 days	3 days	7 days	28 days	28 days
DN-HRWRAA-0%	30mm	0%	22.22	33.78	47.11	2.27	3.41	4.74	**5.79**
DN-HRWRAA-0.5%	45mm	20%	23.41	35.11		2.53	3.79		
DN-HRWRAA-1%	90mm	23%	25.78	38.67		2.91	4.29		
DN HRWRAA-1.5%	120mm	25%	27.56	43.56		3.06	4.70		
DN HRWRAA-2%	175mm	28%	**31.11**	**50.67**	**56.00**	**3.45**	**5.61**	**6.21**	**6.46**
DN-HRWRAA-2.5%	205mm	30%	28.44	40.30		3.02	4.28		
DN-HRWRAA-3%	225mm	33%	15.40	26.68		1.64	3.10		

Table 4-8 Compressive, Tensile and Flexural Strength of concrete using National Cement

Mix -Code and dosage	Slump Value	water reduction %	Compressive Strength			Splitting Tensile Strength			Flexural Strength
	mm		3 days	7 days	28 days	3 days	7 days	28 days	28 days
NT-HRWRAA-0%	10mm	0%	24.89	35.56	44.89	2.64	3.85	4.96	**5.62**
NT-HRWRAA-0.5%	25mm	20%	26.37	39.56		2.96	4.62		
NT-HRWRAA-1%	55mm	23%	29.33	40.44		3.26	4.86		
NT HRWRAA-1.5%	145mm	**25%**	**32.89**	**48.48**	**52.44**	**3.47**	**5.85**	**6.31**	**6.20**
NT HRWRAA-2%	170mm	28%	30.67	42.67		3.41	5.02		
NT-HRWRAA-2.5%	205mm	30%	26.67	36.44		2.96	4.28		
NT-HRWRAA-3%	235mm	33%	16.89	26.22		1.87	2.91		

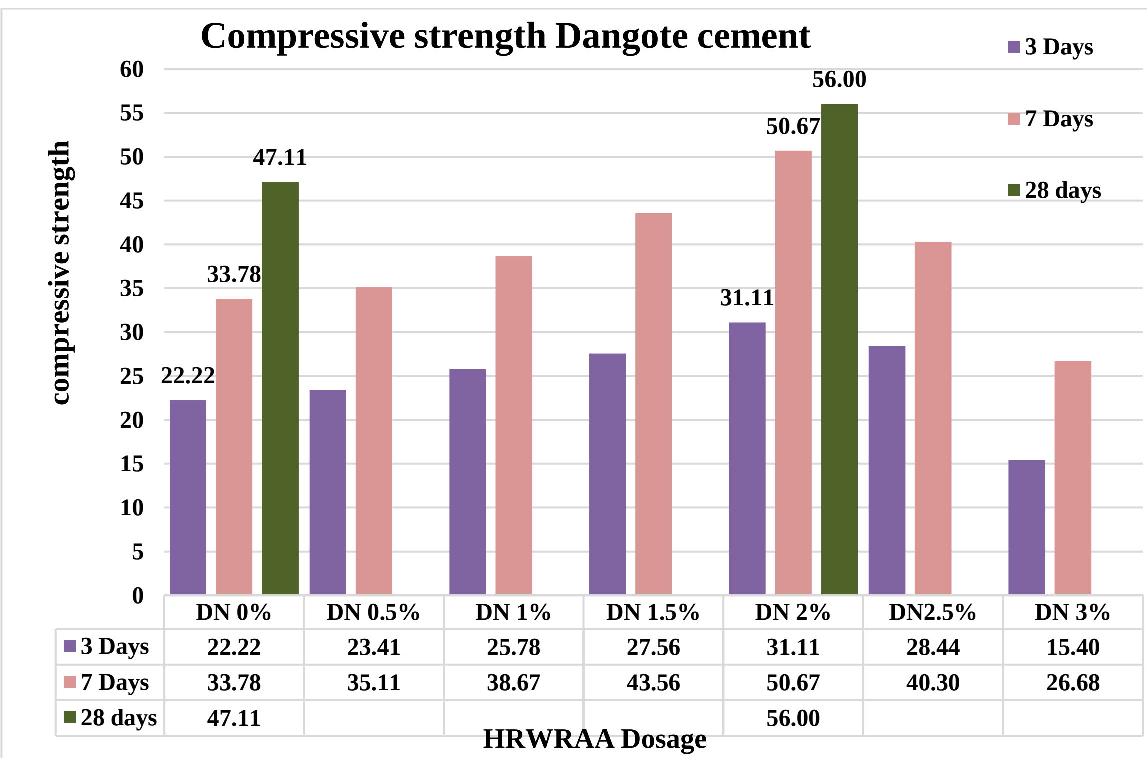
4.3.1 Effect Dosage of High Range Water Reducing and Accelerating Admixture on compressive strength.

To determine the maximum dosage of HRWRAA for high early compressive strength, laboratory tests were conducted at 3 and 7 days for control mix and dosage of HRWRAA of 0.5%, 1%, 1.5%, 2%, 2.5%, and 3% by reducing mixing water by 20%, 23%, 25%, 28%, 30%, and 33%, respectively, for all cement brands. Additionally, for comparison purposes, 28 days of compressive strength for the control mix and maximum dosage that achieved maximum early compressive strength were conducted. All test results were tabulated in Appendix 3. Typical results of control mix concrete specimens and mixes with HRWRAA using Derba, Dangote, and National Cements are presented in Figures 4.5, 4.6, and 4.7, respectively.



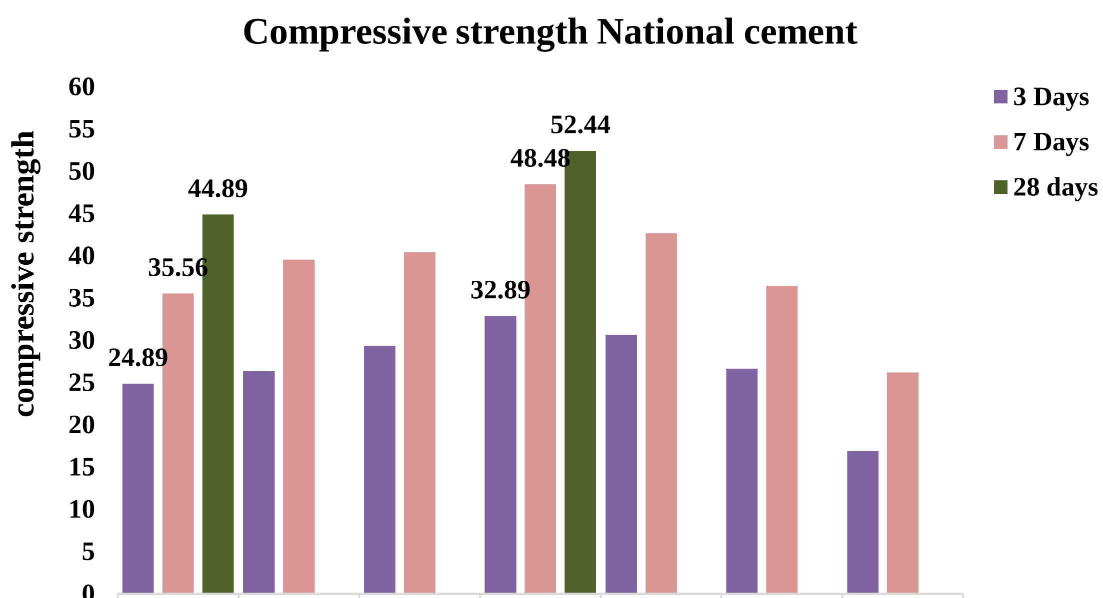
	DR 0%	DR 0.5%	DR 1%	DR 1.5%	DR 2%	DR 2.5%	DR 3%
3 Days	19.56	21.33	24.89	28.44	26.22	22.22	13.56
7 Days	31.11	32.89	37.78	48.89	42.07	39.70	23.78
28 days	46.22			55.11			

Figure 4-5 compressive strength Derba cement



	DN 0%	DN 0.5%	DN 1%	DN 1.5%	DN 2%	DN2.5%	DN 3%
3 Days	22.22	23.41	25.78	27.56	31.11	28.44	15.40
7 Days	33.78	35.11	38.67	43.56	50.67	40.30	26.68
28 days	47.11				56.00		

Figure 4-6 compressive strength Dangote cement



	NT 0%	NT 0.5%	NT 1%	NT 1.5%	NT 2%	NT 2.5%	NT3%
3 Days	24.89	26.37	29.33	32.89	30.67	26.67	16.89
7 Days	35.56	39.56	40.44	48.48	42.67	36.44	26.22
28 days	44.89			52.44			

Figure 4-7 compressive strength National cement

The use of HRWRAA in concrete significantly improved its compressive strength and durability properties. the compressive strength of concrete increased with increasing dosage of HRWRAA up to the optimum dosage, after which the strength started to decline (Ren et al., 2021). According to the above results, HRWRAA dose significantly affects concrete rate of strength development. The compressive strength increases in direct proportion to the dosage. However, the results also show that adding HRWRAA above maximum dosage can have a negative impact on the compressive strength, which is decreasing compressive strength. the compressive strength of concrete may not be continually increased by the addition of HRWRAA rather, high dose greatly decreases the strength. According to (Dorn et al., 2022), Overdosing of HRWRAA can have significant negative effects on the properties of hardened concrete. These admixtures, when used in excessive amounts, can cause the concrete to lose its strength and durability over time.

Figure 4.5 shows compressive strength versus dosage of HRWRAA using Derba Cement in concrete mixture. It is observed that addition of HRWRAA improve early compressive strength of concrete for both three and seven days. However, the percentage of improvement is varied with dosage of HRWRAA. Addition of 0.5% and 1% of HRWRAA has increased the compressive strength of 3 days of control mix 19.56Mpa to 21.33 Mpa and 24.89Mpa respectively, additionally 7days compressive strength of 31.1Mpa to 32.89Mpa and 37.89Mpa respectively. Dose of 1.5% of the HRWRAA dosage results in the maximum increment of early compressive strength of concrete 3days and 7days to 28.44Mpa and 48.89Mpa respectively. Addition of 2.0% and 2.5% of HRWRAA were increased the compressive strength of 3 days to 26.22 Mpa and 22.22 Mpa respectively, additionally 7days compressive strength to 42.07 Mpa and 39.7 Mpa respectively. On the contrary, the addition of 3.0% HRWRAA reduced the compressive strengths of 3 days of control mix (19.56 MPa) and 7 days of 31.11 MPa to 13.56 MPa and 23.78 MPa, respectively. Derba cement results in the maximum increment of early compressive strength of concrete at 1.5% dosage of HRWRAA for both 3 days and 7 days, which is 28.44 MPa and 48.89 MPa respectively. The result shows that a 1.5% dosage of HRWRAA has improved the compressive strength of 3, 7, and 28 days of control mix by 45.4%, 57.15% and 19.23%, respectively.

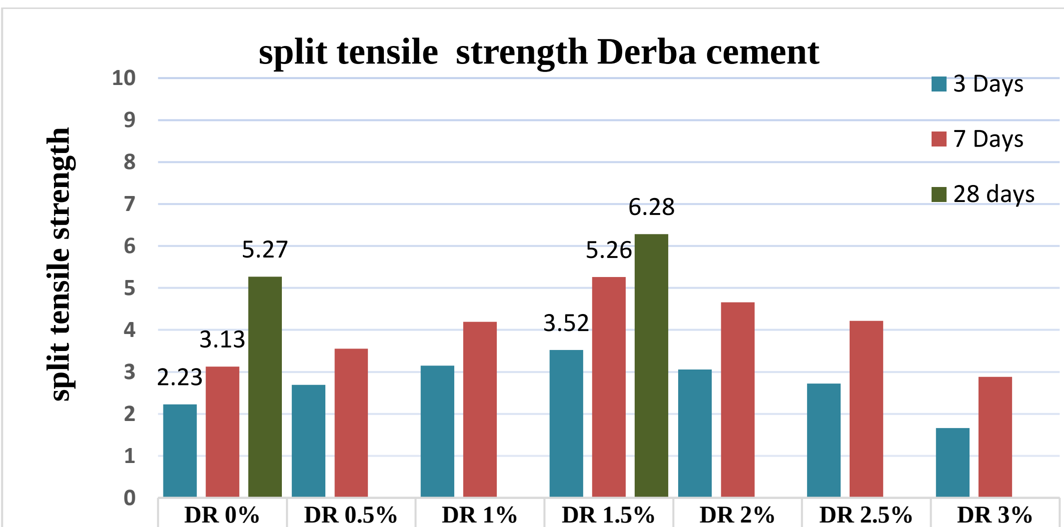
Figure 4.6 shows compressive strength versus dosage of HRWRAA using Dangote Cement in concrete mixture. Addition of 0.5% and 1% of HRWRAA was increased the compressive strength of 3 days of control mix 22.22Mpa to 23.41Mpa and 25.78Mpa respectively. additionally, 7days compressive strength of 33.78Mpa to 35.11Mpa and 38.67Mpa respectively. The addition of 1.5% and 2.0% of HRWRAA has increased the compressive strength of 3 days to 27.56 Mpa and 31.11 Mpa, respectively, and the compressive strength of 7 days to 43.56 Mpa and 50.67 Mpa, respectively. A dose of 2.5% of the HRWRAA dosage results in an increment of the early compressive strength of concrete after 3 days and 7 days to 28.44 MPa and 40.3 MPa, respectively. On the contrary, the addition of 3.0% HRWRAA reduced the compressive strength of 3 days of control mix from 22.22 MPa and 7 days from 33.78 MPa to 15.4 MPa and 26.68 MPa, respectively. The results showed that with Dangote cement, dose of 2.0% of HRWRAA has increased the compressive strength of the control mix over 3, 7, and 28 days by 40.01%, 50%, and 18.87%, respectively.

As shown in figure 4.7, compressive strength versus dosage of HRWRAA using National Cement: addition of HRWRAA 0.5%, 1%, 1.5%, 2%, and 2.5% has increased the compressive strength of the concrete control mix by 3 days to 26.37 MPa, 29.33 MPa, 32.89 MPa, 30.67 MPa, and 26.67 MPa, and by 7 days to 39.56 MPa, 40.44 MPa, 48.48 MPa, 42.67Mpa, and 36.44Mpa, respectively. However, the maximum early compressive strength achieved at 1.5% dosage of HRWRAA is 32.89 MPa and 48.48 MPa for 3 and 7 days, respectively. Similar to other cements, a dose of 3% HRWRAA reduced both 3 and 7-day compressive strengths to 16.89 MPa and 26.12 MPa, respectively, for National cement. The results showed that with national cement, dose of 1.5% of HRWRAA has increased the compressive strength of the control mix over 3, 7, and 28 days by 32.14%, 36.33%, and 16.82%, respectively.

Generally, the results showed that increasing the dose of HRWRAA has increased the compressive strength up to maximum dosage, and then the strength declined. Depending on physical properties of cement brands, the dosage at which maximum compressive strength achieved was varied which is 1.5%, 2%, and 1.5% for Derba, Dangote, and National cements, respectively. As the fineness of Dangote cement is higher than other cement, HRWRAA consumption to achieve Maximum early strength is higher. Because of its faster setting time, fineness properties and may be higher tricalcium silicate and tricalcium aluminate contents, at similar dosage of HRWRAA, National cement has achieved higher compressive strength at 3 and 7 days than Dangote and Derba cement. Furthermore, due to higher percentage of fineness, at optimum dosage, Dangote cement achieved maximum compressive at 7 and 28 days than Derba and National cements. Because of higher water reduction of HRWRAA, at dosage of 1.5%, 2% and 1.5%, for Derba, Dangote and National cements respectively, 28days compressive strength was increased by 19.23%, 18.87% and 16.82% respectively. with all cement brands, 7-day compressive strength has increased more than 3 and 7-day strength. The analysis was based on the recommendation of the ASTM C192 standard, which states that the rate of compressive strength development of concrete is proportional to the addition of chemical admixture. However, adding an excessive amount of HRWRAA leads to the formation of an excessively thick hydration layer around the cement particles. This layer can hinder proper particle interaction and reduce the strength of the cement paste. the addition of HRWRAA dosage of 3% to the control mix has caused segregation and bleeding which has caused reduction on compressive strength for all cement brands.

4.3.2 Effect Dosage of High Range Water Reducing and Accelerating Admixture on Tensile Strength of concrete

Concrete tensile split strength is the measure of a concrete specimen's resistance to failure under tensile stress. Due to the difficulty of test specimen grip, it is challenging to directly measure the tensile strength of concrete using the tension method. These factors lead to the application of indirect testing like the flexural and splitting tensile tests. This splitting test, called the Brazilian test, is an indirect tension test. A splitting tensile test was carried out at 3 and 7 days for the control mix and dosage of HRWRAA (0.5%, 1%, 1.5%, 2%, 2.5%, and 3%) by reducing mixing water by 20%, 23%, 25%, 28%, 30%, and 33%, respectively, for all cement brands to determine the effects of HRWRAA on the tensile strength of the concrete. for comparison purposes 28-day split tensile strengths for the control mix and optimum dosage were conducted. All test results were tabulated in Appendix 3. The specimen was tested in accordance with ASTM (C 496) Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens after 3, 7 and 28 days of curing. The results of tensile strength of control mix concrete specimen and mixes with HRWRAA using Derba, Dangote and National Cements are presented in Figure 4.8, Figure 4.9 and Figure 4.10 respectively.



	DR 0%	DR 0.5%	DR 1%	DR 1.5%	DR 2%	DR 2.5%	DR 3%
3 Days	2.23	2.69	3.15	3.52	3.06	2.72	1.66
7 Days	3.13	3.55	4.19	5.26	4.66	4.22	2.88
28 days	5.27			6.28			

Figure 4-8 split tensile strength Derba cement

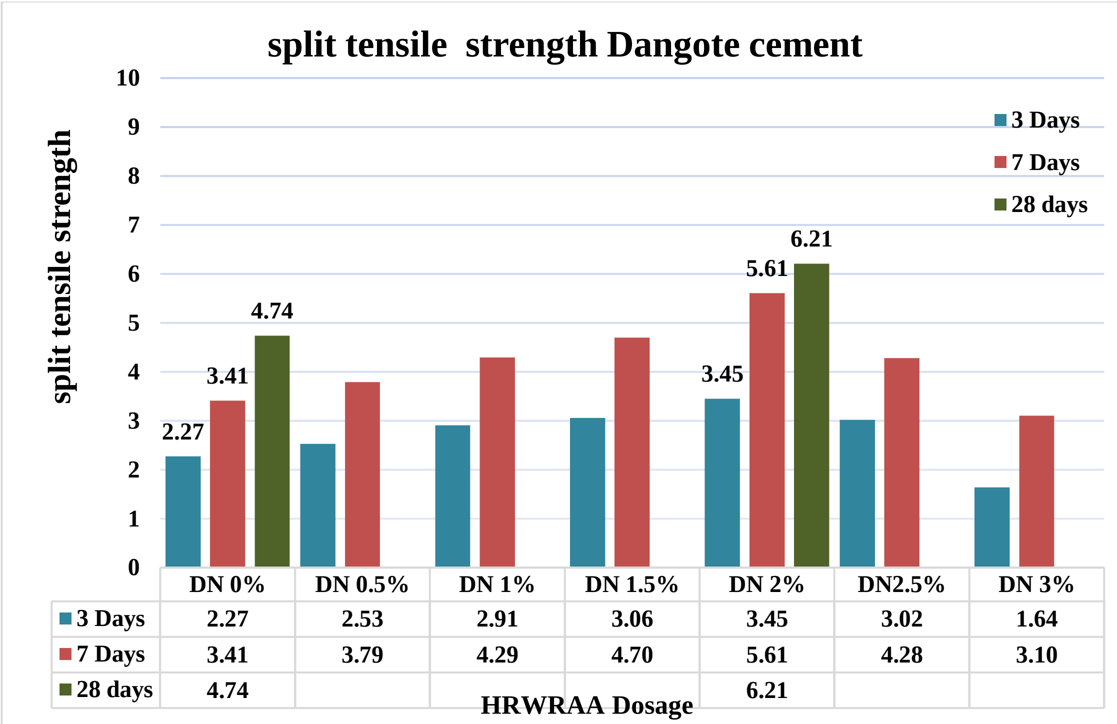


Figure 4-9 split tensile strength Dangote cement

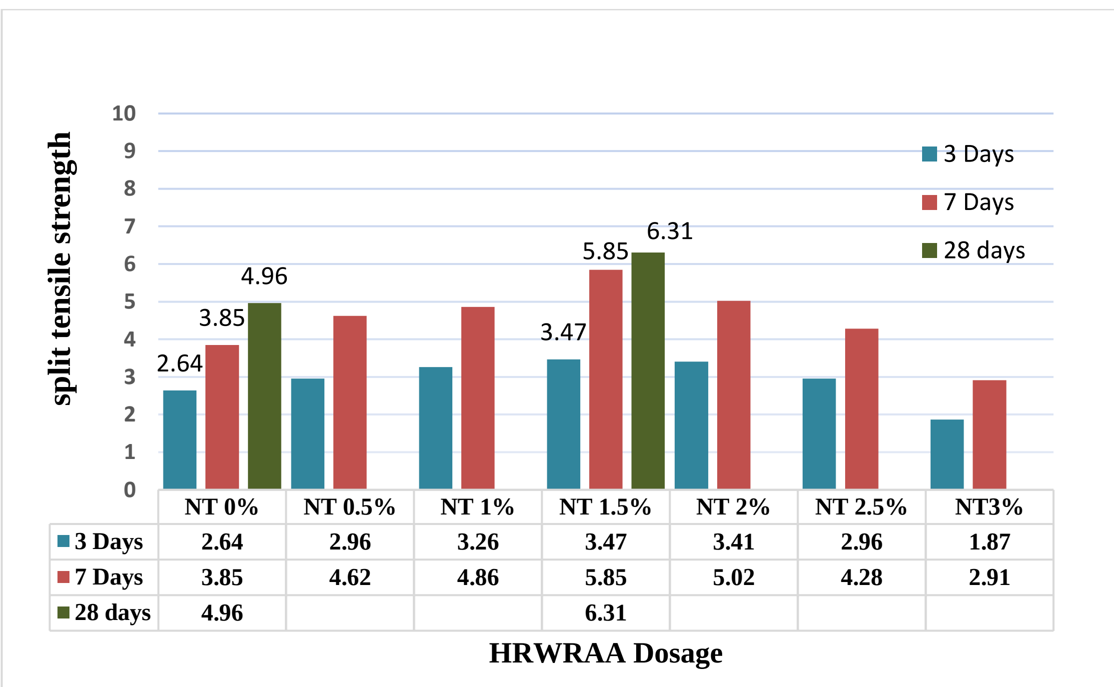


Figure 4-10 split tensile strength National cement

Figure 4.8 shows the effect of the addition of HRWRAA on the tensile strength of concrete for Derba cement. The results show that the addition of HRWRAA increased the tensile strength of the control mix. However, the increment rate varies with dosage. 3, 7, and 28-day split tensile strengths have shown an increment over a control mix without HRWRAA. The addition of 0.5%, 1%, 1.5%, 2%, and 2.5% has increased the tensile strength of the control mix for 3 days and 7 days by 20.63%, 41.26%, 57.85%, 37.22%, 21.97%, and 13.42%, 33.87%, 68.05%, 48.88%, and 34.82%, respectively. But a dose of 3% has reduced the split tensile strength of 3 and 7 days by 25.56% and 7.99%, respectively. From the above results, it can be concluded that a dose of 1.5%, which has achieved maximum compressive strength, has still shown maximum improvement in split tensile strength over a control mix of 3, 7, and 28 days by 57.85%, 68.05%, and 32.64%, respectively.

Similarly, figure 4.9 shows the effect of the addition of HRWRAA on the tensile strength of concrete for Dangote cement. 3, 7, and 28-day split tensile strengths have shown an increment over a control mix. The addition of 0.5%, 1%, 1.5%, 2%, and 2.5% has increased the tensile strength of the control mix for 3 days and 7 days by 11.45%, 28.19%, 34.8%, 51.98%, 33.04% and 11.14%, 25.81%, 37.83%, 64.52%, and 25.51%, respectively. In contrast, the addition of 3% has reduced the split tensile strength of 3 and 7 days by 27.75% and 9.09%, respectively. It can be concluded that a dose of 2.0 %, which has achieved maximum compressive strength, has shown maximum improvement in split tensile strength over a control mix of 3, ,7 and 28 days by 51.98%, 64.52%, and 20.4%, respectively.

The results in Figure 4.10 show the effect of the addition of HRWRAA on the tensile strength of concrete for National Cement. The results reveal that, the addition of HRWRAA increased the tensile strength of the control mix. However, the increment rate varies with dosage. 3, 7, and 28-day split tensile strengths have shown an increment over a control mix without HRWRAA. The addition of 0.5%, 1%, 1.5%, 2%, and 2.5% has increased the tensile strength of the control mix for 3 days and 7 days by 12.12%, 23.48%, 31.44%, 29.17%, 12.12%, and 20%, 26.23%, 51.95%, 30.39%, and 11.17%, respectively. Adversely, a dose of 3% has reduced the split tensile strength of 3 and 7 days by 29.17% and 24.42%, respectively. From the above results, it can be concluded that a dose of 1.5%, which has achieved maximum compressive strength, has still shown maximum improvement in split tensile strength over a control mix of 3, 7, and 28 days by 31.44%, 51.95%, and 23.59%, respectively.

According to a study conducted by (Sounthararajan & Sivakumar, 2012), The addition of high-range water-reducing and accelerating admixture (HRWRAA) to concrete can increase its tensile strength by up to 35%. However, the actual degree of increase is dependent on many factors, such as the type and dosage of the admixture, the type of cement, the properties of the concrete, and the curing conditions. The result of this research has also shown that the degree of increment in tensile split strength is varied with age of the test and cement brands. As shown in the results, Derba cement has shown a higher increment of tensile strength at 3, 7, and 28 days than Dangote and National cements. However, all cement brands have shown a maximum improvement in tensile strength at 7 days, compared to 3 and 28 days. Generally, the above results showed that the addition of HRWRAA increased the tensile strength of the control mix. Similarly, at the dosage at which the maximum early compressive has been achieved, on all cement brands, an improvement in tensile strength was achieved when compared with the control mix. But the addition of an excessive dosage of HRWRAA has shown a reduction in tensile strength.

4.3.3 Effect Dosage of High Range Water Reducing and Accelerating Admixture on Flexural Strength of Concrete

Flexural strength tests are indirect tests to determine the tensile strength of concrete. It is a measure of the ability of an unreinforced concrete beam or slab to resist failure in bending. The theoretical maximum tensile stress reached at the bottom fibers of the tested beam is known as the modulus of rupture. It is important for the design and construction of road and airport concrete pavements. Flexural strength tests were conducted after curing the samples for 28 days for the control mixes and for the mix with a dosage of HRWRAA, which has achieved maximum early strength for all cement brands. The tests were carried out on the specimen of 100 x 100 x 500 mm beams loaded at the center point according to ASTM C293. the failure load at which the concrete cracks were then recorded in KN, and by using a formula, calculated flexural strength in MPa resulting in maximum bending moment in the middle third of the specimen is obtained. The results of the concrete mixture using Derba, Dangote, and National Cement with HRWRAA are presented in Figure 4.11.

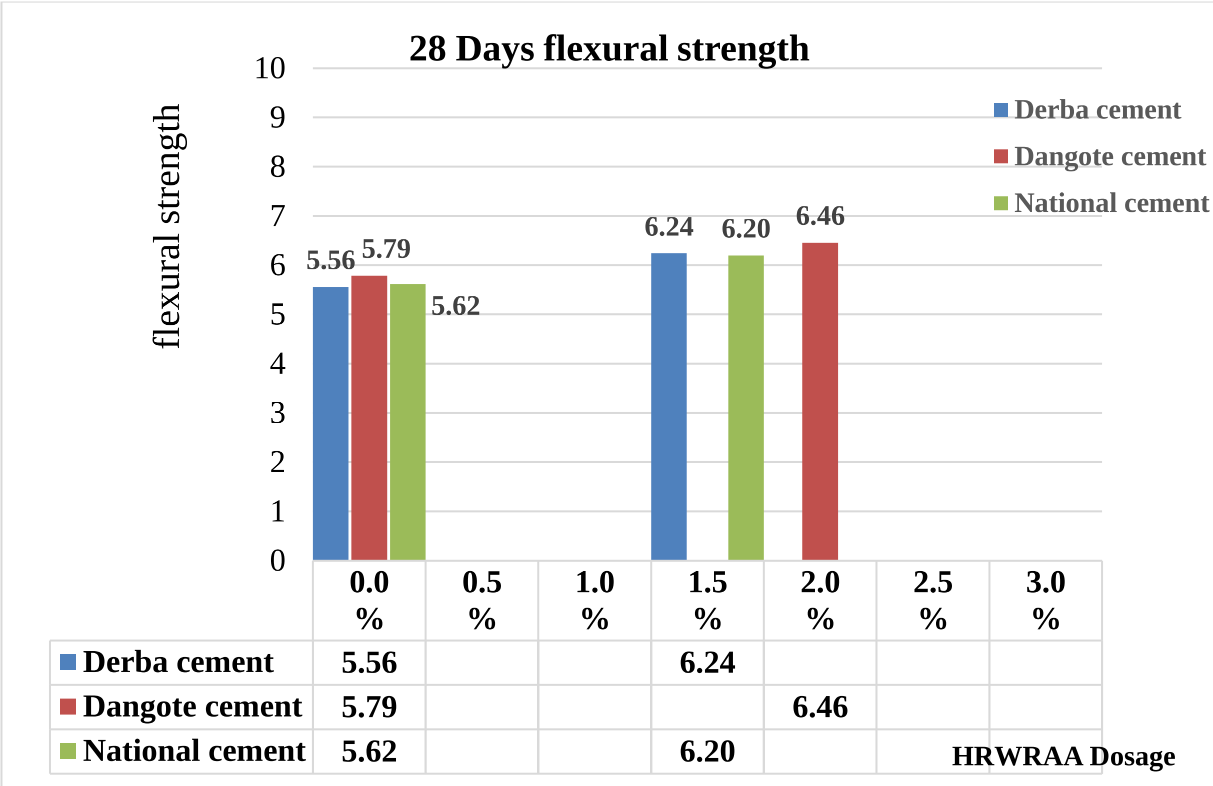


Figure 4-11 28 Days flexural strength for Derba, Dangote and National cements

Figure 4.11 shows that the effect of HRWRAA on flexural strength of concrete with different cement brands. The test was done only for the control mix and for the mix with dose, which has achieved maximum compressive strength at 3 and 7 days for all cement brands. As shown in the figure for Derba cement, At the age of 28 days, the flexural strength of the control mix with 0% and 1.5% dosages of HRWRAA in concrete was 5.56 MPa and 6.24 MPa, respectively. The results reveal that a 1.5% dose of HRWRAA has increased the flexural strength of the concrete mix by 12.23%, which is from 5.56 MPa to 6.24 MPa. For Dangote cement concrete mix, the flexural strengths of the control mix at 0% and 2.0% dosages of HRWRAA to concrete were 5.79 MPa and 6.46 MPa, respectively. The results show that the addition of a 2.0% dose of HRWRAA has increased the flexural strength of the concrete mix by 11.57%, from 5.79 MPa to 6.46 MPa. Similarly, for National Cement Concrete Mix, the flexural strength of the control mix at 0% and 1.5% dosages of HRWRAA to concrete was 5.62 MPa and 6.20 MPa, respectively. The results show that the addition of a 1.5% dose of HRWRAA has increased the flexural strength of the concrete mix by 10.32%, which is from 5.62 MPa to 6.20 MPa.The test was done only for the control mix and for the mix with dose, which has achieved maximum compressive strength at 3 and 7 days for all cement brands. As shown in the figure for Derba cement, At the age of 28 days, the flexural strength of the control mix with 0% and 1.5% dosages of HRWRAA in concrete was 5.56 MPa and 6.24 MPa, respectively. The results reveal that a 1.5% dose of HRWRAA has increased the flexural strength of the concrete mix by 12.23%, which is from 5.56 MPa to 6.24 MPa. For Dangote cement concrete mix, the flexural strengths of the control mix at 0% and 2.0% dosages of HRWRAA to concrete were 5.79 MPa and 6.46 MPa, respectively. The results show that the addition of a 2.0% dose of HRWRAA has increased the flexural strength of the concrete mix by 11.57%, from 5.79 MPa to 6.46 MPa. Similarly, for National Cement Concrete Mix, the flexural strength of the control mix at 0% and 1.5% dosages of HRWRAA to concrete was 5.62 MPa and 6.20 MPa, respectively. The results show that the addition of a 1.5% dose of HRWRAA has increased the flexural strength of the concrete mix by 10.32%, which is from 5.62 MPa to 6.20 MPa.

According to the literature, use of high-range water-reducing and accelerating admixtures in concrete has been shown to generally improve its flexural strength. an optimal dosage of HRWRAA can improve the flexural strength of concrete, but excessive dosage can result in a decrease in strength the use of HRWRAA resulted in an increase in the flexural strength of concrete by up to 11% for PCE-based admixture and up to 9% for NF-based admixture (Ren et al., 2021). This research has also shown that, at 28 days, the flexural strength of the concrete mix with a dose of HRWRAA, which has achieved maximum compressive strength, has shown an increment in flexural strength for all cement brands. However, the percentage of increment varies with cement brands. The increment was 12.23% from the control mix concrete for Derba cement, 11.57% from the control mix concrete for Dangote, and 10.32% from the control mix concrete for National cement. Derba cement has shown a higher increment of flexural strength in the control mix than Dangote and National cements. Generally, based on the test results, even though the improvement percentage is different with different cement brands, the flexural strength has been well improved when the dosage of HRWRAA is increased up to the optimum point by reducing the amount of mixing water for all types of cement brands.

4.3.4 Effect Dosage of High Range Water Reducing And Accelerating Admixture on Permeability Test of Concrete

The test was performed for control mix and for the mix with dosage of HRWRAA which has achieved maximum early compressive strength for all types of cement brands. In this research, a non-steady-state water permeability test was selected to study the effect of high-range water-reducing and accelerating admixtures on concrete permeability. The test was conducted on 15-cm-thick concrete cubes that had been cured for 28 days and surface dried on air. Figure 4.12 and Table 4.9 below shows result of permeability test for optimum dosage of HRWRAA.

Table 4-9 water penetration test results

Cement Brands	HRWRAA %	Penetration depth(mm)		
		Minimum	maximum	Mean
Derba cements	0%	13.6	16.6	15.1
	1.50%	8.5	9.5	9.1
Dangote cements	0%	15.6	19.6	17.6
	2%	7.8	15.4	11.6
National cements	0%	14.4	18.7	16.5
	1.50%	8.4	14.4	11.4

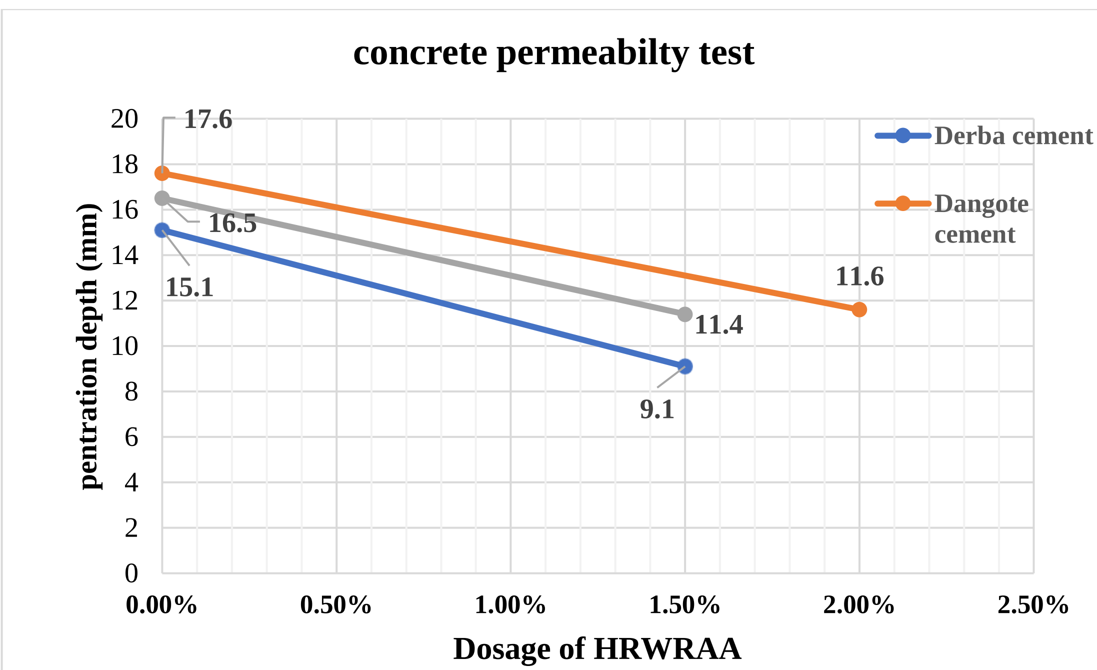


Figure 4-12 concrete permeability test

Table 4.9 shows the minimum, mean and maximum non-steady flow depth penetrations obtained for control mix and with HRWRAA for Derba, Dangote and National cements. The depth penetration test on Derba, Dangote, and national cement C-40 concrete with different dosages of HRWRAA admixture by reducing the amount of mixing water are shown in Table 4.9. The penetration of water through concrete with 0% HRWRAA admixture was 15.1 mm, 17.6 mm, and 16.5 mm for Derba, Dangote, and national cement, respectively. for Derba and National Cement. At the dosage of 1.5%, which has achieved maximum compressive strength, the penetration values are reduced to 9.1 mm, or 39.6%, and 11.4 mm, or 31%, respectively. For Dangote cement, the reduction in water penetration was 11.6 mm, or 34.2%.

The results indicates that, the penetration depth of water through concrete which is produced without adding HRWRAA admixture was reduced by the addition of HRWRAA in concrete mix. However, the percentage of reduction in water penetration varies with cement brands and dosage of HRWRAA. For Derba, Dangote and National cements at their dosage which achieved maximum compressive strength the reduction in water penetration was 39.6%, 34.2% and 31% respectively. Derba cement has shown higher penetration improvement than Dangote and national cements. The depth of penetration of water through concrete was less than 50mm classifies the concrete as impermeable; and depth less than 30mm, as impermeable under aggressive conditions (Neville, 1995). Therefore, based on the experiment results Even the reduction in water penetration has a variation with cement brands, all the concrete produced samples are classified impermeable under aggressive conditions.

4.4 Cost impact of using HRWRAA with Different Cement Brands

It can be difficult to compare the cost of HRWRAA concrete mixture with different brands of cement and draw a general conclusion because of price changes and inconsistent market data. The following part deals with the cost analyses of the concrete mixtures on the basis of the price that is currently being charged on the market, a comparative analysis was conducted.

Table 4-10 material price

Item No.	Materials	Unit	Quantity	Birr(ETB)
1	Dangote Cement	Quintal	1	1750.00
2	Derba Cement	Quintal	1	1700.00
3	National Cement	Quintal	1	1842.50
4	HRWRAA	kg	1	95.83
5	Fine aggregate	kg	1	1.65
6	Coarse aggregate	kg	1	1.26
7	Water	kg	1	0.03

Table 4-11 Cost of concrete mix with Dangote cement

Admixture	Amount of cement(kg/m^3)	Water (lt/m3)	Amount of admixture (kg/m^3)	Sand used (kg/m^3)	Gravel used (kg/m^3)	Total Cost incurred by per 1m^3
0.00%	471	160.0		666	1083	
Cost(birr)	8242.5	4.0		1097.9	1363.5	10707.9
0.50%	471	128.0	2.4	698	1083	
Cost(birr)	8242.5	3.2	225.7	1150.7	1363.5	10932.8
1.00%	471	123.2	4.7	703	1083	
Cost(birr)	8242.5	3.1	451.4	1158.9	1363.5	11158.4
1.50%	471	120.0	7.1	706	1083	
Cost(birr)	8242.5	3.0	677.1	1163.9	1363.5	11384.0
2.00%	471	115.2	9.4	711	1083	
Cost(birr)	8242.5	2.9	902.8	1172.1	1363.5	**11609.6**
2.50%	471	112.0	11.8	718	1083	
Cost(birr)	8242.5	2.8	1128.4	1183.7	1363.5	11835.2
3.00%	471	107.2	14.1	723	1083	
Cost(birr)	8242.5	2.7	1354.1	1191.9	1363.5	12060.7

Table 4-12 Cost of concrete mix with Derba cement

Admixture	Amount of cement(kg/m^3)	Water (lt/m3)	Amount of admixture (kg/m^3)	Sand used (kg/m^3)	Gravel used (kg/m^3)	Total Cost incurred by per 1m^3
0.00%	471	160.0		666	1083	
Cost(birr)	8007.0	4.0		1097.9	1364.6	10473.5
0.50%	471	128.0	2.4	698	1083	
Cost(birr)	8007.0	3.2	225.7	1150.7	1364.6	10698.4
1.00%	471	123.2	4.7	705	1083	
Cost(birr)	8007.0	3.1	451.4	1162.2	1364.6	10924.0
1.50%	471	120.0	7.1	706	1083	
Cost(birr)	8007.0	3.0	677.0	1163.9	1364.6	**11149.6**
2.00%	471	115.2	9.4	711	1083	
Cost(birr)	8007.0	2.9	902.7	1172.1	1364.6	11375.1
2.50%	471	112.0	11.8	718	1083	
Cost(birr)	8007.0	2.8	1128.4	1183.7	1364.6	11600.7
3.00%	471	107.2	14.1	723	1083	
Cost(birr)	8007.0	2.7	1354.1	1191.9	1364.6	11826.3

Table 4-13 Cost of concrete mix with National cement

Admixture	Amount of cement(kg/m^3)	Water (lt/m3)	Amount of admixture (kg/m^3)	Sand used (kg/m^3)	Gravel used (kg/m^3)	Total Cost incurred by per 1m^3
0.00%	471	160.0		666	1083	
Cost(birr)	8675.8	4.0		1097.9	1364.6	11142.3
0.50%	471	128.0	2.4	698	1083	
Cost(birr)	8675.8	3.2	225.7	1150.7	1364.6	11367.2
1.00%	471	123.2	4.7	703	1083	
Cost(birr)	8675.8	3.1	451.4	1158.9	1364.6	11592.8
1.50%	471	120.0	7.1	706	1083	
Cost(birr)	8675.8	3.0	677.0	1163.9	1364.6	**11818.4**
2.00%	471	115.2	9.4	711	1083	
Cost(birr)	8675.8	2.9	902.7	1172.1	1364.6	12043.9
2.50%	471	112.0	11.8	718	1083	
Cost(birr)	8675.8	2.8	1128.4	1183.7	1364.6	12269.5
3.00%	471	107.2	14.1	723	1083	
Cost(birr)	8675.8	2.7	1354.1	1191.9	1364.6	12495.1

The results provided in Tables 4.11, 4,12, and 4,13 show that the dose of HRWRAA impacts the prices of producing concrete, even though the price instability of cement has its own impact on the price of concrete mix. When compared to control mix, the price of concrete mix increases when the dosage of HRWRAA increases for all cement brands. When 0.5%, 1%, 1.5%, 2%, 2.5% and 3% dosage of HRWRAA are added in the production using Dangote cement, the cost is 10698.4 birr/m^3, 10924.0 birr/m^3, 11149.6 birr/m^3 birr/m^3, 11375 birr/m^3, 11600.7 birr $^/$$m^3$ and 11826.3 birr $^/$$m^3$ respectively. As shown in table 4.9 in the production of concrete using Derba cement when 0.5%, 1%, 1.5%, 2%, 2.5% and 3% dosage of HRWRAA are added, the cost is 10932.8 birr/m^3, 11158.4 birr/m^3, 11384.0 birr/m^3, 11609.6 birr/m^3, 11835.2 birr/m^3 birr/m^3 and 12060.7 birr/m^3 respectively. For National cement, 11367.2 birr/m^3, 11592.8 birr/m^3, 11818.4, 12043.9 birr/m^3, 12269.5 birr/m^3 and 12495.1 birr/m^3 respectively.

As comparison of all brand of cement at specific dosage of 1.5% and 2%. Concrete with Dangote. Derba and National cement costs (11384.0 birr and 11609.6 birr), (11149.6 birr and 11375 birr) and (11818.4 and 12043.9 birr) respectively for production of 1m^3 concrete. At 1.5% dosage National cement demand 6% more price than Debra cement and 3.8% than Dangote cement. Dangote cement demand 2.1% more price than Derba cement to produce 1m^3 of concrete mix. At 2% dosage, National cement demand 5.7% more price than Dangote cement and 3.7% than Dangote cement. Dangote cement demand 2% more price than Derba cement to produce 1m^3 of concrete mix. From the results it can be conclude that at specific dosage National cement demands higher cost to produce 1m^3 of concrete mix. In addition to this as the dosage of HRWRAA increase, the percentage of cost variation at specific dosage has reduced.

The study's third goal was to figure out the right amount of HRWRAA to use on Derba, Dangote, and National cement. From the descriptions in Tables 4.11, 4,12, and 4,13, it can be seen that a dosage of HRWRAA of (1.5%) was needed for Derba and National cement and (2.0%) for Dangote cement to produce a concrete mix that was more effective and had higher maximum compressive strength, tensile strength, flexural strength, and permeability. Therefore, compared to Dangote and national cement, Derba cement is more cost-effective in enhancing desirable fresh and hardened concrete qualities.

CHAPTER FIVE

5 CONCLUSSION AND RECOMMENDATION

5.1 CONCLUSSION

In this study, physical properties of three cement brand have been characterized, the effects of HRWRAA dosage on the properties of fresh and hardened C-40 concrete, including workability, compressive strength, split tensile strength, flexural strength, and permeability, were examined. The following conclusions are drawn from the study's results.

The physical properties of three brands of cement have shown variation because of the brands' relative proportions, sources of raw materials, manufacturing processes, equipment used, and quality control standards. National cement has a 32% percentage of normal consistency, which is higher than Derba (27%) and Dangote (29%) cement. Derba cement has an initial and final setting time of 197.5 minutes and 290 minutes, respectively, which is slower than Dangote and National cements. Dangote cement has a fineness of 96.29%, which is finer than Derba (93.39%) and national (95.09%) cements. These differences in physical properties within cement brands can vary the hydration reaction, workability, setting time, dosage of HRWRAA, and rate of strength development of concrete with different cement brands.

The addition of HRWRAA to the concrete mix has shown improvement in the slump value of the concrete. The addition of 1%, 1.5%, 2%, and 2.5% HRWRAA with 23%, 25%, 28%, and 30% mix water reduction, respectively, in the concrete mix provides a significant improvement in workability on Derba, Dangote, and national cement compared to their control concrete mixes. However, the addition of 0.5% dosage of HRWRAA with a reduction of 20% of mix water does not provide a significant improvement in the workability of the control mix for three cement brands. While The addition of 3% of HRWRAA dosage has shown collapsed slump, which results in bleeding and segregation, negatively impacting the compressive strength of the concrete. Due to the variation in chemical and physical properties of cement brands, even with the same dosage of HRWRAA, there is a difference in the initial slump and workability duration. At a specific dosage of HRWRAA, due to its lower normal consistency and slower setting time, Derba cement has achieved a higher initial slump and higher workability than Dangote and National cement.

The optimum dosage of HRWRAA for Derba, Dangote, and National cements was 1.5%, 2%, and 1.5%, respectively. As the fineness of Dangote cement is higher than other cements, HRWRAA consumption to achieve maximum early strength is higher. At optimum dosage, concrete mixes with Derba, Dangote, and National cements have achieved 7days compressive strength of 48.89Mpa, 50.67Mpa and 48.48Mpa respectively. Due to its higher finer properties, at optimum dosage of HRWRAA Dangote cement has achieved higher compressive strengths at 7 and 28 days than National and Derba cement. Because of its fast-setting time, National cement has achieved higher 3- and 7-days compressive strengths at a similar dosage than Derba and Dangote cements. Because of higher water reduction capacity of HRWRAA, 28 days compressive strength of control mix of Derba, Dangote, and National cements was increased by 19.23%, 18.87% and 16.82% respectively. However, the dosage of 3% to the control mix has caused segregation and bleeding, which has reduced compressive strength for all cement brands.

The addition of HRWRAA increased the tensile strength of concrete. The dosage of HRWRAA for achieving the highest tensile strength was 1.5% for Derba Cement, 2.0% for Dangote Cement, and 1.5% for National Cement. At optimum dosage, 7 days tensile strength was 5.26Mpa, 5.61Mpa and 5.85Mpa for Derba, Dangote and National cements respectively. Additionally, at optimum dosage 28 days tensile strength of control mix has improved by 32.64%, 20.4% and 23.56% respectively for Derba, Dangote and National cements.

The use of HRWRAA has improved the flexural strength of concrete. At 28 days, the flexural strength of control mix was 5.56Mpa, 5.79Mpa and 5.62Mpa for Derba, Dangote, and National cements, respectively. But at optimum dosage, for Derba, Dangote and National cements, the flexural strength of control mix was increased by 12.23%, 11.57% and 10.32% respectively.

The penetration of water through concrete has been reduced as HRWRAA was added to the concrete mix. For Derba, National, and Dangote Cements at doses of 1.5 %, 2 %, and 1.5 %, respectively, the percentage of reduction in water penetration was 39.6%, 34.6%, and 31.6 %.

The cost of the concrete mix increases as HRWRAA is applied for concrete production. As a comparison of three brands of cement at their optimum dosage, National cement demands 5.8% and Dangote cement demands 4.1% more than Derba cement to produce 1m3 of concrete mix. From the results, it can be concluded that at optimum dosage, National Cement demands a higher cost to produce 1m3 of concrete mix, while Derba Cement was found to be economical.

5.2 RECOMMENDATION

1. it is recommended to use 1.5%, 2% and 1.5% dosage of HRWRAA with Derba, Dangote and National cements.
2. Due to its short working hours, HRWRAA is best used in situations that demand quick placing and finishing of concrete, such as bridges, high rises, dams, the production of precast concrete, on-site production plants, and concrete repair works.
3. It is also recommended to conduct further research on other physical and chemical properties of different cement brands and to determine the dosage of HRWRAA to achieve a desired concrete performance development.
4. It is Recommended for Future to Conduct research on Cement Reduction and Cost Minimization of HRWRAA and determine the optimum dosage of HRWRA required for achieving effective cement reduction and cost savings without compromising the concrete's performance.

5.3 REFERENCES

ACI. (2009). *Manual of Concrete Practice 2009*. American Concrete Institute.

Aggarwal, P., Singh, R. P., & Aggarwal, Y. (2015). Use of nano-silica in cement based materials—A review. *Cogent Engineering*, *2*(1), 1078018. https://doi.org/10.1080/23311916.2015.1078018

Akanni, Oluyemisi, A., Awofadeju, Samuel, A., Adeyemo, & Goke, B. (2014). Comparative Analysis of the Chemical Composition of Various Brands of Portland Cement Available in South- Western Parts of Nigeria. *International Journal of Engineering Research & Technology*, *3*(8). https://doi.org/10.17577/IJERTV3IS081023

Akinkurolere, O. O. (2021). Water Absorption, Sorptivity and Permeability Properties of Concrete Containing Chemical and Mineral Admixtures. *LAUTECH Journal of Civil and Environmental Studies*, *6*(2). https://doi.org/10.36108/laujoces/1202.60.0201

Antoni, Halim, J. G., Kusuma, O. C., & Hardjito, D. (2017). Optimizing Polycarboxylate Based Superplasticizer Dosage with Different Cement Type. *Procedia Engineering*, *171*, 752–759. https://doi.org/10.1016/j.proeng.2017.01.442

Aswed, K. K., Hassan, M. S., & Al-Quraishi, H. (2022). Optimisation and Prediction of Fresh Ultra-High-Performance Concrete Properties Enhanced with Nanosilica. *Journal of Advanced Concrete Technology*, *20*(2), 103–116. https://doi.org/10.3151/jact.20.103

Azmee, N. M., & Shafiq, N. (2018). Ultra-high performance concrete: From fundamental to applications. *Case Studies in Construction Materials*, *9*, e00197. https://doi.org/10.1016/j.cscm.2018.e00197

Biernacki, J. J., Bullard, J. W., Sant, G., Brown, K., Glasser, F. P., Jones, S., Ley, T., Livingston, R., Nicoleau, L., Olek, J., Sanchez, F., Shahsavari, R., Stutzman, P. E., Sobolev, K., &

Prater, T. (2017). Cements in the 21 st century: Challenges, perspectives, and opportunities. *Journal of the American Ceramic Society*, *100*(7), 2746–2773. https://doi.org/10.1111/jace.14948

Chatveera, B., & Lertwattanaruk, P. (2009). Use of ready-mixed concrete plant sludge water in concrete containing an additive or admixture. *Journal of Environmental Management*, *90*(5), 1901–1908. https://doi.org/10.1016/j.jenvman.2009.01.008

Chu, S. H. (2019). Effect of paste volume on fresh and hardened properties of concrete. *Construction and Building Materials*, *218*, 284–294. https://doi.org/10.1016/j.conbuildmat.2019.05.131

Collepardi, M. (1998). Admixtures used to enhance placing characteristics of concrete. *Cement and Concrete Composites*, *20*(2–3), 103–112.

Dams, B., Chen, B., Shepherd, P., & Ball, R. J. (2023). Development of Cementitious Mortars for Aerial Additive Manufacturing. *Applied Sciences*, *13*(1), Article 1. https://doi.org/10.3390/app13010641

Delgado, Ana. H., Paroli, R. M., & Beaudoin, J. J. (1996). Comparison of IR Techniques for the Characterization of Construction Cement Minerals and Hydrated Products. *Applied Spectroscopy*, *50*(8), 970–976. https://doi.org/10.1366/0003702963905312

Dodson, V. H. (1990). Pozzolans and the Pozzolanic Reaction. In V. H. Dodson, *Concrete Admixtures* (pp. 159–201). Springer US. https://doi.org/10.1007/978-1-4757-4843-7_7

Dorn, T., Blask, O., & Stephan, D. (2022). Acceleration of cement hydration – A review of the working mechanisms, effects on setting time, and compressive strength development of accelerating admixtures. *Construction and Building Materials*, *323*, 126554. https://doi.org/10.1016/j.conbuildmat.2022.126554

Duggal, S. K. (2017). *Building Materials*. CRC Press.

Farokhzad, R., Mahdikhani, M., Bagheri, A., & Baghdadi, J. (2016). Representing a logical grading zone for self-consolidating concrete. *Construction and Building Materials, 115*, 735–745. https://doi.org/10.1016/j.conbuildmat.2016.04.006

Ferraris, C. F., Peltz, M. A., & Toman, B. (2018). Certification of Standard Reference Material® 46h: Fineness of cement - Addition of Blaine and Particle Size Distribution. *NIST*. https://www.nist.gov/publications/certification-standard-reference-materialr-46h-fineness-cement-addition-blaine-and

Fohrer, B., Nemyrovska, T. I., Samankassou, E., & Ueno, K. (2007). The Pennsylvanian (Moscovian) Izvarino Section, Donets Basin, Ukraine: A Multidisciplinary Study on Microfacies, Biostratigraphy (Conodonts, Foraminifers, and Ostracodes), and Paleoecology. *Journal of Paleontology*, *81*(S69), 1–85. https://doi.org/10.1666/06-121.1

Gooi, S., Mousa, A. A., & Kong, D. (2020). A critical review and gap analysis on the use of coal bottom ash as a substitute constituent in concrete. *Journal of Cleaner Production*, *268*, 121752. https://doi.org/10.1016/j.jclepro.2020.121752

H.Kosmatka, S., Kerkhoff, B., & Panarese, W. C. (2008). *Design and Control of Concrete Mixtures: 14th (fourth) edition* (14th edition, 4th Printing). Portland Cement Association258.

James, T. K., & Mattew, L. A. (2016). Compatibility study of an admixture with different cement brands of varying chemical composition for SCC. *International Journal of Engineering Research & Technology*, *5*(09).

Kett, I. (2014). *: Mix Design and Test Methods, Second Edition* (2nd ed.). CRC Press. https://doi.org/10.1201/9781420091175

Lee, J. C., Shafigh, P., & Bahri, S. (2019). Comparative study of mechanical properties for substitution of normal weight coarse aggregate with oil-palm-boiler clinker and lightweight expanded clay aggregate concretes. *Journal of Design and Built Environment*, *19*(3), Article 3. https://doi.org/10.22452/jdbe.vol19no3.7

Li, Z. (2011). *Advanced Concrete Technology*. John Wiley & Sons.

Mehta, P., & Monteiro, P. J. M. (2005). *Concrete: Microstructure, Properties, and Materials* (3rd edition). McGraw-Hill Professional.

Naqash, Dr. J. A. (2014a). Effect of Accelerating Admixture on Properties of Concrete. *IOSR Journal of Engineering*, *4*(3), 48–55. https://doi.org/10.9790/3021-04314855

Naqash, Dr. J. A. (2014b). Effect of Accelerating Admixture on Properties of Concrete. *IOSR Journal of Engineering*, *4*(3), 48–55. https://doi.org/10.9790/3021-04314855

Naqash, Dr. J. A. (2014c). Effect of Accelerating Admixture on Properties of Concrete. *IOSR Journal of Engineering*, *4*(3), 48–55. https://doi.org/10.9790/3021-04314855

Neville, A. M. (1995). *PROPERTIES OF CONCRETE. 4TH AND FINAL EDITION*. https://trid.trb.org/view/454875

Neville, A. M., & Brooks, J. J. (2010). *Concrete Technology*. Prentice Hall. https://books.google.com/books?id=iVr8QQAACAAJ

Omoniyi, K., & Okunola, O. (2016). Comparative Studies of Physico-chemical Properties of Some Selected Cements in Nigeria. *Nigerian Journal of Technological Development*, *12*(2), 54. https://doi.org/10.4314/njtd.v12i2.4

Plank, J., Sakai, E., Miao, C. W., Yu, C., & Hong, J. X. (2015). Chemical admixtures—Chemistry, applications and their impact on concrete microstructure and durability.

Cement and Concrete Research, *78*, 81–99. https://doi.org/10.1016/j.cemconres.2015.05.016

Rafi, M. M., & Murtaza Nasir, M. (2014). Experimental Investigation of Chemical and Physical Properties of Cements Manufactured in Pakistan. *Journal of Testing and Evaluation*, *42*, 20130158. https://doi.org/10.1520/JTE20130158

Raheem, A. A., Oyebisi, S. O., Akintayo, S. O., & Oyeniran, M. I. (2010). Effects of admixtures on the properties of corn cob ash cement concrete. *Leonardo Electronic Journal of Practices and Technologies*, *16*(1), 13–20.

Ramachandran, V. S. (1996). *Concrete Admixtures Handbook, 2nd Ed.: Properties, Science and Technology*. William Andrew.

Ren, G., Tian, Z., Wu, J., & Gao, X. (2021). Effects of combined accelerating admixtures on mechanical strength and microstructure of cement mortar. *Construction and Building Materials*, *304*, 124642. https://doi.org/10.1016/j.conbuildmat.2021.124642

Rendon Diaz Miron, L. E., & Koleva, D. A. (Eds.). (2017). *Concrete Durability*. Springer International Publishing. https://doi.org/10.1007/978-3-319-55463-1

Shrivastava, A. K., & Kumar, M. (2016). Compatibility issues of cement with water reducing admixture in concrete. *Perspectives in Science*, *8*, 290–292. https://doi.org/10.1016/j.pisc.2016.04.055

Siegel, J. A., Mirakovits, J. A., & Hudson, B. (2013). *Concrete Mix Design, Quality Control and Specification* (0 ed.). CRC Press. https://doi.org/10.1201/b15624

Simmons, H. L. (2011). *Olin's Construction: Principles, Materials, and Methods*. John Wiley & Sons.

Southararajan, V. M., & Sivakumar, A. (2012). The Effect of Accelerators and Mix Constituents on the High Early Strength Concrete Properties. *ISRN Civil Engineering*, *2012*, 1–7. https://doi.org/10.5402/2012/103534

Sours, T. J. (2015). *Concrete Made Easy: From Planning To Completion*. CreateSpace Independent Publishing Platform.

Tao, Y., Rahul, A. V., Lesage, K., Yuan, Y., Van Tittelboom, K., & De Schutter, G. (2021). Stiffening control of cement-based materials using accelerators in inline mixing processes: Possibilities and challenges. *Cement and Concrete Composites*, *119*, 103972. https://doi.org/10.1016/j.cemconcomp.2021.103972

Taylor, H. F. W. (1997). *Cement Chemistry*. Thomas Telford.

Tkaczewska, E. (2014). Effect of the superplasticizer type on the properties of the fly ash blended cement. *Construction and Building Materials*, *70*, 388–393. https://doi.org/10.1016/j.conbuildmat.2014.07.096

Xie, T., Yang, G., Zhao, X., Xu, J., & Fang, C. (2020). A unified model for predicting the compressive strength of recycled aggregate concrete containing supplementary cementitious materials. *Journal of Cleaner Production*, *251*, 119752. https://doi.org/10.1016/j.jclepro.2019.119752

Yaphary, Y. L., Yu, Z., Lam, R. H. W., & Lau, D. (2017). Effect of triethanolamine on cement hydration toward initial setting time. *Construction and Building Materials*, *141*, 94–103. https://doi.org/10.1016/j.conbuildmat.2017.02.072

Yuan, Q., Zhou, D., Li, B., Huang, H., & Shi, C. (2018). Effect of mineral admixtures on the structural build-up of cement paste. *Construction and Building Materials*, *160*, 117–126. https://doi.org/10.1016/j.conbuildmat.2017.11.050

APPENDIX

APPENDIX 1- MATERIAL PROPERTIES TEST RESULTS

APPENDIX 1-1 CEMENT PROPERTIES

fineness of cement

Cement Brands	Sample	Cement (gm.)	Sieve size(mµ)	Residue (gm.)	%finer	Average %finer	Remark
Derba	1	50	75	3.2	93.16	**93.16**	**Recommended**
	2	50	75	2.1	95.62		
	3	50	75	4.25	90.71		
Dangote	1	50	75	1.4	97.12	**96.15**	**Recommended**
	2	50	75	1.8	96.27		
	3	50	75	2.35	95.07		
National	1	50	75	2.15	95.51	**95.17**	**Recommended**
	2	50	75	2	95.83		
	3	50	75	2.75	94.18		

Normal consistency of cement

National cement

Wt of cement (gm)	500	500	500	500	500	500	500	500
% of water	26	27	28	29	30	31	32	33
Wt of water (gm)	130	135	140	145	150	155	160	165
Penetration depth(mm)	2	5	8	10	-	-	-	-

Normal consistency 32%

Dangote cement

Wt of cement (gm)	500	500	500	500	500	500	500	500
% of water	26	27	28	29	30	31	32	33
Wt of water (gm)	130	135	140	145	150	155	160	165
Penetration depth(mm)	5	9	19	-	-	-	-	-

Normal consistency 27%

Derba cement

Initial and final setting time Derba cement

Trial No.	start	1	2	3	4	5	6	7	8	9	10	11	12	13
Time (min)	7:30	8:00	8:10	8:20	8:30	8:40	8:50	9:00	9:10	9:20	9:30	9:40	9:50	10:00
Penetrat ion(mm)	-	40	40	40	40	40	40	40	40	40	40	40	38	36
Trial No.	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Time (min)	10:10	10:20	10:30	10:40	10:50	11:00	11:10	11:20	11:30	11:40	11:50	12:00	12:10	12:20
Penetrat ion(mm)	34	32	30	28	24	21	20	18	14	10	8	5	3	0

Initial setting time 197.5min

final setting time 290 min

Initial and final setting time Dangote cement

Trial No.	start	1	2	3	4	5	6	7	8	9	10	11	12
Time (min)	7:30	8:00	8:10	8:20	8:30	8:40	8:50	9:00	9:10	9:20	9:30	9:40	9:50
Penetrat ion(mm)	-	40	40	40	40	40	40	40	40	40	39	38	36
Trial No.	13	14	15	16	17	18	19	20	21	22	23	24	25
Time (min)	10:00	10:10	10:20	10:30	10:40	10:50	11:00	11:10	11:20	11:30	11:40	11:50	12:00
Penetrat ion(mm)	33	30	28	25	17	15	13	10	6	4	2	1	0

Initial setting time 180min

final setting time 270min

Initial and final setting time National cement

Trial No.	start	1	2	3	4	5	6	7	8	9	10	11
Time (min)	7:30	8:00	8:10	8:20	8:30	8:40	8:50	9:00	9:10	9:20	9:30	9:40
Penetrat ion(mm)	-	40	40	40	40	40	40	40	40	40	40	40
Trial No.	12	13	14	15	16	17	18	19	20	21	22	23
Time (min)	9:50	10:00	10:10	10:20	10:30	10:40	10:50	11:00	11:10	11:20	11:30	11:40
Penetrat ion(mm)	36	33	30	27	20	18	15	13	10	8	4	0

Initial setting time 172.9min
final setting time 250min

APPENDIX 1-2 FINE AGGREGATE PROPERTIES

Gradation of fine Aggregate

Sieve size(mm)	Weight. retained (gm)	Percentage retained (%)	Cumulative coarser (%)	Cumulative passing (%)	ASTM Cumulative Passing (%)
9.5 mm	0	0.0	0.0	**100.0**	100
4.75 mm	12	2.4	2.4	**97.6**	95-100
2.36 mm	63	12.6	15.0	**85.0**	80-100
1.18 mm	87	17.4	32.4	**67.6**	50-85
600 µm	125	25.0	57.4	**42.6**	25-60
300 µm	99	19.8	77.2	**22.8**	10-30
150 µm	93	18.6	95.8	**4.2**	2-10
Pan	21	-	-	-	
Total	**500**		**280**		

FM = 2.80

Silt content of fine Aggregate

Sample	Amount of total sand before washing (gm)	Amount of clear sand(gm)	Amount of Silt deposit (gm)	Silt content
Sample 1	300	291	9	3.09%
Sample 2	300	294	6	2.04%
Sample 2	300	293	7	2.39%
		mean		2.51%

Natural moisture content of fine Aggregate

Sample	Amount of total wet sand (gm)	Amount of oven dry sand(gm)	Amount of water (gm)	Silt content
Sample 1	500	480	20	4.17%
Sample 2	500	458	42	9.17%
Sample 2	500	469	31	6.61%
		mean		6.6%

Unit weight of fine Aggregate

Compacted Unit weight

Sample	Weight of cylindrical metal(kg)	Weight of container + aggregate (kg)	Weight of aggregate (kg)	Volume of container (m3)	Compacted unit weight (kg/m3)
Sample 1	2.65	10.46	7.81	0.0050	1562.0
Sample 2	2.65	10.26	7.61	0.0050	1522.0
Sample 2	2.65	10.18	7.53	0.0050	1506.0
				mean	1530

Loose Unit weight

Sample	Weigt of cylindrical metal(kg)	Weigt of container + aggregate (kg)	Weigt of aggregate (kg)	Volume of container (m3)	Compacted unit weight (kg/m3)
Sample 1	2.65	9.25	6.6	0.0050	1320.0
Sample 2	2.65	9.84	7.19	0.0050	1438.0
Sample 2	2.65	9.56	6.91	0.0050	1382.0
				mean	1380

Specific gravity and water Absorption

A - Weight of the sample, SSD = 500gm

B - Weight of pycnometer + water = 1454gm

C - Weight of pycnometer + water + sand to calibration mark = 1764gm

D - Weight of oven dried sample in air = 489 g

$$Bulk\ specific\ gravity\ (SSD) = \frac{A}{(A+B-C)}$$

$$Aparent\ specific\ gravity\ = \frac{D}{(B+D-C)} \qquad Absorption, \% = \frac{(A-D)}{D} * 100$$

Item	Description	
D	Mass of oven dry sample in air	489
B	Mass of pycnometer filled with water	1454
C	Mass of pycnometer + sample + water	1764
A	Mass of saturated suface sample	500
	Bulk specifc Gravity	2.57
	Bulk specifc Gravity (SSD)	2.63
	Absorption (%)	2.32%

APPENDIX 1-3 COARSE AGGREGATE PROPERTIES

Gradation of coarse Aggregate

Sieve size(mm)	Weight Retain(gm.)	Weight Retained (%)	Cumulative Retained (%)	Cumulative Passing (%)	Cumulative passing (%)
37mm	0.0	0.0	0.0	**100.0**	100
25 mm	43.3	2.165	2.2	**97.8**	90-100
19 mm	613.2	30.7	32.8	**67.2**	40-85
12.5 mm	820.3	41.0	73.8	**26.2**	10-40
9.5 mm	326.4	16.3	90.2	**9.8**	0-15
4.75 mm	173.8	8.7	98.8	**1.2**	0-5
Pan	23.0	1.2			
total	**2000**				

Unit weight of coarse Aggregate

Compacted Unit weight

Sample	Weight of cylindrical metal(kg)	Weight of container + aggregate (kg)	Weight of aggregate (kg)	Volume of container (m3)	Compacted unit weight (kg/m3)
Sample 1	2.65	10.89	8.24	0.0050	1648.0
Sample 2	2.65	10.52	7.87	0.0050	1574.0
Sample 2	2.65	10.66	8.01	0.0050	1602.0
				mean	1608

Loose Unit weight

Sample	Weight of cylindrical metal(kg)	Weigt of container + aggregate (kg)	Weigt of aggregate (kg)	Volume of container (m3)	Compacted unit weight (kg/m3)
Sample 1	2.65	9.45	6.8	0.0050	1360.0
Sample 2	2.65	9.86	7.21	0.0050	1442.0
Sample 2	2.65	9.68	7.03	0.0050	1406.0
				mean	1403

Natural moisture content of coarse Aggregate

Sample	Amount of total wet sand (gm)	Amount of oven dry sand(gm)	Amount of water (gm)	Silt content
Sample 1	1000	986	14	1.42%
Sample 2	1000	975	25	2.56%
Sample 2	1000	980	20	2.04%
		mean		2.01%

Specific gravity and water Absorption

Oven dry weight (ODW) = 4925gm

Weight of saturated surface dry sample on air (SSD in air) = 5000 g

Weight of saturated surface dry sample in water (SSD in water) = 3130g

$$\text{Bulk specific gravity (SSD)} = \frac{(SSD\ in\ air)}{(SSD\ in\ air)-(SSD\ in\ water)}$$

$$\text{Aparent specific gravity (SSD)} = \frac{(ODW)}{(ODW)-(SSD\ in\ water)}$$

$$\text{Water absorption} = \frac{(SSD)-(ODW)}{(SSD)} * 100$$

Description	
Mass of oven dry sample in air	4925
Mass of saturated surface-dry sample in air	5000
Mass of saturated surface-dry sample in water	3130
Bulk specific Gravity (dry)	2.63
Bulk specific Gravity (SSD)	2.67
Absorption (%)	1.52%

APPENDIX 2 – CONCRETE MIX DESIGN

C-40 Concrete Mix Design

ACI 301-99, 1999 concrete mix design procedure was used to design a concrete that can achieve a desired workability and provides an average adequate compressive strength. According to ACI , average compressive strength must equal or exceed the required average compressive strength The required average compressive strength f'_{cr} was calculated for the specified class of concrete in accordance with one of the following:

$$f'_{cr} = f'_{c} + 1.35Ks$$

$$f'_{cr} = f'_{c} + 2.33Ks + 500$$

Where: f'_{cr} = required average compressive strength (Mpa)

f'_{c}= specified strength (Mpa)

k = constant factor

s = standard deviation

When field test records are not available to establish a standard deviation, the required average compressive strength can be selected from the following equations (ACI 301-99, 1999).

$\mathbf{f^{i}_{cr} = f^{i}_{c} + 7\ MPa}$	when specified compressive strength is less than **21 Mpa**
$\mathbf{f^{i}_{cr} = f^{i}_{c} + 8.5MPa}$	when specified compressive strength is between **21 to 35Mpa**
$\mathbf{f^{i}_{cr} = 1.1f^{i}_{c} + 5\ MPa}$	when specified compressive strength is greater than **35 Mpa**

So, Target mean strength for C-40 grade concrete is calculated by using $\mathbf{f^{i}_{cr} = 1.1f^{i}_{c} + 5\ MPa}$ which is 49 N/mm2.

1. Slump selection

From table 3 (ACI-2111_91), maximum slump = 100 mm and minimum slump= 75mm.

2. Maximum size of aggregate selection

The maximum Nominal aggregate size of coarse aggregate was used 25 mm

3. Estimation of mixing water and air content

Slumps and Nominal Maximum Sizes of Aggregates (ACI-2111_91)

NON AIR ENTRAINED CONCRETE								
Slump (mm)	9.5mm	12.5mm	19mm	25mm	37.5mm	50mm	75mm	150mm
25 to 50	207	199	190	179	166	154	130	113
75 to 100	228	216	205	193	181	169	145	124
150 to 175	243	228	216	202	190	178	160	-
more than 175	-	-	-	-	-	-	-	-
Approximate amount of entrapped air in non-air entrained concrete (%)								
Slump (mm)	9.5mm	12.5mm	19mm	25mm	37.5mm	50mm	75mm	150mm
All	3.0	2.5	2.0	1.5	1.0	0.5	0.3	0.2

From the table, for non-air entrained and slump of 75-100, the water in 1m³ of concrete is 193 Kg

4. Water to cement ratio selection

From ACI 211-1-81 the water to cement ratio is 0.41

5. Calculation of cement content

For slump of 75-100mm

Water content=193 Kg/m^3

Water/cement = 0.41

Cement content = water content / (W/C) = 193/0.41 = 471 Kg/m^3

6. Estimation of coarse aggregates content

Volume of coarse aggregate per unit volume of concrete for different fineness moduli of fine aggregate (ACI-2111_91)

Volume of coarse aggregate per unit volume of concrete

Nominal maximum size of aggregate (mm)	**2.40**	**2.60**	**2.80**	**3.00**
9.5	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
19	0.66	0.64	0.62	0.60
25	0.71	0.69	0.67	0.65
37.5	0.75	0.73	0.71	0.69
50	0.78	0.76	0.74	0.72
75	0.82	0.80	0.78	0.76
150	0.87	0.85	0.83	0.81

The quantity of coarse aggregate estimated from ACI 211-1-81 Table A- 1.5.3.6 for fineness modules of 2.8 and 25mm Nominal size of coarse aggregate, the table indicates the volume of Coarse aggregate to be used is 0.67.

Mass of coarse aggregate = bulk volume*Dry rodded Unit Weight of Course Aggregate

=1608*0.67 = 1077.4 Kg/m^3

7. Determining content of mass of fine aggregate.

Known mass of ingredients

Mass of water =193kg

Mass of cement= 471kg

Mass of coarse aggregate= 1077.4kg

From ACI table A.1.5.3.7.1. mass of fresh concrete with 25mm nominal maximum aggregate size is $2380kg/m^3$

Mass of fine aggregate = total mass – (Mw+Mc+MCA)

= 2380- 1741.4

= 638.6Kg

8. Adjustments for moisture in the aggregate

Fine aggregate adsorption =2.32% and coarse aggregate absorption = 1.52%

Natural moisture content of fine aggregate 6.6% and for coarse aggregate 2.01%

Free water in fine aggregate= 6.6-2.32= 4.28%

Free water in coarse aggregate= 2.01-1.53= 0.48%

Water supplied by coarse aggregate = 1,077.4 kg/m^3 x 0.0048 =5.17 kg

Water supplied by fine aggregate =638.6 kg/m^3x 0.0428 = 27.33 kg

Amount of water needed =193 kg – 5.17 kg – 27.33 kg

= 160.49 kg

Amount of Cement = 471 kg/m^3

Amount of Fine aggregate = 638.6 kg + 27.33 kg= 665.93 kg/m^3

Amount of Coarse aggregate = 1077.4 kg + 5.17 kg = 1082.57 kg/m^3

Hence the estimated batch weight for 1m^3 of concrete is given in the table below

Water	160.49 kg
Cement	471 kg
Fine Aggregate	665.93 kg
Coarse Aggregate	1082.57 kg

APPENDIX 3- EXPERIMENTAL RESULTS

APPENDIX- 2.1 DERBA CEMENT

COMPRESSIVE STRENGTH CONTROL MIX 0%

No	Test age (days)	Dimensions (cm) L	W	H	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
1	3	15	15	15	0%	45	8080	3375	2.39	455	20.2
2		15	15	15			8030	3375	2.38	425	18.9
3		15	15	15			8060	3375	2.39	440	19.6
						mean	8057	**3375**	**2.39**	440	**19.56**
No	Test age (days)	Dimensions (cm) L	W	H	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
1	7	15	15	15	0%	45	8120	3375	2.41	715	31.8
2		15	15	15			8160	3375	2.42	700	31.1
3		15	15	15			8150	3375	2.41	685	30.4
						mean	8143	**3375**	**2.41**	700	**31.11**
No	Test age (days)	Dimensions (cm) L	W	H	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
1	28	15	15	15	0%	45	8260	3375	2.45	1020	45.3
2		15	15	15			8120	3375	2.41	1035	46.0
3		15	15	15			8160	3375	2.42	1065	47.3
						mean	8180	**3375**	**2.42**	1040	**46.22**

COMPRESSIVE STRENGTH 0.5%(HRWRAA)

No	Test age (days)	Dimensions (cm) L	W	H	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
1	3	15	15	15	20%	60	8000	3375	2.37	485	21.6
2		15	15	15			8230	3375	2.44	465	20.7
3		15	15	15			8160	3375	2.42	490	21.8
						mean	8130	**3375**	**2.41**	480	**21.33**
No	Test age (days)	Dimensions (cm) L	W	H	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
1	7	15	15	15	20%	60	8220	3375	2.44	760	33.8
2		15	15	15			8330	3375	2.47	715	31.8
3		15	15	15			8260	3375	2.45	745	33.1
						mean	8270	**3375**	**2.45**	740	**32.89**

COMPRESSIVE STRENGTH 1.0%(HRWRAA)

No	Test age (days)	Dimensions (cm)			water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		L	W	H							
1	3	15	15	15	23%	110	8000	3375	2.37	555	24.7
2		15	15	15			8100	3375	2.40	580	25.8
3		15	15	15			8150	3375	2.41	545	24.2
						mean	8083	**3375**	**2.40**	560	**24.9**
No	Test age (days)	Dimensions (cm)			water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		L	W	H							
1	7	15	15	15	23%	110	8220	3375	2.44	850	37.8
2		15	15	15			8300	3375	2.46	835	37.1
3		15	15	15			8200	3375	2.43	865	38.4
						mean	8240	**3375**	**2.44**	850	**37.8**

COMPRESSIVE STRENGTH 1.5%(HRWRAA)

No	Test age (days)	Dimensions (cm)			water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		L	W	H							
1	3	15	15	15	25%	135	8120	3375	2.41	625	27.8
2		15	15	15			8380	3375	2.48	635	28.2
3		15	15	15			8230	3375	2.44	660	29.3
						mean	8243	3375	**2.44**	640	**28.4**
No	Test age (days)	Dimensions (cm)			water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		L	W	H							
1	7	15	15	15	25%	135	8180	3375	2.42	1065	47.3
2		15	15	15			8120	3375	2.41	1140	50.7
3		15	15	15			8250	3375	2.44	1095	48.7
						mean	8183	3375	**2.42**	1100	**48.9**
No	Test age (days)	Dimensions (cm)			water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		L	W	H							
1	28	15	15	15	25%	135	8180	3375	2.42	1255	55.8
2		15	15	15			8320	3375	2.47	1205	53.6
3		15	15	15			8350	3375	2.47	1260	56.0
						mean	8283	3375	**2.45**	1240	**55.1**

COMPRESSIVE STRENGTH 2.0%(HRWRAA)

No	Test age (days)	Dimensions (cm)			water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		L	W	H							
1	3	15	15	15	28%	195	8030	3375	2.38	615	27.3
2		15	15	15			8010	3375	2.37	585	26.0
3		15	15	15			8100	3375	2.40	570	25.3
						mean	8047	**3375**	**2.38**	590	**26.2**
No	Test age (days)	Dimensions (cm)			water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		L	W	H							
1	7	15	15	15	28%	195	8020	3375	2.38	965	42.9
2		15	15	15			8090	3375	2.40	950	42.2
3		15	15	15			8050	3375	2.39	925	41.1
						mean	8053	**3375**	**2.39**	947	**42.1**

COMPRESSIVE STRENGTH 2.5%(HRWRAA)

No	Test age (days)	Dimensions (cm)			water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		L	W	H							
1	3	15	15	15	30%	215	8000	3375	2.37	500	22.2
2		15	15	15			8090	3375	2.40	485	21.6
3		15	15	15			7900	3375	2.34	515	22.9
						mean	7997	**3375**	**2.37**	500	**22.2**
No	Test age (days)	Dimensions (cm)			water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		L	W	H							
1	7	15	15	15	30%	215	8000	3375	2.37	875	38.9
2		15	15	15			8010	3375	2.37	910	40.4
3		15	15	15			8050	3375	2.39	895	39.8
						mean	8020	**3375**	**2.38**	893	**39.7**

COMPRESSIVE STRENGTH 3.0%(HRWRAA)

No	Test age (days)	Dimensions (cm)			water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		L	W	H							
1	3	15	15	15	33%	240	8020	3375	2.38	355	15.8
2		15	15	15			8090	3375	2.40	360	16.0
3		15	15	15			8000	3375	2.37	335	14.9
						mean	8037	**3375**	**2.38**	350	**15.6**
No	Test age (days)	Dimensions (cm)			water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		L	W	H							
1	7	15	15	15	33%	240	7950	3375	2.36	535	23.8
2		15	15	15			8010	3375	2.37	550	24.4
3		15	15	15			8000	3375	2.37	520	23.1
						mean	7987	**3375**	**2.37**	535	**23.8**

SPLIT TENSILE STRENGTH CONTROL MIX 0%

No	Test age (days)	Dimensions (cm)		water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	split tensile strength (MPa)
		dia	length							
1	3	15	30	0%	45	12801	5299	2.42	135.0	1.91
2		15	30			12384	5299	2.34	155.0	2.19
3		15	30			12328	5299	2.33	180.0	2.55
					mean	12505	**5299**	**2.36**	157	**2.22**
No	Test age (days)	Dimensions (cm)		water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		dia	length							
1	7	15	30	0%	45	12701	5299	2.40	240	3.40
2		15	30			12825	5299	2.42	205	2.90
3		15	30			12501	5299	2.36	220	3.11
					mean	12676	**5299**	**2.39**	222	**3.14**
No	Test age (days)	Dimensions (cm)		water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		dia	length							
1	28	15	30	0%	45	12401	5299	2.34	395	5.59
2		15	30			12865	5299	2.43	370	5.24
3		15	30			12701	5299	2.40	355	5.02
					mean	12656	**5299**	**2.39**	373	**5.28**

SPLIT TENSILE STRENGTH 0.5% (HRWRAA)

No	Test age (days)	Dimensions (cm)		water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	split tensile strength (MPa)
		dia	length							
1	3	15	30	20%	60	12401	5299	2.34	205	2.90
2		15	30			12765	5299	2.41	170	2.41
3		15	30			12501	5299	2.36	195	2.76
					mean	12556	**5299**	**2.37**	190	**2.69**
No	Test age (days)	Dimensions (cm)		water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		dia	length							
1	7	15	30	20%	60	12425	5299	2.34	270	3.82
2		15	30			12765	5299	2.41	250	3.54
3		15	30			12601	5299	2.38	235	3.33
					mean	12597	**5299**	**2.38**	252	**3.56**

SPLIT TENSILE STRENGTH 1.0% (HRWRAA)

No	Test age (days)	Dimensions (cm)		water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	split tensile strength (MPa)
		dia	length							
1	3	15	30	23%	110	12425	5299	2.34	210	2.97
2		15	30			12546	5299	2.37	230	3.26
3		15	30			12890	5299	2.43	225	3.18
					mean	12620	**5299**	**2.38**	222	**3.14**
No	Test age (days)	Dimensions (cm)		water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		dia	length							
1	7	15	30	20%	110	12470	5299	2.35	310	4.39
2		15	30			12666	5299	2.39	290	4.10
3		15	30			12800	5299	2.42	285	4.03
					mean	12645	**5299**	**2.39**	295	**4.18**

SPLIT TENSILE STRENGTH 1.5% (HRWRAA)

No	Test age (days)	Dimensions dia	Dimensions length	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	split tensile strength (MPa)
1		15	30			12580	5299	2.37	270	3.82
2	3	15	30	25%	135	12760	5299	2.41	245	3.47
3		15	30			12880	5299	2.43	230	3.26
					mean	12740	**5299**	**2.40**	248	**3.51**

No	Test age (days)	Dimensions dia	Dimensions length	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
1		15	30			12690	5299	2.39	370	5.2
2	7	15	30	25%	135	12755	5299	2.41	385	5.4
3		15	30			12870	5299	2.43	360	5.1
					mean	12772	**5299**	**2.41**	372	**5.26**

No	Test age (days)	Dimensions dia	Dimensions length	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
1		15	30			12750	5299	2.41	435	6.2
2	28	15	30	25%	135	12895	5299	2.43	440	6.2
3		15	30			12980	5299	2.45	455	6.4
					mean	12875	**5299**	**2.43**	443	**6.28**

SPLIT TENSILE STRENGTH 2.0% (HRWRAA)

No	Test age (days)	Dimensions dia	Dimensions length	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	split tensile strength (MPa)
1		15	30			12490	5299	2.36	205	2.9
2	3	15	30	28%	195	12690	5299	2.39	220	3.1
3		15	30			12750	5299	2.41	225	3.2
					mean	12643	**5299**	**2.39**	217	**3.07**

No	Test age (days)	Dimensions dia	Dimensions length	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
1		15	30			12430	5299	2.35	315	4.5
2	7	15	30	28%	195	12620	5299	2.38	320	4.5
3		15	30			12790	5299	2.41	350	5.0
					mean	12613	**5299**	**2.38**	328	**4.65**

SPLIT TENSILE STRENGTH 2.5% (HRWRAA)

No	Test age (days)	Dimensions dia	Dimensions length	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	split tensile strength (MPa)
1		15	30			12450	5299	2.35	185	2.6
2	3	15	30	30%	215	12620	5299	2.38	190	2.7
3		15	30			12730	5299	2.40	200	2.8
					mean	12600	**5299**	**2.38**	192	**2.71**

No	Test age (days)	Dimensions dia	Dimensions length	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
1		15	30			12450	5299	2.35	285	4.0
2	7	15	30	30%	215	12670	5299	2.39	300	4.2
3		15	30			12890	5299	2.43	310	4.4
					mean	12670	**5299**	**2.39**	298	**4.22**

SPLIT TENSILE STRENGTH 3.0% (HRWRAA)

No	Test age (days)	Dimensions dia	length	water reduction	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/	140	split tensile strength (MPa)
1	3	15	30	33%	240	12490	5299	2.36	110	1.6
2		15	30			12690	5299	2.39	115	1.6
3		15	30			12750	5299	2.41	130	1.8
					mean	12643	**5299**	**2.39**	118	**1.67**
No	Test age (days)	Dimensions dia	length	water reduction	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/	Failure load (kN)	Comp.Strength (MPa)
1	7	15	30	33%	240	12430	5299	2.35	195	2.8
2		15	30			12620	5299	2.38	200	2.8
3		15	30			12790	5299	2.41	215	3.0
					mean	12613	**5299**	**2.38**	203	**2.88**

FLEXURAL STRENGTH CONTROL MIX

No	Test age (days)	Dimensions (cm) W	D	L	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/ cm3)	Failure load (kN)	Flexural strength (MPa)
1	28	10	10	50	0%	45	12252	5000	2.45	8.56	5.8
2		10	10	50			12280	5000	2.46	8.25	5.6
3		10	10	50			12100	5000	2.42	8.1	5.5
						mean	12211	**5000**	**2.44**	8.3	**5.6**

FLEXURAL STRENGTH 1.5% (HRWRAA)

No	Test age (days)	Dimensions (cm) W	D	L	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/ cm3)	Failure load (kN)	Flexural strength (MPa)
1	28	10	10	50	25%	135	12452	5000	2.49	9.53	6.4
2		10	10	50			12380	5000	2.48	9.25	6.2
3		10	10	50			12260	5000	2.45	8.96	6.0
						mean	12364	**5000**	**2.47**	9.2	**6.2**

CONCRETE PERMEABILITY TEST

PENETRATION DEPTH (mm)		D1	D2	D3	D4	D5	D6	Minimum	Mean	maximum
CONTROL MIX	**0%**	15.1	13.6	13.8	16.6	15.2	16.4	**13.6**	**15.1**	**16.6**
OPTIMUM HRWRAA %	**1.50%**	10	9.2	9.5	8.5	8.5	9.15	**8.5**	**9.1**	**9.5**

APPENDIX- 2.2 DANGOTE CEMENT

COMPRESSIVE STRENGTH CONTROL MIX 0%

No	Test age (days)	Dimensions (cm)			water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		L	W	H							
1	3	15	15	15	0%	45	8080	3375	2.39	485	21.6
2		15	15	15			8150	3375	2.41	495	22.0
3		15	15	15			8150	3375	2.41	520	23.1
						mean	8127	**3375**	**2.41**	500	**22.2**
No	Test age (days)	Dimensions (cm)			water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		L	W	H							
1	7	15	15	15	0%	45	8120	3375	2.41	785	34.9
2		15	15	15			8160	3375	2.42	755	33.6
3		15	15	15			8150	3375	2.41	740	32.9
						mean	8143	**3375**	**2.41**	760	**33.78**
No	Test age (days)	Dimensions (cm)			water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		L	W	H							
1	28	15	15	15	0%	45	8265	3375	2.45	1085	48.2
2		15	15	15			8160	3375	2.42	1035	46.0
3		15	15	15			8170	3375	2.42	1060	47.1
						mean	8198	**3375**	**2.43**	1060	**47.11**

COMPRESSIVE STRENGTH 0.5%(HRWRAA)

No	Test age (days)	Dimensions (cm)			water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		L	W	H							
1	3	15	15	15	20%	60	8000	3375	2.37	545	24.2
2		15	15	15			8200	3375	2.43	505	22.4
3		15	15	15			8120	3375	2.41	530	23.6
						mean	8107	**3375**	**2.40**	527	**23.41**
No	Test age (days)	Dimensions (cm)			water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		L	W	H							
1	7	15	15	15	20%	60	8200	3375	2.43	805	35.8
2		15	15	15			8300	3375	2.46	775	34.4
3		15	15	15			8240	3375	2.44	790	35.1
						mean	8247	**3375**	**2.44**	790	**35.11**

COMPRESSIVE STRENGTH 1.0%(HRWRAA)

No	Test age (days)	Dimensions (cm) L	W	H	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
1	3	15	15	15	23%	110	8050	3375	2.39	600	26.7
2		15	15	15			8145	3375	2.41	585	26.0
3		15	15	15			8180	3375	2.42	555	24.7
						mean	8125	**3375**	**2.41**	580	**25.8**

No	Test age (days)	Dimensions (cm) L	W	H	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
1	7	15	15	15	23%	110	8280	3375	2.45	885	39.3
2		15	15	15			8300	3375	2.46	860	38.2
3		15	15	15			8295	3375	2.46	870	38.7
						mean	8292	**3375**	**2.46**	872	**38.7**

COMPRESSIVE STRENGTH 1.5%(HRWRAA)

No	Test age (days)	Dimensions (cm) L	W	H	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
1	3	15	15	15	25%	135	8270	3375	2.45	635	28.2
2		15	15	15			8310	3375	2.46	620	27.6
3		15	15	15			8275	3375	2.45	605	26.9
						mean	8285	3375	**2.45**	620	**27.56**

No	Test age (days)	Dimensions (cm) L	W	H	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
1	7	15	15	15	25%	135	8280	3375	2.45	995	44.2
2		15	15	15			8270	3375	2.45	960	42.7
3		15	15	15			8250	3375	2.44	985	43.8
						mean	8267	3375	**2.45**	980	**43.56**

COMPRESSIVE STRENGTH 2.0%(HRWRAA)

No	Test age (days)	Dimensions (cm) L	W	H	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/ cm3)	Failure load (kN)	Comp.Strength (MPa)
1	3	15	15	15	28%	195	8120	3375	2.41	680	30.2
2		15	15	15			8260	3375	2.45	720	32.0
3		15	15	15			8160	3375	2.42	700	31.1
						mean	8180	**3375**	**2.42**	700	**31.11**

No	Test age (days)	Dimensions (cm) L	W	H	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/ cm3)	Failure load (kN)	Comp.Strength (MPa)
1	7	15	15	15	28%	195	8150	3375	2.41	1165	51.8
2		15	15	15			8240	3375	2.44	1120	49.8
3		15	15	15			8280	3375	2.45	1135	50.4
						mean	8223	**3375**	**2.44**	1140	**50.67**

No	Test age (days)	Dimensions (cm) L	W	H	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/ cm3)	Failure load (kN)	Comp.Strength (MPa)
1	28	15	15	15	28%	195	8250	3375	2.44	1265	56.2
2		15	15	15			8260	3375	2.45	1280	56.9
3		15	15	15			8195	3375	2.43	1235	54.9
						mean	8235	**3375**	**2.44**	1260	**56.00**

COMPRESSIVE STRENGTH 2.5%(HRWRAA)

No	Test age (days)	Dimensions (cm) L	W	H	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/ cm3)	Failure load (kN)	Comp.Strength (MPa)
1	3	15	15	15	30%	215	8000	3375	2.37	655	29.1
2		15	15	15			8090	3375	2.40	625	27.8
3		15	15	15			7985	3375	2.37	640	28.4
						mean	8025	**3375**	**2.38**	640	**28.44**

No	Test age (days)	Dimensions (cm) L	W	H	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/ cm3)	Failure load (kN)	Comp.Strength (MPa)
1	7	15	15	15	30%	215	8100	3375	2.40	920	40.9
2		15	15	15			8120	3375	2.41	910	40.4
3		15	15	15			8060	3375	2.39	895	39.8
						mean	8093	**3375**	**2.40**	908	**40.37**

COMPRESSIVE STRENGTH 3.0%(HRWRAA)

No	Test age (days)	Dimensions (cm) L	W	H	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/ cm3)	Failure load (kN)	Comp.Strength (MPa)
1	3	15	15	15	33%	240	8005	3375	2.37	355	15.8
2		15	15	15			7965	3375	2.36	320	14.2
3		15	15	15			8020	3375	2.38	365	16.2
						mean	7997	**3375**	**2.37**	347	**15.4**

No	Test age (days)	Dimensions (cm) L	W	H	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/ cm3)	Failure load (kN)	Comp.Strength (MPa)
1	7	15	15	15	33%	240	8005	3375	2.37	600	26.7
2		15	15	15			8080	3375	2.39	615	27.3
3		15	15	15			8025	3375	2.38	585	26.0
						mean	8037	**3375**	**2.38**	600	**26.67**

SPLIT TENSILE STRENGTH CONTROL MIX 0%

No	Test age (days)	Dimensions (cm)		water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	split tensile strength (MPa)
		dia	length							
1	3	15	30	0%	45	12801	5299	2.42	150	2.12
2		15	30			12384	5299	2.34	160	2.26
3		15	30			12328	5299	2.33	170	2.41
					mean	12505	**5299**	**2.36**	160	**2.3**
No	Test age (days)	Dimensions (cm)		water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		dia	length							
1	7	15	30	0%	45	12801	5299	2.42	255	3.61
2		15	30			12725	5299	2.40	230	3.26
3		15	30			12601	5299	2.38	240	3.40
					mean	12709	**5299**	**2.40**	242	**3.4**
No	Test age (days)	Dimensions (cm)		water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		dia	length							
1	28	15	30	0%	45	12401	5299	2.34	315	4.46
2		15	30			12865	5299	2.43	345	4.88
3		15	30			12701	5299	2.40	345	4.88
					mean	12656	**5299**	**2.39**	335	**4.74**

SPLIT TENSILE STRENGTH 0.5% (HRWRAA)

No	Test age (days)	Dimensions (cm)		water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	split tensile strength (MPa)
		dia	length							
1	3	15	30	20%	60	12701	5299	2.40	190	2.69
2		15	30			12865	5299	2.43	165	2.34
3		15	30			12601	5299	2.38	180	2.55
					mean	12723	**5299**	**2.40**	178	**2.5**
No	Test age (days)	Dimensions (cm)		water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		dia	length							
1	7	15	30	20%	60	12625	5299	2.38	285	4.03
2		15	30			12765	5299	2.41	265	3.75
3		15	30			12780	5299	2.41	255	3.61
					mean	12724	**5299**	**2.40**	268	**3.8**

SPLIT TENSILE STRENGTH 1.0% (HRWRAA)

No	Test age (days)	Dimensions (cm)		water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	split tensile strength (MPa)
		dia	length							
1	3	15	30	23%	110	12525	5299	2.36	220	3.11
2		15	30			12646	5299	2.39	190	2.69
3		15	30			12790	5299	2.41	205	2.90
					mean	12654	**5299**	**2.39**	205	**2.9**
No	Test age (days)	Dimensions (cm)		water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		dia	length							
1	7	15	30	20%	110	12570	5299	2.37	315	4.46
2		15	30			12766	5299	2.41	300	4.25
3		15	30			12800	5299	2.42	295	4.18
					mean	12712	**5299**	**2.40**	303	**4.29**

SPLIT TENSILE STRENGTH 1.5% (HRWRAA)

No	Test age (days)	Dimensions (cm)		water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	split tensile strength (MPa)
		dia	length							
1	3	15	30	25%	135	12680	5299	2.39	220	3.11
2		15	30			12760	5299	2.41	230	3.26
3		15	30			12880	5299	2.43	200	2.83
	mean					12773	**5299**	**2.41**	217	**3.07**

No	Test age (days)	Dimensions (cm)		water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		dia	length							
1	7	15	30	25%	135	12720	5299	2.40	320	4.5
2		15	30			12755	5299	2.41	345	4.9
3		15	30			12900	5299	2.43	330	4.7
	mean					12792	**5299**	**2.41**	332	**4.7**

SPLIT TENSILE STRENGTH 2.0% (HRWRAA)

No	Test age (days)	Dimensions (cm)		water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	split tensile strength (MPa)
		dia	length							
1	3	15	30	28%	195	12820	5299	2.42	235	3.3
2		15	30			12890	5299	2.43	255	3.6
3		15	30			12700	5299	2.40	240	3.4
	mean					12803	**5299**	**2.42**	243	**3.44**

No	Test age (days)	Dimensions (cm)		water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		dia	length							
1	7	15	30	28%	195	12720	5299	2.40	385	5.4
2		15	30			12700	5299	2.40	390	5.5
3		15	30			12890	5299	2.43	415	5.9
	mean					12770	**5299**	**2.41**	397	**5.61**

No	Test age (days)	Dimensions (cm)		water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		dia	length							
1	28	15	30	25%	135	12800	5299	2.42	425	6.0
2		15	30			12855	5299	2.43	440	6.2
3		15	30			12880	5299	2.43	450	6.4
	mean					12845	**5299**	**2.42**	438	**6.20**

SPLIT TENSILE STRENGTH 2.5% (HRWRAA)

No	Test age (days)	Dimensions (cm)		water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	split tensile strength (MPa)
		dia	length							
1	3	15	30	30%	215	12480	5299	2.36	205	2.9
2		15	30			12640	5299	2.39	220	3.1
3		15	30			12830	5299	2.42	215	3.0
	mean					12650	**5299**	**2.39**	213	**3.02**

No	Test age (days)	Dimensions (cm)		water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		dia	length							
1	7	15	30	30%	215	12550	5299	2.37	295	4.2
2		15	30			12670	5299	2.39	305	4.3
3		15	30			12860	5299	2.43	310	4.4
	mean					12693	**5299**	**2.40**	303	**4.29**

SPLIT TENSILE STRENGTH 3.0% (HRWRAA)

No	Test age (days)	Dimensions (cm)		water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	140	split tensile strength (MPa)
		dia	length							
1	3	15	30	33%	240	12490	5299	2.36	110	1.6
2		15	30			12690	5299	2.39	110	1.6
3		15	30			12550	5299	2.37	125	1.8
					mean	12577	**5299**	**2.37**	115	**1.63**
No	Test age (days)	Dimensions (cm)		water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		dia	length							
1	7	15	30	33%	240	12430	5299	2.35	225	3.2
2		15	30			12620	5299	2.38	215	3.0
3		15	30			12790	5299	2.41	220	3.1
					mean	12613	**5299**	**2.38**	220	**3.11**

FLEXURAL STRENGTH CONTROL MIX

No	Test age (days)	Dimensions (cm)			water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	flexural strength (MPa)
		W	D	L							
1	28	10	10	50	0%	45	12200	5000	2.44	8.45	5.7
2		10	10	50			12150	5000	2.43	8.7	5.9
3		10	10	50			12200	5000	2.44	8.55	5.8
						mean	12183	**5000**	**2.44**	9	**5.8**

FLEXURAL STRENGTH 2.0% (HRWRAA)

No	Test age (days)	Dimensions (cm)			water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	flexural strength (MPa)
		W	D	L							
1	28	10	10	50	25%	135	12340	5000	2.47	9.55	6.4
2		10	10	50			12170	5000	2.43	9.4	6.3
3		10	10	50			12350	5000	2.47	9.75	6.6
						mean	12287	**5000**	**2.46**	10	**6.46**

PENETRATION DEPTH (mm)		D1	D2	D3	D4	D5	D6	**Minimum**	**Mean**	**maximum**
CONTROL MIX	**0%**	16.3	18.5	15.6	17.1	19.6	18.5	**15.6**	**17.6**	**19.6**
OPTIMUM HRWRAA %	**2.00%**	8.6	7.8	13.6	13.6	15.4	10.6	**7.8**	**11.6**	**15.4**

APPENDIX- 2.3 NATIONAL CEMENT

COMPRESSIVE STRENGTH CONTROL MIX 0%

No	Test age (days)	Dimensions (cm)			water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		L	W	H							
1	3	15	15	15	0%	45	8180	3375	2.42	545	24.2
2		15	15	15			8090	3375	2.40	555	24.7
3		15	15	15			8165	3375	2.42	580	25.8
						mean	8145	**3375**	**2.41**	560	**24.89**

No	Test age (days)	Dimensions (cm)			water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		L	W	H							
1	7	15	15	15	0%	45	8180	3375	2.42	815	36.2
2		15	15	15			8200	3375	2.43	785	34.9
3		15	15	15			8260	3375	2.45	800	35.6
						mean	8213	**3375**	**2.43**	800	**35.56**

No	Test age (days)	Dimensions (cm)			water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		L	W	H							
1	28	15	15	15	0%	45	8260	3375	2.45	1010	44.9
2		15	15	15			8240	3375	2.44	995	44.2
3		15	15	15			8300	3375	2.46	1025	45.6
						mean	8267	**3375**	**2.45**	1010	**44.89**

COMPRESSIVE STRENGTH 0.5%(HRWRAA)

No	Test age (days)	Dimensions (cm)			water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		L	W	H							
1	3	15	15	15	20%	60	8100	3375	2.40	585	26.0
2		15	15	15			8250	3375	2.44	590	26.2
3		15	15	15			8160	3375	2.42	605	26.9
						mean	8170	**3375**	**2.42**	593	**26.37**

No	Test age (days)	Dimensions (cm)			water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	920	Comp.Strength (MPa)
		L	W	H							
1	7	15	15	15	20%	60	8170	3375	2.42	900	40.0
2		15	15	15			8300	3375	2.46	895	39.8
3		15	15	15			8250	3375	2.44	875	38.9
						mean	8240	**3375**	**2.44**	890	**39.56**

COMPRESSIVE STRENGTH 1.0%(HRWRAA)

No	Test age (days)	Dimensions (cm) L	W	H	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
1	3	15	15	15	23%	110	8200	3375	2.43	665	29.6
2		15	15	15			8260	3375	2.45	645	28.7
3		15	15	15			8320	3375	2.47	670	29.8
						mean	8260	**3375**	**2.45**	660	**29.33**
No	Test age (days)	Dimensions (cm) L	W	H	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
1	7	15	15	15	23%	110	8300	3375	2.46	925	41.1
2		15	15	15			8290	3375	2.46	900	40.0
3		15	15	15			8360	3375	2.48	905	40.2
						mean	8317	**3375**	**2.46**	910	**40.4**

COMPRESSIVE STRENGTH 1.5%(HRWRAA)

No	Test age (days)	Dimensions (cm) L	W	H	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
1	3	15	15	15	25%	135	8310	3375	2.46	745	33.1
2		15	15	15			8290	3375	2.46	750	33.3
3		15	15	15			8200	3375	2.43	725	32.2
						mean	8267	3375	**2.45**	740	**32.89**
No	Test age (days)	Dimensions (cm) L	W	H	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
1	7	15	15	15	25%	135	8300	3375	2.46	1060	47.1
2		15	15	15			8120	3375	2.41	1115	49.6
3		15	15	15			8350	3375	2.47	1100	48.9
						mean	8240	3375	**2.45**	1092	**48.5**
No	Test age (days)	Dimensions (cm) L	W	H	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
1	28	15	15	15	25%	135	8240	3375	2.44	1145	50.9
2		15	15	15			8360	3375	2.48	1180	52.4
3		15	15	15			8280	3375	2.45	1215	54.0
						mean	8293	3375	**2.46**	1180	**52.44**

COMPRESSIVE STRENGTH 2.0%(HRWRAA)

No	Test age (days)	Dimensions (cm)			water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		L	W	H							
1	3	15	15	15	28%	195	8200	3375	2.43	705	31.3
2		15	15	15			8120	3375	2.41	685	30.4
3		15	15	15			8100	3375	2.40	680	30.2
						mean	8140	**3375**	**2.41**	690	**30.67**
No	Test age (days)	Dimensions (cm)			water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		L	W	H							
1	7	15	15	15	28%	195	8100	3375	2.40	975	43.3
2		15	15	15			8050	3375	2.39	950	42.2
3		15	15	15			8140	3375	2.41	955	42.4
						mean	8097	**3375**	**2.40**	960	**42.67**

COMPRESSIVE STRENGTH 2.5%(HRWRAA)

No	Test age (days)	Dimensions (cm)			water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		L	W	H							
1	3	15	15	15	30%	215	8200	3375	2.43	585	26.0
2		15	15	15			8250	3375	2.44	610	27.1
3		15	15	15			8130	3375	2.41	605	26.9
						mean	8193	**3375**	**2.43**	600	**26.67**
No	Test age (days)	Dimensions (cm)			water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		L	W	H							
1	7	15	15	15	30%	215	8000	3375	2.37	835	37.1
2		15	15	15			8010	3375	2.37	820	36.4
3		15	15	15			8050	3375	2.39	805	35.8
						mean	8020	**3375**	**2.38**	820	**36.44**

COMPRESSIVE STRENGTH 3.0%(HRWRAA)

No	Test age (days)	Dimensions (cm)			water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		L	W	H							
1	3	15	15	15	33%	240	8100	3375	2.40	395	17.6
2		15	15	15			8020	3375	2.38	385	17.1
3		15	15	15			8090	3375	2.40	360	16.0
						mean	8070	**3375**	**2.39**	380	**16.89**
No	Test age (days)	Dimensions (cm)			water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		L	W	H							
1	7	15	15	15	33%	240	7950	3375	2.36	585	26.0
2		15	15	15			8010	3375	2.37	605	26.9
3		15	15	15			8000	3375	2.37	580	25.8
						mean	7987	**3375**	**2.37**	590	**26.22**

SPLIT TENSILE STRENGTH CONTROL MIX 0%

No	Test age (days)	Dimensions (cm)		water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	split tensile strength (MPa)
		dia	length							
1	3	15	30	0%	45	12801	5299	2.42	195.0	2.76
2		15	30			12384	5299	2.34	185.0	2.62
3		15	30			12328	5299	2.33	180.0	2.55
					mean	12505	**5299**	**2.36**	187	**2.64**
No	Test age (days)	Dimensions (cm)		water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		dia	length							
1	7	15	30	0%	45	12801	5299	2.42	270	3.82
2		15	30			12505	5299	2.36	280	3.96
3		15	30			12611	5299	2.38	265	3.75
					mean	12639	**5299**	**2.39**	272	**3.85**
No	Test age (days)	Dimensions (cm)		water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		dia	length							
1	28	15	30	0%	45	12801	5299	2.42	335	4.74
2		15	30			12558	5299	2.37	350	4.95
3		15	30			12770	5299	2.41	365	5.17
					mean	12710	**5299**	**2.40**	350	**4.95**

SPLIT TENSILE STRENGTH 0.5% (HRWRAA)

No	Test age (days)	Dimensions (cm)		water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	split tensile strength (MPa)
		dia	length							
1	3	15	30	20%	60	12982	5299	2.45	220	3.11
2		15	30			12505	5299	2.36	200	2.83
3		15	30			12770	5299	2.41	205	2.90
					mean	12752	**5299**	**2.41**	208	**2.95**
No	Test age (days)	Dimensions (cm)		water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		dia	length							
1	7	15	30	20%	60	12823	5299	2.42	340	4.81
2		15	30			12982	5299	2.45	320	4.53
3		15	30			12770	5299	2.41	320	4.53
					mean	12858	**5299**	**2.43**	327	**4.62**

SPLIT TENSILE STRENGTH 1.0% (HRWRAA)

No	Test age (days)	Dimensions (cm)		water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	split tensile strength (MPa)
		dia	length							
1	3	15	30	23%	110	13035	5299	2.46	250	3.54
2		15	30			12717	5299	2.40	220	3.11
3		15	30			12770	5299	2.41	220	3.11
					mean	12841	**5299**	**2.42**	230	**3.26**
No	Test age (days)	Dimensions (cm)		water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
		dia	length							
1	7	15	30	20%	110	12929	5299	2.44	340	4.81
2		15	30			12717	5299	2.40	340	4.81
3		15	30			12770	5299	2.41	350	4.95
					mean	12805	**5299**	**2.42**	343	**4.86**

SPLIT TENSILE STRENGTH 1.5% (HRWRAA)

No	Test age (days)	Dimensions (cm) dia	Dimensions (cm) length	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	split tensile strength (MPa)
1	3	15	30	25%	135	12770	5299	2.41	255	3.61
2		15	30			12664	5299	2.39	240	3.40
3		15	30			12982	5299	2.45	240	3.40
					mean	12805	**5299**	**2.42**	245	**3.47**
No	Test age (days)	Dimensions (cm) dia	Dimensions (cm) length	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	split tensile strength (MPa)
1	7	15	30	25%	135	12717	5299	2.40	410	5.8
2		15	30			12876	5299	2.43	420	5.9
3		15	30			13035	5299	2.46	410	5.8
					mean	12876	**5299**	**2.43**	413	**5.85**
No	Test age (days)	Dimensions (cm) dia	Dimensions (cm) length	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	split tensile strength (MPa)
1	28	15	30	25%	135	12611	5299	2.38	450	6.4
2		15	30			12717	5299	2.40	440	6.2
3		15	30			12982	5299	2.45	445	6.3
					mean	12770	**5299**	**2.41**	445	**6.30**

SPLIT TENSILE STRENGTH 2.0% (HRWRAA)

No	Test age (days)	Dimensions (cm) dia	Dimensions (cm) length	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	split tensile strength (MPa)
1	3	15	30	28%	195	12717	5299	2.40	230	3.3
2		15	30			12770	5299	2.41	245	3.5
3		15	30			12717	5299	2.40	245	3.5
					mean	12735	**5299**	**2.40**	240	**3.40**
No	Test age (days)	Dimensions (cm) dia	Dimensions (cm) length	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	split tensile strength (MPa)
1	7	15	30	28%	195	12982	5299	2.45	360	5.1
2		15	30			12796	5299	2.42	355	5.0
3		15	30			12532	5299	2.37	350	5.0
					mean	12770	**5299**	**2.41**	355	**5.02**

SPLIT TENSILE STRENGTH 2.5% (HRWRAA)

No	Test age (days)	Dimensions (cm) dia	Dimensions (cm) length	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	split tensile strength (MPa)
1	3	15	30	30%	215	12995	5299	2.45	210	3.0
2		15	30			13157	5299	2.48	210	3.0
3		15	30			12800	5299	2.42	205	2.9
					mean	12984	**5299**	**2.45**	208	**2.9**
No	Test age (days)	Dimensions (cm) dia	Dimensions (cm) length	water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/cm3)	Failure load (kN)	Comp.Strength (MPa)
1	7	15	30	30%	215	12550	5299	2.37	300	4.2
2		15	30			12770	5299	2.41	305	4.3
3		15	30			12650	5299	2.39	305	4.3
					mean	12657	**5299**	**2.39**	303	**4.29**

SPLIT TENSILE STRENGTH 3.0% (HRWRAA)

No	Test age (days)	Dimensions (cm)		water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/ cm3)	140	split tensile strength (MPa)
		dia	length							
1	3	15	30	33%	240	12590	5299	2.38	125	1.8
2		15	30			12540	5299	2.37	135	1.9
3		15	30			12650	5299	2.39	135	1.9
					mean	12593	**5299**	**2.38**	132	**1.86**
No	Test age (days)	Dimensions (cm)		water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/ cm3)	Failure load (kN)	Comp.Strength (MPa)
		dia	length							
1	7	15	30	33%	240	12430	5299	2.35	215	3.0
2		15	30			12620	5299	2.38	205	2.9
3		15	30			12790	5299	2.41	195	2.8
					mean	12613	**5299**	**2.38**	205	**2.90**

FLEXURAL STRENGTH CONTROL MIX

No	Test age (days)	Dimensions (cm)			water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/ cm3)	Failure load (kN)	flexural strength (MPa)
		W	D	L							
1	28	10	10	50	0%	45	12230	5000	2.45	8.42	5.7
2		10	10	50			12180	5000	2.44	8.3	5.6
3		10	10	50			12460	5000	2.49	8.25	5.6
						mean	12290	**5000**	**2.46**	8.3	**5.62**

FLEXURAL STRENGTH 1.5% (HRWRAA)

No	Test age (days)	Dimensions (cm)			water reduction %	Slump (mm)	Weight (gm)	Volume (cm^3)	Unit weight(gm/ cm3)	Failure load (kN)	flexural strength (MPa)
		W	D	L							
1	28	10	10	50	25%	135	12230	5000	2.45	9	6.1
2		10	10	50			12180	5000	2.44	9.4	6.3
3		10	10	50			12460	5000	2.49	9.15	6.2
						mean	12290	**5000**	**2.46**	9.2	**6.20**

CONCRETE PERMEABILITY TEST

PENETRATION DEPTH (mm)		D1	D2	D3	D4	D5	D6	**Minimum**	**Mean**	**maximum**
CONTROL MIX	**0%**	17.8	18.7	14.9	14.4	15.4	17.8	**14.4**	**16.5**	**18.7**
OPTIMUM HRWRAA %	**1.50%**	11.67	8.4	8.6	13.4	14.4	11.9	**8.4**	**11.4**	**14.4**

APPENDIX 4- SAMPLE PHOTO TAKEN DURING THE RESEARCH

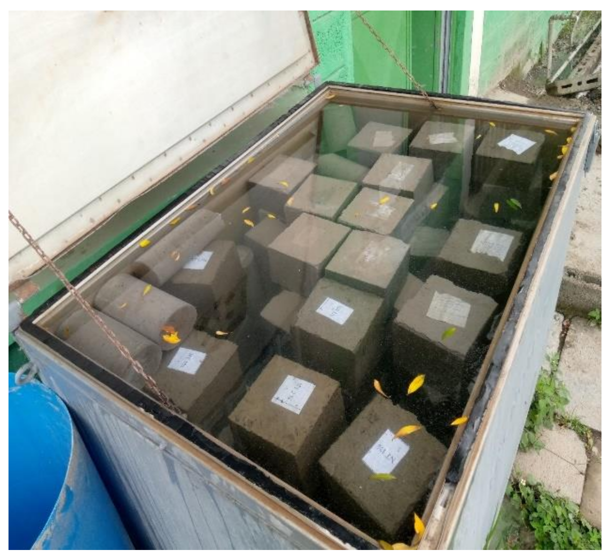
Cement Consistency and Setting Time Test

Fineness of Cement

Fine and Coarse Aggregate sieve Analysis

Unit weight and water absorption of Coarse Aggregate

workability Test **Sample casting**



Casted sample after mold removal **Curing**


Cube ready for test **cube sample under conpressive machine**


Marking center of cylinder **tensile strength Test**

Beam read for test **Beam under flexural testing Machine**

Cube sample ready for permeability test **splitted sample for penetration**