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Study on Application of Portland Pozzolana Cement for Structural Concrete

A thesis submitted to Addis Ababa Institute of Technology, School of Civil and Environmental Engineering in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering

(Construction Technology and Management)

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DECLARATION

I, the undersigned, declare that this thesis is my original work and it has not been presented for a degree in any university and that all sources of materials used for the thesis have been duly acknowledged.

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Date of submission: -

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ABSTRACT

In recent years, sustainability has become a very important issue in the cement manufacturing sector as well as the construction industry as a whole. This leads to seeking the possibility of using alternative materials as a substitute for conventional raw materials used for cement production.It is known that ordinary Portland cement is an expensive and energy-intensive material. Using alternative materials like pozzolans and other industrial by-products as a partial replacement, energy consumption, and cost can be substantially saved. This is because these materials are generally available at significantly lower costs [8, page 22].In Ethiopia, cement types namely:ordinary Portland cement (OPC), Portland pozzolana cement (PPC), and recently Portland limestone cement (PLC) are available in the market. Ordinary Portland cement is the most widely used type of cement in Ethiopia for structural applications. Portland pozzolana cement can be alternatively used with additional benefits like cost reduction, better durability, and positive environmental impacts because of less CO_2 emission in the production process. However, as a trend in the construction industry of Ethiopia, this cement is not being widely used for structural concrete.Therefore, this research mainly focused on studying the application of PPC for structural concrete. A questionnaire and laboratory examination were used for data collection. The purpose of the survey is to assess the current application of PPC for structural concreteand if it is not being widely used, to find out the reason.The result from the survey shows that, currently, PPC is not being widely used for structural concrete. In this study, concrete samples were made for C-25 and C-30 concrete grades, which are the concrete grades mosly used for structural concrete. Concrete mixes were prepared and laboratory tests were conducted.Concrete samples were made with OPC, PPC, and PPC with water-reducing admixture. Water-reducing admixture was used to improve the compressive strength of concrete. Slump and compressive strength tests were conducted and cost comparison was done between concrete mix made with OPC and PPC with water-reducing admixture.The laboratory test result shows that, without affecting the desired slump and compressive strength, the cost of concrete mix made with PPC and water reducing admixture can be reduced by 224br/m^3 and 259br/m^3 for C-25 and C-30 respectively.

Key words; Ordinary Portland cement, Portland pozzolana cement, concrete, water- reducing admixture, compressive strength

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List of Abbreviations

ACI ………………………American Concrete Institute

ASTM ……………………American Society for Testing and Materials

C_3S ……………………….Tri-calcium sulfate

C_2S ……………………….Di-calcium silicate

C_3A ………………………Tri-calcium aluminate

C_4AF ……………………..Tetra-calcium aluminoferrite

HRWRA ………………….High range water-reducing admixture

SCM ………………………Supplementary cementitious materials

RMC ………………………Ready mixed concrete

SP …………………………Super-plasticizer

PC …………………………Portland cement

CHAPTER ONE

INTRODUCTION

1. Background

The cement and concrete industries have an impact on sustainable development.Use of large volumes of raw material that are quarried from the earth, the large amount of energy required during production, and the emission of a large amount of CO_2 during the manufacturing of Portland cement have a considerable negative impact on the environment [5,page1].

According to Pierre Claude & Sidney Mindess, for the cement, concrete, and construction industries, sustainability refers to more cement with less clinker, more concrete with less cement, and more durable structures with a longer life cycle[5, page32].

The global CO_2 emission by different countries is as shown in Figure 1.1. China has the most production of cement and at the same time the most CO_2 emission. Therefore, cement production has a great impact on the environment.

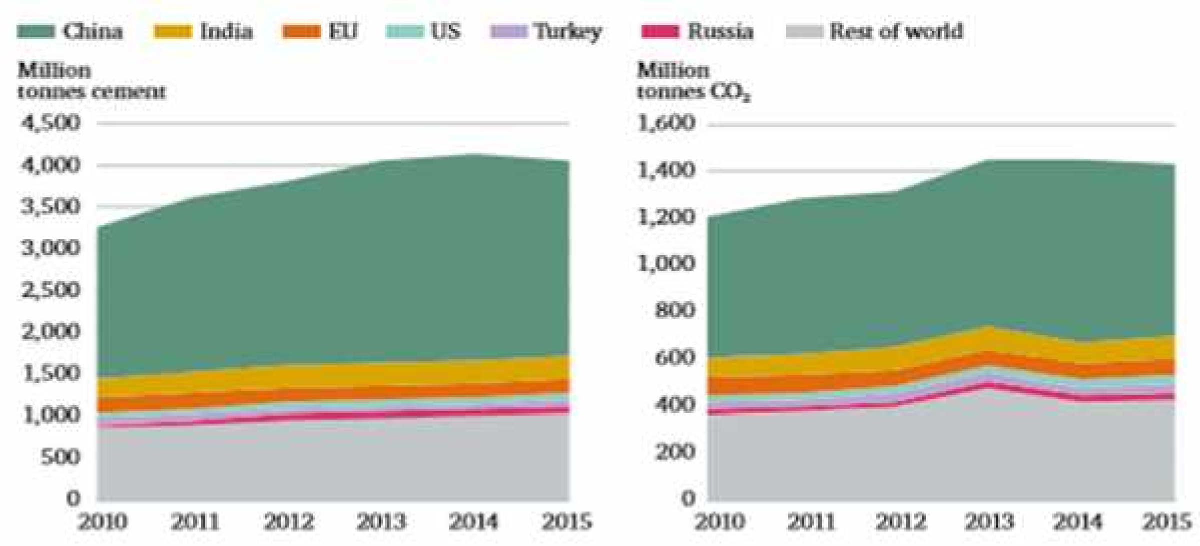

Figure 1.1 Trends in global CO_2 emission (2016 report) [19, page 1]

*Jayant D. Bapat*states “As per several estimates, the cement industry contributes about 5% of the global generation of carbon dioxide, which is a greenhouse gas. At the global level, the cement industry will be required to reduce its CO_2 generation by 30%–40% by 2020 and about 50% by 2050” [6, page36].

Nurdeen. M. Attwir and Shahid Kabir concluded that, for the production of green concrete which eliminates the negative impact of the cement industry, we should try to replace as much Portland cement as possible by supplementary cementitious materials, especially those that are by-products of industrial processes, such as fly ash, rice husk ash, palm oil fuel ash, slag, and silica fume [9].

In general, the reduction of greenhouse gas emissions and the implementation of sustainable development policy are the main objectives of the cement industry. If sustainable Portland cement concrete is required, the use of water-reducing admixtures is also highly recommended. Using these admixtures the amount of mixing water to make concrete of a given slump can be reduced and as a result, cement consumption will be saved and the durability of concrete can be improved [5, page40].

Therefore, this study mainly focused on the application of PPC for structural concrete production. Structural concrete as defined on ACI 318, refers to concrete used for structural purposes, including reinforced and unreinforced [26, page 41]. A structural material is a material that carries not only its self-weight but also the load passing from other members [16, page8].

1.1 Statement of the Problem

Ordinary Portland cement (OPC) is the type of cement mostly used for structural concrete in Ethiopian building construction. However, Portland pozzolan cement (PPC) can be alternatively used and will provide additional benefits:

- Lower cost compared to OPC,
- Better durability,
- For sustainable development, because there is less CO_2 emission in the production process,
- Reduce primary energy useand,
- Saving of quarried material

As a trend in the construction industry of Ethiopia, PPC is not being mostly used for structural concrete. There is a prevailing attitude to consider PPC as inferior cement. This is because PPC develops strength more slowly compared to OPC.Therefore, this research is concerned with the application of this cement for structural concrete by achieving the desired compressive strength of concrete at 28-days. The early age compressive strength of concrete made with PPC can be improved using water-reducing admixtures.Therefore, concrete mixes were made using PPC and Type D water-reducing and retarding admixture. The purpose of using water-reducing admixture is to reduce the water content and to improve the compressive strength of concrete. Type D water-reducing admixture is selected because in Ethiopia, most of the seasons are sunny and the weather condition is warm, so that longer setting time of concrete might be required to easily handleand place concrete. Especially,inready-mixed concrete, longer setting time is required to transport concrete mix from batchplant to the construction site and sometimes it could require some significant travel. Finally, comparison of cost of concrete mixes were made using OPC versus PPC with water-reducing admixtureand the cost reduction is illustrated.

1.2 Objective

The objective of this research is to study the application of Portland pozzolana cement for structural concrete. Specifically, the study aims to:

- Assess the current application of PPC for structural concrete
- Determine how PPC may be used for structural concrete in building construction
- Make a cost comparison of concrete mixtures produced with ordinary Portland cement (OPC) versus PPC with water-reducing admixture.

1.3 Scope of the study

The scope of laboratory examination is limited to:

- OPC and PPC, class 42.5R, and 32.5R respectively.
- Water-reducing and retarding admixture, Type D, conforming to ASTM C-494, .

1.4 Research methodology

This research involved survey and laboratory examination. The purpose of the survey is to answer the following questions:

- For what applications is PPC being used in building construction (structural or non-structural)
- If it is not being used for structural concrete, what is the reason?
- Which concrete strength is widely used for structural concrete?

The survey was done by using a questionnaire. The questionnaires were designed as shown in Appendix A and B and distributed to consulting firms because they are responsible for specifying the cement type. Questionnaires were filled and collected in two ways: by interviewing the representatives and by distributing to the representatives of consulting firms. Category one up to three consultants according to Addis Ababa Construction Bureau were selected for the study.This is because consultants in this category have the largest project sizes. The sample size of consultants was calculated using Slovin's formula as $n = \frac{N}{1+Ne^2}$ where n: is the sample size, N: is the population size, and e: is the error tolerance [38]. After the sample size was calculated, the respondents were randomly selected from the total population using MS Excel, by giving numbers to all category one upto three consultants and then, using the formula RANDBETWEEN, the randomly selected numbers were found and the questionnaires were filled and collected accordingly.

Ready-mixed concrete suppliers are also included in the survey. Since the population size of ready-mixed concrete suppliers is smaller, 100% of the questionnaires prepared for ready-mixed concrete suppliers were distributed in person and filled by interviewing the representatives.

The laboratory examination involved material characterization, mix proportioning, and conducting slump and compressive strength tests on fresh and hardened concrete respectively. Mix proportioning was done for concrete grades used most of the time for structural concrete (C-25 and C-30) as per the results of the survey.

CHAPTER TWO

LITERATURE REVIEW

2. Introduction

One of the main constituents of concrete is cement. It forms a paste when mixed with water.The mixture of paste, fine aggregate, and coarse aggregate makes concrete, the most widely used material for building construction. Concrete is considered as the world's most widely used construction material because of its versatility, durability, sustainability, and economy [10, page1].

The properties of each constituent of concrete: cement, aggregate, water, and admixture will be discussed in the next section. Besides, previous research projects related to application of Portland pozzolana cement for structural concrete will be briefly discussed.

2.1 Constituents of concrete

2.1.1 Cement

Generally, there are two types of cementing materials.

1. **Non-hydraulic cement-** cement which is neither able to set and harden in water (e.g. non-hydraulic lime) nor remain stable in water such as gypsum plasters.
2. **Hydraulic cement-** is cement in a finely ground form and when mixed with water, sets and hardens and which, after hardening retains its strength and stability even underwater. Portland and blended types of cement are categorized as hydraulic cement [10, page29].

Portland cement is by far the most widely used hydraulic cement[14].Constituents, hydration reaction, and classification of this cement will be discussed below.

2.1.1.1 Portland cement

Though there are different types of cement used for the production of concrete, Portland cement concrete is the most popular and widely used building material, due to the availability of the basic raw materials all over the world, and its ease of use in preparing and fabricating different shapes [16, page34].

Portland cement is the name given to cement obtained by mixing together calcareous such as limestone or chalk and argillaceous (shale or clay) or other silica, alumina, and iron-oxide bearing materials, burning them at a clinkering temperature, and grinding the resulting clinker [18, page8].

In Compulsory Ethiopian Standard (CES 28), common types of cement are classified into five main cement types:

- CEM I- Portland cement,
- CEM II- Portland composite cement,
- CEM III- Blast furnace cement,
- CEM IV- Pozzolanic cement, and
- CEM V- Composite cement [24]

According to this standard, cement shall be designated by at least the notation of the cement type and the numbers, 32.5, 42.5, and 52.5 that indicate the minimum compressive strength at 28-days. To signify the early strength class, the letter N, R, or L for ordinary, high, and low early strengths respectively are added[24, Page14].

Types of Portland cement can be varied by their proportions of chemical compounds, degree of fineness in which the clinker is ground to and as a result their specific purpose of the application. According to ASTM C-150, Standard Specification for Portland Cement, types of Portland cement can be classified as:

- Type I (Ordinary Portland cement, used when the special properties specified for any other type are not required),
- Type II (For general use, especially when moderate sulfate resistance or moderate heat of hydration is required),
- Type III (Rapid-hardening Portland cement, used when high early strength is required),
- Type IV (Low heat Portland cement, used when low heat of hydration is desired), and
- Type V (Sulphate resisting Portland cement, used when high sulphate resistance is desired). Also, Type IA, Type IIA and Type IIIA, which have the same uses as Type I, II and III types of cement except that the letter A refers to the cement that can be used where air entrainment is desired [12].

Ordinary Portland cement is currently the most widely used type of cement in the construction industry of Ethiopia as well as all over the world."It is the most common cement used in general concrete construction when there is no exposure to sulphates in the soil or on groundwater" [12].

2.1.1.1.1 Constituents of Portland cement

The specific composition of the cement depends on the specific composition of the raw materials used in its production. These raw materials in a finely ground blended and burned form create the major constituents of Portland cement.

A. Major compounds of Portland cement

There are four major constituents of Portland cement as shown in Table 2.1. The combined content of the four compounds is approximately 90% of the cement weight. This is the reason that these four are referred to as 'major compounds' or 'major constituents' [14, page4].

Table 2.1 Major compounds in Portland cement [15,page10]

Name of compound	Oxide composition	Abbreviation
Tri-calcium silicate	$3CaO.SiO_2$	C_3S
Di-calcium silicate	$2CaO.SiO_2$	C_2S
Tri-calcium aluminate	$3CaO.Al_2O_3$	C_3A
Tetra-calcium alumino-ferrite	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF

The C_3S and C_2S occupy 68 to 75% of Portland cement. Theseare the most important compounds which are responsible for the strength of hydrated cement paste [16, Page 37]. The variation in the properties of the major constituents of Portland cement is used in the production of different types of this cement. The properties are summarized as shown in the table below.

Table 2.2 Properties of the major constituents of Portland cement [14, page11]

Compound	**C_3S**	**C_2S**	**C_3A**	**C_4AF**
Rate of hydration	Rapid (hours)	Slow (days)	Instantaneous	Very rapid (minutes)
Strength development	Rapid (days)	Slow (weeks)	Very rapid (one day)	Very rapid (one day)
Ultimate strength	High	High	Low	Low
Heat of hydration	Medium	Low	Very high	Medium

B. Minor components of Portland cement

The most important minor components of cement are gypsum, alkali sulfates, and MgO.

Gypsum: In the manufacturing of Portland cement, gypsum is added to prevent the flash setting caused by the fast reaction of C_3A.

Alkalies: (Na_2O and K_2O) can increase the PH value of concrete up to 13.5, which is good for reinforcing steel protection. However, high alkali content can also cause durability problems such as, alkali aggregate reaction and leaching [16, page37&38].

2.1.1.1.2 Hydration reaction of Portland cement

Hydration of cement refers to the reaction process of cement with water. The two main compounds in cement, C_3S and C_2S (calcium silicates) and the aluminates (C_3A and C_4AF) in the presence of water form a hard mass, the hydrated cement paste [15, page12].

The most important components of Portland cement from the strength development point of view are C_3S and C_2S. The hydration reaction can be written as a guide, although not as exact stoichiometric equations as shown below.

$2C_3S + 6H \longrightarrow C_3S_2H_3 + 3Ca\,(OH)_2$

$2C_2S + 4H \longrightarrow C_3S_2H_3 + Ca\,(OH)_2$[14, page31]

The hydration reaction stages of Portland cement are as follow.

- ***Pre induction period***–alkali sulphates dissolve immediately, releasing k^+, $Na^{+,}$ and SO_4^{2-}. Gypsum dissolves and releases Ca^{2+} and SO_4^{2-}.C_3S starts to dissolve and a layer of C-S-H precipitates on the cement particles. C_3A dissolves and reacts with Ca^{2+} and $SO4^{\,2-}$ ions in the liquid phase resulting in ettringite that also precipitates on the surface of the cement particles. The ferrite phase also hydrates in a similar manner as C_3A. This period has the highest rate of hydration but lasts only a few minutes.
- ***Induction (dormant) period*** - at this period, the plastic paste formed remains unchanged. This is because the layer formed on the surface of the cement particles upon the precipitation of initial calcium silicate hydrate and calcium alumino hydrates during the pre-induction period acts as a barrier to further hydration and the rate of hydration slowed down significantly.

- ***Accelerated period*** - the rate of C_3S reaction increases significantly.Hydration of C_2S and C_3A becomes acceleratedandC_4AF hydrates at a slower rate.
- ***Deceleration period*** **–** the hydration rate slows down because the amount of un-reacted cement is reduced. And the C-S-H continues to be formed as both the C_3S and C_2S continue to hydrate. The contribution of C_2S in C-S-H formation is more at this stage. The hydration process continues till the cement is hydrated or all the water is consumed [7, page60].

Some of the factors affecting the rate of hydration are

- ✓ **The fineness of cement-** though the ultimate degree of hydration is not affected by the fineness of the cement, at an early age, the hydration rate of cement is directly proportional to its fineness.
- ✓ **Temperature -** the rate of hydration of cement paste increases with temperature.
- ✓ **Admixtures –** the rate of hydration can be accelerated or retarded by using accelerating or retarding admixtures respectively.
- ✓ **Age of paste -** at early ages of hydration, the hydration rate is maximum. However, after a limited time, the rate of hydration gradually decreases, and at a certain stage, it stops completely.
- ✓ **Water to cement ratio -** at an early age, the water to cement ratio has a little effect on hydration. Later, however, when the water to cement ratio decreases, the rate of hydration also decreases. This effect of the water to cement ratio may be attributed to the decrease in the space available for the hydration products at a very lower water-cement ratio [14, page43].

2.1.1.2Blended cement

Blended hydraulic cement types are produced by intimately and uniformly inter-grinding two or more types of fine materials. Portland cement, slag cement, fly ash, silica fume, calcined clay, other pozzolans, and hydrated lime and pre-blended combination of these are the primary materials in the production of blended hydraulic cement [4, page31].

Fly ash **-** is a coal combustion product composed of fine particles that are carried out of the boiler by flue gases in power plants.

Silica fume - is an ultrafine powder collected from the production of silicon and ferrosilicon alloy.

Calcined clay (Metakaolin) - clays, in particular those containing kaolinite, can be used as supplementary cementitious material when calcined.

Limestone - ground limestone can be blended with clinker to reduce the final clinker content of cement.

Granulated blast furnace slag (GBFS) **-** is formed when iron ore, coke, and limestone are melted together in a blast furnace by means of high-pressure hot air blasts through a series of jets located near the bottom of the furnace. The slag is in molten form when it comes out of the blast furnace. Then it is rapidly cooled by applying water that turns the molten slag into small droplets (sand-like granule), which is primarily ground into a cement called granulated blast furnace slag [7, page 25 & 26].

Rice-husk ash - rice husk is a waste product from rice production, which if burnt under controlled conditions, can result in a highly reactive pozzolan (rice husk ash).

Calcined shale **–** is a fine-grained sedimentary rock formed of clay minerals. It can be used as supplementary cementitious material when calcined [19, page97].

The five primary classes of blended cement as per ASTM C 595, Standard Specification for Blended Hydraulic Cements are: Type IS (Portland blast-furnace slag cement), Type I(PM) Pozzolan-modified Portland cement, Type S (Slag cement), Type I(SM) Slag-modified Portland cement, Type IP and Type P (Portland-pozzolan cement).ASTM standard specification for blended cement which was released in 2014, specifies two major groups of blended cement as:

- **Binary blended cement** which consists of Portland cement with either a slag, a pozzolan or limestone and these types of cement are designated as Type IS (Portland-BFS cement), Type IP (Portland-pozzolan cement), Type IL (Portland-limestone cement)
- **Ternary blended cement** consists of Portland cement with a combination of two different pozzolans, a slag and a pozzolan, slag and limestone, or a pozzolan and a limestone. These types of cement are designated by Type IT [7, page225].

Though there are different types of blended cement, in Ethiopia PPC is the most widely used and available.

In Ethiopian Standard (ES), Portland pozzolana cement is defined as cement resulting from a homogeneous mixture of finely ground Portland clinker and less than 35 percent by mass of pozzolan [24]. On the other hand, as per ASTM C-595, PPC is described as a hydraulic cement which consists of an intimate and uniform blend of Portland or Portland blast furnace slag cement and fine pozzolan. The fine pozzolan can be produced either by inter-grinding Portland cement clinker and pozzolan, by blending Portland cement or Portland blast-furnace slag cement and finely divided pozzolan, or a combination of inter-grinding and blending. The constituent of pozzolan is between 15 and 40% by mass of the Portland pozzolan cement [11].

Blended types of cement are already widely used in Europe and are being introduced in the United States. In India, the proportion of blended cement to total cement produced increased from 32.58% in 1999 to about 56% in 2005 and is likely to increase even more [21, page55].

However, the global market is still dominated by high clinker cement. Portland cement, which tends to be made up of >75% Portland clinker is used in more than 98% of concrete produced globally today [19, page5].

2.1.1.2.1Pozzolan

On ASTM 618, pozzolan is defined as a siliceous or siliceous and aluminous material which has little or no cementitious property by itself but can possess this property if it is in a finely divided form and in the presence of moisture by chemically reacting with lime (formed from hydration of Portland cement) [17].

Pozzolans include natural (volcanic ashes, volcanic tuffs, trass, and zeolites) as well as industrial co-products (silica fumes, fly ashes, calcined clays and shales, and rice-husk ash) that contain a certain percentage of vitreous silica. This vitreous (amorphous) silica reacts at ambient temperature with the lime produced by the hydration of C_3S and C_2S to form C-S-H similar to that produced by the direct hydration of C_3S and C_2S [13, page 285].

Adisu Fentaw studied on the uses of Derba ordinary Portland and Portland pozzolana types of cement for structural concrete production. The research stated that, the pozzolan used in the production of PPC is natural material, pumice, which is rated as less active [2, page 88]. Similarly, Nigus G/Egziabher studied on the comparison of concrete properties made with three different brands of cement (both OPC and PPC) in Ethiopia. And as per his study, the pozzolans used in the production of Portland pozzolana cement are volcanic materials, which are less pozzolanic. Besides, pumice and volcanic basalt are the types of pozzolans used in the production of PPC [29, page37]. Therefore, these studies concluded that, because of their less pozzolanic property, the ultimate strength achieved from these pozzolanas cannot be as high as that achieved with active pozzolans.

2.1.1.2.2 Pozzolanic reaction of cement

Pozzolanic materials do not harden by themselves, rather when they are in a finely grounded form and in the presence of water they react with dissolved calcium hydroxide and form strength developing calcium silicate and calcium aluminate compounds.

The pozzolanic reaction is defined as

Pozzolan + calcium hydroxide + water $\longrightarrow$ calcium silicate hydrate……………E.q. 2.1

When a pozzolanic reaction takes place, the lime produced during C_3S and C_2S hydration is transformed into calcium silicate hydrate. Therefore, hydration of blended cement containing a pozzolan can be written as follows:

Portland cement + pozzolan + water $\rightarrow$ C-S-H + sulphoaluminates [13, page286]…E.q.2.2

The formation of a C-S-H gel brought the setting and hardening of the cement paste. The gel fills the space between the cement grains, bridges between them, and thereby causes stiffening of the paste and its subsequent hardening. The continued formation of the gel gradually fills the capillary pores, the porosity of the paste decreases, and its strength is increased [14,page73].

2.1.1.2.3 Effect of pozzolanic materials on hydration reaction

Pozzolanic materials have much less calcium content than Portland cement. Pozzolanic reactions in Portland pozzolana blends first require the formation of CH from the hydration of calcium silicates in Portland cement. Once the CH formation starts, siliceous and aluminous components in the pozzolan begin to react with this hydration product. Consequently, the CH content of hydrated pozzolan-incorporated cement is always lower than that of hydrated Portland cement. Besides the pozzolanic reactions, the presence of pozzolans also modifies the hydration kinetics and the hydration products of Portland cement [7, page68].

Some of the physical effects of pozzolanic materials on hydration can be considered from four aspects:

(1)Cement dilution effect: this is encountered when the pozzolanic material is used as a partial cement replacement material. When there is an increased amount of replacement, a decreased amount of cement is used and naturally less cement refers to less hydrated material.

(2)Dispersion effect: when Portland cement is mixed with water, particles are prone to show some coagulation. Inclusion of any ultra-fine mineral powder into the cementitious system results, dispersion of cement particles and exposes more cement surface area for hydration. Therefore, for a fixed cement amount, the incorporation of pozzolanic materials would result in more cement hydration. This effect is illustrated in Figure 2.1 for fly ash-incorporated cement. However, this may be suppressed if the amount of pozzolanic material used is high.

(**3)Nucleation effect:** It facilitates the early hydration of Portland cement by providing additional sites for the precipitation of hydration products.This is related to the fineness of the pozzolanic materials and its affinity for cement hydrates.

(**4)**Reduction in the thickness of the initial layer of hydrates formed on the surface of the cement particles makes breaking it down easier thus accelerating the hydration process [7, page62].

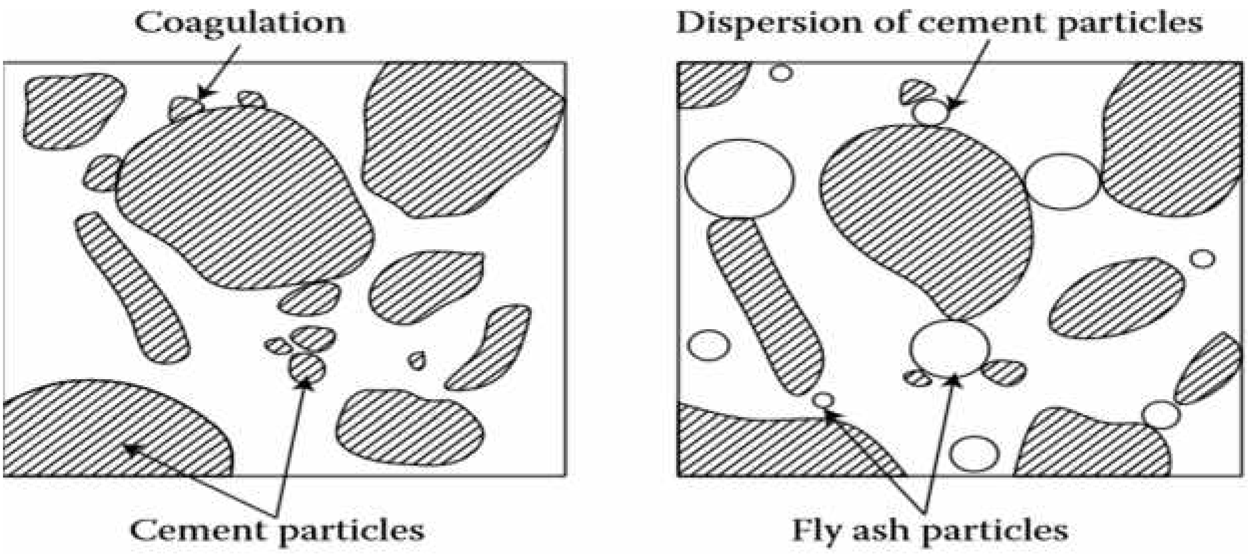

Figure 2.1 Dispersion effects of fly ash particles [7, page 63]

2.1.1.2.4 Effect of pozzolanic materials on the strength of concrete

Blending Portland cement with pozzolanic materials delays the full strength development of concrete. When standard specimens made with such blended types of cement continue to be cured beyond the standard period of 28-days, they continue to increase in strength until 56 or even 91-days. After this, the increase in strengthis not so significant. The increase in strength between 28-days and 56 or 91-days is due to the fact that pozzolanic materials react slowly at room temperature with water and with the lime liberated by the hydration reactions. Therefore, there are now suggestions that compressive strength should be measured at 56 or 91-days instead of the 28-days which has been the rule till now [5, page97].

An experimental study was carried out to examine the properties of dry cast concrete using both types of cement (OPC and PPC). The development of its compressive strength was also examined at 1, 7, 14, 21, 28, and 56-days of age. As a result, the compressive strengths of dry cast concrete made with PPC and with various water-cement ratios i.e. 0.3, 0.4, and 0.5 were found to have a significant differenceat the age of 1 to 21-days. However, because of the pozzolanic reaction,the compressive strength results are further getting closer to one another at the age of over 56-days [3].

2.1.1.2.5 Benefits of using pozzolanic materials in cement

Using natural pozzolans and industrial by-products as a partial replacement of Portland cement considerable savings in cost and energy consumption can be achieved. This is because Portland cement is an expensive and energy-intensive material and these materials are generally available at significantly lower costs than Portland cement. For example, fly ash and ground granulated blast-furnace slag (GGBS) are useful by-products of other industrial processes that can be used as partial replacement of cement.

The following are some of the benefits of using these pozzolanic materials in cement production or as concrete mixer additions;

- Reduction in CO_2 emission
- Reduction in primary energy use
- Saving of quarried material and landfill space for industrial waste [8, page 22 & 23].

An experimental study was done on the sulfate resistance of Portland pozzolan cement and blends with silica fume or fly ash with Portland cement replacement of different levels of these materials. Besides, the reference mortars were made with ASTM Type I, II, and V cement. The test results on mortar bars exposed to sulfate attack in 5% solution over a period of 52-weeks showed that Portland pozzolan cement mortars with the lowest sulfate expansion at 52-weeks. Based on findings of the study, by using Portland pozzolan cement, substantial sulfate resistance equal to or greater than Type II and V can be achieved [20,page67-71].

Advantages of Portland pozzolana blended cement over plain ordinary Portland cement:

- ❖ Lower cost,
- ❖ Enhanced long-term strength,
- ❖ Improved sulfate resistance, workability, and resistance to the alkali-aggregate reaction, [1, page18] and
- ❖ Lower heat of hydration

2.1.1.3Manufacturing of cement

The manufacturing process of Portland cement essentially consists of the following, [15,page8]

- ➢ Grinding the raw materials into powder,

- Mixing them intimately in predetermined proportions and burning in a large rotary kiln at a temperature of about 1400-1600 ,a temperature range in which the mixture forms calcium silicates, [25, page15]
- The material sinters and partially fuses into clinker. The clinker is cooled and with some gypsum added and ground to a fine powder, the resulting product is called Portland cement (has as many as 1.1×10^{12} particles per kilogram).

There are two cement manufacturing processes: wet and dry process. The only difference between the two processes is, the condition in which mixing and grinding of raw materials are done.

In a ***dry process*** of cement manufacturing, the raw materials are crushed, dried in rotary driers, proportioned, and then ground in ball mills. The resulting powder is then burned in its dry condition in the rotary kiln. This process is quite economical because it requires much less fuel as the materials are already in a dry state [18, page9]. However, the difficulties in the control of dry mixing and blending have made this method of production of Portland cement much less popular than the wet process [2, page36].

The ***wet process*** of cement manufacturing compared to the dry process remained the most widely used for many years. This is because of the possibility of more accurate control in the mixing of raw materials. In this process, the slurry contains 35-50% water so that it consumed much more fuel to expel the water and bring the materials in a dry state (in a powder form) [18, page7].

The clinker formation process has four stages.

Stage 1: Drying and pre-heating, free and chemically-bound water released.

Stage 2: Calcination, which is the stage of CO_2 release in the initial reactions associated with the formation of clinker minerals and the intermediate phase.

Stage 3: Sintering, at this stage calcium silicates and the liquid phase formed.

Stage 4: Kiln internal cooling, crystallization of calcium aluminates, and calcium ferrite occurs at this stage [27, page28].

2.1.2 Water

As the phases in Portland cement must chemically react with water in order to develop strength of paste, mortar, or concrete, water is a key ingredient.

Typically, concrete mixture contains 15 to 25% water by volume of concrete mix.The two roles of water are for hydration and workability. Since concrete is required to be both strong and workable, a careful selection of the w/c ratio and the total amount of water is required when making concrete. Too much water results in the reduction of concrete strength, while too little makes the concrete unworkable.

- Mixing water is the free water in freshly mixed concrete. Its functions are reacting with the cement powder, thus producing hydration products, acting as a lubricant, contributing to the workability of the fresh mixture; and securing the necessary space in the paste for the development of hydration products.
- Curing water is in contact with the concrete for only a relatively short time. Though it may contain more inorganic and organic materials than mixing water, the permissible amounts of the impurities are still restricted [16, page 85].

2.1.3 Aggregate

Aggregates occupy 70 to 80% of the volume of concrete and have a very important role in concrete properties and performance.

2.1.3.1 Effects of aggregates on concrete

- **Fresh concrete**: The behavior of fresh concrete, such as fluidity, cohesiveness, and rheological behavior is largely influenced by the amount, type, surface texture, and gradation of the aggregate. The selection of aggregate has to meet the requirement of the end-use, i.e. the type of structure to be built.
- **Hardened concrete**: Aggregateshave a big impact on stiffness, unit weight, strength, thermal properties, and wear resistance of concrete. Moreover, they have an enormous influence on reducing moisture-related deformations (e.g.shrinkage) of concrete, a fact that makes a pure paste and rich mortars very difficult to work with [22, page3].

2.1.3.2 Classification of aggregates

Aggregates have different categories depending on size, source, and unit weight. In accordance with the size, aggregates can be classified as fine and coarse aggregate

- ***Coarse aggregates****:* Aggregates predominantly retained on No.4 (4.75mm) sieve.
- ***Fine aggregates****:* Aggregates passing through No.4 (4.75mm) sieve and predominately retained on a No.200 (75µm) sieve. The most commonly used fine aggregate is river sand.

According to source aggregates can be classified as;

- ***Natural aggregates*** are aggregates like crushed stone, sand, and gravel, which are taken from natural deposits without changing the nature of production.
- ***Manufactured aggregates*** are a result of products or by-products of industry e.g. blast furnace slag and lightweight aggregate.

In accordance with unit weight, aggregates can be classified as ultra-lightweight, lightweight, normal-weight, and heavy-weight aggregates [16, page23].

2.1.4 Admixtures

"Admixtures are ingredients in concrete other than Portland cement, water, and aggregates that are added to the mixture immediately before or during mixing" [4, page105].

As per ASTM C-494, admixtures can be classified as water-reducing admixtures, retarding admixtures, accelerating admixtures, water-reducing and retarding admixtures, water-reducing and accelerating admixtures, water-reducing, high range admixtures, and water-reducing, high range, and retarding admixtures [32].

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 desired quality of concrete during the stages of mixing, transporting, placing, and curing in adverse weather conditions and to overcome certain emergencies during concreting operations [4, page105].

Water-reducing admixtures

Water-reducing admixtures are typically based on either lignosulfonates, hydroxycarboxylic acids, or hydroxylated polymers. The mechanism of action of these water reducers is similar. In fresh concrete, they will be adsorbed onto the surface of cement particles and then limit the attraction between particles (by van der Waals forces) and reduce the viscosity of the cement paste [23, page1].

The effectiveness of water reducers on concrete depends on different parameters: their chemical composition, cement fineness and composition, concrete temperature, cement content, and the presence of other admixtures**.**Water-reducing admixtures can be used in concrete construction in a number of ways to:

- Reduce the amount of mixing water required to produce concrete of a certain slump,

- Reduce water and cement simultaneously for the same workability and strength
- Reduce cement content, and
- Increase slump [4, page109].

Since low dosage may result in loss of fluidity and overdosage could lead to segregation, bleeding, excessive air entrainment etc. in concrete, the optimum use of admixtures is essential. Hence, it is important to find the optimum dosage of water-reducing admixtures to get the required strength and workability. Recommended dosages can be found on the product data sheets prepared by the manufacturer. But by making trial tests with different dosages of admixtures and different types of cement, the optimum dosage for the desired strength and workability can be found.

An experimental study was performed to develop an optimum dosage of super-plasticizer in concrete to get the specified workability. Four brands of locally available PPC and super-plasticizer belonging to four different families namely Polycarboxylate Ether (PCE), Lignosulphate (LS), Sulfonated Naphthalene Formaldehyde (SNF) and Sulfonated Melamine Formaldehyde (SMF) were used. Two different brands of super-plasticizerswere taken from each family. Finally, it was concluded that, after the saturation point, the increase of super-plasticizer dosage doesn’t show any improvement of workability, and the addition of super-plasticizer beyond this dosage causes segregation.The saturation point is the dosage of super-plasticizer beyond which further addition of SP does not increase spread diameter but result in segregation [29].

2.2Previous researchprojectsontheapplication of Portlandpozzolana cement

Different studies have been done on various applications of Portland pozzolana cement.

In a study by Adisu Fentaw [2014]: *Study on the Uses of Derba Ordinary Portland and Portland Pozzolana Cements for Structural Concrete Production*, PPC and OPC from one selected cement brand were selected and used. The mix proportions for normal, intermediate and high strength concretes were made by keeping every condition the same except varying the amount and type of cement (using lower amount of cement for the mix made with OPC). Compressive strength tests were conducted at 3, 7 and 28-days, and it was concluded that the Portland pozzolana cement cannot produce 28-days concrete compressive strength as high as that of the ordinary Portland cement. It's also concluded that the low pozzolanicity of the natural pumice used in the production of the Portland pozzolana cement should be the reason for the ultimate strength of concretes made of the PPC to be lower than that of the OPC. However, Because of its better imperviousness, concrete made with PPC has higher restriction on the ingression of gases and liquids. Therefore it was concluded as, PPC is preferable to OPC as far as workability, impermeability and resistant to chemical attack of concrete is concerned [2].

Nigus G/Egziabher [2005] studied on *Comparison of Concrete Properties Produced using Muger, Messobo, and Diredawa Cements*. Using three different brands of cement in Ethiopia, mix proportions for normal, intermediate and high strength concretes were made. The concrete mixes were made by keeping every condition the same but varying the cement types (ordinary Portland and Portland pozzolana cement). The result shows that, though the compressive strength difference between concrete made of OPC and PPC shows a decreasing trend with age, Portland pozzolana cement cannot produce a compressive strength as high as that of the ordinary Portland cement. Similarly, the reasons believed to make the ultimate strength of concretes made of Portland pozzolana cement to be lower than that of ordinary Portland cement at the age of three months are;

- The pozzolans used in the production of the Portland pozzolana types of cement are volcanic materials which are less pozzolanic and the ultimate strength achieved from these pozzolans cannot be as high as what could be achieved from active pozzolans and,

- The hydration of C_2S in clinker and the silicate in the pozzolan require long moist curing, but in this research, moist curing was made only for 3 and 7 days [29].

Bhaskar Sangoju, Radhakrishna G. Pillai, Ravindra Gettu, B.H. Bharatkumar and Nagesh R. Iyer studied on Use of Portland Pozzolana Cement to Enhance the Service Life of Reinforced Concrete Exposed to Chloride Attack. Comparison of service life of concretes made with OPC and fly ash based PPC at three water to cement ratios (w/c = 0.57, 0.47 and 0.37) were made. As a result, the estimated service life of concrete made with PPC is found to be at least twice that of corresponding OPC based concrete[34].

Dhanya Sathyan, K B Anand, K M Mini, and Aparna S. [2018] studied on *Optimization of Superplasticizer in Portland Pozzolana Cement Mortar and Concrete.* Four brands of Portland pozzolana cement and super-plasticizer belonging to four different families namely Polycarboxylate Ether, Lignosulphate, Sulfonated Naphthalene Formaldehyde, and Sulfonated Melamine Formaldehyde were used for preparing mortar and concrete. Two different brands of super-plasticizers were taken from each family. Compressive strength tests were conducted at 7 and 28-days and the study concluded that, due to improved compaction obtained in the concrete by the addition of super-plasticizer and improvement in the pore structure, super-plasticized concrete yielded higher compressive strength than the PPC control mixtures. Besides, compressive strength variation is only marginal for concretes made using different families of super-plasticizers, at their optimum dosages [30]. Therefore, instead of using plain PPC, by using PPC and water-reducing admixture,an improved compressive strength of concrete can be achieved.

Inastudy by Rajendra Rajdev, Shalini Yadav, and Rakesh Sakale [2013]: *Comparison between Portland Pozzolana Cement & Processed Fly Ash Blended Ordinary Portland Cement*. A comparison of compressive strength test results between two different procedures for the use of fly ash in the cement industry was made. The first is by adding fly ash to clinker as in the manufacture of Portland pozzolana cement and the second is by blending fly ash with ordinary Portland cement. Compressive strength tests were conducted and compared for both types of cement. As a result, the highest compressive strength test results at 7 and 28-days were achieved by concrete made with PPC. However, for the same target strength (M20), the most economical concrete mix proportion was obtained with a 25% replacement of OPC by fly ash. This could be because the quantity of cement used was reduced. 350kg/m^3 and 253 kg/m^3 of cement were used for a concrete mix made with PPC and OPC+25% fly ash respectively.The study also stated that, if all fly ash generated is used as partial replacement of cement in place of grinding it with clinker, 126 million tons of CO_2 can be prevented to emit in the atmosphere in addition to save a large amount of energy(32).

Summary

Previous studies by different scholars conclude that, at 28-days, concrete made with Portland pozzolan cement cannot give as high compressive strength as concrete made with ordinary Portland cement. As per their results, pumice and volcanic basalt are common types of pozzolans used in Ethiopia.The low pozzolancity of the pozzolan used in the production of PPC is one of the reasons believed to make the ultimate strength of concrete made with PPC to be lower than that of OPC. Besides, PPC is preferable to OPC as far as workability, impermeability and resistant to chemical attack of concrete is concerned. It is also shown that using PPC with water-reducing admixture, improved compressive strength can be achieved. Without improving the compressive strength of concrete by using water-reducing admixture, the PPC may not give the desired compressive strength in 28-days.Therefore, this study is concerned withthe application of Portland pozzolana cementfor structural concrete. Because, as different previous studies done in Ethiopia stated, as compared to OPC, PPC has slower strength development. For that reason, it is not being mostly used for structural concrete. Therefore, the intention of this study is,to show how PPC may be used for structural concrete by using water-reducing admixture and achieve the desired compressive strength at 28-days with additional benefit of cost reduction.

CHAPTER THREE

METHODS AND MATERIALS

3. Introduction

In this chapter, methods used to accomplish the data collection will be discussed. In this research, the data collection was done using a questionnaire, interview, and laboratory examination.

3.1 Survey

Questionnaires were filled and collected in two ways: by interviewing and by distributing the questionnaires to the representatives of consulting firms. In the case of ready-mixed concrete suppliers, since there are around 12 ready-mixed concrete suppliers, the total population was taken for the study and all of the questionnaires were filled by interviewing the representatives of ready-mixed concrete suppliers.

In order to limit the number of consulting firms, category one up to three consultants according to Addis Ababa Construction Bureau were selected for the study.The sample size of consultants was calculated using Slovin’s formula.n = $\frac{N}{1+Ne^2}$where n: is the sample size, N: is the population size, and e: is the error tolerance = 0.05. After sample size was calculated, a random sampling method was used to find consulting firms to be included in the data collection (interview and questionnaire distribution) of this study.

3.2 Experimental program

The laboratory tests were conducted in Addis Ababa Institute of Technology, construction materials laboratory.The laboratory examination involved material characterization, mix proportioning, and after the mix proportioning was done, slump and compressive strength tests were conducted on fresh and hardened concrete respectively. Slump and compressive strength tests were conducted for C-25 and C-30 grades of concrete. Concrete specimens were prepared for concrete mixes made with OPC, PPC and PPC with water-reducing admixture to conduct a compressive strength test.

- **Material characterization**

The following tests were conducted to determine the properties of aggregates to be used as an input for mix proportioning.

- Sieve analysis of fine and coarse aggregate was done as per ASTM C-136, Standard Test Method for Sieve Analsis of Fine and Coarse Aggregates.
- Specific gravity and absorption of coarse and fine aggregate were done as per ASTM C-127, Standard Test Method for Relative Density (Specific Gravity) and Absorption of Coarse Aggregate, and ASTM C-128, Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate respectively.

- **Mix proportioning**

The amount of water, cement, sand, and coarse aggregate to prepare the required concrete mix was done as per ACI 211.1, Standard Practice for Selecting Proportion for Normal, Heavy weight, and Mass Concrete. Since C-25 and C-30 are the concrete grades which are being mostly used for structural concrete, concrete mixes were made for C-25 and C-30 grades. The mixes were made with OPC, PPC, and PPC with water-reducing admixture. The mix proportioning was done to give a slump of 80mm. Laboratory tests were conducted for six trial mixes.

- **Laboratory tests**

    - **Slump test**

In order to make sure that the slump of the concrete mixes were within the required limit, slump tests were conducted as per ASTM C-143, Standard Test Method for Slump of Hydraulic Cement Concrete, for each of the concrete mixes and reported to the nearest 5mm.

- **Compressive strength test**

The compressive strength test result of each concrete sample was determined by testing the cubes in a compression testing machine with rate of loading 0.28 MPa/s. For each mix, the average compressive strength test results of three samples was taken. The concrete specimen codes and descriptions are as shown in Table 3.1.

Table 3.1Designation of concrete specimens

No.	**Specimens code**	**Remarks (concrete mix made with, for concrete grade)**
1	O25	OPC, C-25
2	O30	OPC, C-30
3	P25	PPC, C- 25
4	P30	PPC, C- 30
5	PS25	PPC and 1% water-reducing admixture dosage, C-25
6	PS30	PPC and 1% water-reducing admixture dosage, C-30

3.2.1 Cement

The types of cement used in this research are:

- Ordinary Portland cement (OPC) and
- Portland pozzolana cement (PPC) from the same brand i.e. Dangote cement.

3.2.2 Aggregates

The fine aggregate used was washed river sand. The Ethiopian standard limits the silt content of sand not to exceed 6% because the presence of dust, loam, and clay materials in sand decreases the bond between the materials and decreases the compressive strength of concrete [24]. Silt content of the washed river sand was found to be 3% and this is within the acceptable limit.

The type of coarse aggregate used wascrushed basalt stone with a nominal maximum size of 25mm.

Table 3.2 Gradation of fine aggregate as per ASTM C-33

Sieve size	Weight retained (g)	Percent retained	Percent passing	Cumulative percent retained	Percent passing per ASTM C-33
4.75mm	0	0	100	0	95-100
2.36mm	56	11.2	88.8	11.2	80-100
1.18mm	129	25.9	62.9	37.1	50 -85
600µm	169	33.9	29.1	70.9	25-60
300µm	80	16	13	87	5-30
150µm	48	9.6	3.4	96.6	0-10
Pan	0	3.4	0	-	
Total	**499**			**302.8**	

Fineness modulus=$\frac{\sum Cumulativeretained}{100}=\frac{302.8}{100}$=3.02

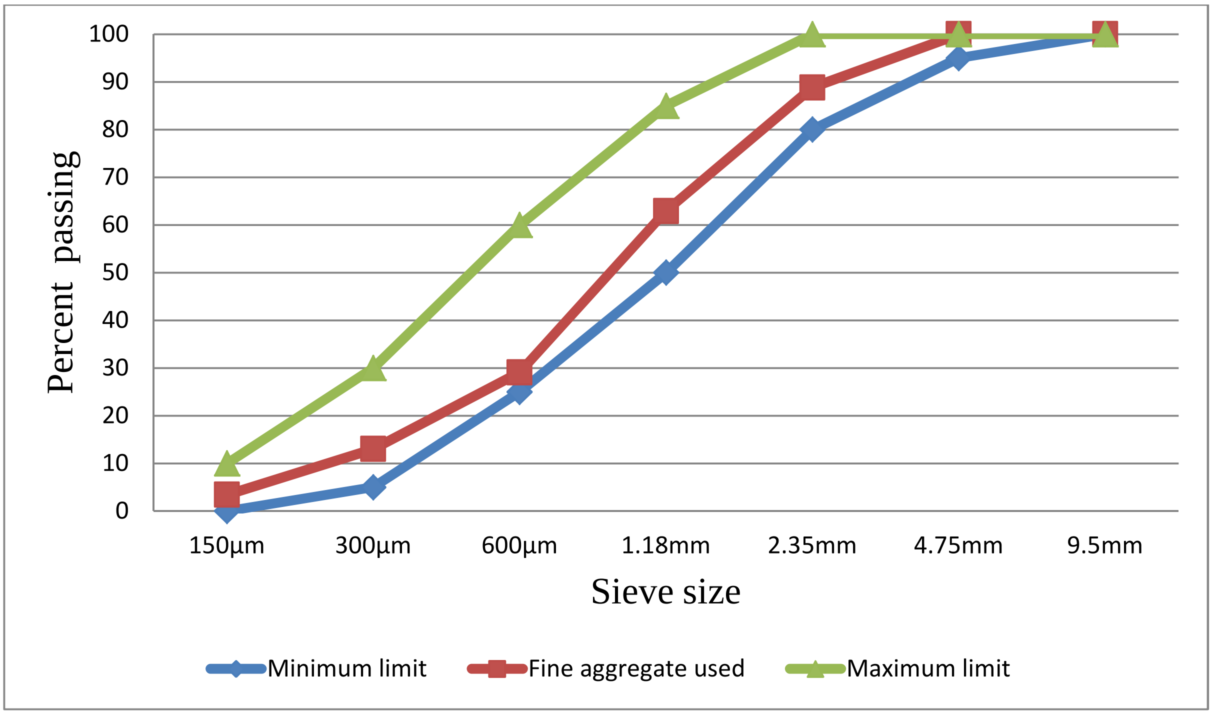

Figure 3.1 Fine aggregate grading curves

Table 3.3 Gradation of coarse aggregate as per ASTM C-33

Sieve size (mm)	Weight retained (g)	Percent retained	Percent passing	Cumulative percent retained	Percent passing (ASTM C-33)
37.5	0	0	100	0	100
25	580	11.6	88.4	11.6	---
19	930	18.6	69.6	30.2	35-70
12.5	1570	31.4	38.4	61.6	---
9.5	1430	28.6	9.8	90.2	0-10
4.75	490	9.8	0	100	0-5
Pan	0	0	0	100	
Total	**5000**	100		**393.6**	

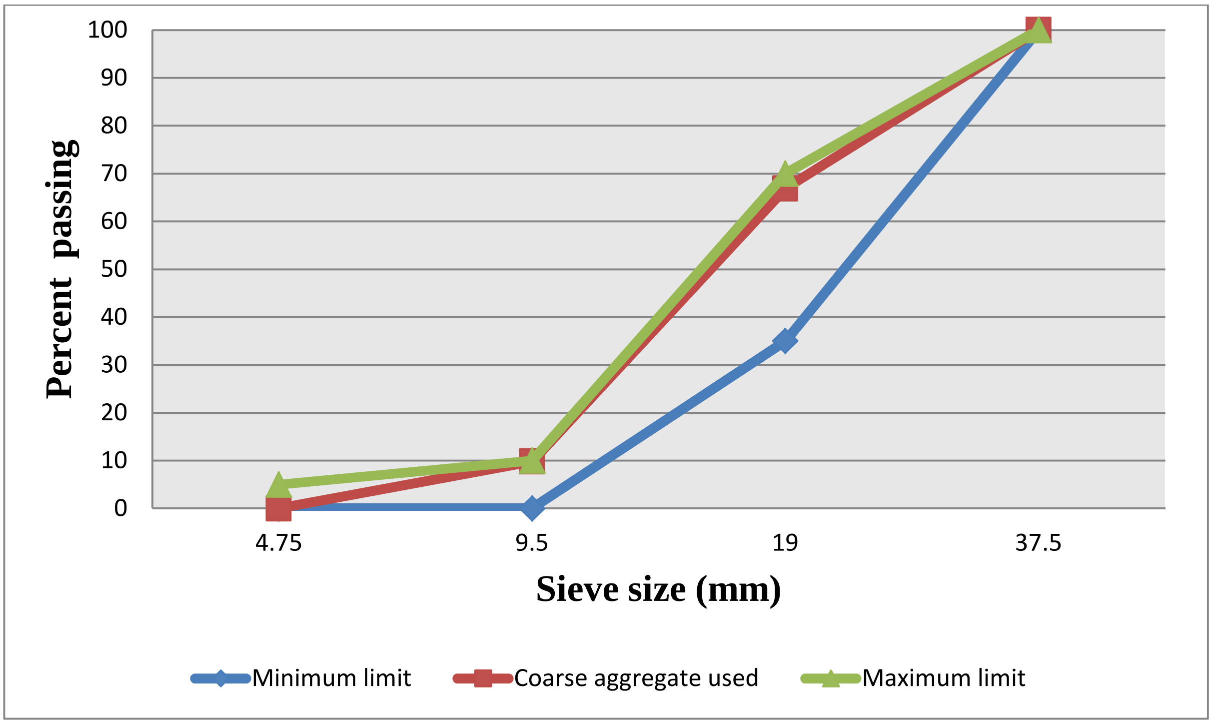

Figure 3.2 Coarse aggregate gradation curves

The unit weight, moisture content, specific gravity, and water absorption capacity of aggregates affect the compressive strength of concrete and these parameters are used for mix proportioning. The test results are summarized as shown in Table3.4.

Table 3.4Summary of test results on fine and coarse aggregate

No.	Test description		Type of aggregate	
			Fine aggregate	Coarse aggregate
1	Unit weight(kg/m^3)	Compacted	1690	1630
		Loose	1610	1470
2	Moisture content (%)		6.6	0.7
3	Absorption capacity (%)		5.0	0.28
4	Specific gravity (Bulk SSD)		2.56	2.8

3.2.3 Water

Tap water of Addis Ababa city was used for mixing and curing the concrete specimens.

3.2.4 Chemical Admixture

The type of admixture used was Sika Plastiment BV-40, water-reducing and retarding admixture, as per ASTM C-494.

3.2.5 Mix Proportioning and Preparation

Mix proportioning was done for concrete grades C-25 and C-30, which are most of the time used for structural concrete.

Table 3.5 Proportion of ingredients per cubic meter of concrete (for C-25)

Ingredients	By Volume (m^3)	By Mass(Kg/ m^3) after batch adjustment
Cement	0.11	345
Coarse aggregate	0.38	1067
Fine aggregate	0.325	834
Water	0.176	176

Table 3.6 Proportion of ingredients per cubic meter of concrete (for C-30)

Ingredients	By Volume (m^3)	By Mass(Kg/m^3) after batch adjustment
Cement	0.12	382
Coarse aggregate	0.38	1067
Fine aggregate	0.31	794
Water	0.177	177

For C-25 and C-30 concrete mixes made with PPC and water-reducer, the mix proportioning is as shown in Table 3.7 below.

Table 3.7 Mix proportioning of concrete mixes made with PPC and water-reducing admixture

Specimen code	Amount of material used per cubic meter(kg/m^3)				(Lt/m^3)
	Cement	Water	Sand	Coarse aggregate	Water reducer
PS25	314	158	885	1067	3.14
PS30	344	159	853	1067	3.44

The water to cement ratio used was 0.56 and 0.51 for C-25 and C-30 respectively. For PS25 and PS30, while doing the mix proportioning, 1% water-reducing admixture dosage was added and 9% water was reduced to improve the compressive strength and similarly 9% cement was reduced.

3.2.5.1 Mixing

The concrete ingredients:fine aggregate, coarse aggregate, and cement were dry mixed for one minute and by adding two third of the total mixing water, mixed for two minutes. Then, the remaining mixing water was added.

3.2.5.2 Specimen Preparation

Three 150 mm cube specimens were prepared for each 7, 14, 28, and 56-days compressive strength tests. Then compaction is done on table vibrator for 30 seconds and 45 seconds for single 150mm cube mold and a couple of 150mm cube molds respectively.

3.2.5.3 Curing

After waiting for 24 hours, hardened specimens were carefully removed from the molds and placed and cured in the water-tank until the testing dates.

3.2.5.4 Testing

For each 7, 14, and 28 and 56-days, specimens were taken out of the water-tank and surface dried using a towel. Then the weight, failure load, and compressive strength of each specimen recorded.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4. Introduction

In this section, the data collected from the survey and laboratory test results are presented, analyzed, and discussed.

One of the objectives of this research is to assess if PPC is currently being used for structural concrete. In order to achieve this objective, questionnaires were designed and as stated in section 1.4, distributed to consulting firmsand also used for interviewing the representatives of ready-mixed concrete suppliers and consulting firms.

4.1 Population size and sample size of the research

The number of consulting firms registered in Addis Ababa Construction Bureau in 2009E.C and are within category one up to three (total population of consulting firms) were found to be 206.The sample size of consultants is calculated using Slovin’s formula with a margin of error of 5% as

$n = \frac{N}{1+Ne^2}$……………………………………..E.q. 4.1

Where, n: is the sample size, N: is the population size, and e: is the error tolerance. Therefore, the sample size is found to be 136. On the other hand, there are around 12 ready-mixed concrete suppliers and 9 of them were found and gave their responses.

4.2 Questionnaire distribution and interviewing

Among randomly selected 136 consulting firms as briefly mentioned in section 1.4, only 116 of them were found by their addresses.Their representatives: structural engineers, managers, office quantity surveyors, site supervisors, and resident engineers have given their responses in the interview and questionnaires.

Around 49% of the questionnaires were filled by interviewing the representatives of the consulting firms and the rest 51% of the questionnaires were distributed in person and via e-mail. And from those questionnaires which are distributed to be filled by the representatives of the firms,76.3% was collected.

For ready-mixed concrete suppliers, 100% of the questionnaires were filled by interviewing the representatives.

4.3 Result and analysis from the responses of consulting firms

Responses from consulting firms were analyzed by counting the frequency of the answers.

As shown in Figure 4.1, the result shows that, only 3.26% of them are using this cement for structural purposes, while the rest 96.74% are mostly using OPC. The reason to prefer OPC over PPC is that it gives the desired strength in 28-days but concrete made with PPC could not achieve the desired compressive strength in 28-days.

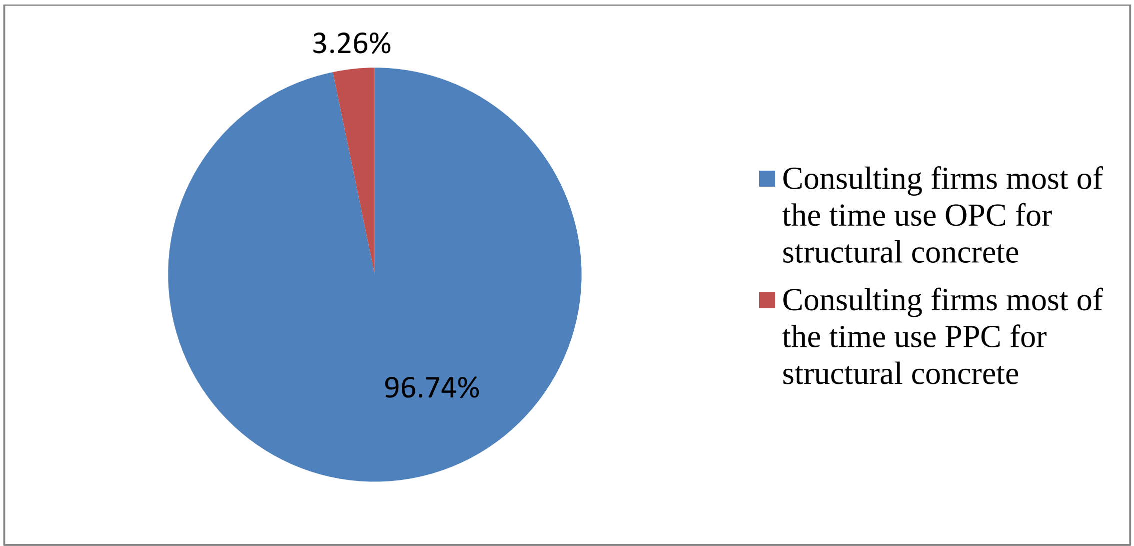

Figure 4.1 Response of consulting firms about the type of cement mostly used

Based on the results of the survey, as shown in Figure 4.2, 32.07% of consulting firms most of the time use C-25 concrete for structural purposes whereas, 67.92% are using both C-25 and C-30 concrete grades.

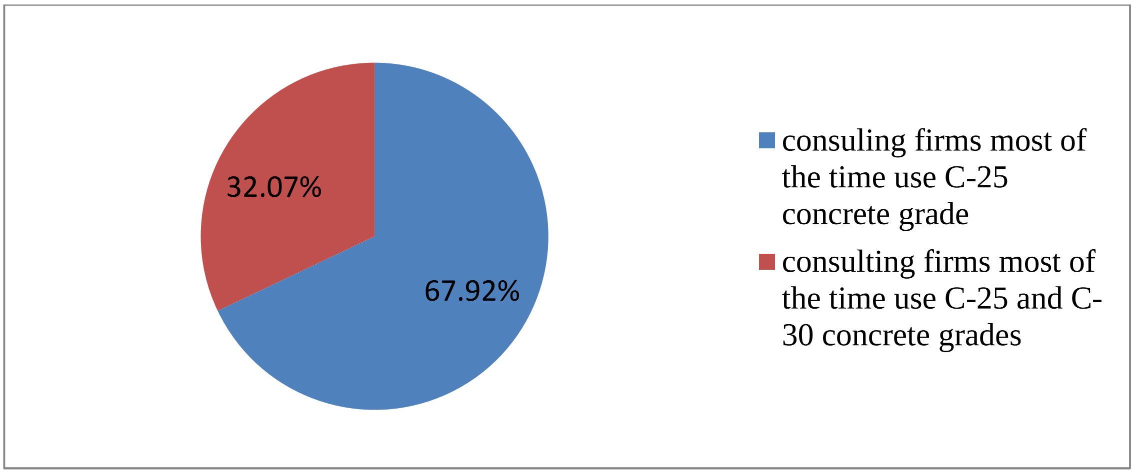

Figure 4.2 Response of consulting firms about the concrete grades mostly used

4.4 Result and analysis from the responses of RMC suppliers

Quality control managers and material engineers have given their responses in the interview and questionnaire. Based on their response, all of them are using OPC. They prefer to use OPC and it is being used for structural concrete purposes. According to their response, the reason to prefer this cement over PPC is, it gives the required strength in 28-days.Therefore, 100% of the ready-mixed concrete suppliers are not most of the time using PPC for structural concrete production. Besides, the concrete grade most of the time used by RMC suppliers is as shown in Figure 4.3. 22.22% of the ready-mixed concrete suppliers are most of the time usingC-25 concrete for a structural concrete while, 77.78% are using both C-25 and C-30 grades of concrete.

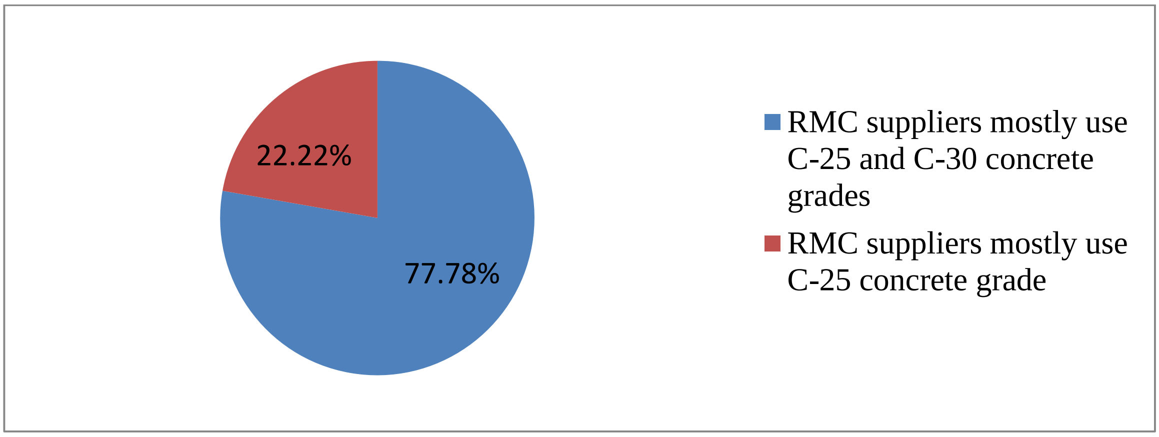

Figure 4.3 Response of RMC suppliers about the concrete grades mostly used

According to the responsesof ready-mixed concrete suppliers and consulting firms, PPC is not being mostly used for structural concrete purposes. It is used for the construction of non-structural elements.The reason for almost all respondents to not use PPC for structural purposes is that it could not give the desired compressive strength in 28-days. On the other hand, the concrete grades mostly used for structural purposes are found to be C-25 and C-30.Therefore, laboratory tests were done for these grades of concrete to determine how to achieve the desired compressive strength in 28-days using PPC and water-reducing admixture.

4.5 Laboratory test results

In this section, the results of the laboratory test and cost comparison of reference and special concrete mixes will be illustrated.

4.5.1 Slump test results

A slump test was conducted for each fresh concrete mix according to ASTM C-143,Standard Test Method for Slump of Hydraulic Cement Concrete at the end of mixing. The results are reported to the nearest of 5 mm as shown in Table 4.1.The required slump limit is 80mm. Therefore, the slump test results are within the required limit.

Table 4.1 Slump test results

Specimen Code	**O25**	**O30**	**P25**	**P30**	**PS25**	**PS30**
Slump(mm)	75	75	75	70	80	80

4.5.2 Compressive strength test results

Compressive strength tests were done for C-25 and C-30. The compressive strength tests were performed on 150mm cube molds. A conversion factor of 1.25 is recommended by EBCS-2 to convert 150mm cube strength to cylindrical strength.[f'c(cylindrical) = f'c(cube)/1.25]. Where: f'c-is specified compressive strength (35). Therefore, in the mix proportioning, the specified cube strength is converted to cylindrical strength.

ACI 301, Specifications for Structural Concrete, gives preconditions for the acceptance of compressive strength of concrete as; “The strength level of concrete will be considered satisfactory when: the averages of all sets of three consecutive compressive strength test results molded and cured in accordance with the requirements of ASTM C-31M equal or exceed fc´ (specified strength), and no individual strength test falls below fc′ by more than 3.5MPa when fc´ is 35MPa or less, or by more than 0.1times fc´ when fc´ is more than 35 MPa” [36, page9]. The average compressive strength test results of reference and special concrete mixes are shown on the tables below. As shown in Table 4.2, the compressive strength results achieved by concrete made with OPC i.e. 25.05 MPa and 34.44 MPa for C-25 and C-30 respectively, are greater than the specified compressive strengths. Therefore, the compressive strength test results at 28-days satisfy the preconditions specified on ACI 301 for acceptance of the compressive strength of concrete.

Table 4.2Compressive strength test results of concrete mix made with OPC

Specimen Code	**Compressive Strength (MPa)**		
	7-days	**14-days**	**28-days**
O25	21.73	**22.34**	**25.05**
O30	26.24	**30.98**	**34.44**

As shown in Table 4.3, compressive strength results achieved by concrete made with PPC and water-reducing admixture i.e. 25.56 and 30.22 for PS25 and PS30 respectively at 28-days are greater than the specified compressive strengths. Therefore, the compressive strengths of concrete made with PPC and water-reducing admixture at 28-days also satisfy the preconditions specified on ACI 301 for acceptance of compressive strength of concrete.

Compressive strength test results of PS25 and PS30 at an early age are also presented in Table 4.3. At 7-days, 70.9% and 68.9% compressive strengths were achieved for PS25 and PS30 respectively. And, at 14-days, the compressive strength achieved by the special concrete mixes (PS25 and PS30) was approximately 90%.Therefore, the early age strengths at 7-days and 14-days are greater than 65% and 90% respectively. Besides, at 56-days, the compressive strengths achieved by PS25 and PS30 show increament from 28-days result by 2.64 Mpa and 2.38 MPa respectively.

Table 4.3 Compressive strength test results of concrete mix made with PPC and water reducing admixture

Specimen code	**Compressive Strength (MPa)**			
	7-days	**14-days**	**28-days**	**56-days**
PS25	17.73	22.48	**25.56**	28.2
PS30	20.67	26.95	**30.22**	32.6

The concrete mix made with plain PPC (PPC with no water-reducing admixture) for both C-25 and C-30 concrete mixes did not achieve the desired compressive strength at 28-days. Therefore, it did not satisfy the preconditions for acceptance of the compressive strength of concrete as specified on ACI 301.

As shown in Figure 4.4, though the compressive strength test results of concrete made with OPC for C-25 concrete grade has a greater result at the early ages (7 and 14-days), for the same concrete grade,the concrete made with PPC and water-reducing admixture achieved almost similar compressive strength at 28-days.

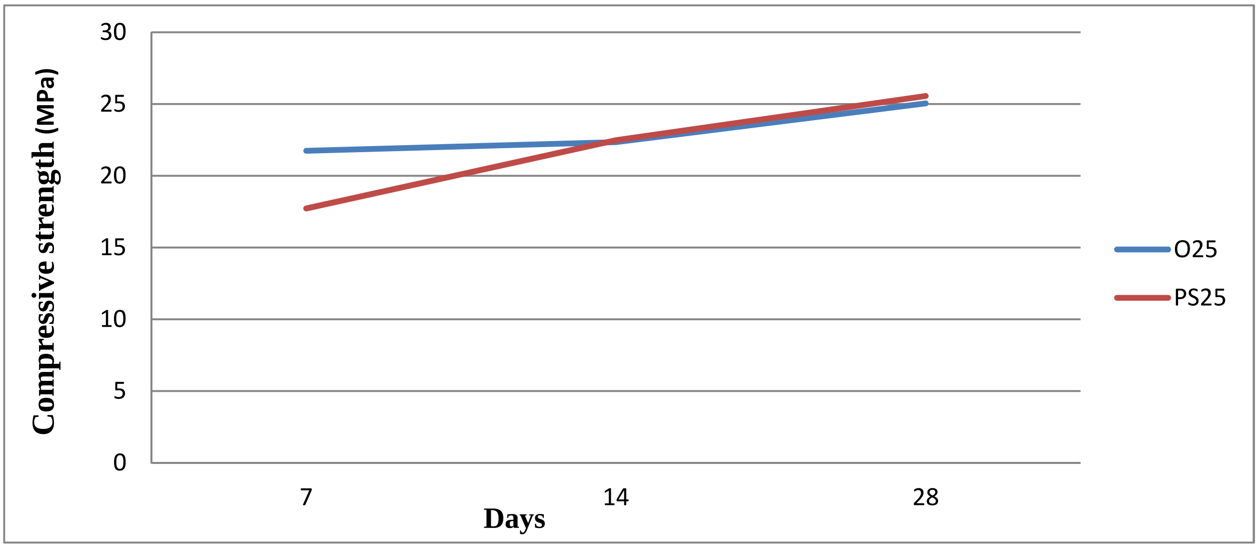

Figure 4.4 Compressive strength test results of C-25 concrete

As shown in Figure 4.5, the compressive strength test results of concrete made with OPC for C-30 concrete grade has a greater result from 7 upto 28-days. However, the compressive strength test results of concrete made with PPC and water- reducing admixture achieved the desired compressive strength at 28- days.

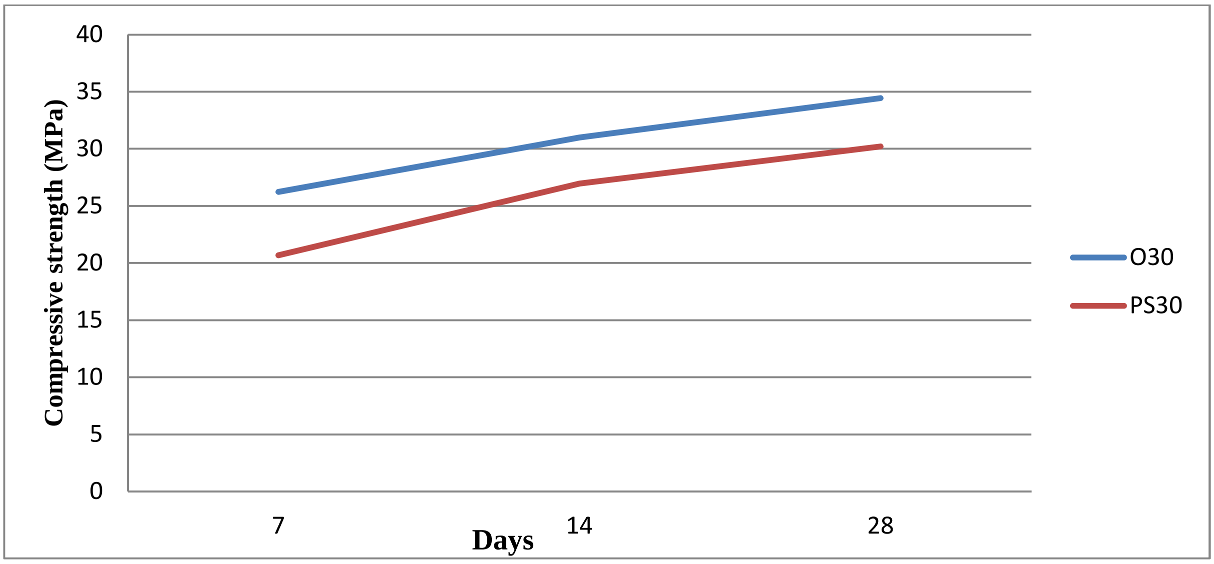

Figure 4.5 Compressive strength test results of C-30 concrete

4.6 Cost Analysis

As shown in Table 4.4 and Table 4.5, cost comparison is made between the concrete mixes made with OPC and the concrete mixes made with PPC and water-reducing admixture.

Compared to the mix made with OPC, the cost of the concrete mix made with PPC water-reducing admixture is decreased by 224 br/m^3 and 259 br/m^3 for C-25 and C-30 respectively. This means, by using concrete mix made with PPC and water-reducing admixture, cost reduction can be achieved without affecting the desired compressive strength.

Note; prices of cements were taken from the factory (price excluding transport cost) in October, 2020.

Table 4.4 Costcomparison between O25 and PS25 [C-25]

`Ingredients	**Unit**	**Price (Birr/Unit)**	**`O25**		**PS25**	
			Quantity	Cost	Quantity	Cost
Fine aggregate	M^3	560	0.325	182	0.345	193.2
Coarse aggregate	M^3	550	0.38	209	0.38	209
Cement (PPC)	Qt	233	--	--	3.14	731.6
Cement (OPC)	Qt	303	3.45	1045.4	--	--
Water reducer	Lt	25	--	--	3.14	78.5
				1436br/m^3		**1212br/m^3**

Table 4.5 Cost comparison between O30 and PS30 [C-30]

`Ingredients	**Unit**	**Price (Birr/Unit)**	**` O30**		**PS30**	
			Quantity	Cost	Quantity	Cost
Fine aggregate	M^3	560	0.31	173.6	0.33	184.6
Coarse aggregate	M^3	550	0.38	209	0.38	209
Cement (PPC)	Qt	233	--	--	3.44	801.5
Cement (OPC)	Qt	303	3.82	1157.5	--	--
Water reducer	Lt	25	--	--	3.44	86
				1540br/m^3		**1281br/m^3**

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

The following conclusions are derived in line with the objective of this research.

1. 96.74% of consultants are most of the time using OPC for structural concrete. Therefore, Portland pozzolana cement is not being mostly used for structural purposes. The reason to prefer OPC over PPC is that it gives the desired compressive strength in 28-days.
2. C-25 and C-30 are the most widely used concrete grades for structural concrete.
3. Compared to the concrete mix made with OPC, using PPC and water-reducing admixture, 224 br/$m^{3,}$ and 259 br/m^3 can be saved for C-25 and C-30 concretes respectively.
4. For both C-25 and C-30, using 9% water and PPC reduction and 1% water reducing admixture dosage, the desired compressive strength can be achievedat 28-days.
5. As the desired 28-days compressive strength requirements are satisfied without affecting the desired compressive strength and slump of concrete and with the additional benefit of cost reduction, it is advantageous to use PPC for structural concrete.

Recommendations for further study

Below are topics which, doing further research would be advantageous.

- Cost optimization of concrete mixtures made with PPC and water-reducers
- Laboratory tests on durability of concrete made with OPC versus PPC and water-reducer

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APPENDIX – A

The questionnaire prepared for consulting firms

Dear respondent

This brief survey is helpful for a research I'm doing for a Masters program in Addis Ababa University. Your response will only be used for educational purpose. Besides, it's required to be in reference to a current construction project.

Thank you for your time and willingness to help.

Questions

Please note that, for those questions with multiple choices, you can have more than one answer. Place an "X" mark in the box of your answer.

1. Are you working for contractor or consultant?

□ Contractor □ Consultant

2. What is your position in the company?

____

3. Which type of cement is **mostly** used in construction projects that you are involved? □Ordinary Portland cement (OPC) □Portland Pozzolan cement (PPC) □Portland lime stone cement (PLC)

4. If your answer for question 3 is OPC, for what application is it being used?

□ Structural concrete

□Beam

□Column

□Slab

□Shear wall

□Footing

□ Non structural application

□Block work

□Plastering

□Other____________________

5. What is the reason for choosing OPC?

____

____

____.

6. If your answer for question 3 is PPC, for what application is it being used?

□ Structural concrete

□Beam

□Column

□Slab

□Shear wall

□Footing

□ Non structural application

□Block work

□Plastering

□Other____________________

7. If your answer for question 6 is in category non structural application, what is the reason to choosePPC for this purpose?____

____

____

8. Which compressive strength is **mostly** used by the construction company for structural concrete production?

□C-25 □C-30 □C-40 □Other_______

Thank you for sharing your thought!

APPENDIX – B

The questionnaire prepared for ready mix concrete suppliers

Dear respondent

This brief survey is helpful for a research I'm doing for a Masters program in Addis Ababa University. Your response will only be used for educational purpose. Besides, it's required to be in reference to the current concrete production.

Thank you for your time and willingness to help.

Questions

Please note that, for those questions with multiple choices, you can have more than one answer. Place an "X" mark in the box of your answer.

1. What is your position in the company?

____

2. Which type of cement is **mostly** used by the company for concrete production?

☐Ordinary Portland cement (OPC) ☐Portland Pozzolan cement (PPC) ☐Portland lime stone cement (PLC)

3. If your answer for question 2 is OPC, for what application is it being used?

☐ Structural concrete

☐Beam

☐Column

☐Slab

☐Shear wall

☐Footing

☐ Non structural application

☐Block work

☐Plastering

☐Other____________________

4. What is the reason for choosing OPC?

____

____

____.

5. If the answer for question 2 is PPC, for what application is it being used?

☐ Structural concrete

☐Beam

☐Column

☐Slab

☐Shear wall

☐Footing

☐ Non structural application

☐Block work

☐Plastering

☐Other____________________

6. If your answer for question 5 is in category non structural application, what is the reason to choose PPC for this purpose?____

____

____

7. Which compressive strength is **mostly** used by the company for structural concrete production?

☐C-25 ☐C-30 ☐C-40 ☐Other__________________________

Thank you for sharing your thought!

APPENDIX – C

7 and 28-day compressive strength of concrete specimens made with OPC

Specimen code	Specimen no	Dimensions (m)			Weight(kg)	Failure load (KN)	7days compressive strength(Mpa)
		L	W	H			
O25	1	0.15	0.15	0.15	7.89	493.3	21.93
	2	0.15	0.15	0.15	7.87	487.9	21.69
	3	0.15	0.15	0.15	7.87	485.5	21.58
	Mean					**488.9**	**21.73**
O30	1	0.15	0.15	0.15	8.03	570.2	25.34
	2	0.15	0.15	0.15	7.97	591	26.26
	3	0.15	0.15	0.15	8.03	610.1	27.11
	Mean					**590.43**	**26.24**

Specimen code	Specimen no	Dimensions (m)			Weight (kg)	Failure load (KN)	28days compressive strength(Mpa)
		L	W	H			
O25	1	0.15	0.15	0.15	7.935	634.5	28.28
	2	0.15	0.15	0.15	8.14	560.1	25.96
	3	0.15	0.15	0.15	8.035	477.2	21.27
	Mean					**557.26**	**25.17**
O30	1	0.15	0.15	0.15	8	789.7	35.1
	2	0.15	0.15	0.15	7.97	781	34.71
	3	0.15	0.15	0.15	8.01	753.7	33.5
	Mean					**774.8**	**34.44**

APPENDIX - D

7 and 14-day compressive strength of concrete specimens for a special mix

Specimen code	Specimen no	Dimensions (m)			Weight (kg)	Failure load (KN)	7days compressive strength(Mpa)
		L	W	H			
PS25	1	0.15	0.15	0.15	7.75	467.4	20.77
	2	0.15	0.15	0.15	7.77	388.4	17.26
	3	0.15	0.15	0.15	7.96	340.8	15.15
					Mean	**398.86**	**17.73**
PS30	1	0.15	0.15	0.15	7.74	457.2	20.32
	2	0.15	0.15	0.15	7.81	487.5	21.67
	3	0.15	0.15	0.15	7.79	450.9	20.04
					Mean	**465.2**	**20.67**
Specimen code	**Specimen no**	**Dimensions (m)**			**Weight(kg)**	**Failure load (KN)**	**14 days compressive strength(Mpa)**
		L	**W**	**H**			
PS25	1	0.15	0.15	0.15	8.01	490	21.06
	2	0.15	0.15	0.15	7.75	532.29	23.65
	3	0.15	0.15	0.15	7.73	511.3	22.73
					Mean	**511.2**	**22.48**
PS30	1	0.15	0.15	0.15	8	594.14	26.4
	2	0.15	0.15	0.15	7.9	610.1	27.5
					Mean	**602.12**	**26.95**

APPENDIX - E

28 and 56-day compressive strength of concrete specimens made for the special mix

Specimen code	Specimen no	Dimensions (m)			Weight (kg)	Failure load (KN)	28days compressive strength(Mpa)
		L	W	H			
PS25	1	0.15	0.15	0.15	7.77	547.6	24.34
	2	0.15	0.15	0.15	7.83	593.6	26.39
	3	0.15	0.15	0.15	7.78	584.2	25.96
					Mean	**575.13**	**25.56**
PS30	1	0.15	0.15	0.15	7.89	690.6	30.69
	2	0.15	0.15	0.15	7.86	669.65	29.76
	3	0.15	0.15	0.15	7.87	679.67	30.21
					Mean	**679.97**	**30.22**

Specimen code	Specimen no	Dimensions (m)			Weight (kg)	Failure load (KN)	56days compressive strength(Mpa)
		L	W	H			
PS25	1	0.15	0.15	0.15	7.84	619.9	27.55
	2	0.15	0.15	0.15	7.84	648.7	28.83
	3	0.15	0.15	0.15	7.9	636.6	28.29
					Mean	**635.07**	**28.22**
PS30	1	0.15	0.15	0.15	7.87	740.4	32.91
	2	0.15	0.15	0.15	7.85	726.5	32.29
					Mean	**733.45**	**32.6**

APPENDIX –F

Photos

F-1 Concrete specimens in a moldfor special C-25 and C-30 concrete mixes

F-2 Curing specimens for reference and special C-25 and C-30 concrete mixes

F-3 Weighing concrete specimens

F-4 Sample concrete of C-25 (OPC), compressive strength test at 7 days

APPENDIX - G

Consulting firms and ready-mixed concrete suppliers which gave their response

Consulting firms

1. NET CONSULT CONSULTING ENGINEERS & ARCHITECTS P.L.C
2. YTH ARCHITECTS
3. ICON ENGINEERING
4. BEACON CON ARCH& ENG PLC
5. SABAWIYAN CON ARCH &ENG
6. YEMA ARCHITECTS
7. MH ENGINEERING PLC
8. GOGOT CONSULTING
9. BEST CONSULTING
10. LIFE CONSULT PLC
11. AFRO DESIGN AND CONSULTING
12. RAEY CONSULTING
13. MOGES DESTA CONSULTING
14. SISAY AMBESOM CONSULTING
15. SALEM ARCHITECTS
16. AXIOM CONSULTING
17. CMC CONSULTANT
18. MEEZAR CONSULTING
19. MGM CONSULTING
20. IMAGE CONSULTING
21. TELDA CONSULTING
22. ASEFA CONSULTING
23. BEYENE BELAY
24. EES ENGINEERING
25. KENMOS CONSILTING
26. YIRGALEM ARCHITECTS
27. BECON CONSULTING
28. YEMSRACH HAILU CONSULTING
29. ABNET HAILU CONSULTING
30. EDGE CONSULTING
31. SIGNATURE CONSULTING
32. NIAT ENGINEERING PLC
33. PACE CONSULTING
34. WESSEN ARCHITECTS
35. MUBKA CONSULTING
36. SILESHI CONSULT PLC
37. LAWE BIRHANU
38. NARGA CONSULTING

39. TESFAYE ADMASIE
40. METAFERIA CON
41. WECON CONSULTING
42. GSB ARCH & ENG PLC
43. SOUND ENGINEERING
44. PLANET CONSULTANCY
45. BKW CONSULTING
46. ARCON DESIGN
47. SABA ENGINEERING
48. LYDA CONSULTING
49. JEWAD ABDELLA
50. BRAVE CONSULTIANTS
51. ALERT ENG PLC
52. ROBSET CON ARCH
53. YEHA ARCHITECTS
54. TEWODROS TAGENE
55. NYS CONSULTING ENG
56. OMEGA CONSULTING ENG
57. ACUTE ENG PLC
58. NUR CONSULTING
59. HILAWE ABRAHAM
60. BST CONSULTING
61. RAHEL SHAWOL CONSULTING
62. TOWERS CONSULT
63. INTELLECTUALS DESIG GROUP
64. ATCON ENG & ARCH
65. STUDIO GP COSULTANTS P.L.C
66. PURE COSULTING
67. EYOB KINFE CONSULTING
68. NOMY ENGINEERING P.L.C
69. MEIGHT CONSULTING
70. ALULA TSHAY
71. VERTUAL CONSULTING
72. ASSOCIATED CONSULTING
73. GET CONSULT P.L.C
74. YONAGU ENGINEERING P.L.C
75. SKYLINE COvN ARCH& ENG P.L.C
76. EMH CONSULTING ARCH &ENG P.L.C
77. DUNIYA CON ARCHI&ENG PLC
78. HITCON ENGINEERING P.L.C
79. LEHULUM CONSULTING P.L.C
80. TYES ARCHITECT
81. ALFA CON ARHI& ENG
82. ADERA ENGINEERING

83. BLACK STUDIO CON AR& ENG
84. AZAD DESIGN
85. JIFFTAD CONSULTING
86. SB CONSULT
87. MAE CONSULTING
88. S 7 ARCHITECTS
89. ATM DESIGNERS P.L.C
90. GT CONSULTING ENGINEERS
91. NYS CONSULTING ENG
92. YERER ENG P.L.C
93. MAE CONSULTING
94. HITEK CONSULT
95. KZH ARCH & ENG
96. GONDWANA ENG P.L.C
97. OTT ARCHTECTS
98. BELES CONSULTING
99. TDO CONSULTING
100. KEEN CONSULTANTS
101. BKW CONSULTING
102. BET ARCHITECTS P.L.C

Ready-mixed concrete suppliers

1. ASER CONSTRUCTION
2. ACCURATE CONCRETE SUPPLIERS
3. DEFENCE CONSTRUCTION
4. MIDROC CONSTRUCTION
5. DUDGA CONSTRUCTION
6. BAMACON CONSTRUCTION COMPANY
7. NATIONAL READY MIX CONSDTRUCTION P.L.C
8. MEPO CONCRETE SUPPLIERS
9. OVID CONSTRUCTION P.L.C

BUILDING TRUST

PRODUCT DATA SHEET

Sika® Plastiment® BV-40

WATER REDUCING ADMIXTURE FOR CONCRETE

DESCRIPTION

Sika® Plastiment® BV-40 is a plasticiser for concrete and mortar based on modified lignosulfonates.

USES

Sika® Plastiment® BV-40 is especially suitable for production of ready mixed and site batched concrete with normal transportation times and workability requirements, high water reduction and improved flow characteristics. Sika® Plastiment® BV-40 is recommended for the following:
- Concrete with S3-S4 class consistency
- Concrete with medium water reduction (up to 10 %)
- Concrete with reduced amount of fines or difficult aggregates
- Concrete with difficult placing conditions
- Concrete with ordinery transport distances

CHARACTERISTICS / ADVANTAGES

Sika® Plastiment® BV-40 is a powerful plasticiser which acts through several different mechanisms including surface adsorption separating the cementitious binder particles due to the electrokinetic potential. The following advantageous properties are achieved:
- Superior plasticising effect, resulting in improved flow, placing and compaction characteristics
- Keeps extended workability time with many difficult cements despite water reduction
- Water reduction, resulting in improved density, higher strength and reduced permeability
- Reduced tendency to shrinkage and creep
- Reduced carbonation of the concrete
- Improved cohesion of the concrete

Sika® Plastiment® BV-40 does not contain chlorides or any other ingredients which promote corrosion of steel. It is therefore suitable for use in reinforced and prestressed concrete structures.

APPROVALS / CERTIFICATES

Complies to EN 934-2 Table 2.

PRODUCT INFORMATION

Composition	Aqueous solution of modified lignosulfonates
Packaging	▪ 1000 litres IBC ▪ 200 litres drum ▪ 20 and 25 litres pails
Appearance / Colour	Brown liquid
Shelf life	36 months from date of production if stored properly in undamaged, unopened, originally sealed packaging.
Storage conditions	Storage at temperatures between +5°C and +30°C. Protect from direct sunlight, frost and contamination.
Density	1.19 ± 0.015
pH-Value	7.7 ± 1

Total Chloride Ion Content	≤0.1 %
Equivalent Sodium Oxide	≤ 6.0 %

TECHNICAL INFORMATION

Concreting Guidance	The standard rules of good concreting practice, concerning production and placing, are to be followed. Fresh concrete must be cured properly and curing applied as early as possible. Laboratory trials shall be carried out before concreting on site, especially when using a new mix design or producing with new concrete components.

APPLICATION INFORMATION

Recommended Dosage	0.2- 1.5% by weight of cement. When accidental overdosing occurs, this will have the effect of extending the setting time. During this period, the concrete must be kept moist in order to prevent premature drying out.
Compatibility	Sika® Plastiment® BV-40 may be combined with many other Sika products. Important: Always conduct trials before combining products in specific mixes and contact Sika Technical Service for more information and advice.
Dispensing	Sika® Plastiment® BV-40 is added to the gauging water or added with it into the concrete mixer. To take advantage of the workability enhancing ability, a wet mixing time, which is depending on the mixing conditions and mixer performance, of at least 60 seconds is recommended. To avoid excess water in the concrete, the final dosage must begin only after 2/3 of the wet mixing time.
Restrictions	Sika® Plastiment® BV-40 shall not be added to dry cement.

IMPORTANT CONSIDERATIONS

For storage in tanks always use cleaned tanks and clean and disinfect them minimum once a year. If frozen, Sika® Plastiment® BV-40 may be used after thawing slowly at room temperature following intensive remix. Retarding according to dosage. Excessive water addition or overdosing may cause bleeding or segregation. Formwork pressure: due to plasticising effect and long opentime concretes with Sika® Plastiment® BV-40 can cause extended formwork pressure. Preliminary trials are a must.

BASIS OF PRODUCT DATA

All technical data stated in this Data Sheet are based on laboratory tests. Actual measured data may vary due to circumstances beyond our control.

LOCAL RESTRICTIONS

Note that as a result of specific local regulations the declared data and recommended uses for this product may vary from country to country. Consult the local Product Data Sheet for the exact product data and uses.

ECOLOGY, HEALTH AND SAFETY

For information and advice on the safe handling, storage and disposal of chemical products, users shall refer to the most recent Safety Data Sheet (SDS) containing physical, ecological, toxicological and other safety-related data.

LEGAL NOTES

The information, and, in particular, the recommendations relating to the application and end-use of Sika products, are given in good faith based on Sika's current knowledge and experience of the products when properly stored, handled and applied under normal conditions in accordance with Sika's recommendations. In practice, the differences in materials, substrates and actual site conditions are such that no warranty in respect of merchantability or of fitness for a particular purpose, nor any liability arising out of any legal relationship whatsoever, can be inferred either from this information, or from any written recommendations, or from any other advice offered. The user of the product must test the product's suitability for the intended application and purpose. Sika reserves the right to change the properties of its products. The proprietary rights of third parties must be observed. All orders are accepted subject to our current terms of sale and delivery. Users must always refer to the most recent issue of the local Product Data Sheet for the product concerned, copies of which will be supplied on request.

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