



**ADDIS ABABA UNIVERSITY SCHOOL OF GRADUATE  
STUDIES SCHOOL OF CIVIL AND ENVIRONMENTAL  
ENGINEERING**

**STUDY ON THE USES OF DERBA ORDINARY  
PORTLAND AND PORTLAND POZZOLANA CEMENTS  
FOR STRUCTURAL CONCRETE PRODUCTION**

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**Study on the Uses of Derba Ordinary Portland and  
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Production**

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## ABBREVIATIONS

AAU -----	Addis Ababa University
ACI -----	American Concrete Institute
ASTM -----	American Society for Testing and Materials
BIS -----	Bureau of Indian Standard
DOE -----	Department of Environment
ERA -----	Ethiopian Roads Authority
ES -----	Ethiopian Standard
ESIA -----	Environmental and Social Impact Assessment
ESMP -----	Environmental and Social Management Plan
ESMS -----	Environmental and Social Management System
IFC -----	International Finance Corporation
ISO -----	International Standards Organization
OHSAS-----	Occupational Health and Safety Assessment Series
OSHA-----	Occupational Safety and Health Administration
PS-----	--Performance Standards
RAP-----	Resettlement Action Plan
RCC -----	Reinforced Cement Concrete
SSD-----	Saturated Surface Dry
TOC-----	--Total Organic Carbon
UHPC-----	--Ultra High Performance Concrete
WHO-----	World Health Organization

## ABSTRACT

By varying the relative proportions of the essential compounds and fineness to which the cement is ground and/or by incorporating pozzolanic materials, it is possible to produce different Portland cement types; and these proportions should be known by the customers. However, almost all the cement factories of Ethiopia are not willing to disclose their manuals and chemical composition of the cements. And even most of the consultants who design structures are simply specifying the ingredients of concrete without enough description of type, reasonable content, and relations with other factors which have direct effect to the hydrolysis reaction of the cements. These and others are costing the country negatively. Therefore this research focuses on the study of the uses of Debra ordinary Portland and Portland pozzolana cements for structural concrete production from the production process of the cements to the final results and their focus to the environment.

To achieve the final output of this research, the cement factory was visited and test results of Derba OPC and PPC were collected from the factory. Then the chemical and physical properties of these cements were analyzed and the cement production process of the factory is also illustrated. Furthermore, ten mix proportions for Normal, Intermediate and High Strength Concretes were conducted in laboratory. In each class of concrete, concreting was made keeping every condition the same except varying the cement amount per trial mixes of both the cements; hence, all attained concrete properties of each class are mainly attributable to the cement's properties; as all things including material properties and gradations are carefully done.

The analyzed cement test results together with literature survey on effect of cement in concrete properties are used to relate with the progress of concrete compressive strength results. The laboratory conducted compressive strength test results are also narrative to the fineness, lime concentration and particle size distribution of the cements.

As shown on the analysis part, the expected concrete strength proposed using the cement test results analysis has turned out to be similar with the laboratory compressive strength test results. In fact, this has created strong confidence with regard to the other concrete properties proposed using the cement test results analysis.

Observation on the test results of this research indicates that for the mix proportions and curing conditions made in this study, at all ages and classes of concrete, Derba OPC has produced high compressive strength concrete, using as much minimum cement as possible. For concretes made

of this cement, as the strength class increases the percentage increment of compressive strengths at 3<sup>rd</sup> and 7<sup>th</sup> days were increased from 46.99% for C-25 to 73.25% for C-90 (101.5MPa) and from 63.37% for C-25 to 86.19% for C-90 respectively. And for concretes made of Derba PPC, as the strength class increases the percentage increment of compressive strengths at 3<sup>rd</sup> and 7<sup>th</sup> days were also increased; i.e. from 41.62% for C-25 to 57.81% for C-70 and from 67.57% for C-25 to 82.09% for C-70 respectively. In doing this, I have found that the mix proportions to produce C-90 using OPC was equivalent to C-70 for PPC; and is therefore hard to produce concrete compressive strength of above C-70 using Derba PPC, but was possible to achieve up to 80.5MPa using it.

Therefore, the PPC cannot produce a 28<sup>th</sup> day concrete compressive strength as high as that of the OPC. The low pozzolanicity of the natural pumice used in production of the PPC should be the reason for the ultimate strength of concretes made of the PPC to be lower than that of the OPC.

Finally, following an in-depth multidimensional analysis of the title, I have recommended potential counter measures to ensure sustainable cement production and development in the construction industry of Ethiopia.

*Key words: Cement, Chemical Composition, Compressive Strength, Concrete, Derba OPC, Derba PPC, Particle Size Distribution.*

# CHAPTER ONE

## INTRODUCTION, OBJECTIVES AND SCOPE OF THE RESEARCH

### 1.1 INTRODUCTION

Concrete, the oldest and the most widely used construction material in the construction of civil engineering structures, is a composite material that consists of essentially cements, aggregate and water. Besides, chemical admixtures are essential when special properties are desired. For instance, super plasticizer is mandatory in the production of high strength concrete where the water/cement ratio is less than 0.4.

Concrete is made to possess different properties by adjusting the proportions and varying the properties of the concrete making materials. Cement being the main constituent of concrete, its properties affects the properties of concrete the most.

By varying the relative proportions of the essential compounds and fineness to which the cement is ground and/or by incorporating pozzolanic materials, it is possible to produce different Portland cement types. Accordingly, in our country there are two cement types; namely: Portland Pozzolana Cement (PPC) and Ordinary Portland cement (OPC); and recently, Messebo and Muger Cement Factory have started to produce a 3<sup>rd</sup> cement type called Portland Limestone Cement (PLC).

Depending on the oxide composition of the raw materials and homogenizing them, degree of fineness in grinding the clinker and particle size distribution of the cements even ordinary Portland cement might vary both in chemical composition and fineness from one manufacturing place to another. Consequently the rate of strength development as well as the ultimate strength may be affected [1]. As a result, the research is planned to study the cement types produced at one of the cement factories of Ethiopia called Derba Cement Factory.

Concrete can be made to possess different properties that comprise strength, elasticity, water tightness, durability and the likes. Concrete strength comprises compressive, tensile and shear strengths; the elasticity stands for modulus of elasticity and creep; and durability of concrete is the ability of concrete to maintain its quality throughout its designed service life.

Since the primary function, practically, of all structures is to carry loads or resist applied forces of whatever nature, concrete used for such purposes must have strength. Hence, although in some cases other characteristics may be more important, the strength of concrete is commonly considered as its most valuable property. Furthermore, strength usually gives an overall picture of the quality of concrete, and it is considered as good index whether direct or inverse, of most of the other properties[1]. Thus, in this research the laboratory tests will be made on compressive strength of concretes made of the two cements so that early and ultimate strength developments for various strength classes will be studied.

High-early-strength concrete, also called fast-track concrete, achieves its specified strength at an earlier age than normal concrete. High-early-strength concrete is used for pre stressed concrete to allow for early stressing; precast concrete for rapid production of elements; high-speed cast-in situ construction; rapid form reuse; cold-weather construction; rapid repair of pavements to reduce traffic downtime; fast-track paving; and several other uses [2].

The primary difference between high-strength concrete and normal-strength concrete relates to the compressive strength that refers to the maximum resistance of a concrete sample to applied pressure. However, there is no precise point of separation between high-strength concrete and normal-strength concrete, but standards like the American Concrete Institute defines high strength concrete as concrete with a cylinder compressive strength greater than 41 MPa (C-50 in Cubic Compressive Strength).

In this thesis, however, such a narrow difference in strength will not be entertained to differentiate normal and high strength concrete. Thus, intermediate strength concrete is going to be introduced between high and normal strength concrete. Thus, by the future context of this paper concrete with compressive strength up to 40 MPa will be considered as normal strength, between 40 and 60 MPa as intermediate and above 60MPa as high strength concrete; and/ or high performance concrete.

Producing high-performance concrete is nothing but knowing what factors affect compressive strength and manipulating those factors to achieve the required strength; nowadays, the world is familiarized with the production of Ultra High Performance Concrete (UHPC) up to 200MPa.

High-performance concrete is specified where reduced weight is important, where architectural considerations call for small support elements or wider space between columns. Carrying loads more efficiently than normal-strength concrete, high-performance concrete also reduces the total amount of material placed and lowers the overall cost of the structure [3].

In practical concrete mixture, the overall properties of the principal components are controlled by the requirements:

- 1) When freshly mixed, the mass be workable or place able.
- 2) When hardened, the mass possesses strength and durability adequate to the purpose it is intended, and
- 3) Cost of the final product be a minimum consistent with acceptable quality

To achieve these requirements, most countries have developed their own mixing proportion standards. However, we don't have our own mixing standard except the traditional volume basis mix proportioning ratios.

In the developed world, it is a usual practice for cement factories to conduct a series of tests on their products and publish the result so that the parties in the construction industry know the merits and demerits of their products. Besides, there are professional associations that undergo researches and prepare standard specifications. However, this is not the custom in our country.

Hence, the parties in the construction industry in general and Contractors and Consultants in particular barely have the desired information about the cements produced in our country. This is, however, of paramount importance in selecting the appropriate cement in the production of concrete at different conditions and in the preparation of material specifications.

As a result, most Contractors and supervisors especially at the lower scale use the traditional volume basis mix proportioning ratios which dictates the mix proportioning ratios of cement, sand and aggregate without mentioning anything about the cement and the large scale ones use other countries' mix proportion standards which are designed based on their own prevailing conditions. For instance, different standards provide different grading limits of aggregate which depend on the fulfillment of the grading requirements but using the more abundant fine aggregate as core of the grading limits determination [4]. Besides, the British and American standards, the commonly used mix proportioning standards in our country, don't accommodate

Portland pozzolana cement. As a result, what is economical to one country may not be true for another country. Hence, both ways of proportioning practiced in this country are problematic to achieve concrete with the above mentioned requirements.

This research by no means can provide all the required information to prepare mix proportioning standard, but it provides important information on the locally produced Derba PPC and OPC cements although it is not the only cement producer of the country; but similar studies should be done to cover all the products; so that Contractors and Consultants can use these information in selecting the appropriate cement for the desired concrete properties. Besides, one of the problems in our country to undertake researches is scarcity of and/or access to data. In this research test results of the cements under study and compressive strength of more than 90 concrete cube samples produced using these cements in production of concrete strength ranging from normal to high are made. Therefore, these data should be believed to be invaluable resource for practitioners who are interested in making further researches relevant to Derba Cements.

To make the study more comprehensive, visits are made to the cement factory and test result data's of both cements are collected in addition to laboratory works conducted on the compressive strength of concretes in the laboratories of AAU.

In addition to all these, literature review on properties of concrete and its constituents, Mix proportioning for the different grades of concrete, material properties tests, test results and their analyses and discussions, conclusions and recommendations are finally Compiled and related to the main objective of the thesis.

## **1.2 OBJECTIVES**

The general objective of this study is to study the cement product and its production process of Derba Cement Factory with a special emphasis to its property as the ingredient of structural concrete in applying to the construction industry of the country with regard to quality, environment and minimization of structural cross sections.

The specific objectives of the thesis is, therefore,

- To know the chemical composition of the cement;
- To study the production process of the factory and its care to the environment;

- To prepare sufficient amount of trial mixes by taking the samples from both cements and therefore to know the compressive strength results at 3<sup>rd</sup>, 7<sup>th</sup> and 28<sup>th</sup> days;
- To know the physical and chemical properties of the cements and to relate with their products;
- And finally, to recommend potential counter measures to ensure sustainable cement production and development in the construction industry of Ethiopia.

### **1.3 SCOPE**

#### **1.3.1 General**

As the title of the thesis reveals the goal of the research is to study Derba Cements with a special emphasis to its property as the ingredient of structural concrete.

Through appropriate adjustment on the constituent materials selection and their proportions, concrete may be made to possess different properties in response to the desired function it is required.

To study all concrete properties, it requires studying and/or conducting laboratory tests on these entire properties that in turn require much longer time, effort, enough budget and other resources that are absolutely beyond the scope of this research. More practically, since the primary function of all structures is to carry loads or resist applied forces of whatever nature, concrete used for such purposes must have strength. Hence, although in some cases other characteristics may be important, the strength of concrete is commonly considered as its most valuable property. Furthermore, strength usually gives an overall picture of the quality of concrete, and it is considered as good index whether direct or inverse, of most of the other properties [1]. Therefore, the research mainly focuses on the cement property and compressive strength of its concrete.

Literature review on properties of concrete and concrete making materials, study on the cement test results collected from the cement factory and laboratory tests on compressive strength of concrete cubes produced from the two cements are the bases to evaluate mainly the compressive strength and partly other properties of the concretes produced using the cements.

The research will, therefore, be made based on not only laboratory test results but also literature surveys and cement test result analysis.

### **1.3.2 Methodology**

To achieve the objectives outlined earlier, the study is made in two ways:-

First, the cement factory was visited and data for each cement test results were collected from the factory. The data was analyzed and the chemical and physical properties of each cement properties were used to propose the properties of concrete produced from each cement type.

Second, laboratory tests on the compressive strengths of different classes of concrete produced from each cement type were done and recorded at different ages. Studies and justifications on compressive strength are based on the laboratory test result and the analyzed cement properties.

The physical properties of aggregate in the production of concrete in general and high strength concrete in particular are very crucial. Hence, the important tests were made on the physical properties of the aggregates and all the required properties are in conformity with the material specification requirements of the Ethiopian Standards and/or ASTM [8].

Aggregates were washed and sieved to meet the grading requirement of Ethiopian standard.

Furthermore, physical properties comprising: Silt Content, Moisture Content, Specific Gravity, Absorption Capacity and unit weight of aggregates were conducted.

The aggregate was brought from ERA site and has shown better result in all the conducted tests. To avoid variation in grading due to segregation of coarse aggregates, the aggregates were Screened and stored in to separate sacks and blended in the pre-determined proportion while making mixes.

Without the use of admixtures, it is difficult to produce workable concrete with water/cement ratio of 0.4 and below. Thus, Hyper plasticizing admixture based on new generation polycarboxylate ether (having production code of Dynamon SP5300) for high performance concrete mixes with very low water cement ratios, high early compressive strengths, long slump retention and self consolidating & self compacting concrete; which is used to reduce the amount of water and water-cement ratio was used in the production of high strength concrete.

In each class of concrete, mixing was made keeping every condition the same except varying the cement amount so that the variation on the concrete properties is directly attributable to the cement properties. Finally, compressive strength tests were made at the ages of 3, 7 and 28.

## CHAPTER TWO

### THE ART OF CONCRETE MAKING; A LITERATURE REVIEW

#### 2.1 INTRODUCTION

Concrete is a composite material made by mixing coarse and fine aggregates, cement, water and at times admixtures are also essential when special properties are desired.

A chemical reaction or hydration process takes place between the cement and water resulting in the formation of new compounds collectively known as cement paste, which bind the aggregates together into a coherent solid mass.

Performance of concrete depends on the quality of the constituent materials as well as on their proportion and on the class of construction that comprises: placing, compaction, and curing.

Hence, to discuss about the performance of concrete it is mandatory to learn about the concrete making materials and some other factors affecting this performance.

This chapter is, therefore, dedicated in discussing about concrete making materials and structure of concrete.

#### 2.2 CONCRETE MAKING MATERIALS

##### 2.2.1 CEMENT

As per Ethiopian Standard of 2005, there are 27 distinct common cement products and their constituents. The definition of each of the cement includes the proportions in which the constituents are to be combined to produce these distinct products in a range of six strength classes.

Cement is a hydraulic binder, i.e. a finely ground inorganic material which, when mixed with water, forms a paste which sets and hardens by means of hydration reactions and processes and which, after hardening, retains its strength and stability even under water. Cement conforming to ES 1177 - 1, termed CEM cement, shall, when appropriately batched and mixed with aggregate and water, be capable of producing concrete or mortar which retains its workability for a sufficient time and shall after defined periods attain specified strength levels and also possess

long-term volume stability. Hydraulic hardening of CEM cement is primarily due to the hydration of calcium silicates but other chemical compounds may also participate in the hardening process, e.g. aluminates. The sum of the proportions of reactive calcium oxide (CaO) and reactive silicon dioxide (SiO<sub>2</sub>) in CEM cement shall be at least 50 % by mass when the proportions are determined in accordance with ES 1176 - 2. CEM cements consist of different materials and are statistically homogeneous in composition resulting from quality assured production and material handling processes. The link between these production and material handling processes and the conformity of cement to ES 1177 - 1 is elaborated in ES 1177 - 2. There are also cements whose hardening is mainly due to other compounds, e.g. calcium aluminate in calcium aluminate cement. [5]

**Reactive Calcium Oxide (CaO):** that fraction of the calcium oxide which under normal hardening conditions can form calcium silicate hydrates or calcium aluminate hydrates. To evaluate this fraction the total calcium oxide content (see ES 1176-2) is reduced by the fraction corresponding to calcium carbonate (CaCO<sub>3</sub>), based on the measured carbon dioxide (CO<sub>2</sub>) content (see ES 1176-1), and the fraction corresponding to calcium sulfate (CaSO<sub>4</sub>), based on the measured sulfate (SO<sub>3</sub>) content (see ES 1176-2) after subtraction of the SO<sub>3</sub> taken up by alkalis.

**Reactive Silicon Dioxide (SiO<sub>2</sub>):** that fraction of the silicon dioxide which is soluble after treatment with hydrochloric acid (HCl) and with boiling potassium hydroxide (KOH) solution. The quantity of reactive silicon dioxide is determined by subtracting from the total silicon dioxide content (see ES 1176-2) that fraction contained in the residue insoluble in hydrochloric acid and potassium hydroxide (see ES 1176-2), both on a dry basis.

Cement has cohesive & adhesive properties; able to bind two or more materials together into a solid mass. Cohesion is the tendency of a material to maintain its integrity without separating or rupturing within itself when subject to external forces. Adhesion is the tendency of a material to bond to another material.

Cement when mixed with water form a paste which sets and harden by means of hydration reactions, and which after hardening retain its strength and stability even under water.

Generally cementing materials are of two types:

- A. **Non-hydraulic cements:** are cements which are 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).
- B. **Hydraulic cements:** are cements which are able to set and harden in water, and give a solid mass which does not disintegrate, i.e. remain stable in water. E.g. Portland cement.

In a concrete mixture the function of the cement is to react with water forming a plastic mass when the concrete is fresh and a solid mass when the concrete is hard. The properties of the hardened paste are affected by the characteristics of the cement and, the completeness of chemical combination between the cement and water.

Thus, it is essential to discuss about the prominent characteristics of cement and the logic behind the hydration of cement.

Types of Portland cement can be varied in type by changing the relative proportions of its prominent chemical compounds, by the degree of fineness of the clinker grinding and/or by adding some pozzolanic materials. As a result, there are several types of cements for different purposes. Some of them are: Ordinary Portland Cement (OPC), Rapid Hardening Portland Cement, Sulfate Resisting Portland Cement, Low heat Portland Cement, Portland Pozzolana Cement (PPC). But, only Ordinary Portland Cement and Portland Pozzolana Cement are produced in the cement factories found across the country abundantly and will be discussed more in detail during the main document preparation.

### **2.2.1.1 History of Cement**

The history of cementing material is as old as the history of engineering construction: Ancient Egyptian (about 5000 years ago) used calcined impure gypsum; and the Greeks (about 1000BC-100BC) and the Romans (about 300BC-300AD) used calcined limestone. The Romans ground together lime and volcanic ash or finely ground burnt clay tiles. The active silica and alumina in the ash and the tiles combined with the lime to produce what became known as pozzolanic cement from the name of the village Pozzuoli, in Italy. The Romans added blood, milk, and lard to their mortar and concrete to achieve better workability.

### 2.2.1.2 Early History of Modern Cement

**John Smeaton (1756)** found that the best mortar was found when Pozzolana was mixed with limestone containing a high proportion of clayey matter. **Joseph Aspedin (1824)** patented Portland cement. This cement was prepared by heating a mixture of finely divided clay and hard limestone in a furnace until carbon dioxide is driven off.

The cement was named after the natural limestone quarried on the Isle of Portland in the English Channel. Later in 1845 **Issac Charles Johnson** burnt a mixture of clay and chalk till the clinkering stage to make better cement and established factories in 1851. In the case of Ethiopia, the first cement factory was established in 1936 by the Italians at the Eastern part of the country, Dire Dawa.

### 2.2.1.3 CONSTITUENTS OF CEMENT [5]

The requirements for the constituents specified in 2.2.1.3.1 to 2.2.1.3.4 shall be determined in principle in accordance with the test methods described in ES 1176 unless otherwise specified.

#### 2.2.1.3.1 Main Constituents of Cement

Specially selected inorganic material in a proportion exceeding 5 % by mass related to the sum of all main and minor additional constituents;

##### *a) Portland Cement Clinker (K)*

Portland cement clinker is made by sintering a precisely specified mixture of raw materials (raw meal, paste or slurry) containing elements, usually expressed as oxides, CaO, SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, Fe<sub>2</sub>O<sub>3</sub> and small quantities of other materials. The raw meal, paste or slurry is finely divided, intimately mixed and therefore homogeneous. Portland cement clinker is a hydraulic material which shall consist of at least two-thirds by mass of calcium silicates (3CaOSiO<sub>2</sub> and 2CaOSiO<sub>2</sub>), the remainder consisting of aluminium and iron containing clinker phases and other compounds. The ratio by mass (CaO)/ (SiO<sub>2</sub>) shall be not less than 2.0. The content of magnesium oxide (MgO) shall not exceed 5.0 % by mass.

**b) Pozzolanic Materials (P, Q)**

Pozzolanic materials are natural substances of siliceous or silico-aluminous composition or a combination thereof. Although fly ash and silica fume have Pozzolanic properties, they are specified in separate clauses (see d and g below).

Pozzolanic materials do not harden in themselves when mixed with water but, when finely ground and in the presence of water, they react at normal ambient temperature with dissolved calcium hydroxide ( $\text{Ca}(\text{OH})_2$ ) to form strength-developing calcium silicate and calcium aluminate compounds. These compounds are similar to those which are formed in the hardening of hydraulic materials. Pozzolanas consist essentially of reactive silicon dioxide ( $\text{SiO}_2$ ) and aluminium oxide ( $\text{Al}_2\text{O}_3$ ). The remainder contains iron oxide ( $\text{Fe}_2\text{O}_3$ ) and other oxides. The proportion of reactive calcium oxide for hardening is negligible. The reactive silicon dioxide content shall be not less than 25.0 % by mass. Pozzolanic materials shall be correctly prepared, i.e. selected, homogenized, dried, or heat - treated and comminuted, depending on their state of production or delivery.

Natural Pozzolanas (P) are usually materials of volcanic origin or sedimentary rocks with suitable chemical and mineralogical composition and shall conform to the above definition of pozzolana.

Natural calcined Pozzolanas (Q) are materials of volcanic origin, clays, shales or sedimentary rocks, activated by thermal treatment and similarly, shall conform to the above definition of pozzolana.

**c) Granulated Blast Furnace Slag (S)**

Granulated blast furnace slag is made by rapid cooling of a slag melt of suitable composition, as obtained by smelting iron ore in a blast furnace and contains at least two -thirds by mass of glassy slag and possesses hydraulic properties when suitably activated.

Granulated blast furnace slag shall consist of at least two -thirds by mass of the sum of calcium oxide ( $\text{CaO}$ ), magnesium oxide ( $\text{MgO}$ ) and silicon dioxide ( $\text{SiO}_2$ ). The remainder contains aluminium oxide ( $\text{Al}_2\text{O}_3$ ) together with small amounts of other compounds. The ratio by mass  $(\text{CaO} + \text{MgO}) / (\text{SiO}_2)$  shall exceed 1.0.

**d) Fly Ashes (V, W)**

Fly ash is obtained by electrostatic or mechanical precipitation of dust-like particles from the flue gases from furnaces fired with pulverized coal. Ash obtained by other methods shall not be used in cement that conforms to ES 1177 - 1. Fly ash may be siliceous or calcareous in nature. The former has Pozzolanic properties; the latter may have, in addition, hydraulic properties. The loss on ignition of fly ash determined in accordance with ES 1176 - 2, but using an ignition time of 1 h, shall not exceed 5.0 % by mass. Fly ash with loss on ignition of 5.0 % to 7.0 % by mass may also be accepted, provided that particular requirements for durability, especially frost resistance, and for compatibility with admixtures are met according to the appropriate standards and/or regulations for concrete or mortar in the place of use. In the case of fly ash with a loss on ignition between 5.0 % and 7.0 % by mass the maximum limit, 7.0 %, shall be stated on the packaging and/or the delivery note of the cement.

Siliceous fly ash (V) is a fine powder of mostly spherical particles having Pozzolanic properties. It consists essentially of reactive silicon dioxide ( $\text{SiO}_2$ ) and aluminium oxide ( $\text{Al}_2\text{O}_3$ ). The remainder contains iron oxide ( $\text{Fe}_2\text{O}_3$ ) and other compounds. The proportion of reactive calcium oxide shall be less than 10.0 % by mass; the content of free calcium oxide, as determined by the method described in CD 6333 shall not exceed 1.0 % by mass. Fly ash having a free calcium oxide content higher than 1.0 % by mass but less than 2.5 % by mass is also acceptable provided that the requirement on expansion (soundness) does not exceed 10 mm when tested in accordance with ES 1176 - 3 using a mixture of 30 % by mass of siliceous fly ash and 70 % by mass of a CEM I cement conforming to CD 5288 - 1. The reactive silicon dioxide content shall not be less than 25.0 % by mass.

Calcareous fly ash (W) is a fine powder, having hydraulic and/or Pozzolanic properties. It consists essentially of reactive calcium oxide ( $\text{CaO}$ ), reactive silicon dioxide ( $\text{SiO}_2$ ) and aluminium oxide ( $\text{Al}_2\text{O}_3$ ). The remainder contains iron oxide ( $\text{Fe}_2\text{O}_3$ ) and other compounds. The proportion of reactive calcium oxide shall not be less than 10.0 % by mass. Calcareous fly ash containing between 10.0 % and 15.0 % by mass of reactive calcium oxide shall contain not less than 25.0 % by mass of reactive silicon dioxide.

Adequately ground calcareous fly ash containing more than 15.0 % by mass of reactive calcium oxide, shall have a compressive strength of at least 10.0 MPa at 28 days when tested in

accordance with ES 1176-1. Before testing, the fly ash shall be ground and the fineness, expressed as the proportion by mass of the ash retained when wet sieved on a 40  $\mu\text{m}$  mesh sieve, shall be between 10 % and 30 % by mass. The test mortar shall be prepared with ground calcareous fly ash only instead of cement. The mortar specimens shall be remolded 48 h after preparation and then cured in a moist atmosphere of relative humidity of at least 90 % until tested. The expansion (soundness) of calcareous fly ash shall not exceed 10 mm when tested in accordance with ES 1176 - 3 using a mixture of 30 % by mass of calcareous fly ash ground as described above and 70 % by mass of a CEM I cement conforming to ES1177 - 1. If the sulfate ( $\text{SO}_3$ ) content of the fly ash exceeds the permissible upper limit for the sulfate content of the cement then this has to be taken into account for the manufacture of the cement by appropriately reducing the calcium sulfate-containing constituents.

***e) Burnt Shale (T)***

Burnt shale, specifically burnt oil shale, is produced in a special kiln at temperatures of approximately 800 °C. Owing to the composition of the natural material and the production process, burnt shale contains clinker phases, mainly Dicalcium silicate and monocalcium aluminate. It also contains, besides small amounts of free calcium oxide and calcium sulfate, larger proportions of pozzolanically reacting oxides, especially silicon dioxide. Consequently, in a finely ground state burnt shale shows pronounced hydraulic properties like Portland cement and in addition Pozzolanic properties. Adequately ground burnt shale shall have a compressive strength of at least 25.0 MPa at 28 days when tested in accordance with ES 1176 - 1. The test mortar shall be prepared with finely ground burnt shale only instead of cement. The mortar specimens shall be remolded 48 h after preparation and cured in a moist atmosphere of relative humidity of at least 90 % until tested.

The expansion (soundness) of burnt shale shall not exceed 10 mm when tested in accordance with ES 1176 - 3 using a mixture of 30 % by mass of ground burnt shale and 70 % by mass of a CEM I cement conforming to this Committee Draft. If the sulfate ( $\text{SO}_3$ ) content of the burnt shale exceeds the permissible upper limit for the sulfate content of the cement then this has to be taken into account for the manufacture of the cement by appropriately reducing the calcium sulfate-containing constituents.

**f) Limestone (L, LL)**

Limestone shall meet the following requirements:

- a) The calcium carbonate (CaCO<sub>3</sub>) content calculated from the calcium oxide content shall be at least 75 % by mass.
- b) The total organic carbon (TOC) content, when tested in accordance with ES 1179:2005, shall conform to one of the following criteria:
  - LL: shall not exceed 0.20 % by mass;
  - L: shall not exceed 0.50 % by mass.

**g) Silica Fume (D)**

Silica fume (D) originates from the reduction of high purity quartz with coal in electric arc furnaces in the production of silicon and ferrosilicon alloys and consists of very fine spherical particles containing at least 85 % by mass of amorphous silicon dioxide. Silica fume shall meet the following requirements:

- a) The loss on ignition shall not exceed 4.0 % by mass determined in accordance with ES 1176 - 2 but using an ignition time of 1 h.
- b) The specific surface of the untreated silica fume shall be at least 15.0 m<sup>2</sup> /g when tested in accordance with ES ISO 9277.

For inter grinding with clinker and calcium sulfate the silica fume may be in its original state or compacted or pelletized (with water).

**2.2.1.3.2 Minor Additional Constituents**

Minor additional constituents are specially selected, inorganic natural mineral materials, inorganic mineral materials derived from the clinker production process or constituents as specified in 2.2.1.3.1 unless they are included as main constituents in the cement; they will be added in a proportion not exceeding a total of 5 % by mass related to the sum of all main and minor additional constituents. Minor additional constituents, after appropriate preparation and on account of their particle size distribution, improve the physical properties of the cement (such as workability or water retention on). They can be inert or have slightly hydraulic, latent hydraulic or Pozzolanic properties. However, no requirements are set for them in this respect. Minor additional constituents shall be correctly prepared, i.e. selected, homogenized, dried and comminuted depending on their state of production or delivery. They shall not increase the water demand of the cement appreciably, impair the resistance of the concrete or mortar to

deterioration in any way or reduce the corrosion protection of the reinforcement. Information on the minor additional constituents in the cement should be available from the manufacturer on request.

#### **2.2.1.3.3 Calcium Sulfate**

Calcium sulfate is added to the other constituents of cement during its manufacture to control setting. Calcium sulfate can be gypsum (calcium sulfate dihydrate,  $\text{CaSO}_4 \cdot \text{H}_2\text{O}$ ), hemihydrates ( $\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$ ), or anhydrite (anhydrous calcium sulfate,  $\text{CaSO}_4$ ) or any mixture of them. Gypsum and anhydrite are found naturally. Calcium sulfate is also available as a by-product of certain industrial processes.

#### **2.2.1.3.4 Additives**

Additives for the purpose of ES 1177 - 1 are constituents not covered in 2.2.1.3.1 to 2.2.1.3.3 which are added to improve the manufacture or the properties of the cement. The total quantity of additives shall not exceed 1.0 % by mass of the cement (except for pigments). The quantity of organic additives on a dry basis shall not exceed 0.5 % by mass of the cement. These additives shall not promote corrosion of the reinforcement or impair the properties of the cement or of the concrete or mortar made from the cement.

#### **2.2.1.4 Composition and Notation**

The 27 products in the family of common cements, covered by ES 1177 - 1, and their notation are given in Table 2.1. They are grouped into five main cement types as follows:

- ✓ CEM I Portland cement;
- ✓ CEM II Portland-composite cement;
- ✓ CEM III Blast furnace cement;
- ✓ CEM IV Pozzolanic cement;
- ✓ CEM V Composite cement.

The composition of each of the 27 products in the family of common cements shall be in accordance with this table below:-

Table 2.1: The 27 products in the family of common cements [5]

Main types	Notation of the 27 products (types of common cement)		Composition (percentage by mass <sup>a)</sup> )										Minor additional constituents
			Main constituents										
			Clinker	Blast-furnace slag	Silica fume	Pozzolana		Fly ash		Burnt shale	Limestone		
K	S	D <sup>b)</sup>	natural P	natural calcined Q	siliceous V	calca reous W	T	L	LL				
CEM I	Portland cement	CEM I	95-100	.	.	.	.	.	.	.	.	.	0 to 5
CEM II	Portland-slag cement	CEM II/A/S	80 to 94	8 to 20	.	.	.	.	.	.	.	.	0 to 5
		CEM II/B/S	85 to 79	21 to 35	.	.	.	.	.	.	.	.	0 to 5
	Portland-silica fume cement	CEM II/A/D	90 to 94	.	8 to 10	.	.	.	.	.	.	.	0 to 5
		Portland-pozzolana cement	CEM II/A/P	80 to 94	.	.	8 to 20	.	.	.	.	.	.
	CEM II/B/P		85 to 79	.	.	21 to 35	.	.	.	.	.	.	0 to 5
	CEM II/A/Q		80 to 94	.	.	.	8 to 20	.	.	.	.	.	0 to 5
	CEM II/B/Q		85 to 79	.	.	.	21 to 35	.	.	.	.	.	0 to 5
	Portland-fly ash cement	CEM II/A/V	80 to 94	.	.	.	.	8 to 20	.	.	.	.	0 to 5
		CEM II/B/V	85 to 79	.	.	.	.	21 to 35	.	.	.	.	0 to 5
		CEM II/A/W	80 to 94	.	.	.	.	.	8 to 20	.	.	.	0 to 5
		CEM II/B/W	85 to 79	.	.	.	.	.	21 to 35	.	.	.	0 to 5
	Portland-burnt shale cement	CEM II/A/T	80 to 94	.	.	.	.	.	.	8 to 20	.	.	0 to 5
		CEM II/B/T	85 to 79	.	.	.	.	.	.	21 to 35	.	.	0 to 5
	Portland-limestone cement	CEM II/A/L	80 to 94	.	.	.	.	.	.	.	8 to 20	.	0 to 5
		CEM II/B/L	85 to 79	.	.	.	.	.	.	.	21 to 35	.	0 to 5
		CEM II/A/LL	80 to 94	.	.	.	.	.	.	.	.	8 to 20	0 to 5
		CEM II/B/LL	85 to 79	.	.	.	.	.	.	.	.	21 to 35	0 to 5
	Portland-composite cement <sup>d)</sup>	CEM II/A/M	80 to 94	<..... 8 to 20 .....									0 to 5
		CEM II/B/M	85 to 79	<..... 21 to 35 .....									0 to 5
	CEM III	Blast-furnace cement	CEM III/A	35 to 64	38 to 65	.	.	.	.	.	.	.	.
CEM III/B			20 to 34	66 to 80	.	.	.	.	.	.	.	.	0 to 5
CEM III/C			5 to 19	81 to 95	.	.	.	.	.	.	.	.	0 to 5
CEM IV	Pozzolanic cement <sup>e)</sup>	CEM IV/A	85 to 89	.	<..... 11 to 35 .....					.	.	0 to 5	
		CEM IV/B	45 to 64	.	<..... 36 to 55 .....					.	.	0 to 5	
CEM V	Composite Cement <sup>f)</sup>	CEM V/A	40 to 64	18 to 30	.	<..... 18 to 30 .....				.	.	0 to 5	
		CEM V/B	20 to 38	31 to 50	.	<..... 31 to 50 .....				.	.	0 to 5	

a) The values in the table refer to the sum of the main and minor additional constituents.  
 b) The proportion of silica fume is limited to 10 %.  
 c) In Portland-composite cements CEM II/A/M and CEM II/B/M, in Pozzolanic cements CEM IV/A and CEM IV/B and in composite cements CEM V/A and CEM V/B the main constituents other than clinker shall be declared by designation of the cement for example see clause 8 .

### 2.2.1.5 Standard Designation [5]

CEM cements shall be identified by at least the notation of the cement type as specified in Table 2.1 above and the figures 32.5, 42.5 or 52.5 indicating the strength class (see table below). In order to indicate the early strength class the letter N (Normal hardening) or the letter R (Rapid hardening) shall be added as appropriate.

Table 2.2: Mechanical and physical requirements given as characteristic values

Strength Class	Compressive strength MPa				Initial setting time min	Soundness (expansion) mm
	Early strength		Standard strength			
	2 days	7 days	28 days			
32,5N	-	$\geq 16,0$	$\geq 32,5$	$\leq 52,5$	$\geq 75$	$\leq 10$
32,5R	$\geq 10,0$	-				
42,5N	$\geq 10,0$	-	$\geq 42,5$	$\leq 62,5$	$\geq 60$	
42,5R	$\geq 20,0$	-				
52,5N	$\geq 20,0$	-	$\geq 52,5$	-	$\geq 45$	
52,5R	$\geq 30,0$	-				

EXAMPLE 1: Portland cement conforming to ES 1177-1 of strength class 42.5 with a high early strength is identified by: Portland cement ES 1177-1 - CEM I 42.5 R

EXAMPLE 2: Portland- limestone cement containing between 6 % and 20 % by mass of limestone with a TOC content not exceeding 0.50 % by mass (L) of strength class 32.5 with an ordinary early strength is identified by: Portland- limestone cement ES 1177-1- CEM II/A-L 32.5 N

EXAMPLE 3: Portland-composite cement containing in total a quantity of granulated blast furnace slag (S), siliceous fly ash (V) and limestone (L) of between 6 % and 20 % by mass and of strength class 32.5 with a high early strength is identified by:

Portland-composite cement ES 1177-1 - CEM II/A-M (S-V-L) 32.5 R

EXAMPLE 4: Composite cement containing between 18 % and 30 % by mass of granulated blast furnace slag (S) and between 18 % and 30 % by mass of siliceous fly ash (V) of strength class 32.5 with an ordinary early strength is identified by:

Composite cement ES 1177-1 - CEM V/A (S-V) 32.5 N

### **2.2.1.6 Conditions of supply [5]**

#### **2.2.1.6.1 Identification**

Cement should be identified on the bag or the delivery note, and on any test report, with the following particulars:

- a) The name, trade mark or other means of identification of the manufacturer to facilitate traceability to the factory in which the cement was manufactured;
- b) The designation/name, the notation/type and strength class of the cement; e.g.
  - I. Portland cement CEM I 42.5N;
  - II. Portland-fly ash cement CEM II/B-V 32.5R;
  - III. Portland-limestone cement CEM II/A-LL 42.5N;
  - IV. Blast furnace cement CEM III/A 42.5N;
- c) The number and date of this Standard i.e. ES 1177-1;
- d) The standard notation of any admixture, where applicable;
- e) The quality marking plus associated information; and in the case of bagged supply only:
- f) The weight of a bag packed with cement.

#### **2.2.1.6.2 Packed/bagged cement**

Where cement is supplied in a bag for manual handling, the weight should be 50 kg, within permitted tolerances. If a test report is requested from the manufacturer, it should include results of the following tests on samples of the cement, and the information, where indicated, relating to the material delivered; including compressive strength at either 2 days or 7 days, as appropriate, and also at 28 days, initial setting time, soundness, chloride content and any other compositions [5].

### **2.2.1.7 Classification of Ordinary Portland Cement**

The cements produced by inter-grinding of cement clinker prepared in rotary cement kiln along with 3-5 % gypsum only are called as Ordinary Portland Cement (OPC). Depending upon the strength requirement OPC is further classified as OPC-33 grade, OPC-43 grade and OPC-53 grade. The range of applications, the Physical / Chemical requirements as per Bureau of Indian Standards (BIS) and strength of OPC are discussed in the following sections [27].

### 2.2.1.7.1 53 Grade OPC

53 Grade OPC is a higher strength cement to meet the needs of the consumer for higher strength concrete. As per BIS requirements the minimum 28 days compressive strength of 53 Grade OPC should not be less than 53 MPa. For certain specialized works, such as pre-stressed concrete and certain items of precast concrete requiring consistently high strength concrete, the use of 53 grade OPC is found very useful. 53 grade OPC produces higher-grade concrete at very economical cement content. In concrete mix design, for concrete C-20 and above grades a saving of 8 to 10 % of cement may be achieved with the use of 53 grade OPC.

53 Grade OPC can be used for RCC works (Preferably where grade of concrete is C-25 and above), Precast concrete items such as paving blocks, tiles building blocks, Pre-stressed concrete components and Runways, concrete Roads, Bridges etc. The physical and chemical requirements of 53 Grade OPC as per BIS Requirement are given in tables 2.3 and 2.4 below:

Table 2.3: Physical Characteristics of 53 Grade OPC (BIS Requirements)

IS Code	Fineness [sq.m/kg], min	Soundness by		Setting Time		Compressive Strength		
		Lechatlier [mm] max	Auto clamp Max [%]	Initial [mts] min	Final [mts] Max	3 day Min [Mpa]	7 day Min [Mpa]	28 day Min [Mpa]
(IS 12269-1987)	225	10	0.8	30	600	27	37	53

Table 2.4: Chemical Characteristics of 53 Grade OPC (BIS Requirement)

IS Code	Lime Saturation Factor	Alumina ratio, Min.	Insoluble Residue [%] Max	MgO [%] Max.	Max. Sulphuric anhydride	Loss on Ignition [%], Max
(IS 12269-1987)	0.8 Min 1.02 Max	0.66	2	6	2.5% Max when C <sub>3</sub> A is 5 or less or 3% Max when C <sub>3</sub> A is greater than 5	4

### 2.2.1.7.2 43 Grade OPC

The 43 grade OPC is the most popular general-purpose cement in the country today. The production of 43 grade OPC is nearly 50% of the total production of cement in the country.

The 43 grade OPC can be used for general Civil Engineering construction work, RCC works (preferably where grade of concrete is up to C-30), Precast items such as blocks, tiles, pipes etc, Asbestos products such as sheets and pipes and non-structural works such as plastering, flooring etc.

The compressive strength of cement when tested as per IS code shall be minimum 43 MPa. The physical and chemical properties of this cement are given in the tables 2.5 and 2.6 below:

Table 2.5: Physical Characteristics of 43 Grade OPC (BIS Requirements)

IS Code	Fineness [sq.m/kg] min	Soundness by		Setting Time		Compressive Strength		
		Lechatlier [mm] max	Auto clave Max [%]	Initial [mts] min	Final [mts] Max	3 day Min [Mpa]	7 day Min [Mpa]	28 day Min [Mpa]
(IS 12269- 1987)	225	10	0.8	30	600 specified	23	33	43

Table 2.6: Chemical Characteristics of 43 Grade OPC (BIS Requirement)

IS Code	Lime Saturation Factor	Alumina ratio, Min.	Insoluble Residue [%] Max	MgO [%] Max.	Max. Sulphuric anhydride	Loss on Ignition [%] Max
(IS 12269- 1987)	0.8 Min 1.02 Max	0.66	2	6	2.5% Max when C <sub>3</sub> A is 5 or less.  3% Max when C <sub>3</sub> A is greater than 5	5

### 2.2.1.7.3 33 Grade OPC

This cement is used for general civil construction work under normal environmental conditions. The compressive strength of cement after 28 days test as per IS specification is 33 MPa. Due to low compressive strength, this cement is normally not used where high grade of concrete C-20 and above is required. The availability of higher grades of OPC in the market are affecting the use of 33 grade OPC and now days 43 grade OPC is normally used for general construction work instead of 33 grade OPC. It is more useful for mass concreting and plain cement concreting; and can be used for plastering and single story individual houses. The physical and chemical requirements as per BIS are given in tables 2.7 and 2.8 below:

Table 2.7: Physical Characteristics of 33 Grade OPC (BIS Requirements)

IS Code	Fineness [sq.m/kg] min	Soundness by		Setting Time		Compressive Strength		
		Lechatlier [mm] max	Auto clave Max [%]	Initial [mts] min	Final [mts] Max	3 day Min [Mpa]	7 day Min [Mpa]	28 day Min [Mpa]
(IS 12269- 1987)	225	10	0.8	30	600 specified	16	22	33

Table 2.8: Chemical Characteristics of 33 Grade OPC (BIS Requirement)

IS Code	Lime Saturation Factor	Alumina ratio, Min.	Insoluble Residue [%] Max	MgO [%] Max.	Sulphuric anhydride	Loss on Ignition [%] Max
(IS 12269- 1987)	0.8 Min 1.02 Max	0.66	4	6	2.5% Max when C <sub>3</sub> A is 5 or less.  3% Max when C <sub>3</sub> A is greater than 5	5

Some countries have only one grade of cement whereas others prescribe different grades. The main advantage (some people say: the only advantage) in using higher grade cement is the faster rate of gain in strength during the initial two or three weeks. Also, though a bit costlier than low grade cement, it is claimed that they offer 10-20% saving in cement consumption [28].

However a faster rate of hydration results in higher heat, increased shrinkage, and lower later-age strength. There are many other disadvantages also in using higher grade cements. Higher grade cements are promoted by the industry as economical cements as less quantity of cement is required. Reduction in the amount of cement, when the quantity of water is based on workability, leads to higher water to cement ratio and more voids in concrete.

Further, without adequate quantity of fine material the concrete becomes unworkable. A reduction in the quantity of cement in ordinary concrete produces a harsh mixture, honey combing, and more voids. Moreover, concrete exposed to humidity and moisture requires a minimum cement content to prevent the corrosion of steel reinforcement. This means exposed structures should be made with a minimum quantity of cement, independent of the grade of cement to make them durable.

It can be said that Higher Grade Cements do not have much utility for normal construction works & their use is generally recommended only for higher grades of concrete say C-30 and above.

The usage of higher grade cement is becoming more & more popular. In fact 33 grade cement is now almost out of market in many countries.

However, the use of high grade cement should not be taken for granted to yield high grade (strength) concrete as the strength of concrete depends on the mixture of cement, sand, coarse aggregate and water. In fact, the cement's grade has no relationship to the strength of concrete. It is possible to produce concretes of wide-ranging strengths using a particular grade of cement, as it is done in the West using ASTM Type 1 cement [28].

Moreover, the term 'grade' has nothing to do with quality; increase in the grade does not increase the quality of the cement. The quality guarantees a set of minimum standards prescribed. Two cements of different grades can have the same quality.

Every structure has to satisfy the requirements of strength and durability. Strength is the ability of the structure (or its elements) to with stand load. Durability refers to the period of trouble-free life.

A structural element of concrete may possess high strength, but may deteriorate sooner than expected, making it a material of poor quality. Here the quality is with reference to-concrete and not that of cement. But if a brand or grade of cement is directly responsible for producing bad quality of concrete, the cement can be blamed as that of low quality. But any grade or brand of cement that satisfies the minimum requirements prescribed by the code, generally, should produce concrete of desired properties if the mix proportioning is done properly.

To put it in a proper perspective, a brand or grade of cement can be said to be of good quality if the concrete made with it satisfies both the strength and durability requirements.

The strength requirements (that is, the strength of concrete) is satisfied by choosing the proper amount of cement, limiting the amount of water, consolidating the mixture well, and curing the hardened concrete as long as possible.

Durability, on the other hand, depends on several factors that are attributable both to the material and to the exposed environment. Exposed structures should be made with a minimum quantity of cement, independent of the grade of cement to make them durable.

It may be stated that manufacture of higher grade cement has been made possible by modern equipment/plants, better quality control on processes/products, using superior quality limestone, finer grinding, better particle size distribution & better packing [28].

### **2.2.1.8 Components of Portland Cement**

Portland cement as per ES is a cementing material which is obtained by thoroughly mixing together calcareous (having High calcium oxide ingredients) or other lime bearing material with, if required, argillaceous (having Combination of silica & alumina) and/or other silica, alumina or iron oxide bearing materials burning them at a clinkering temperature and grinding the resulting clinker. Examples of Calcareous materials are limestone, chalk, marine shell and that of clay, sandstone, shell will be grouped in to Argillaceous.

Portland cement is composed of four main oxides, namely: lime (CaO), Silica (SiO<sub>2</sub>), Alumina (Al<sub>2</sub>O<sub>3</sub>) and Iron Oxide (Fe<sub>2</sub>O<sub>3</sub>). The Iron oxide added to the raw mixture is to aid in controlling the composition. Minor amounts of other materials, such as magnesia, MgO, and alkalis, Na<sub>2</sub>O, K<sub>2</sub>O are usually present in relatively small amount as impurities. The function of the gypsum is to control the time of setting of the cement when it is mixed with water in job [1]. However, the principal compounds, in Portland cement exist not in the form of simple oxides but as minerals of more complex molecular structure.

Table 2.9: Usual composition limits of Portland cement [9]

Oxide	Content [%]
CaO	60-67
SiO <sub>2</sub>	17-25
Al <sub>2</sub> O <sub>3</sub>	3.0-8.0
Fe <sub>2</sub> O <sub>3</sub>	0.5-6.0
MgO	0.5-4.0
Alkalis (such as Na <sub>2</sub> O)	0.3-1.2
SO <sub>3</sub>	2.0-3.5

### 2.2.1.9 Compound Composition of Portland Cement

These four principal chemical compounds that make up Portland cement are: Tricalcium silicate (3CaOSiO<sub>2</sub>), Dicalcium silicate (2CaOSiO<sub>2</sub>), Tricalcium aluminate (3CaOAl<sub>2</sub>O<sub>3</sub>) and Tetracalcium aluminoferrite (4CaOAl<sub>2</sub>O<sub>3</sub>Fe<sub>2</sub>O<sub>3</sub>).

The names of oxide composition and abbreviation of the four principal reactive compounds present in clinker and dehydrated Portland cement are shown in Table 2.10 below.

Therefore, depending on the relative proportions of its four prominent chemical compounds, the degree of fineness of the clinker grinding and/or by incorporating pozzolanic materials, it is possible to produce different Portland cement types.

The raw materials used for the manufacture of cement consist mainly of lime, silica, alumina and iron oxide. These oxides interact with one another in the kiln at high temperature to form more complex compounds. The maximum amount of alumina and iron oxide is determined by the need to control the rapidity of the setting of cement. The silicate phases form about 70% of the weight of an ordinary Portland cement. Despite their small percentages, the minor compounds can have strong influence on

the properties of fresh and hardened cement paste. Gypsum is added to clinker in the last stage in order to regulate the setting time of cement. The amount of gypsum added depends on the  $C_3A$  content of the cement and its fineness.

Table 2.10: Main Chemical Compounds of Portland Cement

Chemical Compound	Oxide composition	Abbreviation
<b>I. Major compounds</b>		
Tricalcium silicate	$3CaO.SiO_2$	$C_3S$
Dicalcium silicate	$2CaO.SiO_2$	$C_2S$
Tricalcium Aluminate	$3CaO.Al_2O_3$	$C_3A$
Tetracalcium alumino ferrite	$4CaO. Al_2O_3. Fe_2O_3$	$C_4AF$
<b>II. Minor compounds</b>		
Gypsum	$CaSO_4.2H_2O$	$CSH_2$
Free lime	$CaO$	$C$
Magnesia	$MgO$	$M$
Alkali Oxides		
✓ Soda	$Na_2O$	$N$
✓ Potash	$K_2O$	$K$
Manganese Oxide	$Mn_2O_3$	
Titanium Oxide	$Ti_2O$	
Phosphorus pentoxide	$P_2O_5$	

The gypsum content must be limited because an excess may cause deterioration in the cement due to the expansive nature of hydrating gypsum. Free lime may present in cement due to the raw material containing more lime than can combine with the acidic oxides such as  $SiO_2$ ,  $Al_2O_3$ ,  $Fe_2O_3$  and

insufficient burning at the clinkering stage. Free lime in cement is undesirable since after being hard burnt it is very slow to hydrate when cement is mixed with water. The presence of free lime in cement may cause volume instability in the hardened cement. Magnesia which has a similar hydration to CaO may cause unsoundness if it exists greater than the upper limit.

Table 2.11: Properties and percentage mass of the compounds of cement

Compound	Chemical Formula	Common Formula	Usual Range, weight (%)	Properties
<b>Tricalcium silicate</b>	3CaO .SiO <sub>2</sub>	C <sub>3</sub> S	45 – 60	Harden rapidly. Provides early strength, high heat generation. Responsible for concrete strength. About 70% of hydration of C3S takes place in 28 days.
<b>Dicalcium silicate</b>	2CaO .SiO <sub>2</sub>	C <sub>2</sub> S	15 – 30	Reacts & harden slowly, provide later strength, high resistance to sulfate & chloride. Gain of strength due to C2S within 2-3 weeks is only 15% of that due to C3S.
<b>Tricalcium aluminate</b>	3CaO.Al <sub>2</sub> O <sub>3</sub>	C <sub>3</sub> A	6 – 12	First compound to hydrate, highest heat of generation, responsible for initial setting of cement, Does not contribute to strength. Reactive with soils and water containing sulfate: this is undesirable in a higher percentage since formation of calcium sulfoaluminate may cause expansion during setting.
<b>Tetracalcium aluminoferrite</b>	4CaO. Al <sub>2</sub> O <sub>3</sub> .Fe <sub>2</sub> O <sub>3</sub>	C <sub>4</sub> AF	6 – 8	Does not affect the behavior of cement. (No contribution to strength).
<b>Gypsum</b>	CaSO <sub>4</sub> .2H <sub>2</sub> O	CSH <sub>2</sub>	5	Slow down setting time.

### 2.2.1.10 Determination of Compound Composition

Although it is possible to determine the compound composition by direct analysis, the methods employed are complex and require special skills and expensive equipment. The “potential” compound composition can be computed from a complete oxide analysis on the assumption that the chemical reaction involved in the formation of clinker has proceeded to equilibrium, that no “glass” or non-crystalline material is present, that the condition of cooling are such as not to alter these compounds, and the presence of minor constituents may be ignored [6].

For commercial production, the kiln reaction is not always completed, and usually the cooling is too rapid for complete crystallization in which case some of the liquid cools to glass. In addition, small amounts of other compounds may be formed with some of the minor constituents. These factors result in an actual composition that differs from the “potential” composition. The fact remains, however, that the calculated compound composition has proven to be a very valuable index in judging the characteristics of a Portland cement [6].

Therefore, it is usually estimated by calculation using the ideal compound stoichiometries and an oxide analysis determined by standard method. The calculation of the phases from the composition is known as *Bogue calculation*.

Bogue equations for the percentage of main compounds in cement are given below. The terms in brackets represent the percentage of the given oxide in the total mass of cement.

#### Case A: A/F $\geq$ 0.64

$$\left. \begin{aligned} C_3S &= 4.071(\text{CaO}) - 7.600(\text{SiO}_2) - 6.718(\text{Al}_2\text{O}_3) - 1.430(\text{Fe}_2\text{O}_3) - 2.852(\text{SO}_3) \dots\dots \\ C_2S &= 2.867(\text{SiO}_2) - 0.7544(3\text{CaOSiO}_2) \dots\dots\dots \\ C_3A &= 2.650(\text{Al}_2\text{O}_3) - 1.692(\text{Fe}_2\text{O}_3) \dots\dots\dots \\ C_4AF &= 3.043(\text{Fe}_2\text{O}_3) \dots\dots\dots \end{aligned} \right\} \text{Eq. [2.1]}$$

#### Case B: A/F $\leq$ 0.64

$$\left. \begin{aligned} C_3S &= 4.071(\text{CaO}) - 7.600(\text{SiO}_2) - 4.479(\text{Al}_2\text{O}_3) - 2.859(\text{Fe}_2\text{O}_3) - 2.852(\text{SO}_3) \dots\dots \\ C_2S &= 2.867(\text{SiO}_2) - 0.7544(3\text{CaOSiO}_2) \dots\dots\dots \\ C_3A &= 0 \dots\dots\dots \\ C_4AF &= 2.1(\text{Al}_2\text{O}_3) + 1.702(\text{Fe}_2\text{O}_3) \dots\dots\dots \end{aligned} \right\} \text{Eq. [2.2]}$$

It should be noted that small changes in oxide composition of the raw materials leads to considerable changes in the proportion of the compounds.

Table 2.12: Proportion of the compounds during small changes in oxide compositions

Composition	Cement		
	1	2	3
<b>I. Oxide</b>			
CaO	66	63	66
SiO <sub>2</sub>	20	22	20
Al <sub>2</sub> O <sub>3</sub>	7	7.7	5.5
Fe <sub>2</sub> O <sub>3</sub>	3	3.3	4.5
Others	4	4	4
<b>II. Compound</b>			
C <sub>3</sub> S	65	33	73
C <sub>2</sub> S	8	38	2
C <sub>3</sub> A	14	15	7

These four principal cement compounds differ greatly in their properties as shown summarized in Table 2.7 below.

Table 2.13: Characteristics of Principal Compounds That Occur in Portland Cement

Property	Relative behavior of each compound			
	C <sub>3</sub> S	C <sub>2</sub> S	C <sub>3</sub> A	C <sub>4</sub> AF
Rate of reaction	Medium	Slow	Fast	Fast
Heat liberated	Medium	Small	Large	Small
Cementing value, per unit compound:				
Early	Good	Poor	Good	Poor
Ultimate	Good	Good	Poor	Poor

A small variation in the composition or proportion of its raw materials leads to a larger variation in compound composition. Thus, to produce uniform cement, it requires stringent care in keeping the oxide composition of the raw materials uniform [7].

In addition to the main compounds, there are minor compounds such as MgO, TiO<sub>2</sub>, Mn<sub>2</sub>O<sub>3</sub>, Na<sub>2</sub>O and K<sub>2</sub>O; which usually amount to not more than a few percent of the mass of cement. Two of the minor compounds are of particular interest: the oxides of sodium and potassium known as the alkalis (although other alkalis also exist in cement). They have been found to react with some aggregates, the products of the reaction causing disintegration of the concrete, and have also been observed to affect the rate of the gain of strength of cement. It should, therefore, be pointed out that the term ‘minor compounds’ refers primarily to their quantity and not necessarily to their importance.

### **2.2.1.11 Hydration of Portland cement**

The main role of cement in concrete is to bind the aggregate particles so as to produce good strength and durable concrete. Perhaps, the single most important factor that has a strong effect on these properties is the hydration of the cement, which in turn is affected by the composition, and fineness of the cement.

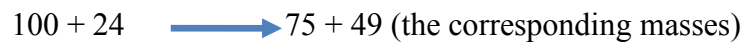
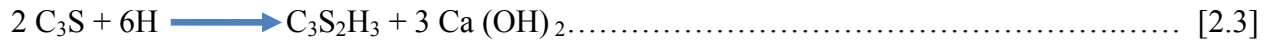
Hydration of Portland cement is the chemical reaction it undergoes when brought in contact with water. However, hydration of Portland cement is far more complex phenomenon. This is so because Portland cement is a heterogeneous mixture of several chemical compounds that are complex in themselves. Hydration of cement exerts an influence of primary importance on practically all other properties of the paste and yet it is not fully understood.

The reaction of cement with water is a reaction of individual compounds. This reaction may occur in two ways. In the first, a true reaction of hydration, which is a recombination of the dehydrated compounds with water, i.e. a direct addition of molecules of water to the chemical compounds, takes place. In the second type of reaction with water, hydrolysis, leads to chemical changes [1].

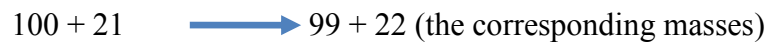
The two calcium silicates are the main cementitious compounds in cement, and the chemical behavior of cement during hydration is similar to that of those two compounds alone.

Making the appropriate assumption that  $C_3S_2H_3$  is the final product of hydration of both of  $C_3S$  and  $C_2S$ , the reactions of hydration can be written (as a guide although not as exact stoichiometric equations) as follows.

For of  $C_3S$ :

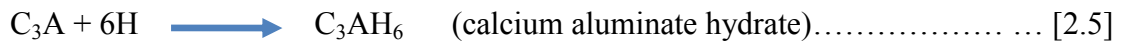


For  $C_2S$ :



Thus, on mass basis, both silicates require approximately the same amount of water for their hydration, but  $C_3S$  produces more than twice as much  $Ca (OH)_2$  as is formed by the hydration of  $C_2S$ . The presences of  $Ca (OH)_2$  makes cement paste highly alkaline (PH 12.5). This is the reason why ordinary Portland cement pastes are sensitive to acid attack. The high PH index also makes cement parts provide good protection to embedded steel against corrosion [1].

For  $C_3A$ : Pure  $C_3A$  reacts with water very rapidly and immediately converts to a stiff paste.



In cement, however  $C_3A$  hydrates differently due to the presence of gypsum



For  $C_4AF$ :



The instantaneous hydration of aluminates, and hence the untimely loss of plasticity is avoided by adding the required amount of gypsum which will prevent the passage of alumina into solution. Gypsum reacts with  $C_3A$  to form a coating of ettringite, a practically insoluble complex compound of needle like crystals ( $C_6AS_3H_{32}$ ). The hydration of the ferrite phase in the presence of gypsum in cement is similar to that of  $C_3A$ . As the hydration of cement is an exothermic reaction, the rate of

evolution of heat is an indication of the rate of hydration. And depending on the grain size distribution in the cement and the presence of water, hydration may continue for several years after mixing but at a much reduced rate.

### 2.2.1.12 Pozzolanic Reaction of Cement

The pozzolanic reaction is the chemical reaction that occurs in Portland cement containing pozzolans. [29].

At the basis of the pozzolanic reaction stands a simple acid-base reaction between calcium hydroxide, also known as Portlandite, or  $(\text{Ca}(\text{OH})_2)$ , and silicic acid ( $\text{H}_4\text{SiO}_4$ , or  $\text{Si}(\text{OH})_4$ ), and . Simply, this reaction can be schematically represented as follows:

$\text{Ca}(\text{OH})_2 + \text{H}_4\text{SiO}_4 \rightarrow \text{Ca}^{2+} + \text{H}_2\text{SiO}_4^{2-} + 2 \text{H}_2\text{O} \rightarrow \text{CaH}_2\text{SiO}_4 \cdot 2 \text{H}_2\text{O}$  or summarized in abbreviated notation of cement chemists:  $\text{CH} + \text{SH} \rightarrow \text{C-S-H}$

The product of general formula ( $\text{CaH}_2\text{SiO}_4 \cdot 2 \text{H}_2\text{O}$ ) formed is a calcium silicate hydrate, also abbreviated as C-S-H in cement chemist notation, the hyphenation denotes the variable stoichiometries. The ratio Ca/Si, or C/S, and the number of water molecules can vary and the above mentioned stoichiometries may differ [29].

If a concrete contains a pozzolan, less cement is required to obtain a specified strength. The amount of cement reduction will vary depending upon the reactivity of the pozzolan. A highly reactive pozzolan has more cementitious strength value than a lower reactive pozzolan. The amount of cement reduction will be greater with a more reactive pozzolan. By definition, a pozzolan by ACI is: “siliceous or siliceous and aluminous materials that in it possess little or no cementitious value but that will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide (lime) at ordinary temperatures to form compounds having cementitious properties [29].

By definition to form a compound that has cementitious value a pozzolan must react with lime which in concrete comes from the cement. Two factors or assumptions must be defined.

#### 2.2.1.12.1 Availability of Lime

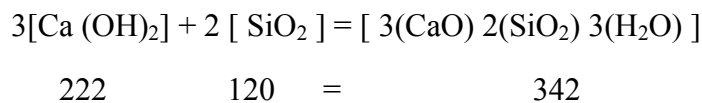
The amount of lime available is the lime produced during cement hydration and this will be reduced relative to the percentage of pozzolan. The amount of lime that is available will vary with cements. It

will depend upon the amount of  $C_3S$  and  $C_2S$  in the cement. Each of these compounds react with water to form C-S-H (Calcium Silicate Hydrate) and lime- $Ca(OH)_2$ . A small portion of this lime enters into reactions with cement alumina and sulfates to form compounds such as ettringite. Therefore not all of the lime produced is available or free to react with a pozzolan.

The amount of lime is also related to the amount of cement hydration. At early ages, only a small amount of cement has hydrated and thus the amount of lime is low. In addition, when a pozzolan is used, the percentage of pozzolan will reduce the available amount of lime.

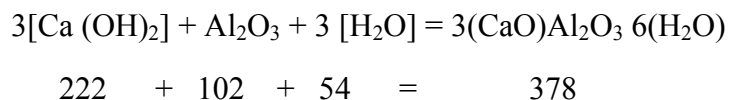
### 2.2.1.12.2 Pozzolanic Reaction

It will be assumed that all pozzolanic reactions are lime reactions with siliceous pozzolanic materials. The dominate hydration product of Portland cement is C-S-H. If it is assumed that the reaction of pozzolan and lime produces the same hydration products as cement consider the following reaction:



In this reaction 222 parts lime reacts with 120 parts silica for a mass ratio of  $222/120 = 1.85$ .

In contrast to siliceous reactions, pozzolanic reactions could be between lime and aluminous pozzolanic materials. In this case the final hydration product of aluminous compounds in cement is assumed to be  $3(CaO) Al_2O_3 6(H_2O)$ . Consider the following reaction



The relationship between lime and alumina is  $222/102 = 2.18$ . Alumina combines with more lime than does silica.

### 2.2.1.13 Mechanism of Hydration and Setting

- A. Dormant period: - The 1<sup>st</sup> peak is observed, which is very high and corresponds to the initial hydration at the surface of the cement particles, largely involving  $C_3A$ . The formation of dense layers leads to a relatively inactive or very slow reaction period. This period lasts b/n 30-120 minutes and the paste remains plastic and workable.
- B. Second period:- In this period, there is an increase in rate of heat liberation and relatively rapid chemical reactions will be takes place. It lasts normally less than 8hrs and the mechanism is that at the beginning the paste loses its plasticity, and acquires a certain degree of firmness and becomes

unworkable (initial set). The paste becomes stiffer and at the end of this period it converts to a rigid mass (final set). The rate of heat evolution reaches a second peak.

- C. Last period: - A gradual decrease in heat of hydration is observed and a slow rate of hydration by diffusion through solid hydration products. With most, but not all, cements, there is a renewed increase in the rate of hydration up to a third lower peak b/n 18 and 30 hrs. Of the four major compounds those which contribute most to hardening and consequent strength gains are the silicates.  $C_3S$  contribute most to strength development of the hardened paste during early age whereas  $C_2S$  influences the gain in strength from one month onwards.

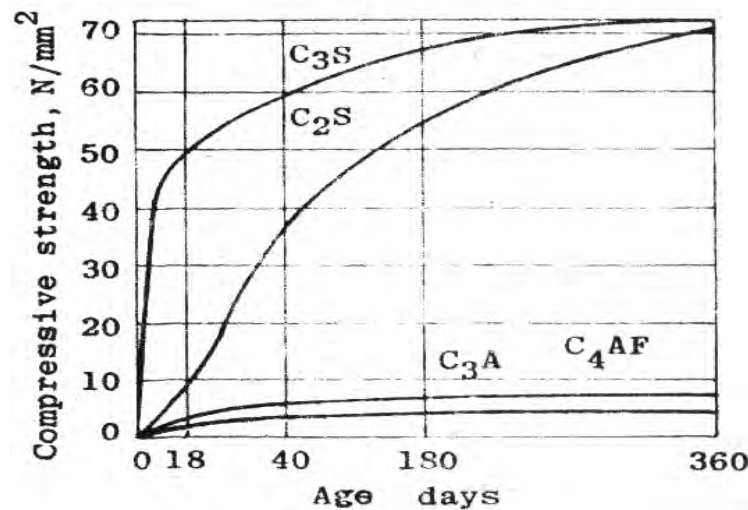


Fig 2.1: Development of hydration of pure Compounds

#### 2.2.1.14 PORTLAND POZZOLANA CEMENT

In the Ethiopian Standard ES definition [5], 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 pozzolana and it does not necessarily satisfy the test for pozzolanicity. (Pozzolanicity is assessed by comparing the quantity of  $Ca(CH)_2$  present in a liquid phase in contact with the hydrated cement with the quantity of  $Ca(OH)_2$  capable of saturating a medium of the same alkalinity). Pozzolanic Cement means cement resulting from a homogeneous mixture of finely ground Portland clinker from 21 to 35 percent by mass of pozzolana and it satisfies the test for pozzolanicity.

In the same standard pozzolana is defined as a natural volcanic material having pozzolanic properties. But the same standard also states that other natural and artificial materials such as diatomaceous earth,

calcined clay and pulverized fuel ash which also have pozzolanic properties, but it does not include blast furnace slag.

Pozzolanic properties mean the ability of a material to combine with lime at ambient temperature and in the presence of water in order to produce compounds that set and hardened with the formation of hydrated phases [5].

The Activity of Pozzolanas when mixed with cement is that the silica of the pozzolana combines with the free lime released during the hydration of the cement. Silicas of amorphous form react with lime more readily than those of crystalline form and this constitutes the difference in many cases between active pozzolanas and materials of similar chemical composition which exhibit little pozzolanic activity.

The most active of the natural pozzolanas are the diatomites, opaline cherts, and some shales. Volcanic materials such as pumicites and tuffs are generally less active, whilst many materials such as some clay require calcination or heat treatment before they become reactive [8].

#### **2.2.1.14.1 Effect of Pozzolana on Heat of Hydration**

A comparison of the temperatures generated with normal, modified, Pozzolanic and low heat cements, it is seen that pozzolanic cement has a similar heat of hydration to that of low heat cement. The gain is in both the lower total amount of heat generated and the slower rate of evolution [8].

#### **2.2.1.14.2 Effect of Pozzolana on Strength of Concrete**

At early ages the replacement of cement by a pozzolana usually results in a decrease in the compressive strength, but the difference in strengths becomes less and may disappear at ages of 3 months or more [6].

A number of tests were carried out by Heath and Brandenburg with Oregon Pumicites and their results given in Fig. 2.2 illustrating the development of strength of Portland cement mortars with various replacements of pumicites are typical of the effect on strength of pozzolanas of medium reactivity. The mortars consisted of 1 part of ordinary Portland cement or 1 part of cement plus pumice to 2.75 parts of Ottawa sand by weight [8].

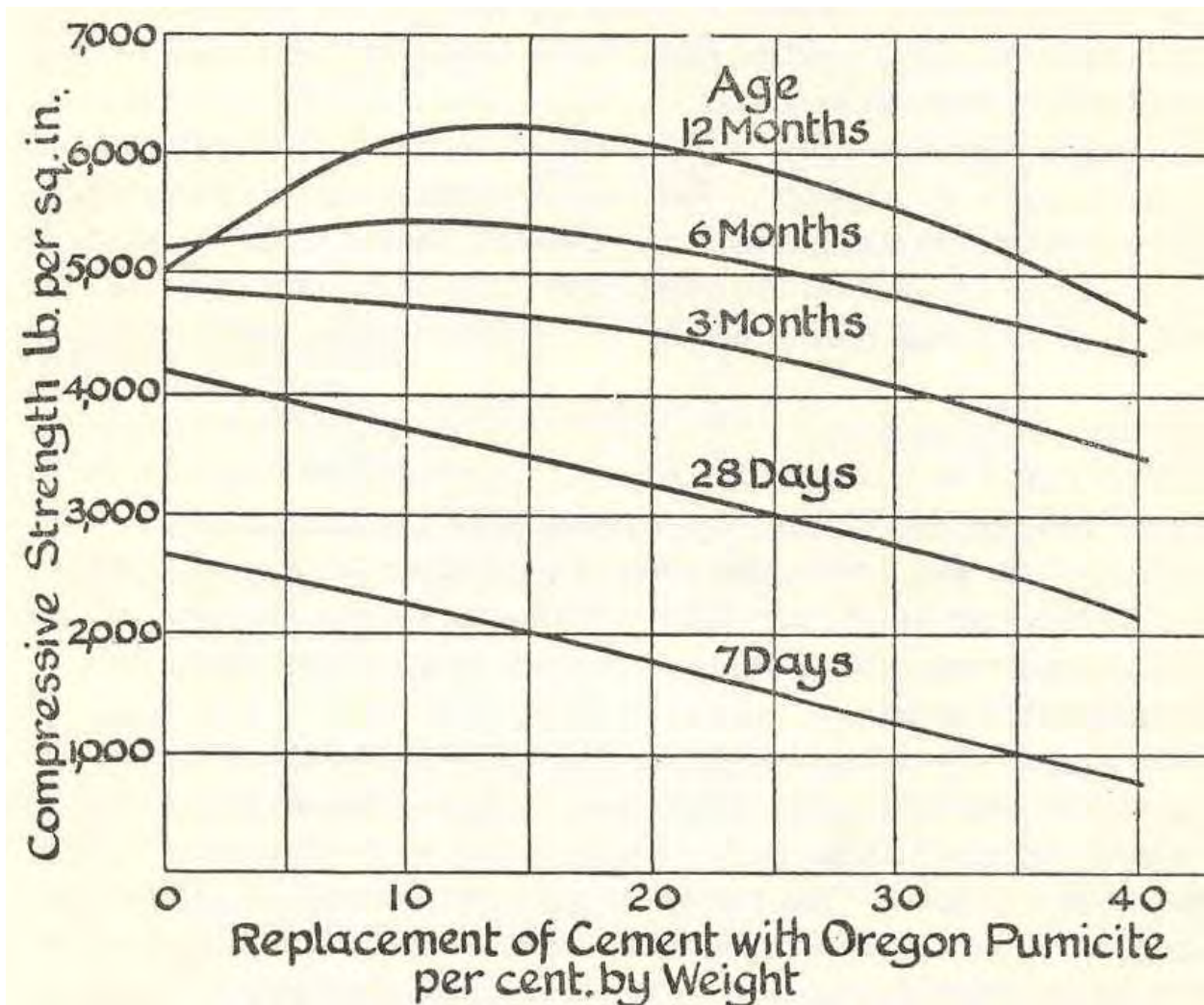


Fig. 2.2 The effect on concrete strength due to the replacement of cement by a pozzolana [8]

#### 2.2.1.14.3 Chief Applications of Portland Pozzolana Cement

The chief use in constructional work for pozzolana cements and for natural and artificial pozzolanas as a substitution for part of the cement is in the building of large dams and mass structures generally where the reduction effected in the heat of hydration is of great importance and the slower gain in strength is not of much consequence. Possible other uses are for mass retaining walls, mass foundations, breakwaters and harbor works, culverts and drains. The improvement in workability which the incorporation of the pozzolana causes is a considerable advantage in the lean harsh mixes normally used in the construction of dams [8].

### **2.2.1.15 Manufacturing of Portland Cement and its Chemistry**

In principle, the manufacture of Portland cement is simple. It is made from abundant raw materials. Intimately blended raw materials, usually limestone and clay, are heated in a kiln to 1400 to 1600 °C (2550 to 2900 °F), the temperature at which these materials chemically interact to form the cementitious compounds in Portland cement. Considerable attention is paid to the various stages of processing to maintain good quality control. This processing requires 60 to 80 separate and continuous operations, the use of a great deal of heavy machinery and equipment, and the consumption of large amounts of fuel and electrical energy [14].

#### **2.2.1.15.1 Overview of the Cement Manufacturing Process**

The cement manufacturing process involves four distinct stages, and these are Quarrying, Raw material preparation, Clinkering and Cement milling.

##### **Step 1 – Quarrying**

The raw material for cement manufacture is a rock mixture which is about 80% limestone which is rich in  $\text{CaCO}_3$  and 20% clay or shale, a source of silica, alumina and  $\text{Fe}_2\text{O}_3$ . These are quarried and stored separately. The lime and silica provide the main strength of the cement, while the iron reduces the reaction temperature and gives the cement its characteristic grey color.

##### **Step 2 - Raw material preparation**

The manufacture of Portland cement requires blending raw materials to obtain appropriate proportions of lime ( $\text{CaO}$ ), silica ( $\text{SiO}_2$ ), alumina ( $\text{Al}_2\text{O}_3$ ), and iron oxide ( $\text{Fe}_2\text{O}_3$ ). High-quality cements require raw materials of proper chemical composition and proportioned to precise quantities. Limestone, which consists primarily of calcium carbonate, is the most common source of lime, although other raw materials such as dolomite, chalk, shell deposits, and calcareous muds are used for this purpose. The location of cement plants is most often determined by the occurrence of suitable calcareous (lime-rich) deposits, and proximity to the market area. A suitable source of silica can usually be obtained close at hand. Iron-bearing aluminosilicates are often used as the primary source of silica. Clays or silts are preferred since they are already in a finely divided state; but shales, schist, and other argillaceous rocks are also used.

The steps involved here depend on the process used. There are two main cement manufacturing processes currently used: the dry process and the wet process. The dry process uses more energy in

grinding but less in the kiln and the wet process has lower overheads than the dry process. The two processes are discussed separately below.

### ***The dry process***

The quarried clay and limestone are crushed separately until nothing bigger than a tennis ball remains. Samples of both rocks are then sent off to the laboratory for mineral analysis. If necessary, minerals are then added to either the clay or the limestone to ensure that the correct amounts of aluminum, iron etc. is present. The clay and limestone are then fed together into a mill where the rock is ground until the majority of the material is less than 75 $\mu$ m. In the dry process the raw materials are crushed, dried in rotary driers, proportioned, and then ground in ball mills. The resulting powder is then burnt in its dry condition in the rotary kiln. 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. The dry process requires much less fuel as the materials are already in a dry state. As a result, the dry process is much more thermally efficient than the wet process. Firstly, and most obviously, this is because the meal is a dry powder and there is little or no water that has to be evaporated. Secondly, and less obviously, the process of transferring heat is much more efficient in a dry process kiln [24].

### ***The wet process***

The clay is mixed to a paste in a wash mill - a tank in which the clay is pulverized in the presence of water. Crushed lime is then added and the whole mixture further ground. Any material which is too coarse is extracted and reground. The slurry is then tested to ensure that it contains the correct balance of minerals, and any extra ingredients blended in as necessary. In the wet process the materials are first crushed and then ground and dispersed in water to form slurry in a wash mill. This process is done for the combined calcareous and argillaceous materials or for each constituent separately which are then mixed in predetermined proportion. The resulting cement slurry with a water content of 35-50% is made to pass through screens to a storage tanks where it is continuously agitated to prevent sedimentation. For many years the wet process remained popular because of the possibility of more accurate control in the mixing of raw materials. The vertical shaft technology employed by mini cement units, use the wet process where as the rotary kiln technology uses the modern dry process.

The original rotary cement kilns were called ‘wet process’ kilns. In their basic form they were relatively simple compared with modern developments. The raw meal was supplied at ambient temperature in the form of slurry and the slurry may contain about 40% water.

A wet process kiln may be up to 200m long and 6m in diameter. It has to be long because a lot of water has to be evaporated and the process of heat transfer is not very efficient. This takes a lot of energy to evaporate and various developments of the wet process were aimed at reducing the water content of the raw meal [24].

Table 2.14: Typical composition of some raw materials

Component	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	SO <sub>3</sub>	K <sub>2</sub> O	Na <sub>2</sub> O
Limestone	2.68	0.62	0.46	51.85	1.94	0.03	0.05	0.02
Sandy Cay	81.56	11.29	1.79	0.12	0.09	0.05	0.14	0.03
Clay	65.18	21.91	3.36	0.11	0.08	0.06	0.19	0.04
Iron ore	14.88	16.79	57.74	0.12	0.56	0.04	0.04	0.03
Shale	61.10	16.42	7.01	1.02	2.34	0.01	4.12	1.65
Sand	94.70	2.90	0.24	0.35	0.13	0.01	0.60	0.21
Bauxite	3.11	57.59	15.74	4.16	0.16	0.29	0.08	0.08
Gypsum	4.31	0.34	0.14	31.19	0.11	43.88	-	-
Fuel Ash	57.20	17.36	9.11	3.95	1.80	3.40	0.78	2.50

### **Step 3 – Clinkering**

This is the step which is characteristic of Portland cement. The finely ground material is dried, heated and then cooled down again. While it is being heated various chemical reactions take place to form the major mineral constituents of cement.

The powder from the dry process doesn't contain much moisture, so can be dried in a preheated tower. As it falls through the tower the moisture evaporates, decarbonation (loss of CO<sub>2</sub>) occurs and some intermediate phases such as CaOAl<sub>2</sub>O<sub>3</sub> begin to appear. The mixture is then fed into the kiln.

The slurry from the wet process contains too much moisture to be successfully dried in a preheated tower. Instead, the slurry is fed directly into the kiln where it is formed into dry balls by the heat and rotation of the kiln. Because of this extra role of the kiln, wet process kilns are 120 -165m in length,

whereas dry process kilns are approximately 45 m long. The kilns used in both processes may be rotary or vertical roller which is fired with an intense flame produced by burning coal, coke, oil, gas or waste fuels. The rotary kiln discharges the red hot clinker under the intense flame. Immediately following a large cooler designed to drop the temperature of the clinker which is around 1450 °C. At this point in the process the materials have been formed into all the required minerals to make cement.

#### **Step 4 - Cement milling**

To produce the final product the clinker is mixed with gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ), which is added as a set retarder, and ground for. The cement flows from the inlet to the outlet of the mill (a rotating chamber), being first ground with steel balls. The first grinding break up the material and the second grinds it to a fine powder. The amount of grinding is governed by the volume of cement fed into the mill: the greater the volume the coarser the grind. Each cement product is stored in an individual bulk silo until needed by the customer & can be distributed by truck or other mode of transportation depending on customers need.

Table 2.15: The Manufacturing process of Portland Cement

Steps	Activities Description
1	Digging, grinding and mixing the raw material
2	Burning in rotary kiln (Clinker is produced)
3	Cooling, grinding of clinker and sieving
4	Storing, packing and distributing

#### **2.2.1.15.2 Brief Overview of Kiln Operations**

The rotary kiln is an important component of a cement factory. It is a thick steel cylinder of diameter 3-8 meters and length sometimes reaching 200m. It is lined with refractory materials and rotates slowly on its axis which is slightly inclined. At the lower end fire is blown in by an air blast. The fuel is powered coal, oil or natural gas. As the slurry moves downward in the kiln, it encounters a progressively increasing temperature and undergoes a number of chemical changes. At 100°C – water is driven off and at 850°C – limestone changes to calcium oxide and carbon dioxide ( $\text{CO}_2$ ) will be given off. Upon reaching the hottest part, where the temperature reaches 1400-1500°C, the material sinters becoming 20-30% liquid. At this temperature lime, silica and alumina recombine to form new chemical compounds which fuses into balls, 10-25mm in diameter, which is the clinker. At the lower end of the kiln the cement clinker then drops into coolers.



Fig 2.3: Burning the mixture in the kiln and formation of Clinker [24]

### 2.2.1.15.3 Clinker Chemistry

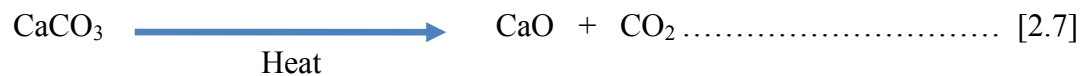
The reaction processes occurring within the kiln are not easily understood due to the wide variations in raw-mix chemistry, raw-mix physical properties and kiln operating conditions and the physical difficulties of extracting hot materials from the process for investigation before they cool.

Breaking the reaction processes into a number of simple zones means we can make some approximations about the cement formation process.

#### **Zone 1: 0 - 35 min, 800 – 1100 °C**

Decarbonation: Formation of  $3\text{CaOAl}_2\text{O}_3$  above  $900\text{ °C}$ ; Melting of fluxing compounds

$\text{Al}_2\text{O}_3$  and  $\text{Fe}_2\text{O}_3$ :



#### **Zone 2: 35 - 40 min, 1100 – 1300 °C**

Exothermic reactions and the formation of secondary silicate phases as follows:



#### **Zone 3: 40 - 50 min, 1300 - 1450 – 1300 °C**

Sintering and reaction within the melt to form ternary silicates and tetracalcium aluminoferrates:



**Zone 4: 50 - 60 min, 1300 – 1000 °C**

Cooling and crystallization of the various mineral phases formed in the kiln.

Immediately following the kiln is a large cooler designed to drop the temperature of the clinker (as the fused material is now called) from 1000°C to 150°C. This is achieved by forcing air through a bed of clinker via perforated plates in the base of the cooler. The cool clinker which is characteristically black, glistening, hard and porous is then fed into ball mills where it is inter ground with 5% of gypsum. The plates within the cooler slide back and forth, shuffling the clinker down the cooler to the discharge point and transport to a storage area. Once the desired degree of fineness is reached, to about 1 billion particles per gram, the cement is conveyed to storage silos. From the silos it is packed to 50Kg bags or fed directly to bulk cement Lorries.

The purpose of a cooler is, obviously, to cool the clinker. This is important for several reasons:

- ✓ From an engineering viewpoint, cooling is necessary to prevent damage to clinker handling equipment such as conveyors.
- ✓ From both a process and chemical viewpoint, it is beneficial to minimize clinker temperature as it enters the clinker mill. The clinker gets hot in the mill and excessive mill temperatures are undesirable. It is clearly helpful, therefore, if the clinker is cool as it enters the mill.
- ✓ From an environmental and a cost viewpoint, the cooler reduces energy consumption by extracting heat from the clinker, enabling it to be used to heat the raw materials.
- ✓ From a cement performance viewpoint, faster cooling of the clinker enhances silicate reactivity.

The cooled clinker is then conveyed either to the clinker store or directly to the clinker mill. The clinker store is usually capable of holding several weeks' supply of clinker, so that deliveries to customers can be maintained when the kiln is not operating.

At this point in the process the materials have been formed into all the required minerals to make cement. Like cement, the clinker will react with water and harden, but because it is composed of 1-3 cm diameter fragments it is too coarse to be used [24].

Generally, the four main compounds that are present in cement and percentage of which decides (one of the parameter) the quality of cement are Tricalcium Silicate, Dicalcium Silicate, Tricalcium Aluminate and Tetracalcium Alumino Ferrite.

Table 2.16: Reaction in the kiln and formation of compounds

Temperature in Degree Centigrade	Reactions	Thermal Change	Clinker Compounds Formed
100	Evaporation of free water from raw meal	Endothermic	
500+	Evolution of combined water from clay	Endothermic	
800+	$\text{CaCO}_3 = \text{CaO} + \text{CO}_2$	Endothermic	
800-900	$\text{CaO} + \text{SiO}_2 = \text{CaO} \cdot \text{SiO}_2$	Exothermic	C <sub>2</sub> S
900-950	$5\text{CaO} + 3\text{Al}_2\text{O}_3 = 5\text{CaO} \cdot 3\text{Al}_2\text{O}_3$	Exothermic	C <sub>3</sub> A <sub>3</sub>
950-1200	$2\text{CaO} + \text{SiO}_2 = 2\text{CaO} \cdot \text{SiO}_2$	Exothermic	C <sub>2</sub> S
	$2\text{CaO} + \text{Fe}_2\text{O}_3 = 2\text{CaO} \cdot \text{Fe}_2\text{O}_3$	Exothermic	C <sub>2</sub> F
1200-1300	$3\text{CaO} + \text{Al}_2\text{O}_3 = 3\text{CaO} \cdot \text{Al}_2\text{O}_3$	Exothermic	C <sub>3</sub> A, C <sub>4</sub> AF
1250-1280	Beginning of Liquid formation	Endothermic	Molten
1260-1450	$3\text{CaO} + \text{SiO}_2 = 3\text{CaO} \cdot \text{SiO}_2$	Endothermic	C <sub>3</sub> S
1100-1300	Formation of clinker compounds	“Cooling zone”	C <sub>3</sub> S, C <sub>2</sub> S, C <sub>3</sub> A, C <sub>4</sub> AF

Of these compounds, C<sub>3</sub>S and C<sub>3</sub>A are mainly responsible for the strength of the cement. High percentages of C<sub>3</sub>S (low C<sub>2</sub>S) results in high early strength but also high heat generation as the concrete sets. The reverse combination of low C<sub>3</sub>S and high C<sub>2</sub>S develops strengths more slowly (over 52 rather than 28 days) and generates less heat. C<sub>3</sub>A causes undesirable heat and rapid reacting properties, which can be prevented by adding CaSO<sub>4</sub> to the final product. C<sub>3</sub>A can be converted to the more desirable C<sub>4</sub>AF by the addition of Fe<sub>2</sub>O<sub>3</sub> before heating, but this also inhibits the formation of C<sub>3</sub>S. C<sub>4</sub>AF makes the cement more resistant to seawater and results in a somewhat slower reaction which evolves less heat.

The balance of the formed compounds versus the performance characteristics required from the cement is a chemically controlled parameter. For this reason considerable efforts are made during the

manufacturing process to ensure the correct chemical compounds in the correct ratios are present in the raw materials before introduction of the materials to the kiln.

### **2.2.1.16 TESTING OF CEMENT**



Tests are conducted to ensure the quality of cement and/or determine the chemical and physical properties of cement. There are many ways and methods for the testing of cement. Some of them need a proper laboratory setup while other can be conducted at field itself. For the sake of convenience we will divide the methods under following two categories as (i) Tests in Field and (ii) Tests in Laboratory.

#### **i. Tests in Field**

Field tests are convenient way of primary inspection of cement when it is used in small scale works or when decision has to be made during purchase process. These are some of the steps that can ensure you good quality cement while inspection at site:-

- a. First cement bags should be open a little wide for visible inspection. There should not be any lumps formation inside the bag.
- b. Put your hand inside the bag and ensure additionally that there are not any hidden lumps. Also this activity should give you a feel of cool sensation on your hands.

- c. Take a sample of cement in your hand and rub it in between your fingers. It should be smooth in nature.
- d. Take another handful sample of cement and throw it in the bucket full of water. Particles of cement should float a while before sinking down.
- e. Take about 100 grams of cement and a small quantity of water and make a stiff paste. From the stiff paste, pat a cake with sharp edges. Put it on a glass plate and slowly take it under water in a bucket. See that the shape of the cake is not disturbed while taking it down to the bottom of the bucket. After 24 hours the cake should retain its original shape and at the same time it should also set and attain some strength.

If the cement satisfies the above field tests it may be concluded that the cement is not bad, however this test does not give any quantitative result.

## **ii. Tests in Laboratory**

Field tests only indicate that cement is not bad and can be used for small scale works. Thus Laboratory tests are necessary to confirm that cement is good in nature and can even be used for important works too. Following tests are necessary to be conducted on cement in laboratory:-

### **ii.1) Physical Tests**

- a) **Fineness Test**-The fineness of cement can be defined as the measure of size of particles of cement or in simple form “Specific Surface of Cement”. This test is usually carried out using IS sieve no.9 or 90 microns. Fineness of cement is tested in two ways; by sieving (rarely used) and by determination of specific surface (total surface area of all the particles in one gram of cement). The specific surface can be determined by the Air permeability and Blain test apparatus.

The fineness of cement has a direct effect on the rate at which cement hydrates. Finer cements cause a more rapid generation of heat and greater strength gain, particularly during the early period of hydration. Coarser-ground cement (250 to 280m<sup>2</sup>/kg) tends to produce lower early strength than conventionally ground cement (320 to 400m<sup>2</sup>/kg) and may affect the workability and bleeding of the concrete. Higher fineness (exceeding 400m<sup>2</sup>/kg) tends to increase early strength development and

reduce bleeding. The fineness of cement has increased over the years primarily because of user demands for more rapid strength development in concrete. Concrete mixtures with high fineness ground cements will generally have a higher water demand for the required consistency and will bleed at a slower rate. Cements having fineness above 400m<sup>2</sup>/kg typically requires higher dosages of air entraining admixtures to achieve a given level of air entrainment in concrete.

b) **Setting Time Test-** Cement forms a solid and hard mass when mixed with water upon hydration.

This phenomenon is known as setting of cement. The duration of cement paste requires to undergo setting is setting time. As setting is the consequence of hydration of cement, setting time is affected by the amount of water used to prepare cement paste, i.e. its water – cement ratio. Cement pastes with different water – cement ratio will, generally, have different setting times. Therefore it seems confusing, at first, which setting time to use. As a convention, it is the setting time of cement paste with normal consistency that is referred to as the setting time of cement.

Generally there are two types of setting time to be determined in the laboratory, initial and final setting times. The initial setting time is the duration of cement paste related to 25mm penetration of the vicat needle in to the paste in 30 seconds after it is released while the final setting time is that related to zero penetration of the vicat needle into the paste.

Ethiopian standard recommends that the initial setting time for cement not to be less than 45 minutes and the final setting time not to exceed 10hrs [17].

The setting characteristics of Portland cement paste are defined by initial set and final set. Initial set indicates the approximate time at which the paste begins to stiffen considerably, while final set roughly indicates the time at which the paste has hardened and can support some load. These times of set are tested according to standardized procedures and have no special relationship to concrete setting behavior. Generally, initial set occurs within 1 to 4 h, and final set in 3 to 6 h.

Setting times are affected by minor constituents in the cement such as alkalis and sulfates, by fineness, water-cement ratio, ambient temperature, and inclusion of mineral and chemical admixtures. Concretes generally set more slowly than cement paste because of the higher water-cement ratios. There are two types of abnormal setting behavior that should be mentioned:

- I. **False set:** This refers to the rapid setting that occurs without the liberation of much heat. Plasticity can be regained by further mixing without the need to add more water, and thus is not a problem where concrete is mixed for long periods (ready-mixed concrete). Increasing mixing time when possible will help to reduce a false set problem.
- II. **Flash set (or quick set):** This behavior is accompanied by the liberation of considerable heat. The plasticity of the mixture cannot be regained with additional mixing or water.
- c) **Strength Test-** The strength of cement is defined in MPa or N/mm<sup>2</sup>. For grade 33 Portland cement, strength should be around 33MPa in 28 days. Compression test is carried out to check the strength of cement.
  - d) **Soundness Test-** Soundness of cement can be defined as a process in which cement does not show any considerable change in volume after setting. Autoclave tests and Le Chateleur tests are carried out to check the soundness of cement.
  - e) **Heat of Hydration Test-** The heat of hydration can be defined as heat from cement paste liberated as a reaction of water with cement. This test is usually carried out in thermos flask.

Heat is liberated during the hydration reactions of the cement compounds. The amount of temperature rise in a concrete mass will depend on the cement content, the rate of hydration (determined by cement fineness, ambient temperature, and admixtures), the cement composition, the volume of aggregate, the thickness of the concrete member, and the rate at which heat is lost by the concrete to the surroundings. The heat of hydration may cause considerable rise in concrete temperatures in the first few days of hydration, and temperature will continue to rise in mass concrete over longer periods. In cold weather, the heat of hydration may be utilized to help protect the concrete from freezing and increase the rate of hydration. Fly ash and other pozzolans or ground granulated blast-furnace slag can be used as a partial replacement for Portland cement to control the heat gain of mixtures during hot weather or in mass concrete. Cement composition and fineness affect the rate of heat generation. C<sub>3</sub>A and C<sub>3</sub>S are primarily responsible for high early heat generation. The rate of hydration will be faster as the fineness of the cement grind increases, although the total heat of hydration over a long time will not be particularly affected. Concrete proportions influence the amount of generated heat primarily as a result of cement content, with higher cement contents raising the heat of hydration.

## ii.2) Chemical Composition Test

Chemical tests are normally conducted by the manufacturer on regular basis in order to check the quality of the product. They may also be conducted in research laboratories in order to determine the compound composition of the cement used in a research. Chemical tests are of little importance to the ordinary consumer. The results of chemical tests are reported in terms of oxides which are used to calculate the compound composition by Borgue method.

Ethiopian Standard ES 1176-2:2005 sets quality requirements of Portland cement as follows:

### A. Lime Saturation Factor

The lime saturation factor (L.S.F.) shall not be less than 0.66 or more than 1.02 when calculated by the following formula:

$$\text{L.S.F.} = \frac{\text{CaO} - 0.7(\text{SO}_3)}{2.8(\text{SiO}_2) + 1.2 (\text{Al}_2\text{O}_3) + 0.65(\text{Fe}_2\text{O}_3)} \quad [2.11]$$

### B. Alumina-Iron Oxide ratio ( $\text{Al}_2\text{O}_3:\text{Fe}_2\text{O}_3$ )

The ratio of the percentage of alumina to the percentage of iron oxide shall not be less than 0.66. The decrease in the ratio may result from an increase in ferric oxide content which reduces the proportion of  $\text{C}_3\text{A}$  and increases that of  $\text{C}_4\text{AF}$  in the cement.

C. **Magnesia (MgO):** The mass of magnesia (magnesium oxide) contained in Portland cement shall not exceed 5.0%. The upper percentage limit is to avoid the long-term unsoundness that results from higher percentage content of MgO.

D. **Sulphur trioxide ( $\text{SO}_3$ ):** The mass of sulphur trioxide shall not exceed 3% if the  $\text{C}_3\text{A}$  is 8% or less, and shall not exceed 4% if  $\text{C}_3\text{A}$  exceeds 8%. An upper limit of  $\text{SO}_3$  is specified in order to avoid unsoundness resulting from the delayed hydration of the sulphate phase.

E. **Loss in mass on ignition:** The total loss in mass when Portland cement is heated to a temperature of  $925 \pm 25^\circ\text{C}$  shall not exceed 4%. The loss in mass on ignition is determined in order to check on possible pre-hydration or carbonation which may result from improper or prolonged storage of the clinker or resulting cement.

- F. **Insoluble residue:** The mass of insoluble residue shall not exceed 1.5%. The insoluble residue is that part of a cement sample which is insoluble in HCl. It derives from the clay minerals of the raw materials which have not reacted to form the cement compounds which are soluble in this acid. The amount of insoluble residue indicates the efficiency of the burning process, the completeness of the reactions in the kiln.

A test is carried out on cement that tests the ratio of chemicals in the cement. Different standards and codes specify different value of such ratios. Ethiopian Standard, ES 1176-2:2005 is intended for the determination of the major oxide contents of Portland cement, conforming to BS12:1991, within the following compositional ranges.

Table 2.17: Compositional Ranges of Oxides of Portland Cement [13]

Chemical Compound	Percentage
Lime, CaO	61-69
Silica, SiO <sub>2</sub>	18-24
Alumina, Al <sub>2</sub> O <sub>3</sub>	2.6-8
Iron Oxide, Fe <sub>2</sub> O <sub>3</sub>	1.5-7.0
Magnesia, MgO	0.5-4.0
Sulphur trioxide, SO <sub>3</sub>	0.2-4.0
Alkalis	0.3-1.2

### ii.3) Principles of Chemical Test to Determine the Main Constituents

The analysis is carried out after the sample is completely dissolved. The cement is decomposed by sintering with sodium peroxide or by treatment with hydrochloric acid in the presence of ammonium chloride. In the first case, after dissolution of the sintered solid in hydrochloric acid, the major part of the silica is precipitated either by hydrochloric acid with coagulation by polyethylene oxide or by double evaporation; in the second case, the major part of the silica is separated by the treatment. The impure silica precipitated is treated with hydrofluoric acid and Sulphuric acid to volatilize silica; the residue, treated with a mixture of sodium carbonate and sodium chloride, is dissolved in hydrochloric acid and added to the silica filtrate.

In the case of the treatment with hydrochloric acid in the presence of ammonium chloride, if the residue obtained after volatilization of impure silica by means of hydrofluoric acid and sulfuric acid is

greater than 0.5 %, the method is not applicable. The cement shall in this case be decomposed by sodium peroxide. In the final solution made up to 500ml, the silica in solution is determined by photometric determination, and iron (III) oxide, aluminium oxide, calcium oxide and magnesium oxide are determined by complexometric methods [13].

### **2.2.2 AGGREGATES**

Aggregates are part of a large parent material, which may have been fragmented by a natural process of weathering and abrasion or artificially by crushing. As a result, many properties such as chemical and mineral composition, specific gravity, hardness, strength, physical and chemical stability, pore structures; colors depend entirely on the properties of the parent rock. These properties are very essential in production of quality concrete.

Apart from the properties of the parent material, there are aggregate properties such as grading, shape, surface texture which are very important than the properties of the parent material in producing strong, durable and economical concrete.

In a concrete mixture the aggregates form the inert mineral filler material which the cement paste binds together. Cement is the most expensive of the materials used to make concrete. For this reason and because the aggregates provide a relatively cheap filler, it is advisable to use as much aggregates as a given amount of paste will bind together. In addition to being relatively cheap filler, the aggregates reduce the volume changes resulting from the setting and hardening process and from moisture changes in the paste.

Contributing about 75 % by volume of concrete; creating stability from volume change and by far cheaper than cement, aggregate affects not only the properties of the concrete but also its economy. Thus, care should be given in choosing aggregate in concrete production.

While choosing an aggregate for the production of a particular concrete attention should be given, among other things, to three important requirements:

1. **Workability:** The size and gradation of the aggregate should be such that undue labor in mixing and placing will not be required.

2. **Strength and durability:**

When hardened – for which the aggregate should:

- a. be stronger than the required concrete strength
- b. contain no impurities which adversely affect strength and durability
- c. not go into undesirable reaction with the cement
- d. be resistant to weathering action

**3. Economy of the mixture:** - meaning to say that the aggregate should be

- a. available from local and easily accessible deposit or quarry
- b. well graded in order to minimize paste, hence cement, requirement

Strength of concrete depends on the strength of aggregate, cement paste, the bond between the aggregate and the surrounding cement paste and the overall adhesion and compaction of the concrete particles.

Aggregate strength and other prominent properties of aggregate that affect the bond between the aggregate and the cement paste and the overall adhesion and compaction of concrete are of paramount importance in producing strong, durable and economical concrete. It is, therefore, not over-emphasized to discuss in detail these aggregate properties.

#### **2.2.2.1 Aggregate Strength**

For normal concrete, the compressive strength of concrete cannot significantly exceed that of the major part of the aggregate contained therein; however, the same may not be true for aggregates in high strength concrete.

Hence, although it is not easy to state what the strength of the individual particles is, it is crucial to measure the crushing strength of aggregates particularly for high strength concrete. Indeed, it is difficult to test the crushing strength of individual aggregate particles, and the required information has to be obtained usually from indirect tests of the physical or mechanical properties like: Aggregate Crush Value, Aggregate Impact Value, force required to compact bulk aggregate, and performance of aggregate in concrete.

The latter simply means either previous experience with the given aggregate or a trial use of the aggregate in a concrete mix known to have certain strength with previously proven aggregates. If the aggregate under test leads to a lower compressive strength of concrete and especially if numerous individual aggregate particles appear fractured after the concrete specimen has been crushed, then the strength of the aggregate is lower than the nominal compressive strength of the concrete mix in which

the aggregate was incorporated. Clearly, such aggregate can be used only in a concrete of lower strength.

The strength of concrete is influenced not only to the mechanical strength of the aggregate but also, to considerable degree, by its absorption and bond characteristic. So, it is important to learn about aggregate properties that affect the bond between the aggregate and cement paste.

### **2.2.2.2 Properties Affecting The Bond Strength Between Aggregate And Cement Paste**

The shape, surface texture, the chemical properties like Alkali – silica reaction, compatibility between the aggregate and the surrounding hydrated cement paste in terms of the modules of elasticity, poisson's ratio, shrinkage, creep and thermal properties are measures of the bond strength between the aggregate and cement paste. Besides, deleterious substances are one of the factors, of course the main factor, which affects this bond.

To ensure good bond between the coarse aggregate particles and the matrix, the particles should be approximately equal in dimension, rough in texture, cleanliness of the aggregate, absence of adhering dust, and uniformity of grading are essential. Gravel is satisfactory as far as shape is concerned and it can be used in all classes of concrete, but the aggregate-matrix bond may be inadequate when the surface texture of the gravel is very smooth.

### **2.2.2.3 Aggregate Properties Affecting Degree of Compaction**

For a concrete to have better strength, the aggregate should be well compacted and grading, shape and surface texture are also among the main factors in determining the degree of compaction with a reasonable effort and without causing segregation.

There are criteria like flakiness index and elongation on shape of aggregates and generally the effects of aggregate shape and texture on compaction are well established, but it is not easy and economical to put restriction on aggregate shape and texture for its usage. As a result most standards emphasize more on aggregate grading than in shape and texture.

#### **2.2.2.3.1 Grading**

Grading stands for grain – size distribution of aggregates. As a matter of convenience, aggregates are generally divided into two size ranges, namely: coarse aggregate and fine aggregate. Coarse aggregate

is the fraction of materials retained on No.4 (4.75mm) sieve and fine aggregates the fraction passing No.4 and retaining No.100 (0.15mm).

### **2.2.2.3.1.1 Grading Requirement and Practical Grading**

The strength of fully compacted concrete with a given water/cement ratio is independent of the grading of the aggregate. Grading is, however, important for its effect on workability. That is, achieving the strength corresponding to a given water/cement ratio requires full compaction, and it is necessary to produce a mix that can be compacted a maximum density with a reasonable amount of work [9].

It has been suggested that the main factors governing the desired aggregate grading are: the surface area which determines the amount of water necessary to wet all the solids, the relative volume occupied by the aggregate, the workability of the mix, and the tendency of segregation.

It is obvious that coarser aggregates have smaller surface area and need lesser amount of water and hence better strength for a given workability. However, the voids between these aggregates have to be filled with cement paste which is uneconomical, or honey combed concrete is to be produced which is undesirable for strength and durability of the concrete. When more fine is used, there is high surface area and a corresponding higher amount of water is required. For a given water/cement ratio this is uneconomical and also a danger of shrinkage. The increase in specific surface area of the aggregate for a constant aggregate/cement ratio has also been found to lead to a lower strength. The requirement that the aggregate occupies as large a relative volume as possible is, in the first instant, an economical one the aggregate being cheaper than the cement paste, but there are also strong technical reasons why too rich mix is undesirable.

For better compaction or strength, the mix should be sufficiently workable and as much as possible segregation should be avoided. However, the requirements of consistency and absence of segregation tend to be opposed one another.

The above facts are the background that there is no ideal grading curve that fulfills all the aforementioned requirements, but a compromise is aimed at. Moreover, while ensuring appropriate grading of aggregate is of considerable important, arbitrarily imposition of limits, which are uneconomical or nearly impossible in a given location, is inappropriate. From the above fact there is a need for good grading limits of each standard aggregate size. These grading limits have been

determined intending to provide fairly dense packing of aggregate practices which again to minimize the cement paste requirement and a reasonable workability and minimum segregation.

Finally it is worthy to remember that not lesser important than devising a good grading is ensuring that the grading is kept constant, otherwise a variable workability results and when this is corrected at the mixer by a variation in the water content, concrete of variable strength is obtained.

In all standards the main criteria in the classification of aggregate in to different grading is the aggregate maximum size. Hence, it is crucial to discuss about what makes this aggregate maximum size important.

#### **2.2.2.3.1.2 Maximum Aggregate Size**

The maximum aggregate size of an aggregate is defined the largest size through which at least 90% of the aggregate passes. Before hand, the maximum aggregate size shall be specified. And there are three criteria to be considered in determining the maximum aggregate size [10]. These are:

- 1) Bond area,
- 2) The desired performance of the concrete, and
- 3) Structural imitation

##### **2.2.2.3.1.2.1 Bond Area**

It is obvious that the larger the aggregate particle the smaller the surface area to be wetted per unit mass. Thus, extending the grading of aggregates to larger mean size lowers the water requirement of the mix, so that for a specified workability and cement content, the W/C ratio can be lowered with a consequence increase in strength.

However, there is a limit of maximum aggregate size above which the detrimental effects of a lower bond area offset the decrease water demand and of discontinuities introduced by the large particles .In consequence, concrete becomes grossly heterogeneous, with a resulting lowering of strength.

The adverse effect of an increase in size of the largest particles in the mix exists; in fact, throughout the range of sizes, but below 40 mm (1 ½ in) the advantage of the lowering the water requirement is dominant [9].

### **2.2.2.3.1.2.2      *The Desired Performance of The Concrete***

In producing high performance concrete, the required quality of aggregate is the size of the coarse aggregate. Large particles of aggregate are undesirable because they introduce heterogeneity in the system that, at the interface, there may be an incompatibility between the aggregate and the surrounding hydrated cement paste in terms of the modules of elasticity, poisson's ratio, shrinkage, creep and thermal properties. This incompatibility may lead to more micro cracking than when the maximum size of aggregate is smaller than 10 to 12 mm. Although a smaller maximum size of aggregate leads to higher water demand, this is of little important when the dosage of super plasticizer is used [9].

The larger total surface area of the aggregate with smaller maximum size also means that the bond stress is lower so that the bond failure does not occur. That is why failure occurs through the coarse aggregate and the hydrated cement paste while in compression or flexural test.

### **2.2.2.3.1.2.3      *Structural Limitation***

Size of concrete section and the horizontal and vertical reinforcing bars spacing are the structural limitations that dictate for the maximum size of aggregate. The governing values are prescribed in codes of practice.

## **2.2.3      WATER**

Water that is acceptable for drinking (except in respect of bacteriological requirements) is suitable for making concrete. Curing water should be free of materials that significantly affect the hydration reaction of the cement or promote possible alkali – silica reaction or produce unsightly stain or deposit on the surface [11].

The function of the water, other than enabling the chemical reactions which cause setting and hardening to proceed, is to lubricate the mixture of aggregates and cement in order to facilitate placing.

The amount of water mixed with the cement determines the strength of the hardened paste. The use of too much mixing water will thin or dilute the fresh cement paste and weaken its cementing properties when hard. Consequently, it will be readily seen that the strength and quality of concrete depend primarily upon the quality and quantity of water mixed with the cement. The relation between the amounts of water and cement used in a mixture is called the water-cement ratio.

## 2.2.4 ADMIXTURE

Admixtures are chemicals which are added to concrete at the mixing stage to modify some of the properties of the mix. Admixtures should never be regarded as a substitute for good mix design, good workmanship, or use of good materials [30].

### 2.2.4.1 Uses of admixtures

The most common reasons for using admixtures in concrete are:

- ✓ To increase workability without changing water content.
- ✓ To reduce water content without changing workability.
- ✓ To effect a combination of the above.
- ✓ To adjust setting time.
- ✓ To reduce segregation and/or bleeding.
- ✓ To improve pump ability.
- ✓ To accelerate the rate of strength development at early ages.
- ✓ To increase strength.
- ✓ To improve potential durability and reduce permeability.
- ✓ To reduce the total cost of the materials used in the concrete.
- ✓ To compensate for poor aggregate properties.

### 2.2.4.2 Types of admixtures

Admixtures are normally categorized according to their effect:

- ❖ Plasticizers (water-reducing agents)
- ❖ Superplasticizers (high range water reducers)
- ❖ Air entrainers
- ❖ Accelerators
- ❖ Retarders
- ❖ Others

Many admixtures provide combinations of properties such as plasticizer/retarders or plasticizer/air entrainers. Each admixture type is discussed in the following sections.

#### 2.2.4.3.1 Plasticizers

When added to a concrete mix, plasticizers (water-reducing agents) are absorbed on the surface of the binder particles, causing them to repel each other and deflocculated. This results in improved workability and provides a more even distribution of the binder particles through the mix.

The main types of plasticizers are lignosulphonic acids and their salts, hydroxylated carboxylic acids and their salts, and modifications of both.

**Uses:-**

- ✚ Plasticizers usually increase the slump of concrete with given water content.
- ✚ Plasticizers can reduce the water requirement of a concrete mix for a given workability, as a rule-of-thumb, by about 10%.
- ✚ The addition of a plasticizer makes it possible to achieve a given strength with lower cement content.
- ✚ Plasticizers may improve pump ability.

**Practical considerations:-**

- A number of plasticizers contain a retarder and can cause problems if overdosed.
- While some plasticizers entrain varying amounts of air, others are reasonably consistent in the amount of air they entrain.
- Where plasticizers are used to increase workability, the shrinkage and creep will invariably be increased.

**2.2.4.3.2 Superplasticizers**

These admixtures are chemically distinct from normal plasticizers and although their action is basically the same, it is more marked. When they are used to produce flowing concrete a rapid loss of workability can be expected and therefore they should be added just prior to placing.

Superplasticizers are usually chemical compounds such as sulphonated melamine formaldehyde, sulphonated naphthalene formaldehyde, modified lignosulphonates and Polycarboxylate based materials.

**Uses:-**

Superplasticizers are used to best advantage:

- In areas of congested reinforcement.
- Where a self-leveling consistence facilitates placing.
- For high-strength concretes by decreasing the water: cement ratio as a result of reducing the water content by 15–25%.

**Practical considerations:-**

- ➔ Special mixes must be designed for Superplasticizers and their use must be carefully controlled.
- ➔ The effect of a Superplasticizer will last between 30 minutes to 6 hours depending on the admixture used.
- ➔ They have a relatively high unit cost.

**2.2.4.3.3 Air entrainers**

An air-entraining agent introduces air in the form of minute bubbles distributed uniformly throughout the cement paste. The main types include salts of wood resins, animal or vegetable fats and oils and sulphonated hydrocarbons.

**Uses:-**

- ✓ Where improved resistance of hardened concrete to damage from freezing and thawing is required.
- ✓ For improved workability, especially in harsh or lean mixes.
- ✓ To reduce bleeding and segregation, especially when a mix lacks fines.

**Practical considerations:-**

- ✚ Air entrainment may reduce the strength of concrete and overdosing can cause major loss of strength. As a rule-of-thumb, 1% air may cause a strength loss of 5%. It is therefore important that mixes be specially designed for air entrainment and that the percentage of air entrained during construction is monitored.
- ✚ Because the doses are so small, special dispensers and accurate monitoring are required.
- ✚ Different types and sources of cement/cement extenders may result in the entrainment of different amounts of air for the same dose and mix proportions.
- ✚ A change in cementitious content, in the grading or proportions of the fine fractions of sand will normally alter the volume of air entrained.
- ✚ The amount of air entrained may depend on the source and grading of sand in concrete.
- ✚ Forced-action mixers entrain larger volumes of air than other types.
- ✚ Increasing ambient temperature tend to reduce the volume of air entrained.
- ✚ The use of ground granulated blastfurnace slag (GGBS) and fly ash (FA) tends to reduce the amount of air entrained.

✚ Duration of mixing can also affect air content.

#### **2.2.4.3.4 Accelerators**

These admixtures speed up the chemical reaction of the cement and water and so accelerate the rate of setting and/or early gain in strength of concrete. Among the main types of accelerators are chloride based, non chloride bases and shotcrete accelerators.

##### **Uses:-**

- Where rapid setting and high early strengths are required (e.g. in shaft sinking).
- Where rapid turnover of moulds or formwork is required.
- Where concreting takes place under very cold conditions.

##### **Practical considerations:-**

- ❑ All chloride-based accelerators promote corrosion of reinforcing steel and should not be used in Reinforced concrete, Water-retaining structures, prestressed concrete, and Steam-cured concrete.
- ❑ Overdosing with these materials can cause instant setting of the concrete resulting in equipment damage.
- ❑ Accelerators work more effectively at lower ambient temperatures.

#### **2.2.4.3.5 Retarders**

These admixtures slow the chemical reaction of the cement and water leading to longer setting times and slower initial strength gain. The most common retarders are hydroxylated carboxylic acids, lignin, sugar and some phosphates.

##### **Uses:-**

- When placing concrete in hot weather, particularly when the concrete is pumped.
- To prevent cold joints due to duration of placing.
- In concrete which has to be transported for a long time.

##### **Practical considerations:-**

- ✓ If a mix is overdosed beyond the limit recommended by the supplier, retardation can last for days.
- ✓ Retarders often increase plastic shrinkage and plastic settlement cracking.
- ✓ Delayed addition of retarders can result in extended retardation.

#### **2.2.4.3.6 Other admixtures**

Other admixtures with different chemical compositions and effects are available (e.g. pumping aids, pigments, expansion aids and grouting admixtures).

#### **2.2.4.3 Design of mixes**

A laboratory test program should be carried out to optimize dosages of admixtures with the cements/blended cements and aggregates which will be used on the site. This program should be based on good concrete mix design and correct laboratory methods. It is also essential to verify the proposed mixes under site conditions.

The control mix (i.e. one without admixture), should be prepared before any other to prevent trace contamination with the admixture under test.

Changes in materials or ambient conditions (e.g. temperature) may also change the effectiveness of admixtures; trials are essential if such changes are envisaged.

If more than one effect is desired, then more than one admixture may be required. The compatibility of admixtures, particularly if from different suppliers, needs to be tested using materials from the site.

#### **2.2.4.4 Storage and handling**

Most admixtures are aqueous solutions of active chemicals that are biodegradable. These two factors define the general rules for storage.

Admixtures should be protected from frost, as most have freezing points at or below 0°C. When an admixture freezes, the chemicals crystallize out of the solution and do not readily go back into solution on thawing.

It is also necessary to protect admixtures from heat because their degradation is accelerated at elevated temperatures. They should be stored out of direct sunlight and away from other heat sources.

Admixtures generally contain preservatives to reduce biodegradation and extend shelf life. Despite this, the activity and effectiveness of an admixture will gradually decrease with time. Therefore they should be used on a first-in-first-out basis.

Admixtures are normally stored on site in 200 l drums or in bulk storage tanks. Bulk liquid storage tanks are often supplied, serviced and maintained by the admixture supplier. Drums should be handled with care.

#### **2.2.4.5 Dosage and dispensing**

The correct dosage of admixture is crucial for satisfactory mix performance and the proper use of well maintained and calibrated dispensing equipment is essential. The optimum dosage of admixtures meet specific job site requirements should be determined by site trials using the selected cement, cement replacement materials (mineral additions) and aggregates. In addition to this, it is important to follow the manufacturer's technical details and recommendations and if necessary, it is possible to contact the company's local technical representatives.

Admixture suppliers normally provide, install and service dispensers which are either manual or automatic.

Admixtures should be added to a concrete during mixing with the last portion of the mix water in order to ensure even dispersion of the admixture throughout the concrete, unless delayed addition is necessary for a specific purpose. The admixture should not be added directly to the dry cement or aggregates.

For the majority of admixtures it is not necessary to change the concrete mixing procedure. Any special requirements will be given in the admixture manufacturer's product literature.

#### **2.2.4.6 Safety**

While most admixtures are not hazardous to health, certain admixtures are caustic in nature and some may be flammable.

The following safety procedures apply to all admixtures.

Avoid eye, mouth and skin contact as all chemicals should be regarded as toxic and corrosive. Contamination should be washed off immediately with plenty of fresh water. Contaminated clothing should be removed and washed.

Seek medical advice in cases of serious eye contamination, ingestion or excessive inhalation of fumes.

Admixture spillage will cause floor areas to become slippery and unsafe. Spillage should immediately be hosed down with water to prevent accidents.

## **CHAPTER THREE**

### **PRODUCTION PROCESS OF DERBA CEMENT**

#### **3.1 BACKGROUND ABOUT THE COUNTRY ETHIOPIA [12]**

Cement is an important ingredient in concrete locking together the sand and gravel constituents in an inert matrix. It is one of the principal building and construction materials in building and construction sectors. It is therefore essential to meet society's needs for housing and basic infrastructure such as bridges, roads, water treatment facilities, schools and hospitals.

The cement industry is a well- established manufacturing industry dating back to the Greek and Roman Empires where cement was used in structures over 2000 years ago. The modern cement industry dates back to the 1800s.

Cement, one of the major inputs for the construction industry, has been an obstacle for the sector over the past decade especially three and four years ago in Ethiopia. Following governmental and private construction investment in the sector, a surplus demand occurred in tandem with the pace of development in the country. According to a survey done by Muger in 2007, the country's demand for cement was 17.8 million tons annually, whereas the country's total production was only limited to 1.9 million tons per annum. But now the demand is not greater than 6 million tons which implies that decline in the sector. The problem was partly due to a foreign exchange reserve shortfall in the country, which has led to a drop in imports.

After some years, DMC had started to supply up to 400 quintal of cement for interested buyers using its own transportation system, which was new for the sector. But this product was not highly anticipated in the market despite the fact that the company offers large discount when compared with others. The product newness was the main reason. This took a few months until clients verify the product quality, and that is why, among the many reasons, I decided to study the uses of this cement especially for structural concrete production.

Quality wise, retailers reckoned, Muger was a favorite for customers more than any other products; but, Muger Cement Enterprise, the biggest player of the five cement factories in the country of the

time, could only meet five percent of the total demand. In addition to this, the production cut of Mugher for maintenance purpose had been one of the factors for the price hike at that time.

In Ethiopia, a cement factory was established by Italians in 1936 during the five year fascist occupation of the Country in Dire Dawa. Currently, there are 18 cement plants with a combined production capacity of about 12 million metric tons per year. However, cement demand in Ethiopia is not greater than 6 million tones, thus raising per capita cement consumption in the country to 67 kilograms. This goes against with the government's expectations for a significant rise in cement demand, in its Growth & Transformation Plan (GTP). It had predicted that the demand would grow to 27 million tons of cement, against the 12 million tons that the existing 18 plants would be able to supply by 2014/15. Successful achievement of the plan means the country's cement consumption per capita will jump from 35Kg to 300Kg. However, such a level would still be behind the global average of 390kg/capita/yr.

These cement plants presently manufacture cement mainly for the local market. However, the Messebo Cement plant has started exporting cement to the neighboring countries, the Sudan and Djibouti. But currently, a huge cement factory called Derba MIDROC Cement PLC is inaugurated and is executing a number of cement production projects in different parts of the country since January 2012. The 5500 tpd clinkerization (7500 tpd cement) production plant to be put up at Derba 70 km from Addis Ababa will be the largest and state-of-the-art cement production plant in the country.

### **3.1.1 Resource Availability**

#### **3.1.1.1 Raw Material**

Limestone, Sand stone, Clay, Gypsum and Pumice are the major raw materials required for the production of cement. All these ingredients, which are essential to manufacture cement, are plentifully available in Ethiopia.

They occur in most of the Mesozoic sequences of the Country. High quality limestone, clay, gypsum and pumice occur in the vicinity of most of the cement plants in the Country.

#### **a. Limestone**

Limestone is one of the most abundantly available sedimentary rocks in Ethiopia and is presently used extensively to manufacture cement. The cement and lime industries are the main consumers of

limestone in Ethiopia. The lime stones of Mekele, the Mughher Valley and Dire Dawa have been well explored for utilization in the production of cement. Presently the widely available crystalline limestone is extensively used to manufacture Portland cement in the Country. High quality limestone is also exposed in other parts of the Country, but these occurrences require further assessment of their potential utilization in various industries.

**b. Clay**

Suitable clays for the manufacture of cement occur in the vicinity of Addis Ababa, between Debre Birhan and Debressina and at Mulo and Zega Wedem between Debre Zeit and Kaliti, at Sululta, near to the rift valley lake region and at Awzeit, Debre Tabor and Kerker in the Gondar Region of northern Ethiopia.

**c. Sandstone**

Sandstone is abundantly found in Tigray, Ambo, Harar and in the Abay River gorge, etc.

**d. Gypsum**

Gypsum is one of the most abundant mineral resources of Ethiopia. It occurs more abundantly in association with limestone in the Abay Gorge, Mekele, Mughher and Jemma Valleys, Ferfer, Dawalle and Hagera Selam. Gypsum also occurs in the Denakil depression (northern Ethiopia). Patches of gypsum are also found in the lacustrine beds of the Lower Awash River Valley near Asaita in the Southern Afar Region. A limited amount of gypsum is currently produced for domestic consumption, mainly for the cement and stucco production, at Mughher and at Filiklik near the Abay bridge and at Dewelle near Dire Dawa.

**e. Pumice**

Pumice is glassy, felsic lava, which is common in the regions of recent volcanic activity. Although the occurrence of pumice is widespread in Ethiopia, it is utilized mainly for the purpose of cement manufacture. The best known deposit is at Gari Baldi, about 60 km east of the town of Adama. Other occurrences, including that at Kimbibit in the Rift Valley, require more detailed assessment.

As shown below, geological studies in the past statistically substantiated the presence of most of the above cement raw material resources in different localities of Ethiopia.

Table 3.1: Localities of Cement Raw Materials Occurrences and Reserves of Ethiopia

Raw Material Type	Locality	Amount (metric ton)
Limestone	Oromia, Tigray, amhara, Harare, Dire Dawa	171550000
Clay	Tigray, Dire Dawa	21600000
Silica Sand	Oromia	3400000
Gypsum	Tigray, Oromia	57400,000
Pumice	Oromia, Afar, southern Ethiopia	Many million tones

Source: Ministry of Mines & Energy

### 3.1.1.2 Labor

Ethiopia is a large country with a population of over 90 million. This large population is the pool from which investors draw their employees (unskilled and semi-skilled workers or highly qualified professionals) and provides potential market for investors' products. Wages and salaries vary depending on the type of profession and level of skill required and is determined by agreement between the employer and the employee. The workforce is generally honest and low-cost.

### 3.1.1.3 Packaging Materials

The necessary packaging materials (paper sacks) for packaging cement are currently produced by Paper Sacks and Shopping Bag Making Plant with the production capacity of 60 million pcs of paper sacks. This plant was established in the year 2000 by Muger Cement Enterprise. So, the plant has sufficient capacity of producing and supplying paper sacks for the market.

### 3.1.1.4 Power Supply

The cement industry is highly energy intensive, requiring the availability of adequate energy supply for the smooth functioning of the industry. The country has currently sufficient power supply. The installed capacity of hydro and thermal plants of the country is presently about 4000 MW.

### 3.1.1.5 Water Supply

The water supply comes from river dams and from rainfall amounting to 500-2500 mm per year. Ground water at depths of less than 200 meters is available in many areas of the Country.

### 3.1.1.6 Telecommunications

At present the Ethiopian Telecommunication Corporation (ETC) provides all the telecommunication services in Ethiopia.

### **3.1.1.7 Road**

The density of the country's road network was 42.6km per 1000 km<sup>2</sup> and 0.57km per 1000 persons up to the end of RSDP III in 2009. However, the Government plans to increase the density from the current figures and to reach the average road density of Africa, that is, 60km per 1000km<sup>2</sup>. (ERA 2008b).

## **3.2 GENERAL ABOUT THE FACTORY**

Derba MIDROC Cement PLC is executing a number of cement production projects in different parts of the country. The 5000 tpd clinkerization (7000 tpd cement) production plant to be put up at Derba 70 km northwest of Addis Ababa will be the largest and state-of-the-art cement production plant in the country. The Client of the factory is Derba MIDROC PLC; the main production activities are outsourced and operated by the Chinese Contractor called CNBM and the Consultant is Indian Company called HOLTEC.

The project involves the construction of a Greenfield, integrated cement plant with captive quarry operations and a production capacity of up to 2.46 million tons per annum (tpa) in the western part of Ethiopia. The project company, Derba Midroc Cement Company (DMC), is sponsored by Sheikh Mohammed Hussein Ali Al-Amoudi, a Saudi businessman of Ethiopian descent.

The plant produces Ordinary Portland Cement (OPC) and Portland Pozzolana Cement (PPC) that will meet the requirements of Ethiopian National Standard ES 1177-1: 2005 or European Standard EN-197. The OPC will be produced as per CEM-I-42.5 grade and will contain 95% clinker and 5% gypsum. The PPC will be produced as per CEMII-32.5 grade and will contain 64-67% clinker, 25-28% pumice and 5% gypsum. The design and manufacturing of all production machineries of the plant are based on the latest state-of-the-art cement technology. The fuel used is Coal and HFO (Heavy Fuel Oil) alternatively.

The Power requirement of the plant is estimated to 46MVA. Power to the plant will be conveyed through a 132kv transmission line up to a substation at the boundary of the plant, then stepped down and distributed to the different user departments. Another 5 MW will be required for residential area

and related facilities. The total water requirement for the plant and domestic uses has been estimated as 3,000m<sup>3</sup>/day, which is planned to be availed by drilling a number of water wells to tap the ground water reserves [25].

### **3.2.1 Client's Community Engagement**

According to the ESIA report [15], a substantial stakeholder engagement process was undertaken during its preparation. This included a total of about 1,250 stakeholders, including members of affected households and communities, local administration officials, and peasant association (village) leaders from the project-affected area. Discussions were held in two main languages: Amahric, the national language, and Oromiffa, the local dialect spoken in the Mughher Valley area and in Oromia Region. Based on the information in the ESIA report and meetings with resettled households, village leaders, and local administration officials during the IFC appraisal mission, the team believes that the project has achieved broad community support. This support has been achieved via a process of free, prior and informed consultation.

### **3.2.2 Community Development Planning**

Based on comments received during the consultation process DMC has committed to provide a number of tangible benefits for surrounding communities. These include:

- ❖ Establishing a revolving fund to support local small and medium enterprises;
- ❖ preferential hiring of able-bodied locals (especially those whose land or housing has been affected by the project);
- ❖ Establishing a community development fund;
- ❖ upgrading local roads and creating access to isolated valley villages;
- ❖ providing basic health services to surrounding communities via funding for a new government clinic;
- ❖ upgrading local educational institutions; and
- ❖ Extending clean water supply to seven local villages [15].

### **3.2.3 Environmental Prevention and social issues**

The Company has acquired significant land acquisition resulting in physical and economic displacement of a significant number of local inhabitants of the project affected areas and associated

conversion of agricultural land to industrial usage in an area with little or industrial tradition. The project has been classified as a Category A project according to IFC's Environmental and Social Review Procedure because this land acquisition impact is considered to be significant, adverse and largely irreversible.

While all Performance Standards (PS) are applicable to this investment, IFC's (International Finance Corporation) environmental and social due diligence indicates that the investment will have impacts which must be managed in a manner consistent with the following Performance Standards:

**PS1:** Social and Environmental Assessment and Management Systems with respect to the company's management of its environmental, health and safety performance in the construction and operation of all facilities; compliance with national and local requirements; and its engagement with local communities regarding environmental, health and safety performance.

**PS2:** Labor and Working Conditions with regard to transparent and fair utilization of labor as well as safe and healthy working conditions, including subcontractors.

**PS3:** Pollution Prevention and Abatement with regard to emissions to air and water arising from transport of raw materials including fuel, cement manufacturing and quarrying operations, energy efficiency and possible use of alternative fuels, and issues related to the large number of trucks and drivers servicing the facilities.

**PS4:** Community Health, Safety and Security with respect to emissions control, quarry operations including quarry management and closure, management of community safety in relation to transportation of raw materials, inputs and product, and control of communicable diseases.

**PS5:** Land Acquisition and Involuntary Resettlement in respect of the need for land acquisition for the project and its infrastructure.

**PS6:** Biodiversity Conservation and Sustainable Natural Resource Management to ensure that no endangered species or critical habitats will be negatively influenced [26].

### **PS1: Social and Environmental Assessment and Management Systems**

Derba MIDROC is a new company and does therefore not currently have a fully developed Environmental and Social Management System (ESMS). The company has in its initial planning phase

relied on experienced international consultants, and these consultants have prepared the needed planning and documentation and undertaking the project and also the production process in accordance with good international practices.

The ESMS work carried out to date has been of high quality and has resulted in a good understanding of the basic risks and mitigation measures needed for a project of this size and complexity. This includes the development of a full Environmental and Social Impact Assessment (ESIA), an Environmental and Social Management Plan (ESMP), and a Resettlement Action Plan (RAP). These plans have been developed in consultation with a substantial number of project affected people. These plans are summarized in the following sections, according to their relevance for the specific Performance Standards.

DMC, in accordance with the ESMP, has established an ESMS to ensure ongoing compliance with the environmental, health and safety and social measures contained in the ESMP and to meet Ethiopian and lender requirements as the project develops further. DMC has also prepared quarry reclamation plans, in accordance with IFC Environmental, Health and Safety guidelines, for new quarries (limestone, clay, basalt, gypsum, and pumice) before operations commence. IFC and the other international lenders will require that Derba MIDROC's internal organization be established to comply with the principle of good ESMS practices as reflected in ISO and OHSAS norms. A monitoring plan to ensure these commitments are fulfilled in due time will be part of the loan documentation.

### **PS2: Labor and Working Conditions**

DMC is developing a Greenfield project and currently employs mostly senior employees as well as some Chinese contractors. Ethiopian labor laws are relatively strong and no inconsistencies were identified in relation to this Performance Standard at this early project development stage. DMC has agreed to incorporate the requirements of PS2 into its Human Resources Department once established. A monitoring plan to ensure these commitments are fulfilled in due time will be part of the loan documentation.

### **PS3: Pollution Prevention and Abatement**

The proposed plant is designed according to Best Practice (State-of-the-Art principles) and is producing with low energy consumption, good emission controls with continuous monitoring of key

pollutant emissions (particulate, nitrogen oxides, and Sulfur dioxide), zero discharge of waste water, and no solid or hazardous production waste, except for broken cement bags, canteen, office and laboratory waste, and maintenance wastes (used refractory bricks, lubricants, etc).

The energy efficiency of the kiln operation is, despite a location approximately 2,400 meters above sea level, resulting in a highly efficient performance at 745 kcal/kg clinker. Furthermore pumice, a volcanic material found locally, is used to lower the requirement of clinker in the final cement. With 80% of the cement being blended cement (67% clinker and the balance additives) and the remaining 20% being Portland cement (95% clinker and 5% additives); the final CO<sub>2</sub> emissions from a production of up to 2.64 million tons of cement per year will be 1.62 million tons CO<sub>2</sub>. This is equivalent to 614 kg CO<sub>2</sub> per tons of cement on average. The fuel source is coal, as no other reliable fuel source is available. Later it might be possible to consider alternative fuels based on agricultural waste products, but these sources are not available at this time.

Particulate emissions are controlled at the quarrying sites and in the general material handling systems by designs requiring minimal material drops during handling, fully enclosed conveying systems with bag filters installed at all transfer points. Water based dust suppression are also used where evacuation and filtration systems are not practical, such as crusher feeding chute and road transport within the quarry operations. At the cement plant all operations are fully equipped with particulate emission control systems. These systems are based on bag filters and recycling of the captured materials to the feed stock for the kiln. All filters are designed for maximum emissions of 25 mg particulate/Nm<sup>3</sup>. This is well within the IFC guidelines of 30 mg particulate/Nm<sup>3</sup> and the local requirements.

Sulfur dioxide emissions are therefore low, as the alkaline conditions in the kiln will result in the absorption of the majority of the sulfur entering the systems either through the raw materials or the fuel. The sulfur dioxide emissions are also kept below the local requirements and the IFC guidelines value of 400 mg/Nm<sup>3</sup>.

Formation of nitrogen oxides is caused by fuel burning at high temperatures in the kiln. To minimize the formation of nitrogen oxides the kiln is using advanced burning principles, including the usage of low-NO<sub>x</sub> (NO and/or NO<sub>2</sub>) burners, which by controlling the flame shape is able to ensure a relative low core flame temperature. By applying these techniques the NO<sub>x</sub> emissions are kept below the 600 mg/Nm<sup>3</sup>, as stipulated in the IFC guidelines.

A sewage treatment plant is constructed to cater for the waste water produced by the plant and the housing colony establishing to house foreign construction workers and later the senior management of DMC and other staffers not originally from the project area. This sewage treatment plant is treating the waste water to comply with IFC's guidelines, and the water will thereafter be used for greenbelt irrigation. No waste water is foreseen to be discharged from the plant. The solid and hazardous waste are either be sold (used refractory bricks) or handled by authorized waste handlers.

Ambient air has been intensively monitored during the ESIA preparation period, and Derba MIDROC is carrying out a full year monitoring to support these preliminary data. Both ambient air and local rivers fully comply with WHO standards and local Ethiopian regulations. This compliance will not be compromised due to the proposed project.

#### **PS4: Community Health, Safety and Security**

The appropriate emission and discharge controls at the new facilities are ensuring that no wastewater will leave the premises and the ambient air quality is remained well within the national and WHO limits. Transport of limestone and other mined raw materials from the valley are carrying out via fully enclosed conveyor belt systems. Hereby heavy road transport between the quarries in the valley and the processing plant has been eliminated.

To limit the community impacts of the transport of the final product (cement) Derba MIDROC is constructing a new road from Derba to the plant site and upgrading, broadening, and hardtop the existing road from Derba to Chancho By ERA. Nevertheless, the trucking of construction materials, raw materials, and finished product as well as key inputs, such as coal, is expected to lead to significant increases in road traffic. This traffic increase will pose a safety risk to local people, especially the herders who utilize or cross the road network for moving their livestock. DMC has agreed to address this risk by means of community and driver education programs in conjunction with the local authorities in affected areas.

Construction of the steep mountainous access road between the plant and quarry sites – involving a vertical drop of roughly 700-800 m – poses a safety risk of falling rocks to the households living at the foot of the plateau edge. To mitigate this risk, DMC has negotiated the temporary relocation of affected households during the construction process.

Finally, the influx of outsiders, including truck drivers, Chinese contractors, and job-seekers, could lead to the spread of sexually transmitted diseases, such as HIV-AIDS, into local communities. To reduce and actively manage this risk, DMC has agreed to undertake health awareness and education initiatives to sensitize their workforce in relation to disease prevention and treatment; and provide adequate access to health facilities.

#### **PS5: Land Acquisition and Involuntary Resettlement**

Land has been acquired for the plant area, the various quarrying areas, several key access roads, and linear facilities, such as the conveyor belt, the water pipeline, and (possibly) the power line route. The land acquisition and compensation process has been undertaken by Ethiopian Government agencies, as required by national law. Compensation had by late 2007 been paid out to 354 landowners who have lost part of their landholdings and 74 house owners who have lost their houses (some on a temporary basis due to construction activities). DMC has compiled a RAP which addresses the land acquisition and compensation process in accordance with IFC's requirements. An IFC review has found the Ethiopian land acquisition and compensation process to be fair to those whose land and houses have been affected, although additional monitoring and evaluation is required by DMC to comply with IFC's requirements in this regard.

#### **PS6: Biodiversity Conservation and Sustainable Natural Resource Management**

A detailed ecological study has been carried out in the area and the vegetation composition, abundance, cover, and other relevant ecological information of the area has been collected. The ecological study covers both the plant and quarry areas, and a buffer area of 10 kilometers radius around the plant and mining area. The area is rich in biodiversity and a total of 241 floral species were recorded. Among these five are highly endangered and 10 are of least concern as per Ethiopian statutes. None of the endangered or "of least concern" species were found in the actual plant, quarry, or right-of-way areas, and none will be affected by the project development, as the project will not encroach on any area considered critical for the survival of these species.

With respect to wildlife (fauna) the area is highly impacted by deforestation, agricultural activities, and hunting. There is no record of endangered, threatened or vulnerable species in the area. It is believed that the complete deforestation could be the cause of lacking wildlife migration in the area.

Derba MIDROC therefore intend to establish forested greenbelts around the quarry operations, and tree planting in rehabilitated quarry areas, to provide hiding grounds for potential returning wildlife.

### **3.2.4 Naming and Notation of the Cements**

During my study of Derba Cement, I found that name and notation of the cements are missed and customers are confusing to differentiate OPC from the PPC; the then designations are simply ES 1177-1\_2005, 42.5N for OPC and ES 1177-1\_2005, 32.5N for PPC. One cannot understand them simply in a glance reading from the bags for that the PPC lacks information on the main constituents and the name by itself; this is because cement strength of 32.5N may not necessary represent PPC; as there is also OPC of the same grade. By the same token, for the OPC, the name, Portland cement, and the notation, CEM I, are missed; but these were mandatory. In addition, in the language translation of the word Net Weight, it is simply written as ነ/ክ ብደ ገ (single weight) which does not gave me sense; because net weight is the weight of the contents only, excluding the weight of the container or packaging, which is totally different from single weight.

### **3.3 RAW MATERIALS FOR THE CEMENT MANUFACTURING**

Among the major raw materials required for cement production, limestone, clay, basalt, sandstone, and gypsum are abundantly available in the Derba-Mugher Valley. As it was observed from the preliminary geological survey of the raw materials study, the deposit of the above materials is much more than enough for the whole plant life for the 5,000tpd clinker production capacity. Since, pumice, the raw material required for production of PPC cement, is not available in Derba-Mugher valley, this material has to be transported by trucks from Nazareth or Zeway area.

### **3.4 PROPORTIONING OF THE RAW MATERIALS**

In the manufacture of Portland cement, correct proportioning of the raw materials is of prime importance in securing clinker of proper constitution. In order to fix the proportions accurately, they always undergoes chemical analysis on the raw materials. The results of chemical analysis are usually reported in terms of the oxides of the principal constituent elements.

Table 3.2: The guiding principle of material proportions which the factory follows

<b>Proportion [%]</b>	<b>85</b>	<b>12</b>	<b>3</b>
	<b>Limestone</b>	<b>Basalt</b>	<b>Sandstone</b>
LOI	42.8	7.16	0.54
SiO <sub>2</sub>	1.63	46.9	95.4
Al <sub>2</sub> O <sub>3</sub>	0.310	19.5	2.08
Fe <sub>2</sub> O <sub>3</sub>	0.47	12.0	0.16
CaO	53.79	3.99	0.0
MgO	0.84	3.10	0.25
SO <sub>3</sub>	0.25	0.009	0.02
K <sub>2</sub> O	0.07	0.920	1.13
Na <sub>2</sub> O	0.05	3.090	0.09
P <sub>2</sub> O <sub>5</sub>	0.02	0.240	0.02
Cl <sup>-</sup>	0.01	0.083	0.02

All these three basic materials are available in a nearby quarry, Derba-Muger valley. The raw material is transported to the primary crusher by truck. The material is then crushed and is reduced to a maximum size of 100 mm of which 95% should pass 75mm sieve size. The crushed material is transported through a conveyer and then stored in a raw material storage facility. Raw materials are carefully proportioned and ground in roller presses or ball mills to fineness similar to face powder. The ground material is then transported by pneumatic means through a pipeline to storage and blending silos. The material is constantly blended and checked for uniform chemical composition & uniform products; the factory is always trying to keep the targeted composition of the final products to be constant which is tabulated as follows.

Table 3.3: Targeted chemical composition of the Clinker &amp; the Final Products

	<b>Clinker [%]</b>	<b>OPC [%]</b>	<b>PPC [%]</b>
LOI	-	1.06	1.88
SiO <sub>2</sub>	21.2	21.3	28.7
Al <sub>2</sub> O <sub>3</sub>	5.56	5.47	6.44
Fe <sub>2</sub> O <sub>3</sub>	3.91	3.99	4.34
CaO	64.51	61.57	51.44
MgO	2.03	1.78	1.59
SO <sub>3</sub>	0.54	2.81	2.26
K <sub>2</sub> O	-	0.47	0.93
Na <sub>2</sub> O	-	0.16	0.65
Cl <sup>-</sup>	-	0.005	0.004
Total	97.75	98.62	98.23
LSF	92.1	89.6	56.7
SM	2.3	2.25	2.66
AM	1.43	1.37	1.48

The object of processing the raw materials is to ensure that the raw feed entering the kilns is of constant composition, finely divided, and chemically well balanced. This results in a cement of uniform composition and predictable properties. A uniform mixture also ensures that the kiln temperature can be kept fairly constant, near the optimum burning temperature. The actual compositions are a little bit different from the above guides yet; besides, their efforts are appreciated.

Table 3.4: Recorded Mean chemical composition of the raw materials entering the kilns

	<b>Limestone</b> [%]	<b>Basalt</b> [%]	<b>Sandstone</b> [%]	<b>Kiln</b> <b>Feed</b> [%]	<b>Pumice</b> [%]	<b>Gypsum</b> [%]
LOI	39.66	10.08	2.57	35.12	4.62	___
SiO <sub>2</sub>	7.05	42.82	89.32	13.34	65.77	___
Al <sub>2</sub> O <sub>3</sub>	1.84	16.75	4.66	3.46	12.84	___
Fe <sub>2</sub> O <sub>3</sub>	1.11	14.69	2.03	2.47	5.25	___
CaO	47.60	5.28	0.34	42.76	1.17	___
MgO	1.26	3.92	0.36	1.61	0.84	___
K <sub>2</sub> O	0.26	1.00	0.11	0.37	3.88	___
Na <sub>2</sub> O	0.09	0.94	0.08	0.23	2.22	___
SO <sub>3</sub>	0.35	0.21	0.27	0.34	0.55	36.51
Cl <sup>-</sup>	0.005	0.005	0.002	0.006	0.014	___
Sum	99.23	95.70	99.74	99.71	97.15	36.51

### 3.5 PRODUCTION PROCESS

#### 3.5.1 Pyroprocessing:

Once the raw feed has been satisfactorily ground and blended, it is ready to enter the horizontal rotary kiln where pyroprocessing (burning) occurs. It is a modern kiln, with a production capacity exceeding 5000 tons/day. The raw feed enters at the high end and the combination of rotation and inclination slowly moves the material the length of the kiln.

In this factory, the blended raw material enters the kiln via the pre-heater tower. Here, hot gases from the kiln, and probably the cooled clinker at the far end of the kiln, are used to heat the raw meal. As a result, the raw meal is already hot before it enters the kiln.

The raw meal is fed in at the top of the pre-heater tower and passes through the series of cyclones in the tower. Hot gas from the kiln and, often hot air from the clinker cooler are blowing through the cyclones. Heat is transferred efficiently from the hot gases to the raw meal.

The factory is a new cement factory with a development of this process, the ‘pre-calciner’ kiln. The principle is similar to that of the dry process pre-heater system but with the major addition of another burner, or pre-calciner. With the additional heat, about 85%-95% of the meal is decarbonated before it enters the kiln.

### 3.5.2 Basic Principle of the Pre-Calciner Kiln

Since meal enters the kiln at about 900 °C, the kiln is shorter and of similar diameter; this reduces its capital costs.

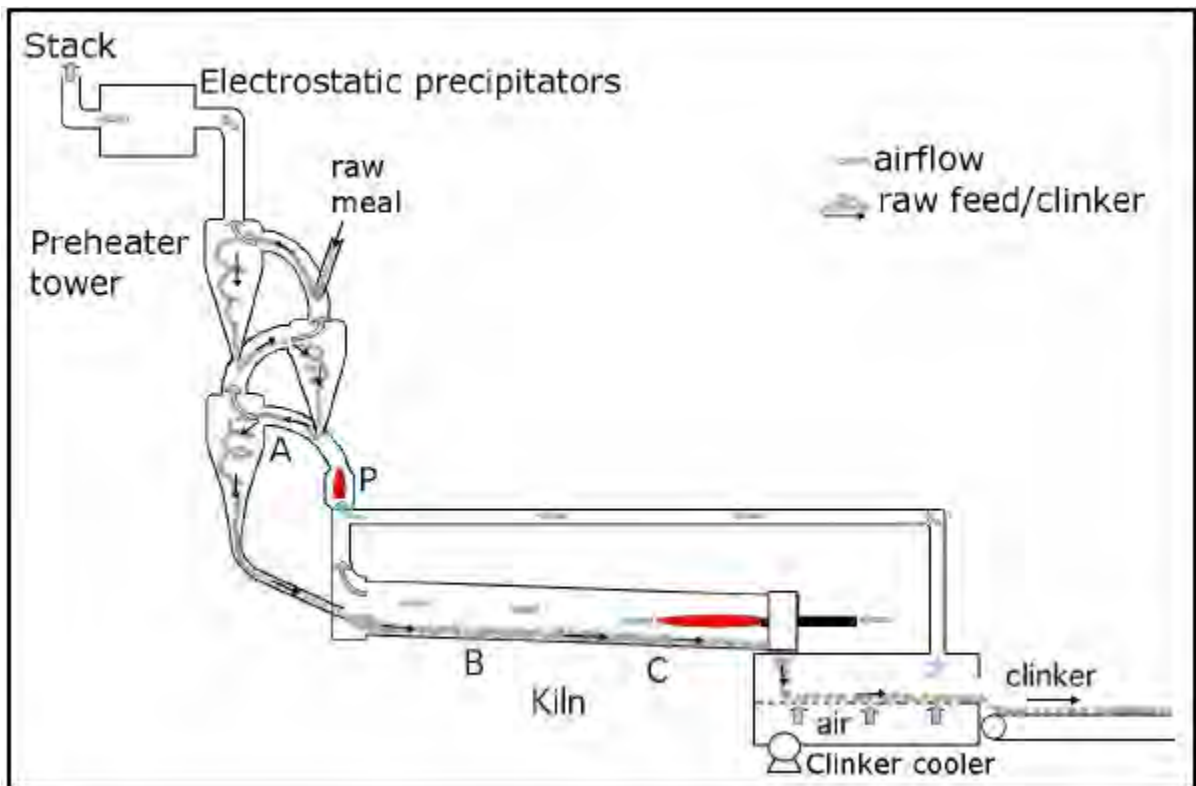


Fig 3.1: Model for the illustration of Derba cement factory [24]

### 3.5.3 Operation Mechanisms of the Kiln and Pre-Heater Tower

Raw meal passes down the tower while hot gases rise up, heating the raw meal. At ‘A’, the raw meal largely decarbonates in a temperature of 900 °C; at ‘B’, the temperature is 1400 °C and intermediate compounds are forming and at ‘C’, the burning zone, clinker nodules and the final clinker minerals form. When the clinker has passed the burning zone, it starts to cool, slowly at first, then much more quickly as it passes over the ‘nose ring’ at the end of the kiln and drops out in to the cooler.

Burning fuel, consisting of powdered coal, fuel oil, or gas, is forced into the lower end of the kiln, producing temperatures of 1400 to 1600 °C (2550 to 2900 °F) in the hottest part of the kiln. Being a dry process the raw materials are crushed, dried in rotary driers, proportioned, and then ground in ball mills. The resulting powder is then burnt in its dry condition in the rotary kiln. As the raw feed moves through the kiln, carbon dioxides are driven off from the constituents in the form of gases (calcination). The residual oxides recombine in the hottest part of the kiln, the clinkering zone, to form new chemical compounds. The heated exhaust gases are used to raise the temperature of the incoming feed in special heat exchangers called pre heaters.

### 3.5.4 Final Processing

Material exiting the kiln is known as clinker; dark-gray, porous nodules (13 to 50 mm [1/2 to 2 in.]) in diameter that are still hot. The clinker is cooled by forced air, and then conveyed to the storage with a capacity of 40,000 tons or immediately to ball mills where it is ground to the fine gray powder. A small amount (5%) of gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) is added to the clinker in order to control setting behavior, strength development, and volume stability. The ball mills used for finish grinding are similar to the mills used to grind the raw materials. They are equipped with air separators that remove the fine particles and return the coarse material to the mills for further grinding. The final cement is relatively so fine having finesses of  $360\text{kg/m}^2$  for OPC and  $350\text{kg/m}^2$  for the PPC. The cement is stored in to the three large silos of each 10, 000 tons of capacity until ready for distribution. It is also shipped in bulk by truck.

Table 3.5: Recorded Mean chemical composition of Clinker & the Final Products

	<b>Clinker [%]</b>	<b>OPC [%]</b>	<b>PPC [%]</b>
LOI	0.15	0.81	2.03
SiO <sub>2</sub>	21.34	22.67	<b>29.62</b>
Al <sub>2</sub> O <sub>3</sub>	5.53	5.52	6.7
Fe <sub>2</sub> O <sub>3</sub>	3.85	3.98	4.47
CaO	64.59	60.02	49.51
MgO	2.02	1.81	1.51
K <sub>2</sub> O	0.67	0.46	<b>0.95</b>
Na <sub>2</sub> O	0.27	0.15	<b>0.70</b>
SO <sub>3</sub>	0.59	2.83	2.21
Cl <sup>-</sup>	0.005	0.005	0.006
Sum	99.02	98.26	97.71
LSF	93.31	82.70	52.81
SM	2.28	2.40	2.65
AM	1.44	1.40	1.5

Note: As shown above in table 3.5, the alkali content of the PPC is high and therefore precautions should be taken in to consideration to prevent alkali silica reactions between the active silica constituents of the aggregate and the alkalis in cement; this is because the expansion of concrete made with a given reactive aggregate is greater the higher the alkali content of the cement.

### **3.5.5 Grinding Aids of Cement**

The main objective of the grinding process is to transform intermediate materials (clinker, gypsum etc.) into final product (cement), with specific fineness and characteristics. The quantity of energy necessary for the process to obtain the right fineness is only partially employed for the creation of new surface: in fact it is demonstrated that 95% of the total energy is lost as heat [32]. The grinding efficacy rapidly decreases when the fineness increase, mainly due to the agglomeration within the finest particles. The high process costs (both in terms of value and environment) induced cement factories to find ameliorative solutions, such as grinding aids.

Grinding aids are organic substances that, added in the mill at low dosages (0.01-0.05% in weight), allow significant mill output increases, that range from 5% to 30% depending on the material and process characteristics [32].

Grinding aids have been widely used for more than 50 years. It is also well known that their ultimate target is to prevent cement particle agglomeration during milling process. As a consequence they reduce mill retention time and improve separation efficiency, which decrease energy consumption of the plant keeping constant quality and quantity of the cement produced.

Besides the grinding aids principal function (output increases), the secondary benefit have also been appreciated (quality improvement of cement), and for this reason a distinction has been made within ‘pure grinding aids’ and ‘grinding aids - performance enhancers’ for the cement and other grinded binders. Cement additives improve mechanical strengths giving a narrower cement particle size distribution [32].

The real mechanism of action of this cement additive in the hydration of cement is not completely understood yet. What is not clear yet are the actual chemical-physical interactions they set with cement, which give it all the properties said. The more accepted thesis is that the grinding aids act to reduce the surface energy forces generated on cement grains during comminution. They are constituted by polar organic compounds, which arrange their dipoles so that they saturate the charges

on the newly formed particle surfaces of the clinker, reducing agglomeration. This thesis [33] stem from the fact that water itself, a polar molecule, has been considered a decent grinding aid, even if not so efficient owing to its low screening effect.

A reduction in energy costs is a notable benefit of grinding aid use. Mills save money and power when using these aids because the aids transform the cement-making process into an endergonic process, consuming energy from the surrounding environment. Because cement aids allow the cement mixture to absorb energy, less external energy is needed for the reactions to take place. In this way, industrial mills save a tremendous amount of money by employing cement grinding aids. The manager of DMC said that, the factory is not getting advantage of these grinding aids yet because of its recent inauguration; may be in the future.

### **3.6 QUALITY CONTROL**

The manufacture of Portland cement involves complex chemical reactions, and all stages of production require close monitoring and control, as is doing the factory under research. Plant chemists and chemical engineers analyze the raw materials from the quarry, the blending of materials, and the finished products using online automated analytical controls.

The Cement is regularly sampled and tested by the Consultants and the Chinese Contractor. Tests include both chemical analysis and physical tests such as strength, fineness, and setting behavior. Tests on cement are done for quality control and to verify that the cement meets the requirements of Ethiopian standard. The cement manufacturer is able to supply these data on request in the form of a mill-test report that serves as a manufacturer certification that the cement meets the requirements of the standard. Requests for this data can be made when required by the project specifications and through the permission of the project manager.

## CHAPTER FOUR

### PROPERTIES OF MATERIALS AND MIX PROPORTIONS

#### 4.1 INTRODUCTION

In this chapter the properties of materials used in the production of concretes are described.

The laboratory tests for the most important properties of the aggregate taken from ERA site and the concretes were carried out in the Material Testing Laboratory of the Institute of Technology of AAU. The data about the chemical and physical properties of the cements were collected from the cement factories and the tests were carried out either by the consultant, HOLTEC and the Contractor, CNBM and/or by external bodies like Quality and Standard Authority of Ethiopia.

#### 4.2 PROPERTIES OF MATERIALS

##### 4.2.1 Cement

In this research work, three mixes were prepared using Portland Pozzolana Cement and seven mixes were prepared using Ordinary Portland Cement. Both Derba OPC, produced at different times, and PPC cements were brought from the factory and were fresh. Except the package (the way to identify on the bag), both cements comply with the requirements of Ethiopian Standards, ES 1177-1\_2005 [5]. The chemical and physical properties of the cements shown in Table 5.1 are summaries of the cement test result data.

##### 4.2.2 Aggregates

The fine aggregate used in the concrete productions is natural/river sand. It was washed, sieved and its grading meets the Ethiopian Standard Requirement [16] and manual recommendations [17].

Typical fine aggregate gradation together with its curve is shown in Table A-1 and Fig.A-1 in Appendix -I and its physical properties are shown below in Table 4.1.

Table 4.1: Physical Properties of the Fine Aggregate

No.	Test Description		Test Result
1	Silt Content		1.80%
2	Moisture Content		0.70%
3	Absorption Capacity		3.00%
4	Specific Gravity	Bulk	2.684
		Bulk (SSD)	2.695
		Apparent	2.72
5	Fineness Modulus		3.00%

The coarse aggregates used are with maximum aggregate sizes of 20 mm used in the normal strength and intermediate strength concretes production and a maximum aggregate size of 12.5 mm used for high strength concrete production. The coarse aggregates were washed to remove deleterious materials and sieved and stored separated in to grades. This has minimized segregation and thus variation in gradation from mix to mix. They were blended to meet the grading requirements of Ethiopian Standard for coarse aggregate.

Typical coarse aggregate gradation together with the curve of the aggregate is shown in Tables A-2 and Fig. A-2 in Appendix -I and the physical properties are tabulated in Table 4.2.

Table 4.2: Physical Properties of the Coarse Aggregate

No.	Test Description		Test Result
1	Moisture Content		1.14%
2	Absorption Capacity		0.875%
3	Unit Weight		1596kg/m <sup>3</sup>
3	Specific Gravity	Bulk	2.74
		Bulk (SSD)	2.76
		Apparent	2.81
4	Fineness Modulus		1.11%

### **4.2.3 Water**

In every laboratory work throughout the research, tap water of the Addis Ababa city was used.

### **4.2.4 Chemical Admixture**

Hyper plasticizing admixture based on new generation polycarboxylate ether , Dynamon SP5300, for high performance concrete mixes with very low water cement ratios, high early compressive strengths, long slump retention and self consolidating & self compacting concrete is used. It is used to reduce the amount of water and water-cement ratio. Dynamon SP5300 is a chloride free hyper-plasticizing admixture based on the new generation of polycarboxylate ether molecules and is specifically designed for the production of high performance and self compacting concrete mixes by significantly reducing water/cement ratio and providing excellent results in flow ability and improvement in both fresh and hardened concrete properties; in particular it will enable high early and ultimate compressive strengths to be achieved [18].

## **4.3 MIX PREPARATION**

For the purpose of this research two types of cements, namely: Derba OPC & PPC were used in every concrete class and in the three classes of concrete a total of ten mixes were made. In the production of normal strength concrete the targeted strengths were C-25, C-30 and C-40 and in the mix proportions of the intermediate concrete strengths, C-50 and C-60 were selected; for both of the classes, a D.O.E. Mix design Method [20] was applied. In the case of the high strength classes of concrete, the targeted strengths were C-70, C-90 and up to C-100 and were made based on ACI 211.4R-08 Guide for selecting proportions for High-Strength Concrete Using Portland cement and Other Cementitious Materials [20].

During mix proportioning, it is necessary to know how much water the aggregate will absorb from the mix water or how much extra water the aggregate might contribute.

Saturated surface dry (SSD) where all pores are full, but the surface is completely dry is the widely used in most mix proportion standards in adjusting the required mixing water [21]; hence, the water amount was determined by making adjustments using the aggregates' moisture content and moisture absorption capacity so that the aggregates are saturated surface dried; in another option, I used to make the trial mixes after washing the aggregates and causing the materials to be in SSD condition by blowing air then storing in the room. Besides, at the mixes that used Hyper-plasticizer, water amounts equal to the recommended amounts was deducted from the total water amount in the mix. In general term like super-plasticizers, Hyper-plasticizers have the capacity to reduce mixing water requirements

from 12% - 30%, thereby increasing Concrete compressive strengths. For the existing Hyper-plasticizer, I used to 20% reduction of the water content which will reduce 35 kg/m<sup>3</sup> of water for the use of Hyper-plasticizer with a dosage rate of 1.5 Lit/100kg of total cementitious material; which I have found from the factory recommendations [18]. The manufacturer's manual confirms that the addition of the admixture has no effect on the strength of concrete as long as water/cement ratio is not changed.

There are ten mix proportions of which three are for the PPC and the rest for the OPC that were conducted to study the effects of the cements on the concrete properties especially to the compressive strengths from normal to high strength. In using OPC, they were made with cement contents of 290kg/m<sup>3</sup>, 340kg/m<sup>3</sup>, 360kg/m<sup>3</sup>, 405kg/m<sup>3</sup>, 485kg/m<sup>3</sup>, 545kg/m<sup>3</sup> and 585kg/m<sup>3</sup> water/cement ratio of 0.65, 0.56, 0.47, 0.42, 0.35, 0.246 and 0.24 and chemical admixture of 0, 0, 0, 0, 0, 8.175 liters/m<sup>3</sup> and 8.775 liters/m<sup>3</sup> respectively for C-25, C-30, C-40, C-50, C-60, C-90 and C-100. In the case of PPC they were made with cement contents of 330kg/m<sup>3</sup>, 400kg/m<sup>3</sup> and 585kg/m<sup>3</sup> water/cement ratio of 0.51, 0.37 and 0.24 and chemical admixture of 0, 0 and 8.775 liters/m<sup>3</sup> respectively for C-25, C-40 and C-70; the mix proportions and slumps are given in tables 4.3 and 4.4 below.

Table 4.3: Mix Proportions and slumps for concretes made with Derba OPC

<i>Category</i>	<b>Strength Class</b>	<b>Cement [kg/m<sup>3</sup>]</b>	<b>W/C</b>	<b>Water [kg/m<sup>3</sup>]</b>	<b>Fine Aggr. [kg/m<sup>3</sup>]</b>	<b>Coarse Aggr. [kg/m<sup>3</sup>]</b>	<b>Admixture [Lit]</b>	<b>Slump [mm]</b>
<i>Normal Strength</i>	C-25	290	0.65	190	607	1290	-	80
	C-30	340	0.56	190	608	1292	-	40
	C-40	360	0.47	170	532	1367	-	30
<i>Intermediate Strength</i>	C-50	405	0.42	170	482	1373	-	20
	C-60	485	0.35	170	426	1348	-	10
<i>High Strength</i>	C-90	545	.246	134	637.5	1085	8.175	200
	C-100	585	0.24	140	604	1085	8.775	200

Table 4.4: Mix Proportions and slumps for concretes made with Derba PPC

<i>Category</i>	<b>Strength Class</b>	<b>Cement [kg/m<sup>3</sup>]</b>	<b>W/C</b>	<b>Water [kg/m<sup>3</sup>]</b>	<b>Fine Aggr. [kg/m<sup>3</sup>]</b>	<b>Coarse Aggr. [kg/m<sup>3</sup>]</b>	<b>Admixture [Lit]</b>	<b>Slump [mm]</b>
<i>Normal Strength</i>	C-25	330	0.51	170	539	1387	-	20
<i>Intermediate Strength</i>	C-40	400	0.37	150	624	1325	-	20
<i>High Strength</i>	C-70	585	0.24	140	604	1085	8.775	200

### 4.3.1 Specimens Preparation

For the normal and intermediate strengths of concrete a D.O.E. Mix design Method is used as starting point and fortunately all the mixes were perfect at first; and this may be due to the high care given during the preparation. Each mix batch was 45.6 liters in volume and was subjected to 1 minute dry mixing and 2 minutes wet mixing [22]. Regarding placing and compaction, placing was started immediately and was done in two layers and compacted in table vibrator for 30 seconds for single 15cm cube mold and for 45 seconds for couple of 15cm cube molds. Compaction and placing were completed within 15 minutes. For the high strength concrete, procedures in the ACI 211.4R-08, guide for selecting proportions for High-Strength Concrete Using Portland cement and Other Cementitious Materials, are the methods used to arrive at this mix proportion. Each mix batch was also 45.6 liters in volume and was subjected to 1.5 minutes dry mixing and 3 minutes wet mixing. After calculating the volume of the admixture for the amount of cement, the admixture, Dynamon SP5300, was added carefully and to maximize the its effect, I have applied the suggested mechanisms, that is, subsequent to adding 50-70% of the mixing water; particularly in this case after the addition of 60% of the water, the admixture was added and then the remaining amount of water. Regarding placing and compaction, placing was started immediately and was done in two layers and compacted in table vibrator and sometimes a hand vibrator for 30 seconds for single 15cm cube mold and for 45 seconds for couples 15cm cube molds. Compaction and placing were completed within 15 minutes.

### **4.3.2 Curing and Crushing**

After 24 hours of placing and compaction, samples were removed from their molds and placed in to water pond until the intended days for testing concrete compressive strengths, that is, 3<sup>rd</sup>, 7<sup>th</sup> and 28<sup>th</sup> days. Then after, the concretes are crushed and their load carrying capacities were recorded; in doing these, I found amazing results of mean concrete compressive strengths up to 100 MPa which is equivalent to a characteristic strength of C-90.

## CHAPTER FIVE

### TEST RESULT ANALYSIS AND DISCUSSIONS

#### 5.1 INTRODUCTION

This Chapter has two parts; in the first part, the test results of the cements collected from the factory are summarized and/or analyzed. Then the literature survey on cement properties and the summarized test results of the cements are used to propose properties of concretes that could be produced using the subject cements.

In the second part, the laboratory conducted compressive strength test results on different classes of concrete made of the two cement types are analyzed and discussed. Besides, correlations are made between concrete properties analyzed using the laboratory test results and proposed using the cement properties test results.

#### 5.2 ANALYSIS AND DISCUSSION ON THE CEMENT TEST RESULTS

As discussed above in chapter three, Derba cements are currently the highest cement producers and the main stakeholders at the market.

The silicates are the cementitious compounds which take the recognition for the overall strength development of the cement paste; hence, an increase in the summation of silicates tends to increase strength at all stages [6]. The early strength of a Portland cement will be higher with higher percentages of  $C_3S$ , but if moist curing is continuous, the later strengths, after about 6 months, will be greater for the higher percentages of  $C_2S$  [6]. Besides, the degree of fineness of the clinker grinding has an effect on the rate of strength development and the higher fineness the higher is the rate of strength development; however, with no significant effect on the ultimate strength development [1].

Regarding Particle Size Distribution of cements, the original size, spatial distribution, and composition of Portland cement particles have a large influence on hydration kinetics, microstructure development, and ultimate properties of cement-based materials. For a given water-to-cement (w/c) ratio, a reduction in median particle size generally results in an increased hydration rate and, therefore, improved early properties such as higher early strengths [23].

As shown on Table 5.1, under the heading: the Mean Chemical Compounds of Clinker, the total percentage of silicates is 75.45 and that of  $C_3S$  is 58.1 and through the row: the Mean Chemical Compounds of OPC, the total silicates is 73.70 and the  $C_3S$  50.5 As shown under the heading: Fineness, the fineness for Derba OPC and Derba PPC are: 360 and 350  $m^2/kg$  respectively.

These figures of fineness are good which are conventional in most of the factories of the world today; of course, these can result in early strengths relatively however as fineness is concerned, no significant and unique effect in early strength development will be expected on both the cements; but as the factories manager explains the cements have best PSD with a narrow particle size distribution; as the factory utilizes the modern technology of cement production. This should be the case for the achievements of early and best ultimate strengths in all classes of concrete made in the laboratory; up to 100MPa. Furthermore, at early ages the replacement of cement by a Pozzolana usually results in a decrease in the compressive strength, but the difference in strengths becomes less and may disappear at ages of 3 months or more [1]. The amount of pozzolana incorporated in producing PPC is in the range of 25-28 and most of the time 25%. Therefore, due to the inclusion of 25% or more pozzolana to the clinker while producing the PPC, generally concrete produced using the OPC is expected to show higher early strength development than that of PPC. As a result of the above facts, concrete produced using Derba OPC is expected to have the higher rate of early strength development followed by that of Derba PPC.

Portland Pozzolana cement is a blend of Pozzolana and clinker. Hence, properties of a particular PPC depend on the properties of its clinker and the amount and oxide composition (or pozzolanicity) of the incorporated Pozzolana.

However, the available and collected data from the cement factory regarding its pozzolana is the oxide composition and not the reactivity of the silicates. Hence, in this thesis, pozzolanicity of PPC is taken as the percentage of silicate in the oxide composition of its pozzolana, Pumice. On the literature survey of pozzolana, Pumice is not among the active pozzolanas [8]. The percentage of silicate of Pumice, as shown under the heading: Mean Oxide Composition of Pozzolana in table 5.1 is: 65.77. The pozzolanas used in production PPC is natural material, pumice, which is rated as less active, and the ultimate strength achieved from this pozzolana may not be as high as what is achieved from active pozzolanas. Besides, for pronounced effect on later age strength development from pozzolana, there is a need for continuous and extended moist curing, and that is why in this thesis moist curing is made for 3, 7 and 28 days. Therefore, the ultimate strength of concrete produced using the PPC is more or

less expected to be comparable with that of the OPC except the shortage of the days for that not known the 91<sup>th</sup> days result.

Table 5.1: Summaries of Test Results on Both of the Derba Cements

<b>Mean Chemical Oxides of ↓</b>	<b>LOI</b> [%]	<b>CaO</b> [%]	<b>SiO<sub>2</sub></b> [%]	<b>Al<sub>2</sub>O<sub>3</sub></b> [%]	<b>Fe<sub>2</sub>O<sub>3</sub></b> [%]	<b>MgO</b> [%]	<b>SO<sub>3</sub></b> [%]	<b>K<sub>2</sub>O</b> [%]	<b>Na<sub>2</sub>O</b> [%]	<b>Cl<sup>-</sup></b> [%]	<b>Total</b>
Clinker	0.15	64.59	21.34	5.53	3.85	2.02	0.59	0.67	0.27	0.005	99.02
OPC	0.81	60.02	22.67	5.52	3.98	1.81	2.83	0.46	0.15	0.005	98.26
PPC	2.03	49.51	29.62	6.70	4.47	1.51	2.21	0.95	0.70	0.006	97.71
<b>Mean Chemical Oxides of Pozzolana ↓</b>	<b>LOI</b> [%]	<b>CaO</b> [%]	<b>SiO<sub>2</sub></b> [%]	<b>Al<sub>2</sub>O<sub>3</sub></b> [%]	<b>Fe<sub>2</sub>O<sub>3</sub></b> [%]	<b>MgO</b> [%]	<b>SO<sub>3</sub></b> [%]	<b>K<sub>2</sub>O</b> [%]	<b>Na<sub>2</sub>O</b> [%]	<b>Cl<sup>-</sup></b> [%]	<b>Total</b>
Pumice	4.62	1.17	65.77	12.84	5.25	0.84	0.55	3.88	2.22	0.014	97.15
<b>Mean Chemical Compounds of ↓</b>	<b>C<sub>3</sub>S</b> [%]	<b>C<sub>2</sub>S</b> [%]	<b>C<sub>3</sub>A</b> [%]	<b>C<sub>4</sub>AF</b> [%]	<b>Total</b>	<b>% of Silicates</b>					
Clinker	58.1	17.35	8.14	11.72	95.31	75.45					
OPC	50.5	23.2	6.01	11.63	91.34	73.70					
<b>Fineness</b>	OPC	360	<b>Initial Setting</b>		OPC	143min	<b>Final Setting</b>		OPC	171min	
	PPC	350			PPC	194min			PPC	211min	
<b>Soundness</b>	OPC	0.5mm									
	PPC	0.6mm									

Based on the total silicates of the chemical compound compositions, concrete from the OPC is expected to have high ultimate strength. As the concretes were caused for continuous and extended moist curing the C<sub>2</sub>S should be well hydrated and thus, contribute to the better ultimate strength.

Derba PPC possesses a higher silicate in its pozzolana oxide, higher C<sub>2</sub>S and total silicates in its clinker compound composition, hence good later strength development is expected from the concrete produced using it. However, comparing the two cements, the OPC with higher C<sub>3</sub>S may show higher early strength and the same to do so for the 28<sup>th</sup> day strengths; thus in this regard concrete from Derba OPC is expected to show the higher ultimate strength followed by that of PPC. As discussed on the literature review part, durability of concrete means maintaining the required strength and serviceability of concrete during its expected service life [9]. This property of concrete depends on its imperviousness and resistance to chemical attack.

At given mass, higher number of particles are available when specific gravity is lesser and specific surface area or fineness is higher. As shown on Table 5.1 under the heading: Mean Fineness, Derba OPC has remarkably the higher specific surface area; hence the more number of cement particles per given mass than is PPC.

When there are more cement particles in a mix, then the higher is cement paste in the concrete; thus, fatty or workable, less segregated and less voided [6], collectively impervious concrete is produced. Failure of concrete to resist chemical attack is primarily of the cement paste; if the cement paste can be made resistant, the concrete will be resistant and serviceable [1].

C<sub>3</sub>A promotes high early strength but is the most vulnerable constituent of Portland cement toward possible chemical attack [8]. Low C<sub>3</sub>A cement generates less heat, develops higher ultimate strength, and exhibits greater resistance to destructive elements than a cement containing large amounts of this compound. [6]. Due to the inclusion of 25% or more pozzolana to the clinker, for sure the PPC has lesser content of C<sub>3</sub>A and C<sub>3</sub>S than the OPC.

Because of its greater imperviousness, concrete produced from PPC has higher restriction on the ingress of gases and liquids and the lesser content of C<sub>3</sub>A gives rise to better resistant to sulphates and generally chemical attacks. Furthermore, the presence of silicates from the pozzolana enables it to have better ability to inhibit or reduce the disruptive effects of alkali silica reaction. Therefore, PPC is

preferable to OPC as far as workability, impermeability and resistant to chemical attack concrete is concerned.

### **5.3 ANALYSIS AND DISCUSSION ON THE COMPRESSIVE STRENGTH TEST RESULTS AND RATE OF GAINING OF STRENGTH**

The raw data of the compressive test results are summarized and presented in Table 5.2; for detail evaluation and comparison among concretes produced using both cement types. Table 5.2 is further analyzed and summarized in Tables 5.3 and graphed as shown on Fig. 5.1 to Fig. 5.4.

To evaluate and compare the rate of strength development among concretes of the same class produced using both cement types, the test results of each concrete at different ages are analyzed relative to their 28<sup>th</sup> day test result which are tabulated in Table 5.3.

As shown on Table 5.2, in all classes of concrete, the OPC have shown better strength development than the PPC. This is actually what was expected to occur while discussing on concrete properties based on the cements test results.

As shown on Table 5.3 and figures 3.3 and 3.4, for the concretes produced using Derba OPC and PPC, the mean increment of three days strengths relative to their respective 28<sup>th</sup> days strengths are: 52.83% and 41.62% for NSC, 64.67% and 51.38% for ISC and 71.2% & 57.81% for HSC, by the same token for the seven days, 66.45% & 67.57% for NSC, 78.5% & 70.09% for ISC and 86.97% & 82.09% for HSC. As far as early strength attainment is concerned, OPC is faster but at later ages, it is already observed that concrete made of PPC was increasing its strength significantly than OPC. Here, I would like to draw some one's intention towards the difference of the increments, that is, when we see the gap between 3<sup>rd</sup> days percentage with that of the 7<sup>th</sup> day of PPC, 25.95% for NSC, 18.71% for ISC and 24.24% for HSC whereas for OPC, 13.62% for NSC, 13.83% for ISC and 15.77% for HSC; which immediately tells us the rate of increment of PPC is higher than that of OPC in all the three strength classes of concrete; and this was predicted in the literature review due to the late hydration of that of C<sub>2</sub>S.

Concrete produced using Derba PPC has shown the smaller compressive strength and the higher rate of strength increment with age where as that of OPC has the higher strength but the lower rate of strength increment with age. However, it is highly unlikely that the concrete produced using the PPC

can narrow and reach the strength of the concrete produced that of the OPC and this was especially proven for C-100; please refer the mix-proportions for C-100 and C-70.

The strength up to the 7<sup>th</sup> day is taken as early strength and despite some irregularities at the Normal Strength concrete; generally, it is apparent that in all classes of concrete, the OPC have better rate of early age strength development than the PPC which is the same as what was proposed on the cement test data analysis and discussion.

Interestingly in all strength classes good strength development is observed in both cements especially in the high strength concrete, strength up to 57.81% & 71.2% in 3 days and 82.09% & 86.97% in 7 days relative to their 28 days strength was possible using Derba PPC and OPC respectively. Hence, the OPC is best in high early strength concrete production.

Therefore, Derba OPC can be used for pre-stressed concrete to allow for early stressing, precast concrete for rapid production of elements, high-speed cast-in situ construction, rapid form reuse, cold-weather construction, rapid repair of pavements to reduce traffic downtime and Fast-track paving and several other uses.

The other points to outline is that also as the strength class increases the percentage increment of compressive strengths at 3<sup>rd</sup> and 7<sup>th</sup> days will also increase; for this particular study of OPC, from 46.99% for C-25 to 73.25% for C-100 and from 63.37% for C-25 to 86.19% for C-100 respectively; and for PPC, from 41.62% for C-25 to 57.81% for C-70 and from 67.57% for C-25 to 82.09% for C-70 respectively.

Table 5.2: Summaries of Compressive Strength Test Results of Normal to High Strength Concrete

Test ages	3 days [MPa]	7 days [MPa]	28 days [MPa]
<b>Normal Strength</b>			
OPC (C-25)	15.38	20.74	32.733
OPC (C-30)	25.57	31.86	48.38
OPC (C-40)	36.09	43.15	61.53
PPC (C-25)	15.44	25.07	37.1
<b>Intermediate Strength</b>			
PPC (C-40)	28.995	39.55	56.43
OPC (C-50)	40.38	48.9	64.6
OPC (C-60)	50.24	61.12	75.17
<b>High Strength Concrete</b>			
PPC (C-70)	46.54	66.08	80.5
OPC (C-90)	63.45	80.5	91.74
OPC (C-100)	74.35	87.48	101.5

Note: mixes which contain admixture are the high strength concretes, C-90 and C-100 produced using OPC and only for C-70 in case of PPC.

As shown in the table above, keeping every condition the same, OPC gives higher strength than PPC and is highly unlikely that the concrete produced using the PPC can narrow and reach the strength of the concretes made of the OPC up to 28 days. But researches show that the strength development of concrete made of PPC and OPC will have no significant differences at 56 days and more.

Table 5.3: Rate of strength development relative to their 28<sup>th</sup> day’s strength

	Days	3days [%]		7days [%]		Difference b/n the means of 3 <sup>rd</sup> & 7 <sup>th</sup> days
			Mean		Mean	
<b>Cement Type</b>	<b>Normal Strength</b>					
OPC	C-25	46.99	<b>52.83</b>	63.37	<b>66.45</b>	<b>13.62</b>
	C-30	52.85		65.85		
	C-40	58.65		70.13		
PPC	C-25	41.62	<b>41.62</b>	67.57	<b>67.57</b>	<b>25.95</b>
	<b>Intermediate Strength</b>					
OPC	C-50	62.5	<b>64.67</b>	75.7	<b>78.5</b>	<b>13.83</b>
	C-60	66.84		81.31		
PPC	C-40	51.38	<b>51.38</b>	70.09	<b>70.09</b>	<b>18.71</b>
	<b>High Strength</b>					
OPC	C-90	69.16	<b>71.2</b>	87.75	<b>86.97</b>	<b>15.77</b>
	C-100	73.25		86.19		
PPC	C-70	57.81	<b>57.81</b>	82.09	<b>82.09</b>	<b>24.24</b>

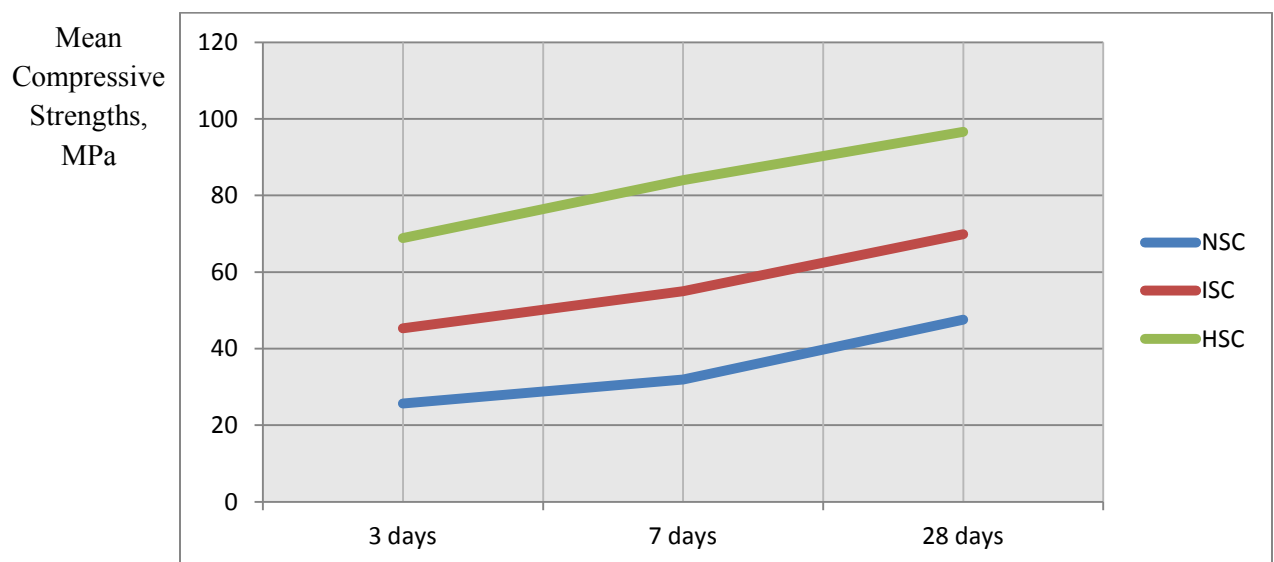


Fig 5.1: Compressive strength development of Derba OPC

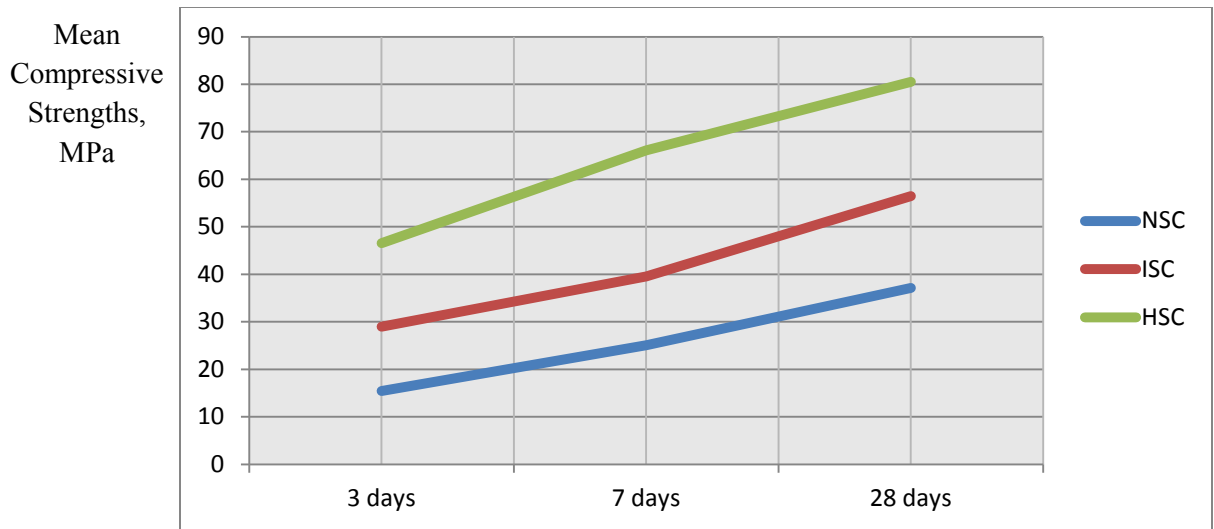


Fig 5.2: Compressive strength development of Derba PPC

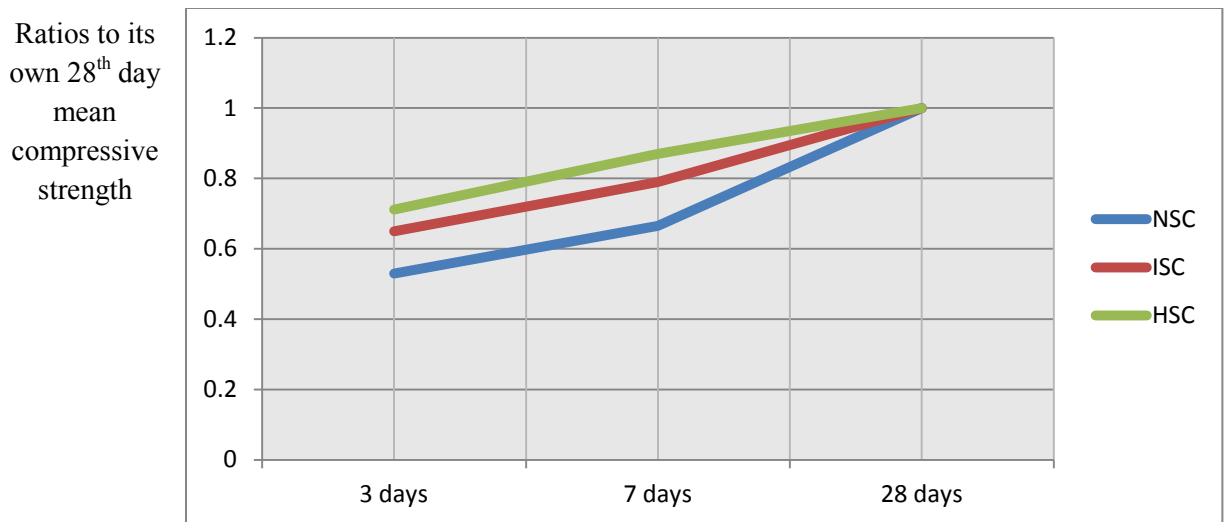


Fig 5.3: Rate of Strength Development of Derba OPC Relative to its Own 28<sup>th</sup> Day's Strength

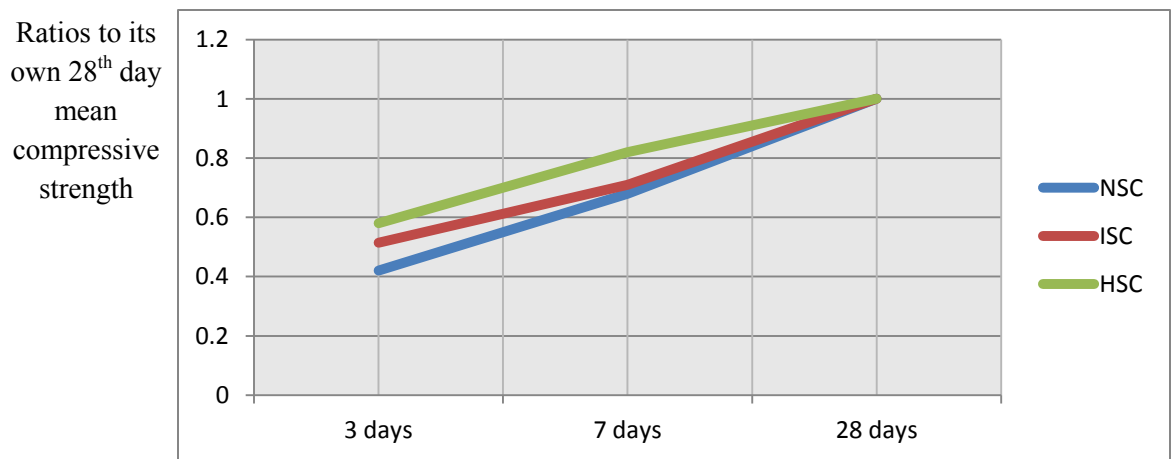


Fig 5.4: Rate of Strength Development of Derba PPC Relative to its Own 28<sup>th</sup> Day's Strength

## CHAPTER SIX

### CONCLUSIONS AND RECOMMENDATIONS

Based on the investigations made and as reported in the previous chapters, the following conclusions are drawn and recommendations are forwarded.

#### 6.1 CONCLUSIONS

In all classes of concrete considered, mixing was made with the same conditions except varying the cement amount and type. Hence, all the concretes compressive strength test results mainly attributes to the characteristic of the cement used, that is, what I got from all the three strength classes of concrete is mainly the indicators of the cement properties. The concrete strength proposed using the cement test results analysis and concrete strength obtained from the compressive strength test results are similar and as expected. This has of course created confidence on the reliability of other concrete properties proposed using the cement test results; and therefore, the following conclusions are drawn.

1. In using OPC, at the age of 28 days mean compressive strengths of: 32.733, 48.38, 61.53, 64.6, 75.17, 91.74 & 101.5MPa have been produced with the possible minimum cement contents respectively for C-25, C-30, C-40, C-50, C-60, C-90 and C-100. In the case of PPC, 37.1, 56.43 & 80.5MPa have been produced respectively for C-25, C-40 and C-70. Therefore, at all ages and classes of concrete, Derba OPC has produced best compressive strength concrete and is also the PPC as it has pozzolanic material.
2. The gap between 3<sup>rd</sup> days percentage with that of the 7<sup>th</sup> day of PPC are, 25.95% for NSC, 18.71% for ISC and 24.24% for HSC whereas for OPC, 13.62% for NSC, 13.83% for ISC and 15.77% for HSC; which immediately tells us the rate of increment of PPC is higher than that of OPC in all the three strength classes of concrete; Concrete produced using Derba PPC has shown the smaller compressive strength and the higher rate of strength increment with age where as that of OPC has the higher strength but the lower rate of strength increment with age; and thus generally, at later ages the PPC has shown larger strength increment as compared to the OPC.
3. Though the strength differences show a decreasing trend with age, it is highly unlikely that the concrete produced using the PPC can narrow and reach the strength of the concretes made of the

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OPC. Hence, keeping every condition the same, the PPC cannot produce a concrete strength as high as the OPC does up to 28 days; please refer the mix-proportions for C-100 and C-70.

4. The pozzolana used in production of the PPC is natural material, Pumice, which has less amount of lime (1.17%), and the ultimate strength achieved from this pozzolana cannot be as high as what could be achieved from active pozzolanas such as fly ash. Besides, the hydration of  $C_2S$  in clinker and the silicate in the pozzolana require long moist curing; but in our traditional way of construction, curing is given less attention which could not be more than a week. These are, therefore, the threats believed to decrease the ultimate strength of the PPC's concretes.
5. For higher early age strength development, both fineness and the percentage of  $C_3S$  are important parameters. But at later ages, fineness has no effect on strength. The other important factor is that Particle Size Distribution of cements, the original size, spatial distribution, and composition of Portland cement particles have a large influence on hydration kinetics, microstructure development, and ultimate properties of cement-based materials. For a given water-to-cement (w/c) ratio, a reduction in median particle size generally results in an increased hydration rate and, therefore, improved early properties such as higher early strengths; the cements have narrow particle size distribution; as the factory utilizes the modern technology of cement production. This should be the case for the achievements of early and best ultimate strengths in all classes of concrete made in the laboratory; up to 100MPa. Therefore, it is its high  $C_3S$  content together with its narrow particle size distribution that gives concrete made of Derba OPC the higher strength at all ages.
6. With the help of Hyper plasticizing admixture based on new generation polycarboxylate ether, Dynamon SP5300, it was possible to make workable concrete with water-to-cement (w/c) ratio of 0.24; and as a result, high performance concrete with excellent results in flow ability in particular high early and ultimate compressive strengths was achieved.

## 6.2 RECOMMENDATIONS

1. In concreting like pre-cast and pre-stressed concrete production, emergency concrete structure construction, and in construction where the construction load is large, there is a demand for high early strength concrete. Long span concrete structures and high-rise building construction are among constructions that demand for high strength concrete. The application of this technology for the coming multistory buildings in Ethiopia is also useful to reduce self weight and maintenance

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costs. In the production of such concretes, Derba OPC is found appropriate and is therefore recommended, if they are proven in their outstanding in the current quality.

2. High early strength implies high rate of hydration. With high rate of hydration, inevitably there is high heat release. This is highly pronounced especially when cement content is high as in high strength concrete. This has its own merits and demerits which are stated as follow:
  - a) This is important in cold area concreting. Thus, OPC is better recommended to be used in colder areas.
  - b) This is susceptible to early age thermal shrinkage and thus the OPC is not recommended in hot area concreting, in mass concreting and in works with high surface area exposed to air, like finishing works, except some modifications like fineness are made.
  - c) In the production of high strength concrete, OPC is also best recommended. However, it releases high heat of hydration and this is more pronounced at high strength concrete as the cement content is very high. This has a danger of early age thermal shrinkage and, therefore, possible precautions that avoid temperature gradient difference, like insulating the concrete, at the early age must be taken in the production of high strength concrete.
3. When moderate early strength and chemical attack resistant concrete is desired at the same time, PPC is preferable.
4. In the building of large dams, mass structures and concreting in hot areas generally where reduction in the heat of hydration is of great importance and the slower gain in strength is not of much consequence, PPC are in general applicable but a concrete made from Derba PPC is gaining its strength moderately; thus this should be studied carefully especially before using it in Renaissance Dam.
5. Interestingly in all strength classes good strength development is observed in both cements especially in the high strength concrete, strength up to 57.81% & 71.2% in 3 days and 82.09% & 86.97% in 7 days relative to their 28 days strength was possible using Derba PPC and OPC respectively. The gap between 3<sup>rd</sup> days percentage with that of the 7<sup>th</sup> day of PPC are, 25.95% for Normal Strength Concrete, 18.71% for Intermediate Strength Concrete and 24.24% for High Strength Concrete whereas for OPC, 13.62% for NSC, 13.83% for ISC and 15.77% for HSC; which immediately tells us the rate of increment of PPC is higher than that of OPC in all the three strength classes of concrete; that is, Concrete produced using Derba PPC has shown the smaller compressive strength and the higher rate of strength increment with age where as that of OPC has

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the higher strength but the lower rate of strength increment with age; and thus generally, at later ages the PPC has shown larger strength increment as compared to the OPC. However, concrete made of PPC can only undergo hydration at later ages due to C<sub>2</sub>S property. Therefore, as much as possible, longer early age moist curing of at least for 14 days is recommended for all concretes, especially for concretes produced using the PPC.

6. Increasing early age moist curing duration enhances the later age strength of the PPC concrete more than that of the OPC. Therefore, extended periods of curing are necessary to develop the benefits of pozzolanic action.
7. The traditional mix proportioning commonly used by the small scale contractors dictates the mix proportioning ratios of cement, sand and aggregate without mentioning anything about the cement type; and a single ratio can result in too many strength values. Besides, the large scale ones use other countries' mix proportion standards which are designed based on their own prevailing conditions and may not be economical to us. Therefore, the concerned government body, professional associations and universities should coordinate to design our own mix design procedures and this research can furnish important information on the locally produced Derba PPC and OPC cements although it is not the only cement producer of the country; but similar studies should be done to cover all the products. The addition of cements is valuable if and only if proper care is given to the gradation and quality of aggregates, and hence standardization of the aggregates should be overemphasized so that Contractors and Consultants can use this information in selecting the appropriate cement for the desired concrete properties.
8. According to ES 1177-1\_2005, Cement should be identified on the bag or the delivery note, and on any test report, with the following particulars:
  - a) The name, trade mark or other means of identification of the manufacturer to facilitate traceability to the factory in which the cement was manufactured;
  - b) The designation/name, the notation/type and strength class of the cement; e.g.
    - V. Portland cement CEM I 42.5N;
    - VI. Portland-fly ash cement CEM II/B-V 32.5R;
    - VII. Portland-limestone cement CEM II/A-LL 42.5N;
    - VIII. Blast furnace cement CEM III/A 42.5N;
  - c) The number and date of this Standard i.e. ES 1177-1\_2005
  - d) The standard notation of any admixture, where applicable;

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- e) The quality marking plus associated information; and in the case of bagged supply only:
  - f) The weight of a bag packed with cement.

However during my study of Derba Cement, I found that name and notation of the cements are missed; the then designations are simply ES 1177-1\_2005, 42.5N for OPC and ES 1177-1\_2005, 32.5N for PPC. One cannot understand them simply in a glance reading from the bags for that the PPC lacks information on the main constituents and the name by itself; this is because cement strength of 32.5N may not necessary represent PPC; as there is also OPC of the same grade. By the same token, for the OPC, the name, Portland cement, and the notation, CEM I, are missed; but these were mandatory. Therefore it is my advice the company, DMC, to modify the descriptions written on the bags as:-

- ❖ Portland Cement CEM I 42.5N, ES 1177-1\_2005
- ❖ Portland Pozzolana Cement CEM II/B-P 32.5N, ES 1177-1\_2005; the same faults were observed in majority of the factories except Mughar and Messebo Cements.

In addition, in the language translation of the word Net Weight, it is simply written as ነ/ክብደት which does not gave me sense; because net weight is the weight of the contents only, excluding the weight of the container or packaging, which is totally different from single weight; so I recommend to be የተጣራ ክብደት.

9. With the help of chemical admixture, which are workable to any degree, concrete can be proportioned with water-to-cement (w/c) ratio below 0.4, in this case up to 0.24. Thus the use of suitable admixture shall be encouraged by practitioners in the construction industry.
10. Low grade cements are more useful for mass concreting and plain cement concreting; and can be used for plastering and single story individual houses. Therefore, it is my advice if the company starts to produce 32.5 grade OPC and Portland Limestone Cements to be competent enough in the market and reduce construction costs for general civil engineering works under normal environmental conditions.
11. In view of the fact that cement grinding aids prevent cement particles from re-agglomeration and making it possible to streamline the cement-making process by increasing process efficiency and material fluidity and also contribute to lower energy costs on the part of industrial mills, it is my recommendation DMC factory to apply this technology and therefore to get advantage of these grinding aids.

### 6.3 Areas of Further Studies

The following points are proposed for further study by practitioners who are interested to study on the locally produced cements.

- I. Laboratory tests on the durability of concretes made of Derba OPC and PPC;
- II. Particle Size Distribution of Cements and its effect on various properties of concrete;
- III. Further study on the rate of gaining of strength, heat evolution and the effect of the alkalis for the concrete made using Derba PPC especially to its particular application in the construction of Renaissance Dam.

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## **APPENDIX – I**

### **Sieve Analysis Results of the Sand and the Aggregates**

Table A-1: Sieve Analysis of the Fine aggregate

Sieve size (mm)	Weight of Sieve (gm)	Wt. Of sieve and retained (gm)	Weight Retained (gm)	Percentage Retained (%)	Cumulative Coarser (%)	Cumulative Passing (%)
9.5	445.5	0	0	0	0	100
4.75	426.5	433	6.5	1.3	1.3	98.7
2.36	383	445	62	12.4	13.7	86.3
1.18	354.5	463.5	109	21.6	35.5	64.5
0.6	312	472	160	32	67.5	32.5
0.3	287	366.5	79.5	15.9	83.4	16.6
0.15	277	353	76	15.2	98.6	1.4
Pan	254	261	7	1.4	100	0
Fineness Modulus					3.00	

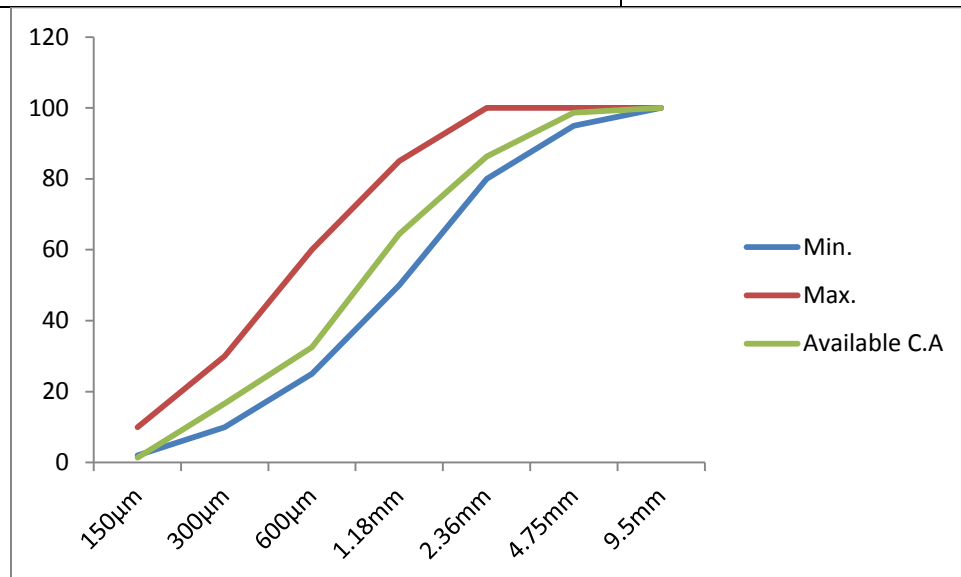


Fig. A-1 Gradation Curve for Sand

Table A-2 Proportion of aggregate blended for the normal and intermediate strength concretes

Sieve size (mm)	Weight of Sieve (gm)	Wt. Of sieve and retained (gm)	Weight Retained (gm)	Percentage Retained (%)	Cumulative Coarser (%)	Cumulative Passing (%)
37.5	440.5	0	0	0	0	100
19	715	813	98	4.9	4.9	95.1
12.5	447.5	1621	1173.5	58.67	63.57	36.43
9.5	445.5	663	217.5	10.87	74.44	25.56
4.75	426.5	909.5	483	24.16	98.6	1.4
Pan	254	282	28	1.4	100	0.0
Total					241.51	

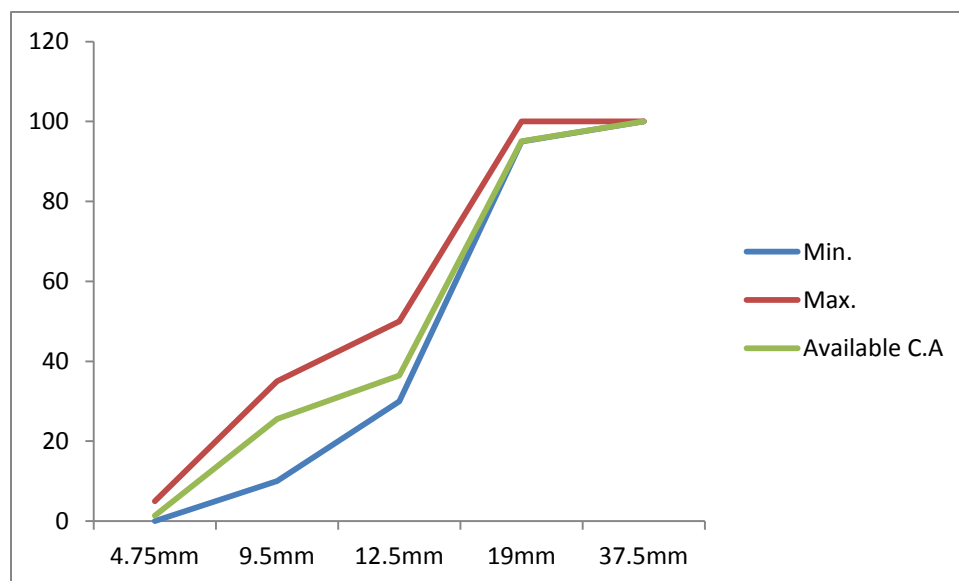


Fig. A-2 Gradation Curve of Coarse aggregate for the normal and intermediate strength concretes

Table A-3 Proportion of aggregate blended for the High strength concretes

Sieve size (mm)	Weight of Sieve (gm)	Wt. Of sieve and retained (gm)	Weight Retained (gm)	Percentage Retained (%)	Cumulative Coarser (%)	Cumulative Passing (%)
19			0	0	0	100
12.5	447.5	447.5	0	0	0	100
9.5	445.5	819.5	374	18.7	18.7	81.3
4.75	426.5	1899.5	1473	73.65	92.35	7.65
Pan	254	407	153	7.65	100	0
Total					111.05	

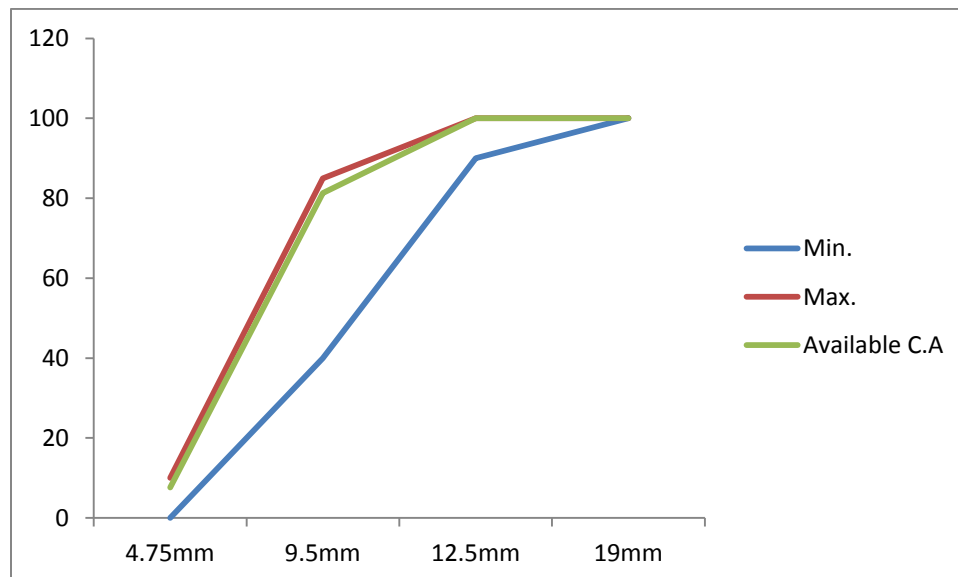


Fig. A-3 Gradation Curve of Coarse aggregate for the High strength concretes

## **APPENDIX – II**

### **Cube Compressive Strength Results [Raw Data] of Normal to High Strength Concrete**

- The moulds are cubical in shape
- The loading rate of the machine is 0.28MPa/s.
- Cement Type: Derba OPC [290kg/m<sup>3</sup>]

**Table B.1. Test results of compressive strength test for C-25 concrete (Targeted for 33MPa)**

No.	Test Age [days]	Dimensions (cm)			Weight (gm)	Volume (cm <sup>3</sup> )	Failure Load [KN]	Compressive Strength (MPa)	Unit Weight [gm/cm <sup>3</sup> ]
		L	W	H					
1	3	15	15	15	8272	3375	334.55	14.87	2.45
2		14.99	15	14.98	8188	3375	337.7	15.01	2.42
3		15	14.97	15	8267	3375	366.3	16.27	2.45
Mean							46.99%	15.38	2.44
1	7	14.98	15.01	14.98	8211	3375	454	20.18	2.43
2		14.99	15.03	15	8284	3375	475.9	21.15	2.45
3		15	14.96	15	8241	3375	470.1	20.89	2.44
Mean							63.37%	20.74	2.44
1	28	14.99	15	15	8181	3375	659.7	31.32	2.42
2		15.04	14.98	15	8334	3375	732.0	34.53	2.47
3		15	15.01	14.98	8286	3375	683.1	32.35	2.46
Mean							100%	32.733	2.45

- The moulds are cubical in shape
- The loading rate of the machine is 0.28MPa/s.
- Cement Type: Derba OPC [340kg/m<sup>3</sup>]

**Table B.2. Test results of compressive strength test for C-30 concrete (Targeted for 42MPa)**

No.	Test Age [days]	Dimensions (cm)			Weight (gm)	Volume (cm <sup>3</sup> )	Failure Load [KN]	Compressive Strength (MPa)	Unit Weight [gm/cm <sup>3</sup> ]
		L	W	H					
1	3	15.02	15	14.99	8485	3375	597.6	26.56	2.51
2		15	15	15	8331	3375	560.2	24.9	2.47
3		14.98	15	15	8357	3375	568.2	25.25	2.48
Mean							52.85%	25.57	2.49
1	7	15	14.97	14.99	8495	3375	721.8	32.07	2.52
2		15	15	14.99	8306	3375	708.9	31.50	2.46
3		15.03	15.01	15	8490	3375	720.3	32.01	2.52
Mean							65.85%	31.86	2.5
1	28	15	14.99	15.01	8505	3375	1067.4	47.44	2.52
2		15	14.98	15	8560	3375	1116.9	49.63	2.54
3		15.02	14.99	15.03	8460	3375	1081.8	48.08	2.51
Mean							100%	48.38	2.52

- The moulds are cubical in shape
- The loading rate of the machine is 0.28MPa/s.
- Cement Type: Derba OPC [360kg/m<sup>3</sup>]

**Table B.3. Test results of compressive strength test for C-40 concrete (Targeted for 55MPa)**

No.	Test Age [days]	Dimensions (cm)			Weight (gm)	Volume (cm <sup>3</sup> )	Failure Load [KN]	Compressive Strength (MPa)	Unit Weight [gm/cm <sup>3</sup> ]
		L	W	H					
1	3	15	15	15	8490	3375	811.6	36.07	2.52
2		15	14.98	15	8462	3375	816.2	36.28	2.51
3		14.99	15	15.02	8539	3375	808.1	35.91	2.53
Mean							58.65%	36.09	2.52
1	7	14.96	14.97	14.98	8473	3375	963.6	42.75	2.51
2		15	15	15	8456	3375	993.5	44.15	2.51
3		15	15.03	15.02	8995	3375	957.1	42.54	2.67
Mean							70.13%	43.15	2.56
1	28	15.01	15.02	15	8556	3375	1399.5	62.20	2.54
2		15	14.99	15	8575	3375	1366.8	60.74	2.54
3		14.98	15	15	8525	3375	1387.4	61.66	2.53
Mean							100%	61.53	2.54

- The moulds are cubical in shape
- The loading rate of the machine is 0.28MPa/s.
- Cement Type: Derba OPC [405kg/m<sup>3</sup>]

**Table B.4. Test results of compressive strength test for C-50 concrete (Targeted for 65MPa)**

No.	Test Age [days]	Dimensions (cm)			Weight (gm)	Volume (cm <sup>3</sup> )	Failure Load [KN]	Compressive Strength (MPa)	Unit Weight [gm/cm <sup>3</sup> ]
		L	W	H					
1	3	14.95	15	15.03	8480	3375	910.8328	40.48	2.51
2		15.02	14.99	15	8465	3375	896.6573	39.85	2.51
3		14.98	15.01	15	8888	3375	918.0331	40.8	2.63
Mean							62.5%	40.38	2.55
1	7	14.99	15.02	15	9010	3375	1114.915	49.55	2.67
2		15.01	14.98	15	8732	3375	1094.439	48.64	2.59
3		14.97	15.02	15	8648	3375	1090.614	48.47	2.56
Mean							75.7%	48.9	2.61
1	28	14.98	14.99	15	8515	3375	1435.552	63.8	2.53
2		15	15.01	15	8650	3375	1453.552	64.6	2.57
3		15	15	15	8725	3375	1470.428	65.35	2.58
Mean							100%	64.6	2.56

- The moulds are cubical in shape
- The loading rate of the machine is 0.28MPa/s.
- Cement Type: Derba OPC [485kg/m<sup>3</sup>]

**Table B.5. Test results of compressive strength test for C-60 concrete (Targeted for 75MPa)**

No.	Test Age [days]	Dimensions (cm)			Weight (gm)	Volume (cm <sup>3</sup> )	Failure Load [KN]	Compressive Strength (MPa)	Unit Weight [gm/cm <sup>3</sup> ]
		L	W	H					
1	3	15	15.02	14.99	8644	3375	1117.6	49.66	2.56
2		15	14.98	15.01	8601	3375	1129.0	50.18	2.55
3		14.97	15	15	9095	3375	1144.9	50.88	2.70
Mean							66.84%	50.24	2.60
1	7	15.01	15	15	8521	3375	1370.1	60.89	2.53
2		15	14.99	14.99	8811	3375	1361.0	60.49	2.60
3		15.02	15	15	8698	3375	1394.9	61.99	2.58
Mean							81.31%	61.12	2.57
1	28	15	15.02	14.99	8795	3375	1696.9	75.41	2.60
2		14.97	15.03	15	8714	3375	1733.4	77.04	2.58
3		14.96	15	15	8700	3375	1644.2	73.07	2.58
Mean							100%	75.17	2.59

- The moulds are cubical in shape
- The loading rate of the machine is 0.28MPa/s.
- Cement Type: Derba OPC [545kg/m<sup>3</sup>]

**Table B.6. Test results of compressive strength test for C-90 concrete (Targeted for 103MPa)**

No.	Test Age [days]	Dimensions (cm)			Weight (gm)	Volume (cm <sup>3</sup> )	Failure Load [KN]	Compressive Strength (MPa)	Unit Weight [gm/cm <sup>3</sup> ]
		L	W	H					
1	3	14.99	15	15	9124	3375	1433	63.68	2.7
2		15	15	15	8622	3375	1422.6	63.22	2.56
3		—	—	—	—	—	—	—	—
Mean							69.16%	63.45	2.63
1	7	14.99	15	15	8205	3375	1798.94	79.95	2.43
2		15	14.99	15	8619	3375	1823.7	81.05	2.56
3		—	—	—	—	—	—	—	—
Mean							87.75%	80.5	2.50
1	28	15	15	15	8607	3375	2009.4	89.91	2.55
2		15	15	14.99	8684	3375	2105.2	93.56	2.57
3		—	—	—	—	—	—	—	—
Mean							100%	91.74	2.56

- The moulds are cubical in shape
- The loading rate of the machine is 0.28MPa/s.
- Cement Type: Derba OPC [585kg/m<sup>3</sup>]

**Table B.7. Test results of compressive strength test for C-100 concrete (Targeted for 112MPa)**

No.	Test Age [days]	Dimensions (cm)			Weight (gm)	Volume (cm <sup>3</sup> )	Failure Load [KN]	Compressive Strength (MPa)	Unit Weight [gm/cm <sup>3</sup> ]
		L	W	H					
1	3	15	15	15	8604	3375	1649.76	73.32	2.55
2		15	14.99	15	8590	3375	1636.1	72.72	2.55
3		15	15	15	9073	3375	1732.8	77.01	2.7
Mean							73.25%	74.35	2.6
1	7	15	15	15	8665	3375	1958.7	87.05	2.57
2		14.98	15	15	9062	3375	2008.9	89.28	2.70
3		15	15	15	8417	3375	1937.4	86.11	2.50
Mean							86.19%	87.48	2.59
1	28	15	15	15	8541	3375	2271.3	100.95	2.53
2		15	14.99	15	8547	3375	2294.9	101.99	2.53
3		15	15	15	8495	3375	—	Not tested	2.52
Mean							100%	101.5	2.53

- The moulds are cubical in shape
- The loading rate of the machine is 0.28MPa/s.
- Cement Type: Derba PPC [330kg/m<sup>3</sup>]

**Table B.8. Test results of compressive strength test for C-25 concrete (Targeted for 35MPa)**

No.	Test Age [days]	Dimensions (cm)			Weight (gm)	Volume (cm <sup>3</sup> )	Failure Load [KN]	Compressive Strength (MPa)	Unit Weight [gm/cm <sup>3</sup> ]
		L	W	H					
1	4	14.98	14.99	15	8515	3375	411.7	15.3	2.53
2		15	15	14.98	8480	3375	422.5	15.78	2.51
3		15.02	15	15	8435	3375	410.5	15.24	2.50
Mean							41.62%	15.44	2.51
1	7	15	14.98	15	8319	3375	574.3	25.50	2.47
2		15.01	15	15	8519	3375	539.3	23.98	2.52
3		15	15	15.01	9054	3375	579.1	25.74	2.68
Mean							67.57%	25.07	2.56
1	28	14.99	15	15	8500	3375	844.6	37.53	2.52
2		15	14.98	15	8426	3375	805.7	36.78	2.50
3		15	15	14.99	8448	3375	810.52	37.00	2.50
Mean							100%	37.10	2.51

- The moulds are cubical in shape
- The loading rate of the machine is 0.28MPa/s.
- Cement Type: Derba PPC [405kg/m<sup>3</sup>]

**Table B.9. Test results of compressive strength test for C-40 concrete (Targeted for 55MPa)**

No.	Test Age [days]	Dimensions (cm)			Weight (gm)	Volume (cm <sup>3</sup> )	Failure Load [KN]	Compressive Strength (MPa)	Unit Weight [gm/cm <sup>3</sup> ]
		L	W	H					
1	3	15	14.99	15	9039	3375	615.7	27.36	2.68
2		15	15	15	8469	3375	689.2	30.63	2.51
3		—	—	—	—	—	—	—	—
Mean							51.38%	28.995	2.60
1	7	15	15	15	8386	3375	892.4	39.66	2.50
2		15	15.02	15	8456	3375	887.5	39.44	2.51
3		—	—	—	—	—	—	—	—
Mean							70.09%	39.55	2.51
1	28	15	15.03	14.99	8479	3375	1253.30	55.7	2.51
2		15	15	15	8696	3375	1286.5	57.16	2.58
3		—	—	—	—	—	—	—	—
Mean							100%	56.43	2.54

- The moulds are cubical in shape
- The loading rate of the machine is 0.28MPa/s.
- Cement Type: Derba PPC [585kg/m<sup>3</sup>]

**Table B.10. Test results of compressive strength test for C-70 concrete (Targeted for 85MPa)**

No.	Test Age [days]	Dimensions (cm)			Weight (gm)	Volume (cm <sup>3</sup> )	Failure Load [KN]	Compressive Strength (MPa)	Unit Weight [gm/cm <sup>3</sup> ]
		L	W	H					
1	3	15	15	15	8474	3375	1072.3	47.66	2.51
2		15	14.99	15	8873	3375	984.3	43.75	2.63
3		15	15	15	8426	3375	1084.9	48.20	2.50
Mean							57.81%	46.54	2.55
1	7	15	15	15	8483	3375	1392.0	61.86	2.52
2		14.98	15	15	8605	3375	1547.4	68.77	2.55
3		15	15	15	8414	3375	1521.5	67.62	2.49
Mean							82.09%	66.08	2.52
1	28	15	15	15	8494	3375	1768.9	78.62	2.52
2		15	14.99	15	8787	3375	1807.6	80.34	2.60
3		15	15	15	8926	3375	1856.32	82.5	2.65
Mean							100%	80.5	2.59

## **APPENDIX – III**

### **Some selected Photos of the Activities**

**Sieving of aggregates during material preparation**

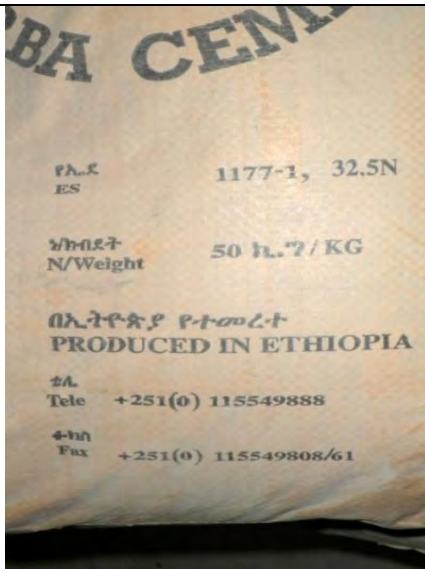


**Preparation of sand for mixing in SSD condition**



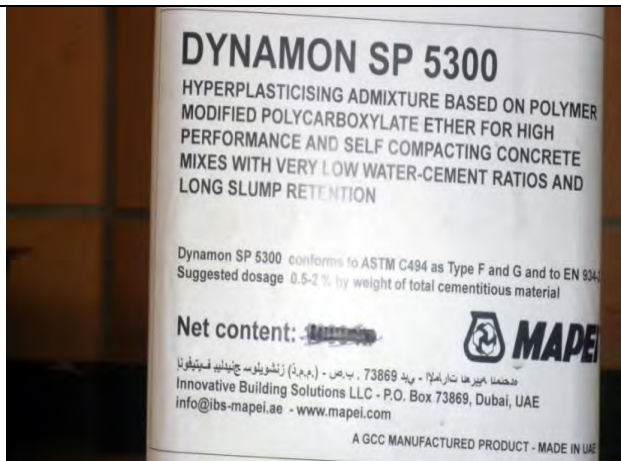
**Paper Sack (bag) of Derba PPC**

**Paper Sack (bag) of Derba OPC**



**The Admixture used**

**Cubical molds used for concreting**



**Slump test of C-25, OPC**



**Slump test of C-30, OPC**



**Slump test of C-40, OPC**



**Slump test of C-60, OPC**



**Slump test of C-90 & C-100 from OPC and C-70 from PPC**



**Batch of C-25 concretes, PPC (after removing the molds)**



**Curing of C-25 Concrete, OPC**



**28th day strength of C-25, OPC**



**28th day strength of C-30, OPC**



**28th day strength of C-30, OPC**



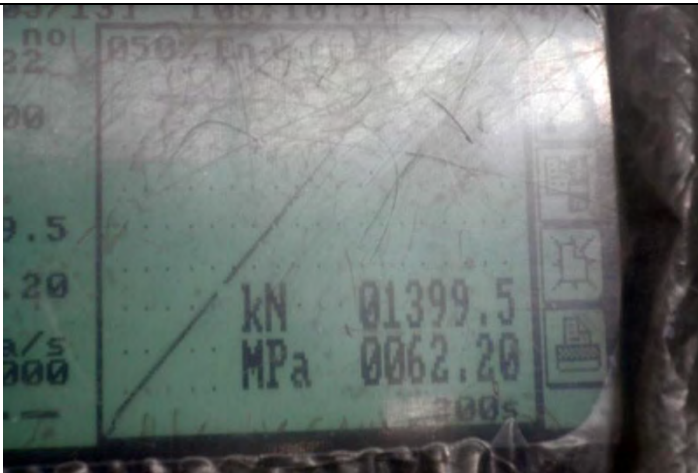
**28th day strength of C-30, OPC**



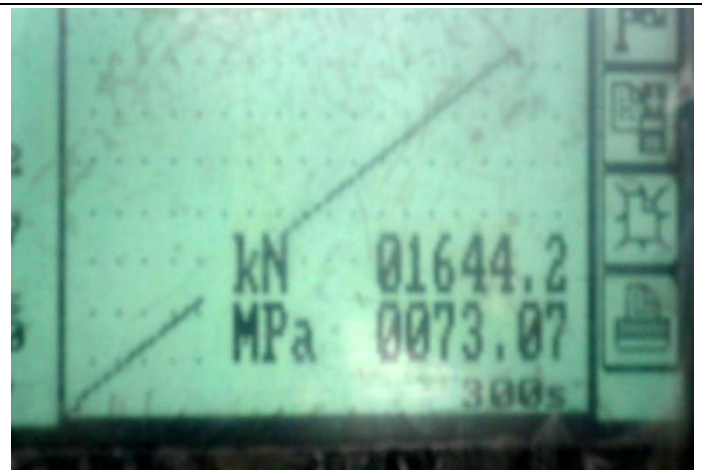
**28th day strength of C-40, OPC**



28th day strength of C-40, OPC



28th day strength of C-60, OPC



28th day strength of C-60, OPC



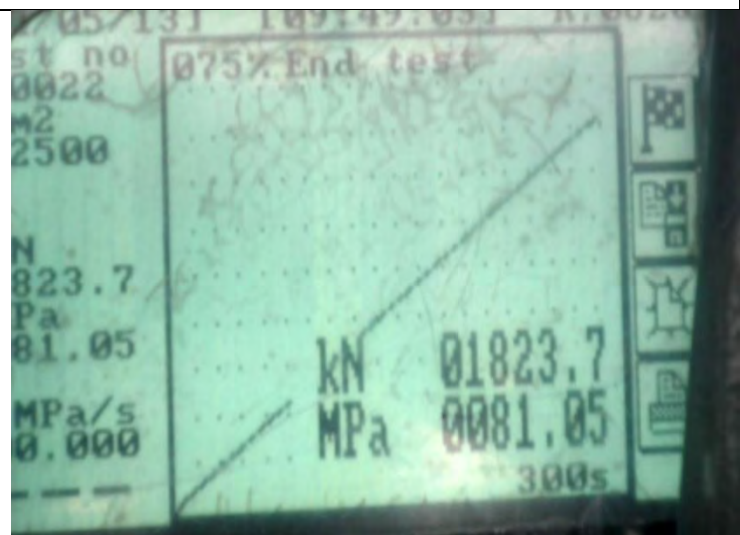
28th day strength of C-60, OPC



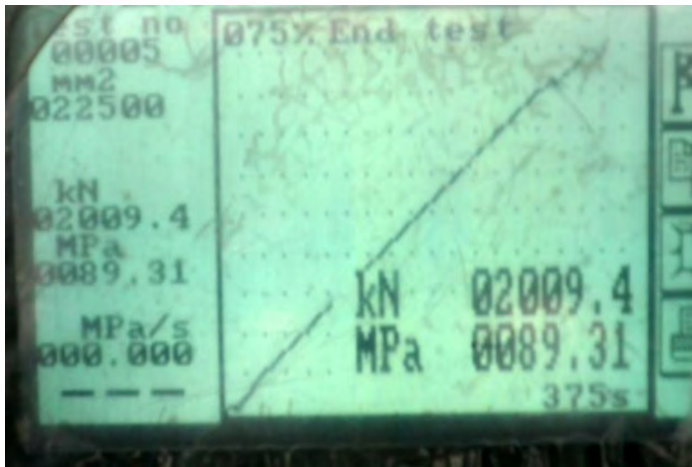
Cracked shape of C-60, OPC



7th day strength of C-90, OPC



28th day strength of C-90, OPC



28th day strength of C-100, OPC



Cracked shape of C-100, OPC



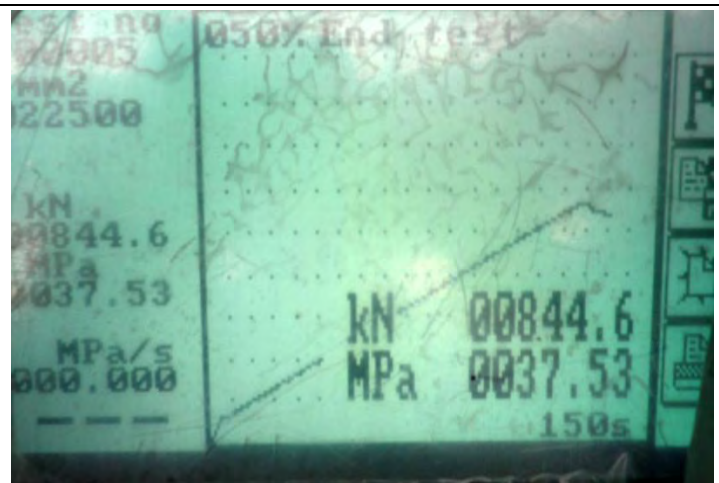
7th day strength of C-25, PPC

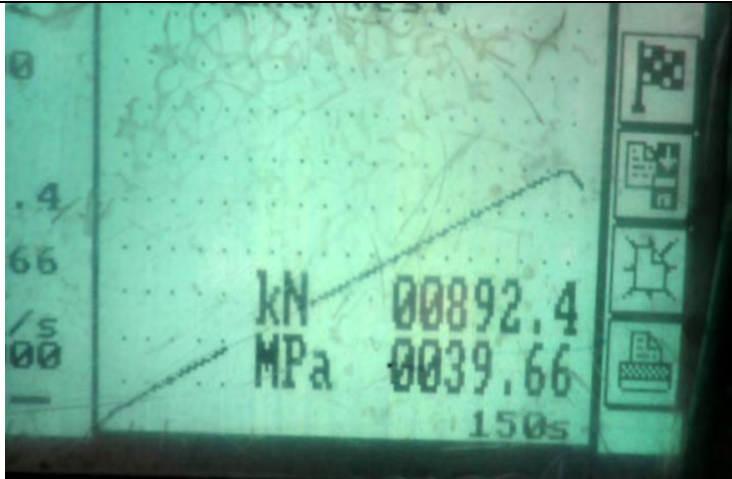


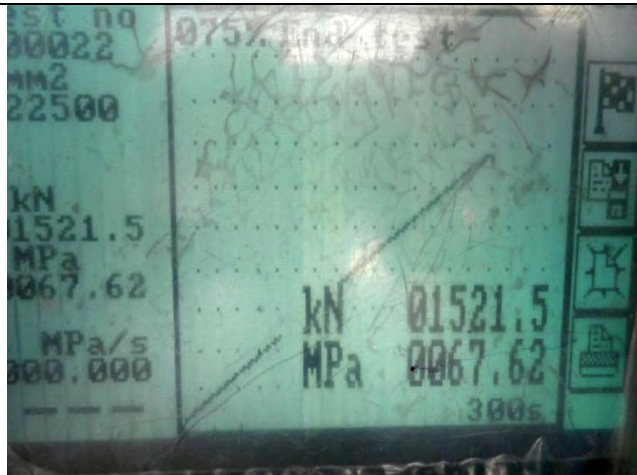




7th day strength of C-25, PPC



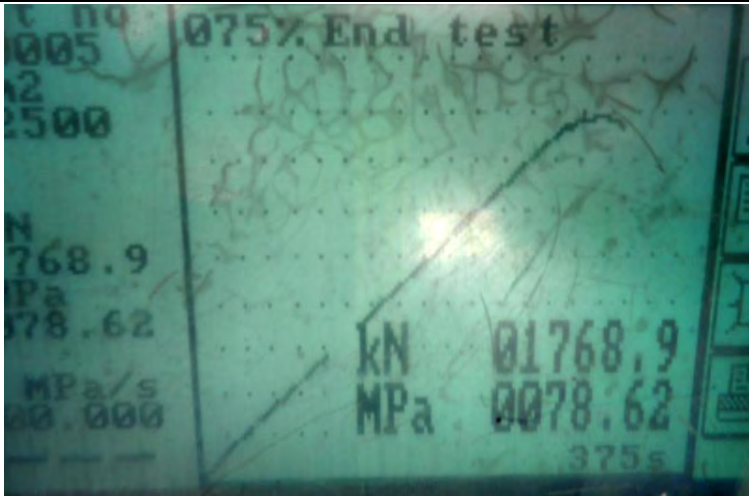
28th day strength of C-25, PPC



<p>7<sup>th</sup> day strength of C-40, PPC</p>	<p>Sample concrete of C-40(PPC) which is ready for testing</p>
	
<p>28<sup>th</sup> day strength of C-40, PPC</p>	<p>7<sup>th</sup> day strength of C-70, PPC</p>
	
<p>7<sup>th</sup> day strength of C-70, PPC</p>	<p>28<sup>th</sup> day strength of C-70, PPC</p>
	

28th day strength of C-70, PPC)

Me myself, while testing compressive strengths



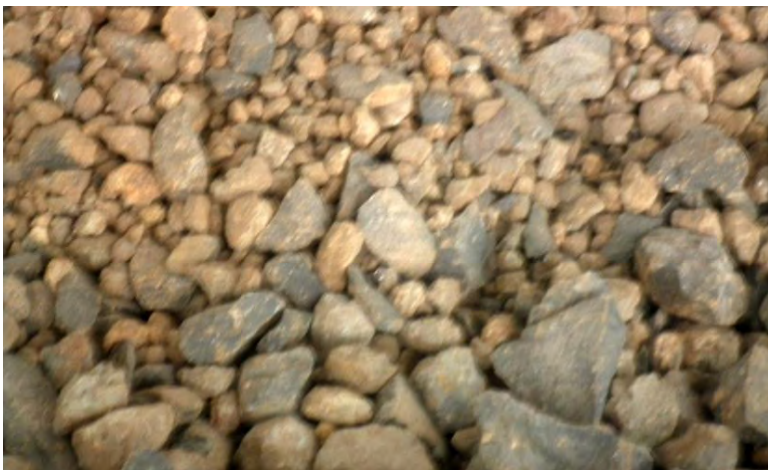
Limestone, ready for proportioning

Limestone, ready for proportioning



Basalt, ready for proportioning

Basalt, ready for proportioning



**Single Basalt**



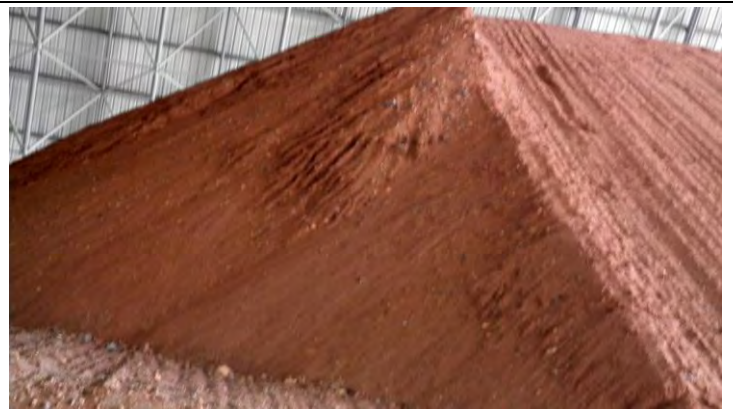
**Gypsum, ready for proportioning**



**Single Gypsum**



**Sand Stone, ready for proportioning**



**Sand Stone, ready for proportioning**



**Clinker of DMC**



Clinker of DMC



Single Clinker



Pumice, ready for milling



Stock for crushed Limestone



Stock for Coal



Raw Material Proportioning Plant



Calcinator of the factory



Kiln of the Factory



Clinker Cylo of DMC



Cement Mill of DMC



Cement Cylo of DMC



Transporting Trucks



## **DECLARATION**

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

Name: Adisu Fentaw

Signature: \_\_\_\_\_

Place: Institute of Technology, AAU

Date of Submission: August 2014