COMPARISON OF CONCRETE PROPERTIES PRODUCED USING MUGHER, MESSEBO AND DIREDAWA CEMENTS

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ABSTRACT

Properties of concrete and its constituent materials are theoretically explained. The three cement factories across the country were visited and test results of Mugher OPC and PPC, Messebo OPC and PPC and Diredawa PPC were collected from their respective factories. Then the chemical and physical properties of these cements were analyzed. Furthermore, three mix proportions for *Normal, Intermediate* and *High Strength Concretes* were conducted in laboratory. At each mix proportion there are five mixes which were made keeping every condition the same but varying the cement types.

To see the effect of curing on strength development among concretes made of the five cement types, different curing conditions were applied.

The analyzed cement test results together with literature survey on effect of cement in concrete properties are used to propose and compare concrete strength and other properties among the concretes made of the five cements. The laboratory conducted compressive strength test results are also used to compare the rate of strength development, the difference in compressive strength values with age and to see the effect of curing on compressive strength development.

In each class of concrete, concreting was made keeping every condition the same except varying the cement type; hence, the variation on the concrete properties is mainly attributable to the cement's properties.

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, Messebo OPC has produced the highest compressive strength concrete, followed by Mugher OPC, Messebo PPC, Mugher PPC and Diredawa PPC in descending order. Besides, though the compressive strength differences between the concretes made of the PPCs and OPCs show a decreasing trend with age, the gap in

strength at the age of 91 days between them is too large to be narrowed and matched with time. Therefore, the PPCs can not produce a concrete strength as high as that of the OPCs.

The low pozzolanicity of the volcanic pozzolanas used in production of the three PPCs as well as shortage of extended moist curing are the reasons believed to make the ultimate strength of concretes made of the PPCs to be lower than that of the OPCs' at the age of three months.

CHAPTER ONE

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 cement, aggregate and water. Besides, chemical admixtures are essential when special properties are desired. For instance, superplasticizer 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).

Depending on the oxide composition of the raw materials and homogenizing them, degree of fineness in grinding the clinker, 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 [4]. As a result, the research is made not only between the different cement types i.e. OPC and PPC but also between the same cement types produced at different factories.

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 through out its designed service life.

Since the primary function of practically 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[4]. Thus, in this research the laboratory tests were made on compressive strength of concretes made of the five cements so that early and ultimate strength developments at different curing conditions are 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 prestressed concrete to allow for early stressing; precast concrete for rapid production of elements; high-speed cast-in-place construction; rapid form reuse; cold-weather construction; rapid repair of pavements to reduce traffic downtime; fast-track paving; and several other uses[16].

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

Producing high-strength concrete is nothing but knowing what factors affect compressive strength and manipulating those factors to achieve the required strength.

High-strength 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-strength concrete also reduces the total amount of material placed and lowers the overall cost of the structure [17].

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 placeable.
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 with out mentioning any thing 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 [6]. 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 five cements by comparing properties of their concretes so that contractors and consultants can use this information in selecting the appropriate cement for the desired concrete properties. Besides, one of the problems in our country to under take researches is scarcity of and/or access to data. In this research cement test results of the five cements and compressive strength of about 450 concrete cube samples produced using the five cements in production of concrete strength ranging from normal to high are made. Therefore, these data are believed to be invaluable resource for practitioners who are interested in making researches relevant to the locally produced five cements.

To make the study more comprehensive, visits were made to all the cement factories and test result data of all cements were collected in addition to laboratory works conducted on compressive strength of concretes made of theses cements.

The literature survey on cement and the analyses on the chemical and physical characteristic of the collected cement test results are used to propose concrete properties made of the subject cements. Besides, analyses and discussions on the laboratory conducted cube compressive strength test results of 450 samples cured at different conditions are made and used to compare the early and ultimate strength development among concretes made of the five cements.

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 and conclusions and recommendations are presented.

CHAPTER TWO

OBJECTIVE AND SCOPE OF THE STUDY

2.1 OBJECTIVE

The objective of this research is to compare properties of concretes produced using the locally produced cements, namely: Mugher OPC & PPC, Messebo OPC & PPC and Diredawa PPC and then to propose their appropriateness in the production of concrete ranging from normal to high strength concrete.

2.2 SCOPE

2.2.1 General

As the title of the thesis reveals the goal of the research is to compare the properties of concrete produced using Mugher, Messebo and Diredawa cements.

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.

Depending on the required services, concrete may made to have 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 .Durability of concrete is the ability of concrete to maintain its quality through out its designed service life.

To study all concrete properties, it requires studying and/or conducting laboratory tests on these entire properties that in turn require huge time, effort, budget and other resources that are absolutely beyond the scope of this research. Moreover, since the primary function of practically 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 [4]. Therefore, the research mainly focuses on compressive strength of concrete.

Literature review on properties of concrete and concrete making materials, study on the cement test results collected from the cement factories and laboratory tests on compressive strength of concrete cubes produced from the five cements are the bases to evaluate mainly the compressive strength and partly other properties of the concretes produced using the different cements so that comparisons on the performance of these concrete are going to be made.

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

2.2.2 Methodology

As discussed earlier the objective of this research is to compare the appropriateness of each locally produced cement types namely: Mugher OPC & PPC, Messebo OPC & PPC and Diredawa PPC, in the production of concrete ranging from normal to high strength concrete.

The comparison is made in two ways:

First, the cement factories were visited and data for each cement test results were collected from its respective 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 test on the compressive strength of different classes of concrete produced from each cement type and cured at different conditions.

Comparison on compressive strength is based on the laboratory test result and the analyzed cement properties; whereas, other properties like durability are made based on 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, extensive 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, extensive physical properties comprising: the Aggregate Crushing Value (ACV), the Ten Percent Fineness Value, wet and dry, (TPFV), the Aggregate Impact Value (AIV), and the Los Angeles Abrasion (LAA) to measure aggregate strength indirectly and Silt Content, Moisture Content, Specific Gravity, Absorption Capacity, Flakiness Index tests were conducted.

Aggregate from Bole-Bulbula quarry site, hereafter called Bole aggregate, fulfilled all coarse aggregate requirements but flakiness index on the 12.5 mm size aggregates. Another aggregate from ERA site, hereafter called ERA aggregate, has shown better result in all the conducted tests. Thus, Bole aggregate was used for the normal and intermediate strength concretes and ERA aggregate for the high strength concrete

To avoid variation in grading due to segregation of coarse aggregates, the aggregates were screened and stored in to separate grades 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, super-plasticizer was used in the production of intermediate and high strength concrete.

In each class of concrete, mixing was made keeping every condition the same except varying the cement type so that the variation on the concrete properties is directly attributable to the cement properties.

To see the effect of curing on strength, samples were subjected to moist curing for 3 and 7 days, and then indoor and out door air curing.

Finally, compressive strength test was made at the ages of 3, 7, 28, and 91 days.

CHAPTER THREE

THE ART OF MAKING CONCRETE, LITERATURE REVIEW

3.1 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.

3.2 CONCRETE MAKING MATERIALS

3.2.1 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 three cement factories found across the country and are discussed in this literature review.

3.2.1.1 Portland Cement

As per the definition sited on the Ethiopian Standard ES C.D5.201 [11], Portland cement means the product obtained by grinding clinker with the possible addition of a small quantity of calcium sulphates and/or water and it is manufactured by thoroughly mixing together calcareous or other lime – bearing materials with argillaceous and/ or other silica, alumina or iron oxide bearing materials burning them at a clinkering temperature and grinding the resulting clinker so as to produce a cement capable of complying with the requirements stipulated in the same standard.

Portland cement is composed of four main oxides, namely: lime (CaO), Silica (SiO_2), Alumina (Al_2O_3) and Iron Oxide (Fe_2O_3). 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_2O, K_2O 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 [4]. However, the principal compounds, in Portland cement exist not in the form of simple oxides but as minerals of more complex molecular structure.

These four principal chemical compounds that make up Portland Cement are: Tricalcium silicate ($3CaOSiO_2$), Dicalcium silicate ($2CaOSiO_2$), Tricalcium aluminate ($3CaOAl_2O_3$) and Tetracalcium aluminoferrite ($4CaOAl_2O_3Fe_2O_3$)

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.

3.2.1.1.1 Chemical Composition of Portland cement

As already mentioned above, the raw materials in Portland cement production consists of four main oxides namely: lime (CaO), Silica (SiO_2), Alumina (Al_2O_3) and Iron Oxide (Fe_2O_3). However, the principal compounds in Portland cement exist not in the form of simple oxides but as minerals of more complex molecular structure.

The names of oxide composition and abbreviation of the four principal reactive compounds present in clinker and unhydrated Portland cement are shown in Table 3.1

Table3.1 Main Chemical Compounds of Portland Cement

Name of compounds	***Oxide composition***	***Abbreviation***
Tricalcium silicate	$3CaOSiO_2$	C_3S
Dicalcium silicate	$2CaOSiO_2$	C_2S
Tricalcium aluminate	$3CaOAl_2O_3$	C_3A
Tetracalcium aluminoferrite	$4CaOAl_2O_3Fe_2O_3$	C_4AF

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 [3].

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* [3].

The calculation of the potential composition of Portland cement is based on the work of R.H. Bogue and others, and it is often referred to as 'Bogue composition'. 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.

$$C_3S = 4.071(CaO)-7.600(SiO_2) - 6,718(Al_2O_3)-1.430(Fe_2O_3) - 2.852(SO_3) \quad [3.1]$$

$$C_2S=2.867(SiO_2) - 0.7544(3CaOSiO_2) \quad [3.2]$$

$$C_2S =2.650(Al_2O_3)-1.692(Fe_2O_3) \quad [3.3]$$

$$C_4AF=3.043(Fe_2O_3) \quad [3.4]$$

These four principal cement compounds differ greatly in their properties as shown summarized in Table 3.2 below.

Table: 3.2 Characteristics of Principal Compounds That Occur in Portland Cement.

Property	Relative behavior of each compound			
	C_3S	C_2S	C_3A	C_4AF
Rate of reaction	Medium	Slow	Fast	Fast
Heat librated	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 [9].

In addition to the main compounds, there are minor compounds such as MgO, TiO_2, Mn_2O_3, Na_2O and K_2O; 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.

3.2.1.1.2 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 [4].

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

$2\ C_3S + 6H \rightarrow C_3S_2H_3 + 3\ Ca\ (OH)_2$ [2.1]

$100 + 24 \rightarrow 75 + 49$ (the corresponding masses)

For C_2S

$2\ C_2S + 4H \rightarrow C_3S_2H_3 + 3\ Ca\ (OH)_2$ [2.2]

$100 + 21 \rightarrow 99 + 22$ (the corresponding masses)

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 presence 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 [4].

3.2.1.2 Portland Pozzolana Cement

In the Ethiopian Standard ES C.D5.210 [6], Portland Pozzolana cement is defined as cement resulting from a homogeneous mixture of finely ground Portland clinker and less than 25 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 25 to 40 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 taht 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 blastfurnace 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 [11].

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 [5].

3.2.1.2.1 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 [5].

3.2.1.2.2 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 [3].

A number of tests were carried out by Heath and Brandenburg with Oregon Pumicites and their results given in Fig. 3.1 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 [5].

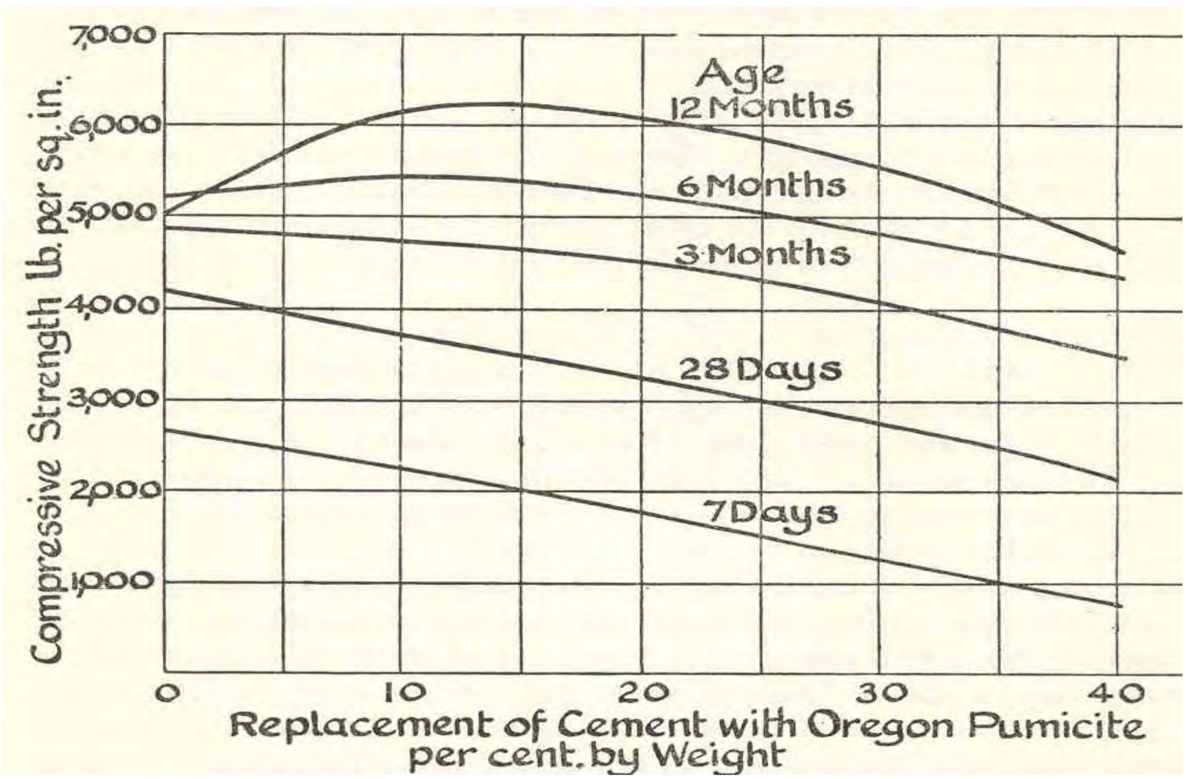


Fig. 3.1 The effect on strength due to the replacement of cement by a pozzolana

3.2.1.2.3 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 harbour 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 [5].

3.2.2 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 over all 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 over all 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.

3.2.2.1 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.

3.2.2.2 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, poison'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 equi-dimensional, 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.

3.2.2.3 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 with out 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.

3.2.2.3.1 Grading

Grading stands for particle – 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).

3.2.2.3.1.1 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 [2].

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.

3.2.2.3.1.2 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*

3.2.2.3.1.2.1 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, through out the range of sizes, but below 40 mm (1 ½ in) the advantage of the lowering the water requirement is dominant [2].

3.2.2.3.1.2.2 The desired performance of the concrete

In producing high performance concrete, the required quality of aggregate is the size of the course 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, poison’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 [2].

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 course aggregate and the hydrated cement paste while in compression or flexural test.

3.2.2.3.1.2.3 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.

3.2.3 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 [1].

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.*

3.2.4 Admixture

Admixture may be used in concrete to improve certain of its properties. They consist chiefly of those which accelerate and retard hydration or setting of the cement, for improving workability, pigments, wetting, dispersing and air entraining agents [3].

Since the water/cement ratio is too low to make workable concrete in the production of high strength concrete, usage of super-plasticizer is mandatory.

Some code of practices reduced the water content by a volume equivalent to the volume of the admixture [1].

3.3 PERFORMANCE OF CONCRETE

Performance of concrete is the ability of a concrete in delivering the desired functions through out the design life of a concrete structure.

Depending on the required service, 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 through out its designed service life.

Since the primary function of practically all structures is to carry loads or resist applied forces of whatever nature, concrete used for such purposes must have strength. This is the reason why the strength of concrete is commonly considered its most valuable property, although in some cases other characteristics may be more important. Nevertheless, 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.

3.3.1 Function of the cement paste

Concrete properties depends on the aggregate, cement paste, the bond between the aggregate and the surrounding cement paste and the over all adhesion and compaction of the concrete particles. All these factors except cement paste are discussed above. Furthermore, being the most important component of concrete, it is essential to discuss about cement paste before proceeding to the details of the performance of concrete.

Cement paste is the most important component of concrete and its properties depend up on:

- The characteristic of the cement
- Water/cement ratio, and
- The completeness of hydration

And with the following main functions:

- Providing lubrication of the plastic mass
- Filling the voids between the aggregates, it imparts imperviousness hence water tightness and durability to the hardened concrete.
- Binding the aggregates, it gives strength to the concrete in its hardened state

3.3.2 Compressive Strength

Of the various strength properties of concrete, it is generally the compressive strength which attracts the greatest interest since it is this property which is made use of in designing building units of structural or of simple load bearing quality. In addition, it has a great practical and economic significance because the sections and sizes of the concrete structures are determined by it.

Since most concrete structures are designed to resist compressive stress, it is this property which is usually prescribed by codes or standards.

3.3.2.1 Factors Affecting Concrete Strength

Strength of concrete depends on the strength of aggregate, cement paste, the bond between the aggregate and the surrounding cement paste and the over all adhesion and compaction of the concrete particles. The cement paste characteristics depend on the characteristic of the cement, Water/cement ratio, and the completeness of hydration. Aggregate properties like strength, shape and texture affect the concrete strength by the strength of aggregate, its effect on aggregate – cement paste bond and compaction.

The aggregate properties and effect of cement composition are discussed on their respective topics above and it will be redundant to discuss them again.

3.3.2.2 Water/Cement Ratio

Water is mandatory for hydration reaction to proceed. But if the amount of water added is exceedingly much, the excess water remains free in the concrete forming capillary pores. These pores remain the concrete to be permeable and weak in strength.

The strength of concrete increases as the water/cement ratio decreases provided that there is sufficient water for hydration of cement.

3.3.2.3 Degree Of Compaction

Immediate upon placement of concrete in the forms, it should be compacted to assure close contact of the constituent materials with themselves, as well as with other forms. This consolidation may be accomplished with the use of hand tools, but vibrators are much preferred. This consolidation eliminates air pores and achieved maximum density which gives the concrete higher strength and durability.

3.3.2.4 Curing of Concrete

The last step, and exceedingly important one in the manufacturing of concrete, is curing. As hydration of cement takes place only in the presence of moisture and at favorable temperatures, these conditions must be maintained for a suitable time interval called curing time.

The degree of completeness of hydration which is an important factor in cement paste characteristic depends on the ability of maintain the moisture in concrete which is called curing of a concrete.

At the time concrete is mixed, sufficient water is added to give workability. The amount of mixing water actually used is ordinarily in excess. Therefore, if the original water can be retained, there is more than sufficient for curing purposes.

Concrete gains strength most rapidly at early ages so that the greatest benefit from curing is secured during this period and each additional day is lesser importance than the preceding one.

Specification usually require that the surface of concrete be protected to prevent loss of moisture for at least 7 days where normal cement is used, and some specification require curing for 14 days. Where high – early – strength cements are used, the curing may be reduced by half, while for slow – hardening cements the time should be longer than for normal cements [3].

3.3.3 Durability

It is essential that every concrete structure should continue to perform its intended functions, that is, maintain its required strength and serviceability, during the expected service life. It follows that concrete must be able to withstand the process of deterioration to which it can be expected to be exposed. Such concrete is said to be durable [2].

Inadequate durability manifests itself by deterioration which can be due either to external factors or internal causes within the concrete itself. The various actions can be physical, chemical or mechanical.

Physical deterioration or weathering is due to the action of rain, freezing and thawing and dimensional changes (expansion and contraction) resulting from temperature variation and/or alternate wetting and drying. Chemical deterioration includes alkali – silica reactions, alkali – carbonate reaction and chemical attacks like: sulphates, chlorides as well as natural and industrial liquids and gases. Mechanical wear includes deterioration from abrasion, impact, erosion or cavitation.

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 [4].

As the core objective is to compare concrete properties produced using the already mentioned cement types, due focus is given on the properties of cement on durability of concrete and is discussed on the literature review for cement under the heading: *Concrete Making Materials*

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. Except the Ten Percent Fineness Value of the aggregates which was carried out at Butajira Site of Ethiopian Roads Authority, all laboratory tests on aggregate and concrete were carried out in the Material Testing Laboratory of the Faculty of Technology of AAU. The data about the chemical and physical properties of the cements were collected from their respective cement factories and the tests were carried out either by the factories and/or by external bodies like Quality and Standard Authority of Ethiopia and Kirton Concrete Services LTD.

4.2. CEMENT

Both Mugher and Messebo cements are available at market in Addis Ababa and fresh cements were purchased from their respective branch offices here in Addis. However, the Diredawa cement is not available at market in Addis and was bought from private shop at Diredawa; hence its freshness cannot be guaranteed.

All five cements comply with the requirements of Ethiopian Standards, ES C.D5 201 and ES C.D5 202[11]. The chemical and physical properties of the cements shown in Table 5.1 are summaries of the cement test result data which are attached for further reference at the end at the appendix III.

4.3. AGGREGATES

The fine aggregate used in the concrete productions is natural/river sand. It was sieved and its grading meets the Ethiopian Standard Requirement [12]. 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

I. No	*Test Description*		*Test Result*
1	Slit Content		2.43%
2	Moisture Content		6.79%
3	Absorption Cap.		5.70%
4	Specific Gravity	Bulk	2.19
		Bulk (SSD)	2.32
		Apparent	2.52
5	Fineness Modulus		2.88

The coarse aggregates used are *Bole aggregate* with maximum aggregate sizes of 25 mm used in the normal strength and intermediate strength concretes production and ERA *aggregate* with 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 gradations together with their curves of both aggregates are shown in Tables A-2, A-3 & A-4 and Fig. A-2, A-3 & A-4 in Appendix -I and the physical properties are tabulated in Table4.2

Table 4.2 Physical Properties of the coarse aggregates

I. No.	Test Description		ERA Aggregate	BOLE Aggregate
1	Maximum Size		12.5 mm	25 mm
2	Aggregate Crush Value (ACV)		17.25%	17.08%
3	Ten Percent Fineness Value (TPFV)		192.85	175.27
4	Aggregate Impact Value (AIV)		8.34%	8.26%
5	Flakiness Index (FI)	On 16 mm -10mm	13.59%	43.86%
		Of the Whole Sample	19.91%	28.42%
6	Los Angeles Abrasion (LAA)		12.33%	12.62%
7	Moisture Content		0.76%	1.70%
8	Dry Unit Wt.		1.63	1.43
9	Absorption Cap.		1.45%	1.73%
10	Specific Gravity	Bulk	2.80	2.60
		Bulk (SSD)	2.84	2.64
		Apparent	2.92	2.72
11	Shape		Angular	Angular
12	Texture		Very Rough	Rough

4.4. WATER

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

4.5. CHEMICAL ADMIXTURE

The superplasticizer Complast SP430, which complies with BSEN 934-2, BS 5075 part 3 and with ASTM C494 as type A and Type F is used. It is chloride free, superplasticing admixture based on selected naphonated naphthalene polymers. It is supplied as a brown solution, which instantly disperses in water. In addition, it has acceleration effect on strength gain at early ages and according to the manufacturer's manual, it is recommended to use in the range of 1.00 to 3.00 liters/100kg of cement [15].

Normally, the admixture should be added to the concrete with the mixing water to obtain the best results [15].

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. This has been proven by tests conducted in the material testing laboratory of the technology faculty [18].

4.6. MIX PREPARATION

For the purpose of this research five types of cements, namely: Mugher OPC & PPC, Messebo OPC & PPC and Diredawa PPC were used in every concrete class and in the three classes of concrete a total of fifteen mixes were made. In the production of normal strength concrete the targeted strength was C-25 and a D.O.E. Mix design Method [22] followed by two trial mixes were used to arrive at this mix proportion; where as the mix proportions for the intermediate and high strength classes of concrete were made based on literature recommendations [20,21] and trial mixes.

For the purposes of 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 [13] 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. Besides, at the mixes that used super-plasticizer, water amounts equal to the volume of the super plasticizer was deducted from the total water amount in the mix.

There are three mix proportions that were conducted to compare the rate of strength development, the difference in compressive strength values with age and to see the effect of curing on compressive strength development on the three classes of concrete using Mugher OPC & PPC, Messebo OPC & PPC and Diredawa PPC. They were made with cement content of 370kg/m^3, 450kg/m^3 and 550 kg/m^3, water/cement ratio of 0.5, 0.4 and 0.27 and chemical admixture of 0, 6.75 and 16.5 litres/m^3 respectively for the normal, intermediate and high strength concretes. The mix proportions and slumps are given in Tables 4.3, 4.4 and 4.5

Table 4.3 Mix Proportion and Slump for Normal Strength Concrete

Mix Code	Cement [kg/m3]	Cement type	W/C	water [kg/m3]	Fine Aggr. [kg/m3]	Coarse Aggr. kg/m3]	Slump [mm]	Admixture [lit/m3]
A1	370	Mugher PPC	0.5	185	620	1265	35	-
A2	370	Diredawa PPC	0.5	185	620	1265	36	-
A3	370	Messebo PPC	0.5	185	620	1265	43	-
A4	370	Mugher OPC	0.5	185	620	1265	43	-
A5	370	Messebo OPC	0.5	185	620	1265	45	-

Table 4.4 Mix Proportion and Slump for Intermediate Strength Concrete

Mix Code	Cement [kg/m3]	Cement type	W/C	water [kg/m3]	Fine Aggr. [kg/m3]	Coarse Aggr [kg/m3]	Slump [mm]	Admixture [lit/m3]
B1	450	Mugher PPC	0.4	180	535	1305	66.5	6.75
B2	450	Diredawa PPC	0.4	180	535	1305	80	6.75
B3	450	Messebo PPC	0.4	180	535	1305	68	6.75
B4	450	Mugher OPC	0.4	180	535	1305	95	6.75
B5	450	Messebo OPC	0.4	180	535	1305	140	6.75

Table 4.5 Mix Proportion and Slump for High Strength Concrete

Mix Code	Cement [kg/m3]	Cement type	W/C	water [kg/m3]	Fine Aggr. [kg/m3]	Coarse Aggr. [kg/m3]	Slump [mm]	Admixture [lit/m3]
C1	550	Mugher PPC	0.27	148.5	450	1345	62	16.5
C2	550	Diredawa PPC	0.27	148.5	450	1345	70	16.5
C3	550	Messebo PPC	0.27	148.5	450	1345	46	16.5
C4	550	Mugher OPC	0.27	148.5	450	1345	55	16.5
C5	550	Messebo OPC	0.27	148.5	450	1345	33	16.5

4.7. SPECIMENS PREPARATION

For the normal strength concrete a D.O.E. Mix design Method is used as starting point and two trial mixes were done to arrive at this mix proportion. Each mix batch was 51 liter in volume and was subjected to 1 minute dry mixing and 2 minutes wet mixing [14]. Regarding placing and compaction, placing was started immediately and was done in two layers and compacted in table vibrator for 30 seconds for single 15 cms cube mold and for 45 seconds for couple of 15 cms cube molds. Compaction and placing were completed with in 15 minutes.

For the Intermediate Strength concrete, literature review for recommended practices and trial mixes are the methods used to arrive at this mix proportion. Each mix batch was 51 liter in volume and was subjected to 1 minute dry mixing and 2 minutes wet mixing. After deducting the volume the admixture from the mixing water, the admixture was added to the water and stirred thoroughly. Regarding placing and compaction, placing was started immediately and was done in two layers and compacted in table vibrator for 30 seconds for single15 cms cube mold and for 45 seconds for couple of 15 cms cube molds. Compaction and placing were completed with in 15 minutes.

For the high strength concrete, literature review for recommended practices and trial mixes are the methods used to arrive at this mix proportion. Each mix batch was 34 liter in volume and was subjected to 1.5 minutes dry mixing and 3 minutes wet mixing. After deducting the volume of the admixture from the mixing water, the admixture was added to the water and stirred thoroughly. Regarding placing and compaction, placing was started immediately and was done in two layers and compacted in table vibrator for 45 seconds for single 15 cms cube mold and for 60 seconds for couple 15 cms cube molds. Compaction and placing were completed with in 15 minutes.

To minimize error each sample should be mixed at a time. However, the capacity of the mixer at the Faculty's Material Test Laboratory is 60liters but each sample required thirty units of 15cm cubes which correspond to about 110 liters. Hence, mixing was done in two or three batches and of course this may contribute some errors among the test result of each cube with in a sample.

4.7.1. Curing and Crushing

After 24 hours of placing and compaction, samples were removed from their molds and placed in to water pond half of them for three and the rest for seven days. Then after, the samples were placed in air, indoor and outdoor.

Had it not been for number of cubes and water pond area shortage, curing in water up to 28 days and outdoor air curing for 91 days were first intended to be done. But due to the above – mentioned reasons, curing in water were made only to 3 and 7 days and curing in air was done up to 91 days at indoor but only 28 days at outdoor.

CHAPTER FIVE

TEST RESULT ANALYSES AND DISCUSSIONS

5.1 INTRODUCTION

This Chapter has two parts.

In the first part, the test results of the cements collected from their respective factories 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 five 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 shown on Table 5.1 under the heading: *Production*, Mugher and Messebo cements are the main stakeholders at the market. The production capacity of Diredawa cement factory is very limited and its contribution is significant only in the Eastern part of the country.

As discussed in the literature review, 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 [3]. 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 [3]. 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 [4].

As shown on Table 5.1, under the heading: *the Mean Chemical Compounds of Clinker*, the total percentage of silicates are: ***75.3:77.4:78.1*** and that of C_3S are: ***58.3:64:57.4*** for Mugher, Messebo and Diredawa clinkers respectively. And under the heading: *the Mean Chemical Compounds of OPC*, the total silicates are***: 73.5: 73.6*** and the C_3S are ***50: 60.4*** for Mugher and Messebo OPCs respectively.

As shown under the heading: *Mean fineness*, the fineness for Mugher OPC, Mugher PPC, Messebo OPC and PPC are: *3100, 4474, 2971 and 2980* cm^2/gm respectively. Except for Mugher PPC, there is no remarkable difference in the fineness.

As a result, as far as fineness is concerned, no significant effect in early strength development is expected among Mugher OPC, Messebo OPC and Messebo PPC.

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. [4]. The amount of pozzolana incorporated in producing PPC of each cement type, as shown on the *Mean Pozzolana Included in PPC (%),* is ***28.3:25:25*** for Mugher, Messebo and Diredawa PPCs respectively. Therefore, due to the inclusion of 25% or more pozzolana to the clinker while producing the PPCs, generally concrete produced using the OPCs are expected to show higher early strength development than that of PPCs.

As a result of the above facts, concrete produced using Messebo OPC is expected to have the highest rate of early strength development followed by that of Mugher OPC and Messebo PPC.

Mugher clinker has higher C_3S than that of Diredawa and Mugher PPC has remarkably the highest fineness and pozzolana content. As there is a tradeoff between high finesse and high pozzolana content of a cement in early strength development, it is difficult to compare early strength of concretes produced using Mugher PPC and Diredawa 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 three cement factories regarding their pozzolana is the oxide composition and not the reactivity of the silicates. Hence, in this thesis, pozzolanicity of each PPC type is taken as the percentage of silicate in the oxide composition of its respective pozzolana.

On the literature survey of pozzolana, volcanic materials are not among the active pozzolanas [5]; but the pozzolana types for all PPCs as shown on Table 5.1 under the heading: *Pozzolana Type*s are Volcanic Materials.

The percentage of silicate in the pozzolana of each cement type, as shown under the heading: *Mean Oxide Composition of Pozzolana* in table 5.1, is: ***64.6:54.8:68.1*** for Mugher, Messebo and Diredawa PPCs respectively.

The pozzolanas used in production of the three PPCs are volcanic materials which are rated as less active, and the ultimate strength achieved from these pozzolanas 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, but in this thesis moist curing is made for 3 and 7 days. Therefore, the ultimate strength of concrete produced using the PPCs is expected to be lower than that of the OPCs.

Based on the total silicates of the chemical compound compositions, concrete from both OPCs are expected to have more or less equal ultimate strength. But due to lack of continuous and extended moist curing the C_2S may not be well hydrated and thus, concrete from cement with higher C_3S i.e. Messebo OPC is expected to show higher ultimate strength.

Diredawa PPC possesses the highest silicate in its pozzolana oxide, the highest C_2S and total silicates in its clinker compound composition relative to the other PPCs, hence if there were continuous and extended moist curing; a relatively the highest strength development is expected from concrete produced using Diredawa PPC. But comparison between concretes from that of Mugher PPC and Messebo PPC is difficult as the lower total silicate in the clinker and higher pozzolana content in the Mugher PPC may tradeoff with the richer silicate in its pozzolana.

However, for short moist curing, the C_2S in the cement and the silicates in pozzolana may not be sufficiently hydrated and hence PPCs with higher C_3S may show higher ultimate strength; thus in this regard concrete from Messebo PPC is expected to show the highest ultimate strength followed by that of Mugher PPC and the least by that of Diredawa 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 [2]. 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: *Specific Gravity*, the OPCs have significantly higher specific gravity than the PPCs; thus, at a given mass, for sure the PPCs have higher number of particles than the OPCs. Besides, under the heading: *Mean Fineness,* Mugher PPC has remarkably the highest specific surface area; hence the highest number of cement particles per given mass.

Table 5.1 Summaries of Test Results on the Five Cement Types Produced in Ethiopia

Mean Chemical Oxides of Clinker (%)						
	CaO	**SIO_2**	**Al_2O_3**	**Fe_2O_3**	**MgO**	**SO_3**
Mugher	65.61	21.26	5.76	3.79	0.95	1.08
Messebo	66.36	21.50	5.21	4.03	1.26	0.68
Diredawa	65.81	22.31	4.95	4.03	1.84	0.70
Mean Chemical Compounds of Clinker (%)						
	C_3S	**C_2S**	**C_3A**	**C_4AF**	**Total**	**% of Silicates**
Mugher	58.3	17.0	8.9	11.5	95.7	75.3
Messebo	64.0	13.3	7.0	12.3	96.6	77.4
Diredawa	57.4	20.7	6.3	12.3	96.6	78.1
Mean Chemical Oxides of OPC (%)						
	CaO	**SIO_2**	**Al_2O_3**	**Fe_2O_3**	**MgO**	**SO_3**
Mugher	63.38	21.36	4.89	3.92	1.27	2.54
Messebo	63.94	20.50	4.75	3.70	1.31	2.41
Mean Chemical Compounds of OPC (%)						
	C_3S	**C_2S**	**C_3A**	**C_4AF**	**Total**	**% of Silicates**
Mugher	50.04	23.48	6.32	11.91	91.76	73.52
Messebo	60.41	13.19	6.32	11.27	91.20	73.61
Mean Chemical Oxides of Pozzolana (%)						
	SIO_2	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**SO_3**
Mugher	64.58	2.27	0.97	4.04	15.17	0.00
Messebo	54.80	8.83	10.55	8.14	6.22	0.03
Diredawa	68.10	11.32	4.82	1.50	0.63	0.00
Mean of Pozzolana included in PPC						
Mugher	28.3					
Messebo	25.0					
Diredawa	25.0					
Mean Fineness, cm^2/gm			**Specific Gravity**			
Cement Source	**Type**		**Cement Source**	**Type**		
Mugher	OPC	3100	Mugher	OPC	3.15	
	PPC	4474		PPC		
Messebo	OPC	2971	Messebo	OPC	3.15	
	PPC	2980		PPC	2.75	
Diredawa			Diredawa			
	PPC	Not Available		PPC	Not Available	
Mean gypsum content in cement			**Production, tons/year**			
Mugher	4 to 5%		**Cement Source**	**Type**	1996EC	1997EC
Messebo	5%		Mugher	OPC		120,000
Diredawa	5%			PPC		730,000
Pozzolana type			Messebo	OPC	600,000	228,830
Mugher	Pumice			PPC	0	511,170
Messebo	Volcanic basalt		Diredawa			
Diredawa	Pumice			PPC		80,000

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 [3], 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 [4].

C_3A promotes high early strength but is the most vulnerable constituent of Portland cement toward possible chemical attack [5]. Low C_3A cement generates less heat, develops higher ultimate strength, and exhibits greater resistance to destructive elements than a cement containing large amounts of this compound. [3]. Due to the inclusion of 25% or more pozzolana to the clinker, for sure the PPCs have lesser content of C_3A and C_3S than the OPCs.

Because of its greater imperviousness, concrete produced from PPC has higher restriction on the ingression of gases and liquids and the lesser content of C_3A 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

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 the five cement types. Table 5.2 is further analyzed and summarized in Tables 5.3, 5.4 and 5.5 and graphed as shown on Fig. 5.1 to Fig. 5.3.

To evaluate and compare the rate of strength development among concretes of the same class produced using the five cement types, the test results of each concrete at different ages are analyzed relative to their 28^{th} day test result which are tabulated in Table 5.3 and graphed as shown on Fig. 5.4 to Fig. 5.6

To have a clear image on both the strength and the rate of development among the five concretes of the same class, the strength of each concrete is rated against to its respective strength of Mugher PPC and is tabulated as shown in Table 5.4 and graphed as shown on Fig.5.7 to Fig. 5.9

Indoor – outdoor air curing is meaningful when it is enriched with data about the ambient conditions. Hence, the relative humidity and temperature, the most important factors, at indoor and outdoor were recorded and summarized on Table5.5.

To see the effect of curing on compressive strength development, the summary of test results on Table 5.2 are further analyzed and summarized as shown on Table 5.6.

As shown on Table 5.2, at the age of 91 days mean compressive strength of: *26.0, 25.8, 27.0, 33.0 & 35 MPa* for Normal Strength concrete (NSC), *40.8, 40.5, 46.4, 55.4 & 59.9 MPa* for Intermediate Strength concrete (ISC) and *75.0, 72.8, 76.1, 82.2, & 91.2 MPa* for High Strength concrete (HSC) have been produced using Mugher PPC, Diredawa PPC, Messebo PPC, Mugher OPC, and Messebo OPC respectively.

From the above result, it is clearly shown that at all ages and classes of concrete, Messebo OPC has the highest compressive strength followed by Mugher OPC, Messebo PPC, Mugher PPC and Diredawa PPC in descending order.

Besides, it is apparent that in all classes of concrete, the OPCs have shown better strength development than the PPCs. This is actually what was expected to occur while discussing on concrete properties based on the cements test results at short moist curing duration.

As shown on Table 5.3 and fig. 5.4 to Fig. 5.6, for the concretes produced using Mugher PPC, Diredawa PPC, Messebo PPC, Mugher OPC, and Messebo OPC respectively, the three days strengths relative to their respective 28th days strengths are: *40%, 36%, 41/%, 38%, & 45%* for NSC, *47%, 44%, 54%, 57% & 56%* for ISC and *55%, 52%, 57%, 58% & 60%* for HSC, by the same token for the seven days, 63%, 63%, 65%, 60%, & 64% for NSC, 65%, 65%, 66%, 73% & 77% for ISC and 71%, 71%, 75%, 76%, & 83% for HSC.

The strength up to the 7th 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 OPCs have better rate of early age strength development than the PPCs which is the same as what was proposed on the cement test data analysis and discussion.

Among the PPCs, concrete produced from Messebo PPC has shown the highest early strength followed by Mugher PPC and then by Diredawa PPC.

Interestingly in the high strength concrete, strength up to *58% & 60%* in 3 days and 76%, & 83%.% in 7 days relative to their 28 days strength was possible using Mugher and Messebo

OPCs respectively. Hence, the OPCs in general and Messebo OPC in particular are the best in high early strength concrete production.

The 91 days strengths relative to their respective 28 days strengths as shown in Table 5.3 are: *110%, 120%, 110%, 106%, & 104%* for NSC, *109%, 114%, 110%, 110% &105%* for ISC and *109%, 115%, 107%, 107% & 107%* for HSC produced using Mugher PPC, Diredawa PPC, Messebo PPC, Mugher OPC, and Messebo OPC respectively

The strength development after 28 days, particular to this thesis at the 91days, is compared using the ratio between the 91 and 28 days strengths. As a result, as shown above, the highest increment, 20% is achieved by Diredawa PPC concrete and the least, 4%, by Messebo OPC concrete. Generally, at later ages concretes made of the PPCs have shown larger strength increment than that of the OPCs and the highest increment is shown on Diredawa PPC and followed by Mugher PPC and Messebo PPC, Mugher OPC and Messebo OPC in descending order.

As shown on Table 5.4 and on fig. 5.7 to fig.5.9, concretes produced using Messebo OPC and PPC and Mugher OPC have a ratio of greater than one where as concretes from Diredawa PPC have a ratio of less than one. However, the trend of the ratios with age is generally decreasing for concrete produced using Messebo OPC and PPC and Mugher OPC and strictly increasing for concrete that of Diredawa PPC, that is, in all classes of concrete, concrete produced using Diredawa PPC has shown the least compressive strength and the highest rate of strength increment with age where as that of Messebo OPC has the highest strength but the least rate of strength increment with age.

From the above fact, with in each class of concrete, it is clear that though the strength gap among the concretes is still significantly large even at the age of 91 days, the strength difference had been getting narrower and narrower with age.

At the 91 days the strength difference between concrete from Messebo OPC and Mugher PPC goes to the average by about 35% where as the strength increment between the 28 and 91 days of concrete produced using Mugher PPC is to the average 10 % and the strength development after 91 days is believed to be little. The same trend exists between the concretes produced using Mugher OPCs and that of the PPCs. Therefore, it is highly unlikely that the concrete produced using the PPCs can narrow and reach the strength of the concrete produced that of the OPCs.

Table 5.2 Summaries of Compressive Strength Test Results of Normal to High Strength Concrete with their Curing Conditions.

Test Age (Days)	3	7			28				91		Mean Values			
Water Curing Duration (Days)	3	7	3		3		7		3	7				
Curing Condition	In Water		In Air											
			Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor	Indoor	Indoor	3Days	7Days	28Days	91Days
Normal Strength														
A_1 (Mugher PPC)	9.42	13.97	14.94	15.43	21.71	23.10	24.49	25.12	24.71	27.26	9.42	13.96	23.61	25.98
A_2 (Diredawa PPC)	7.82	12.51	13.74	14.51	20.58	20.81	22.47	22.23	24.54	27.01	7.82	13.59	21.52	25.78
A_3 (Messebo PPC)	9.96	15.61	16.22	15.97	24.74	23.22	25.29	24.68	25.68	28.23	9.96	15.93	24.48	26.95
A_4 (Mugher OPC)	11.83	18.91	18.63	18.50	30.84	30.15	31.50	31.76	31.49	34.53	11.83	18.68	31.06	33.01
A_5 (Messebo OPC)	15.09	20.66	22.86	20.67	33.51	32.43	35.15	33.21	33.01	36.91	15.09	21.40	33.58	34.96
Intermediate Strength														
B_1 (Mugher PPC)	17.61	23.96	26.50	23.22	39.84	35.39	36.87	38.19	38.81	42.88	17.61	24.56	37.57	40.84
B_2 (Diredawa PPC)	15.69	22.63	24.51	22.73	34.46	35.86	37.25	34.43	38.43	42.53	15.69	23.29	35.50	40.48
B_3 (Messebo PPC)	22.78	30.81	31.16	31.21	41.04	40.54	45.35	42.54	45.30	47.59	22.78	31.06	42.37	46.44
B_4 (Mugher OPC)	27.94	34.72	36.94	36.06	48.65	48.81	51.39	48.47	53.59	57.21	27.94	35.91	49.33	55.40
B_5 (Messebo OPC)	31.87	43.89	46.13	42.03	56.95	55.07	58.24	57.78	58.01	61.69	31.87	44.02	57.01	59.85
High Strength														
C_1 (Mugher PPC)	37.78	49.49	48.82	48.42	68.25	68.12	70.20	68.89	73.84	76.07	37.78	48.91	68.87	74.96
C_2 (Diredawa PPC)	33.10	44.57	46.02	45.26	61.15	62.78	65.01	64.80	69.52	75.99	33.10	45.28	63.43	72.76
C_3 (Messebo PPC)	40.55	54.29	54.71	51.30	70.03	69.35	72.17	73.01	74.21	78.06	40.55	53.43	71.14	76.13
C_4 (Mugher OPC)	44.84	58.89	59.50	56.90	75.70	75.15	78.19	78.15	82.02	82.29	44.84	58.43	76.80	82.15
C_5 (Messebo OPC)	51.31	70.45	72.36	69.12	83.04	86.66	85.50	86.38	90.93	91.39	51.31	70.64	85.39	91.16

Table 5.3 Rate of Strength development Relative to the 28th day Strength

Days	3Days	7Days	28Days	91Days
Normal Strength				
A1 (Mugher PPC)	0.40	0.63	1.00	1.10
A2 (Diredawa PPC)	0.36	0.63	1.00	1.20
A3 (Messebo PPC)	0.41	0.65	1.00	1.10
A4 (Mugher OPC)	0.38	0.60	1.00	1.06
A5 (Messebo OPC)	0.45	0.64	1.00	1.04
Intermediate Strength				
B1 (Mugher PPC)	0.47	0.65	1.00	1.09
B2 (Diredawa PPC)	0.44	0.66	1.00	1.14
B3 (Messebo PPC)	0.54	0.73	1.00	1.10
B4 (Mugher OPC)	0.57	0.73	1.00	1.10
B5 (Messebo OPC)	0.56	0.77	1.00	1.05
High Strength				
C1 (Mugher PPC)	0.55	0.71	1.00	1.09
C2 (Diredawa PPC)	0.52	0.71	1.00	1.15
C3 (Messebo PPC)	0.57	0.75	1.00	1.07
C4 (Mugher OPC)	0.58	0.76	1.00	1.07
C5 (Messebo OPC)	0.60	0.83	1.00	1.07

Table 5.4 Comparison of Strength Relative to Mugher PPC

Days	3Days	7Days	28Days	91Days
Normal Strength				
A1 (Mugher PPC)	1.00	1.00	1.00	1.00
A2 (Diredawa PPC)	0.83	0.92	0.91	0.99
A3 (Messebo PPC)	1.06	1.08	1.04	1.04
A4 (Mugher OPC)	1.26	1.26	1.32	1.27
A5 (Messebo OPC)	1.60	1.45	1.42	1.35
Intermediate Strength				
B1 (Mugher PPC)	1.00	1.00	1.00	1.00
B2 (Diredawa PPC)	0.89	0.95	0.94	0.99
B3 (Messebo PPC)	1.29	1.26	1.13	1.14
B4 (Mugher OPC)	1.59	1.46	1.31	1.36
B5 (Messebo OPC)	1.81	1.79	1.52	1.47
High Strength				
C1 (Mugher PPC)	1.00	1.00	1.00	1.00
C2 (Diredawa PPC)	0.88	0.93	0.92	0.97
C3 (Messebo PPC)	1.07	1.09	1.03	1.02
C4 (Mugher OPC)	1.19	1.19	1.12	1.10
C5 (Messebo OPC)	1.36	1.44	1.24	1.22

Table 5.5 Records of Ambient Conditions for the Indoor and Outdoor Air Cured Samples

Date	Time	Relative Humidity,%		Temperature, °C	
		Indoor	Outdoor	Indoor	Outdoor
18/04/05	11:00AM	40		23	
19/04/05	04:25PM	51	40	19	26
20/04/05	04:25PM	51	46	21	23
21/04/05	07:30AM	53		19	
	07:45AM		61		18
22/04/05	06:40AM	53		18.5	
	07:00AM		62		16
	07:30AM		46		27
23/04/05	06:30AM	53		19	
	06:50AM		68		15
24/04/05	06:55AM	55		18.5	
	07:15AM		75		13
25/04/05	08:10AM	55		19	
	12:00AM		40		27
26/04/05	06:45AM		100		12
	02:40PM		38		24
27/04/05	07:00AM	53		18.5	
	08:00AM		98		14
	02:00PM		47		22
30/04/05	06:35AM	50		18	
	06:45AM		68		16
	08:30AM		45		18
	10:25AM		45		35
1/5/2005	03:50PM	53		26	
2/5/2005	09:30AM	54		21	
	04:00PM		54		18
3/5/2005	11:30AM	55		20	
	12:30 PM		75		17
4/5/2005	10:30AM	56		20	
5/5/2005	07:15AM	53		18	
	08:20AM		48		24
20/05/05	11:45AM	52		21	

Table 5.6 ***Effect of Curing on Strength Development***

	3days Indoor/Outdoor		7days Indoor/ Outdoor	3 days Indoor/ 7 days Outdoor	3 days Outdoor/ 7 days Indoor	3 days / 7 days Indoor		3 days/ 7days Outdoor	3 days in door/ 7 days in water	3 days out door/ 7 days in water
TEST AT	**7th Day**	**28th Day**	**28th Day**	**28th Day**	**28th Day**	**28th day**	**91th Day**	**28th day**	**7th day**	**7th day**
Normal Strength										
A1 (Mugher PPC)	0.97	0.94	0.98	0.86	0.94	0.89	0.91	0.92	1.07	1.10
A2 (Diredawa PPC)	0.95	0.99	1.01	0.93	0.93	0.92	0.91	0.94	1.10	1.16
A3 (Messebo PPC)	1.02	1.07	1.02	1.00	0.92	0.98	0.91	0.94	1.04	1.02
A4 (Mugher OPC)	1.01	1.02	0.99	0.97	0.96	0.98	0.91	0.95	0.99	0.98
A5 (Messebo OPC)	1.11	1.03	1.06	1.01	0.92	0.95	0.89	0.98	1.11	1.00
Intermediate Strength										
B1 (Mugher PPC)	1.14	1.13	0.97	1.04	0.96	1.08	0.90	0.93	1.11	0.97
B2 (Diredawa PPC)	1.08	0.96	1.08	1.00	0.96	0.92	0.90	1.04	1.08	1.00
B3 (Messebo PPC)		1.01	1.07	0.96	0.89	0.90	0.95	0.95	1.01	1.01
B4 (Mugher OPC)	1.02	1.00	1.06	1.00	0.95	0.95	0.94	1.01	1.06	1.04
B5 (Messebo OPC)	1.10	1.03	1.01	0.99	0.95	0.98	0.94	0.95	1.05	0.96
High Strength										
C1 (Mugher PPC)	1.01	1.00	1.02	0.99	0.97	0.97	0.97	0.99	0.99	0.98
C2 (Diredawa PPC)	1.02	0.97	1.00	0.94	0.97	0.94	0.91	0.97	1.03	1.02
C3 (Messebo PPC)	1.07	1.01	0.99	0.96	0.96	0.97	0.95	0.95	1.01	0.94
C4 (Mugher OPC)	1.05	1.01	1.00	0.97	0.96	0.97	1.00	0.96	1.01	0.97
C5 (Messebo OPC)	1.05	0.96	0.99	0.96	1.01	0.97	0.99	1.00	1.03	0.98

Table 5.7 Mugher OPC Concrete Strength Relative to That of Messebo OPC

Class of Concrete	3Days	7Days	28Days	91Days
Normal	78%	87%	92%	94%
Intermediate	88%	82%	87%	93%
High	87%	83%	90%	90%
Average	84%	84%	90%	92%

Comparison is also made between the OPCs. As can be seen on Table 5.7 and Figure 5.10 at all ages compressive strength of Messebo OPC excels that of Mugher OPC. Concrete made of Mugher OPC attains to the average 90% of compressive strength that of Messebo OPC at the age of 28 days

5.3.1 Effect of curing

As can be seen in Table 5.5 the humidity and temperature for the indoor air curing is some what consistent; whereas, for the outdoor air curing, the temperature and humidity were so erratic and sometimes even opposite during the day and night(100% RH and 14^{o}C in the morning and 38% and 24 ^{o}C in the afternoon). As the outdoor ambient condition didn't have defined pattern, it gives little sense to investigate the effects by comparing indoor and out door air cured samples. Hence, only like with like, i.e. indoor with indoor and outdoor with outdoor, comparisons are made.

The compressive strength ratios of concretes water cured for 3 days against to 7 days as shown on the 7th, 8th and 9th columns of table 5.6 are almost entirely less than one and this is a clear indication of the fact that a little longer early time moist curing has a significant increase on the ultimate strength, on the 28 and 91 days strength in this case.

The admixture used in the production of intermediate and high strength concretes has accelerating effect on top of superplasticizing; hence this may undermine the early time water curing effect on strength at later ages. As a result, the effect can be seen well if we see them on the normal strength concrete.

All the ratios at the NSC are less than one; particularly at the 91 days strength, the difference is very significant that nearly a 10% increase in strength is shown on samples water cured for 7 days over the samples water cured for 3 days.

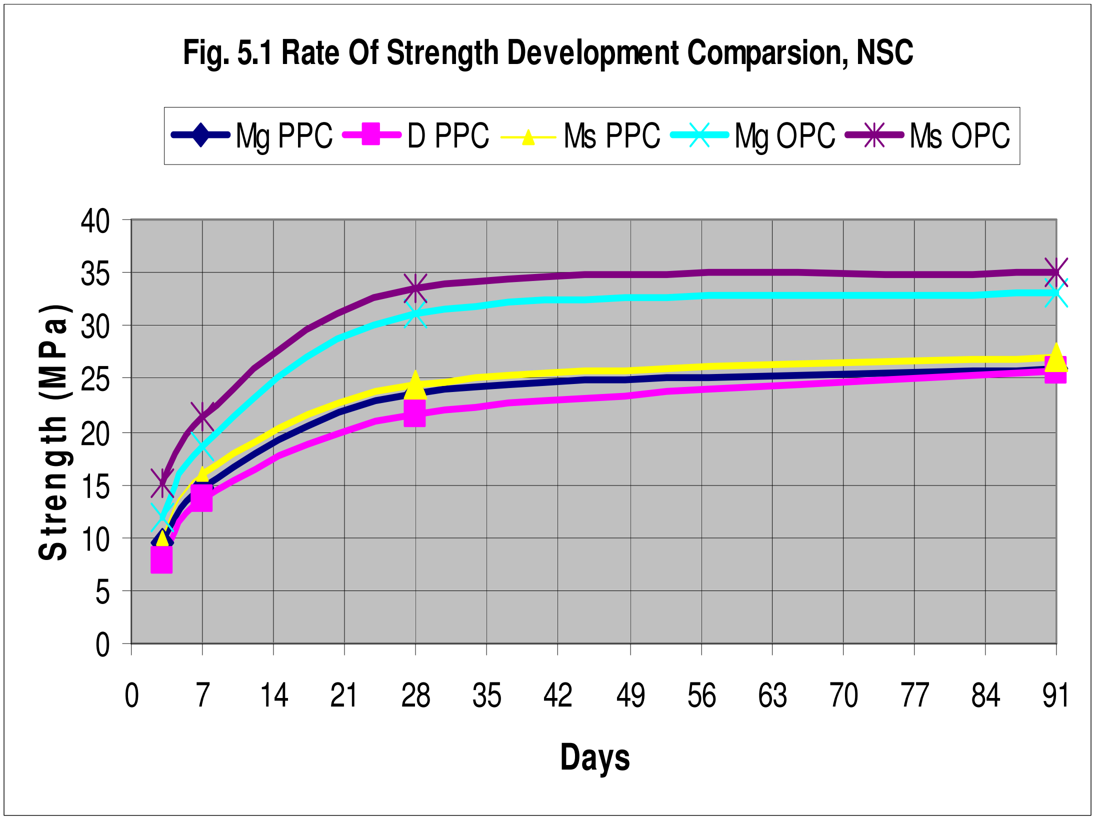


Fig. 5.1 Rate Of Strength Development Comparsion, NSC
Mg PPC
D PPC
Ms PPC
Mg OPC
Ms OPC
Strength (MPa)
0
5
10
15
20
25
30
35
40
0
7
14
21
28
35
42
49
56
63
70
77
84
91
Days

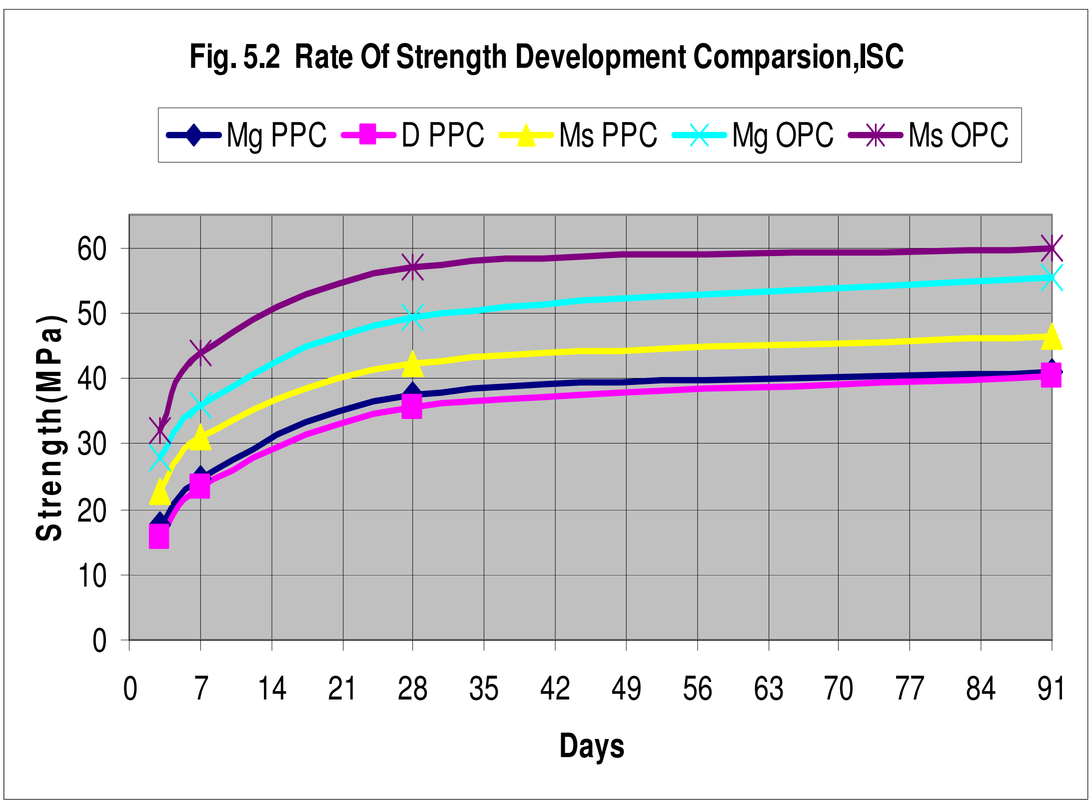


Fig. 5.2 Rate Of Strength Development Comparsion,ISC
Mg PPC
D PPC
Ms PPC
Mg OPC
Ms OPC
Strength(MPa)
0
10
20
30
40
50
60
0
7
14
21
28
35
42
49
56
63
70
77
84
91
Days

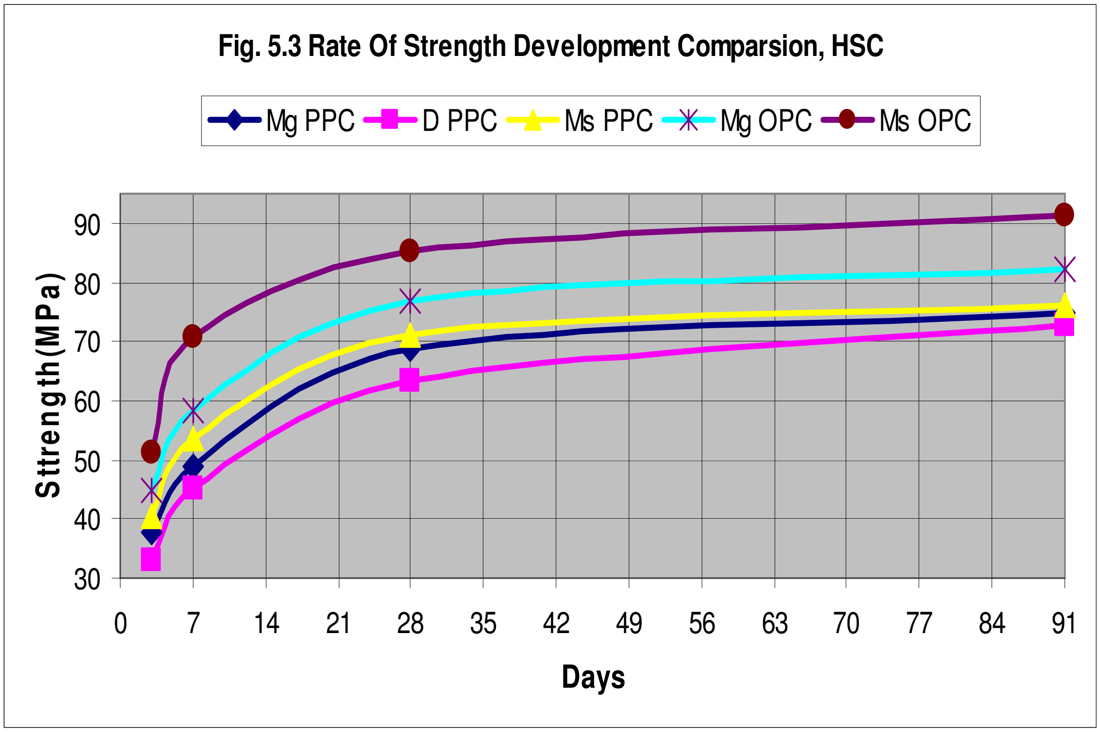


Fig. 5.3 Rate Of Strength Development Comparsion, HSC

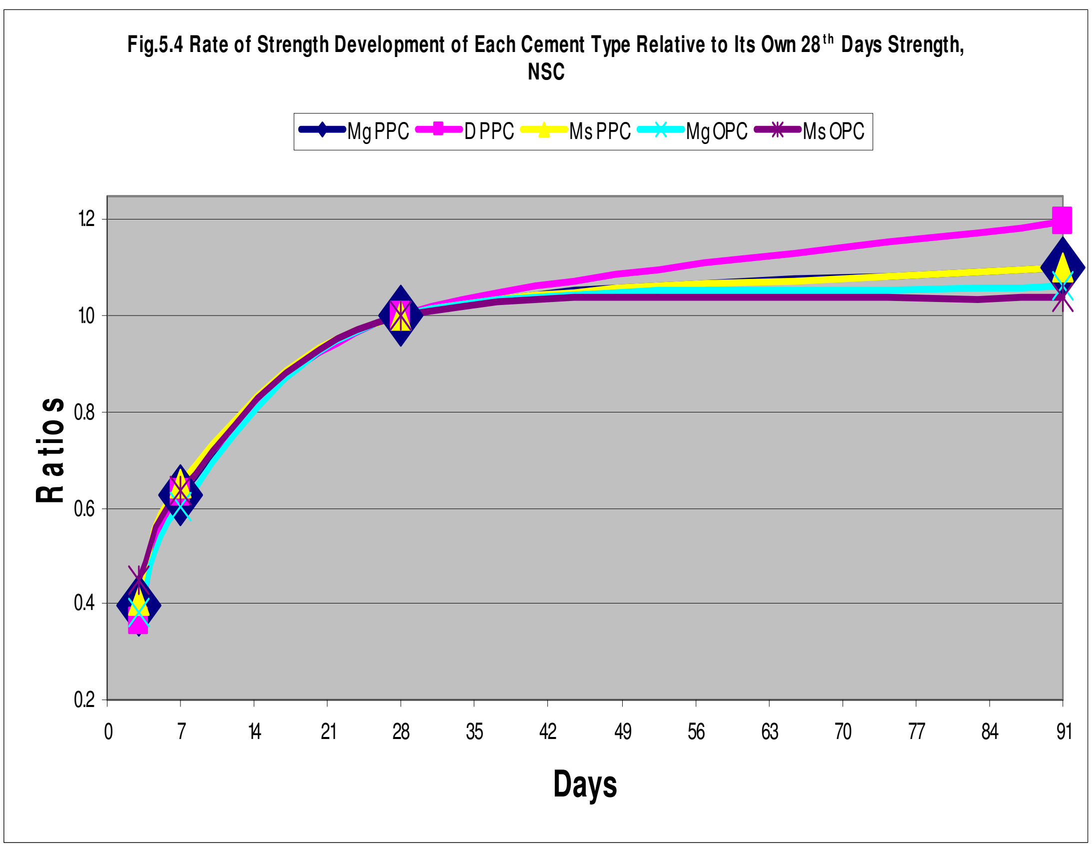


Fig.5.4 Rate of Strength Development of Each Cement Type Relative to Its Own 28th Days Strength, NSC

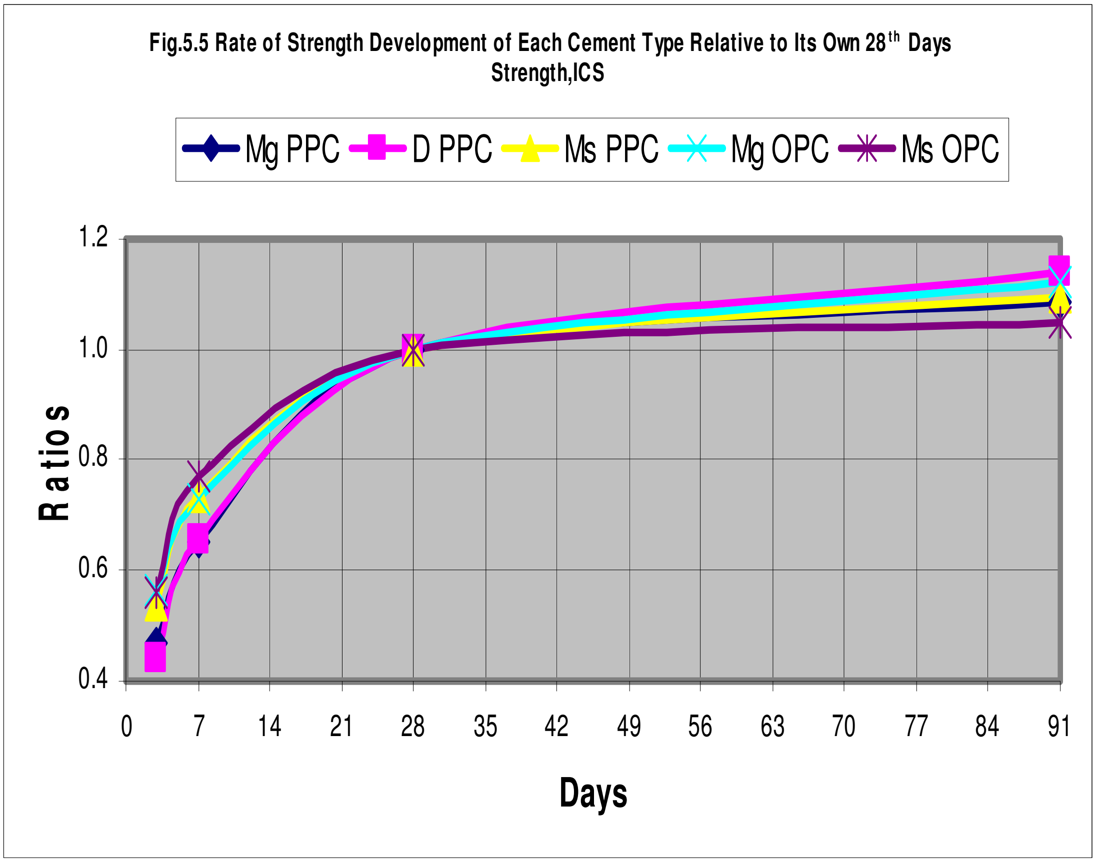


Fig.5.5 Rate of Strength Development of Each Cement Type Relative to Its Own 28th Days Strength,ICS
Mg PPC
D PPC
Ms PPC
Mg OPC
Ms OPC
Ratios
1.2
1.0
0.8
0.6
0.4
0
7
14
21
28
35
42
49
56
63
70
77
84
91
Days

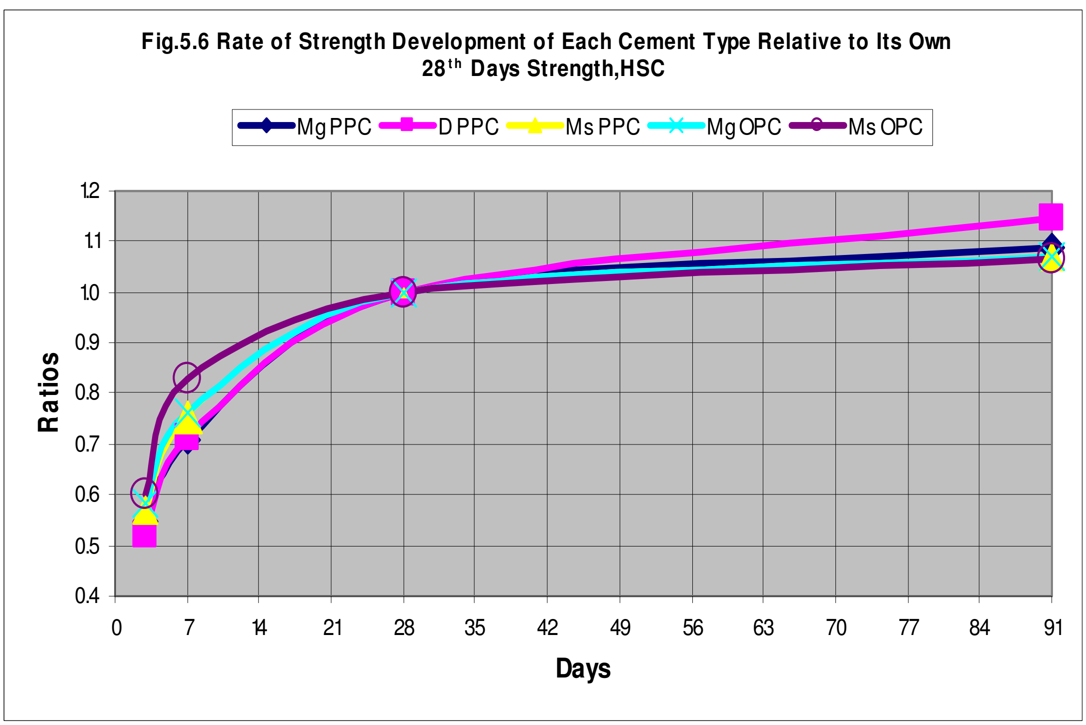


Fig.5.6 Rate of Strength Development of Each Cement Type Relative to Its Own 28th Days Strength,HSC
Mg PPC
D PPC
Ms PPC
Mg OPC
Ms OPC
Ratios
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0
7
14
21
28
35
42
49
56
63
70
77
84
91
Days

Fig.5.7 Strength Comparsion Relative to Mugher PPC, NSC

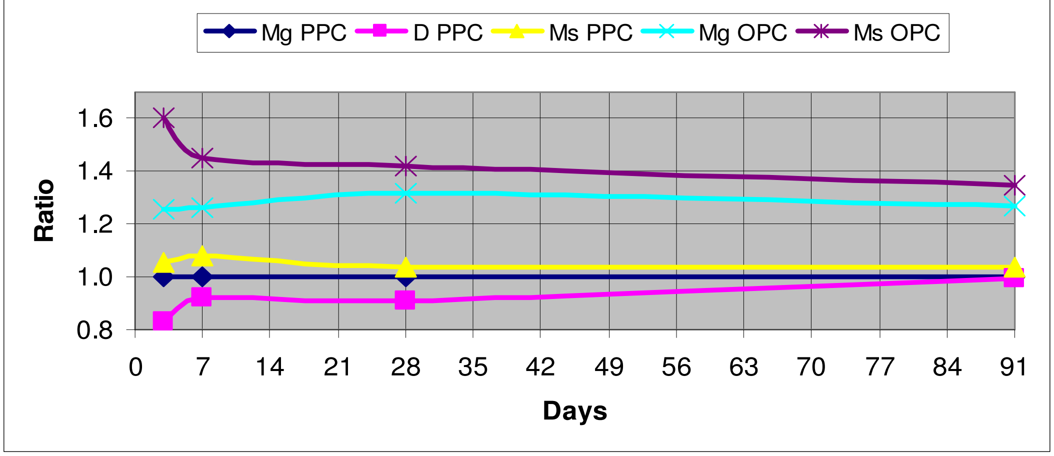


Fig.5.8 Strength Comparsion Relative to Mugher PPC,ISC

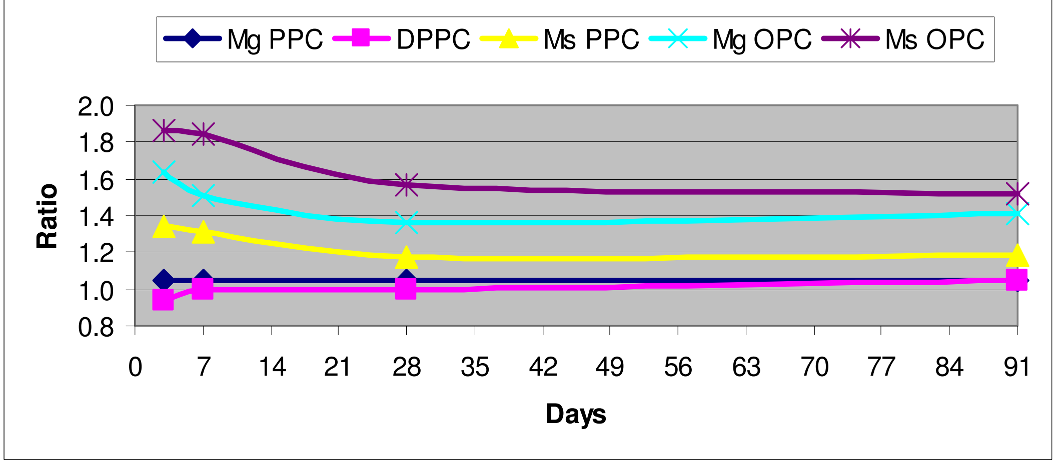
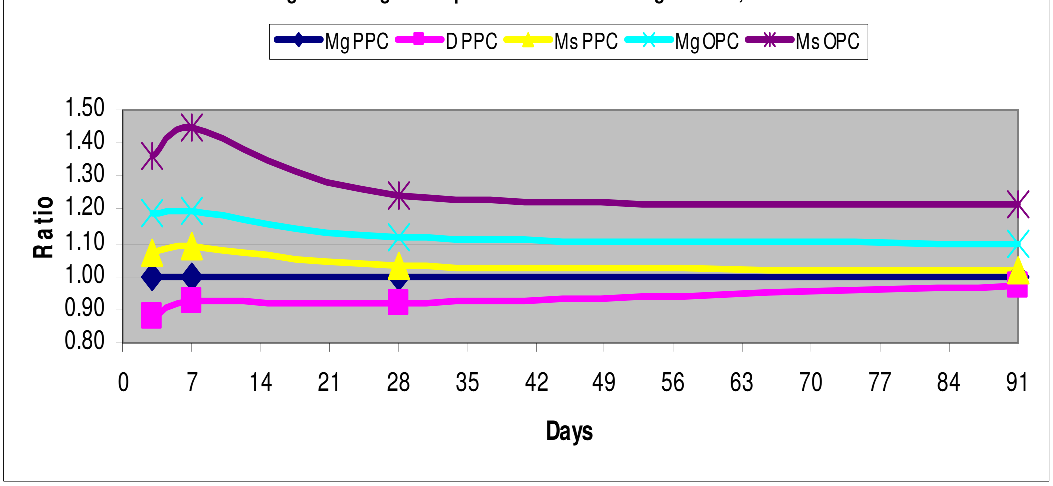


Fig.5.9 Strength Comparsion Relative to Mugher PPC,HSC



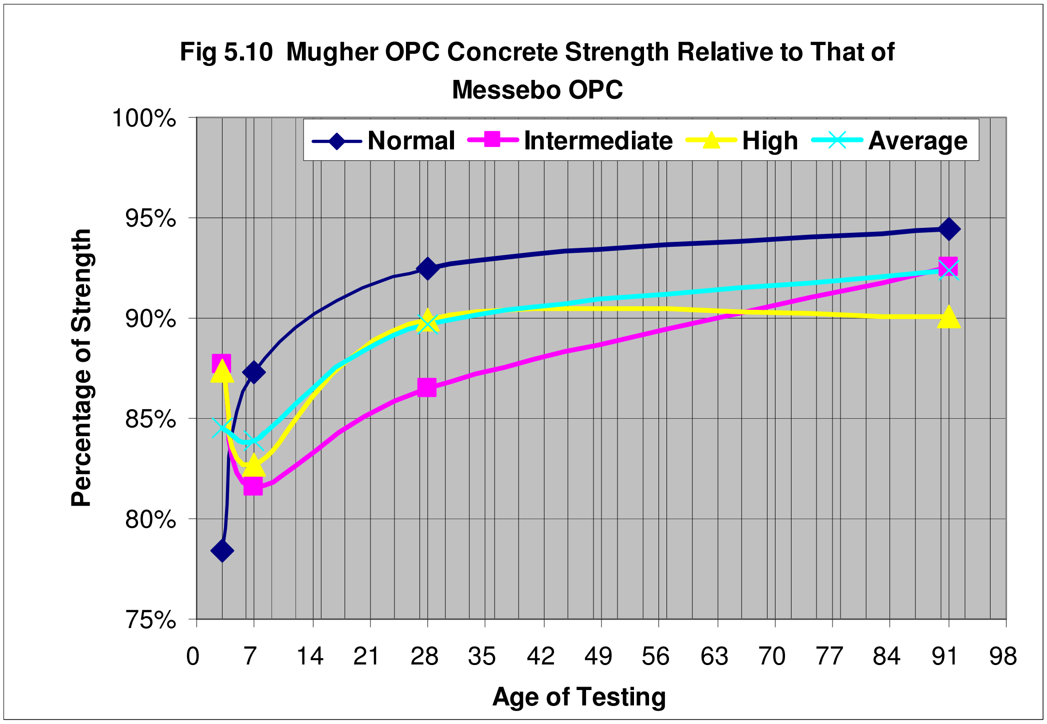


Fig 5.10 Mugher OPC Concrete Strength Relative to That of Messebo OPC
Normal
Intermediate
High
Average
100%
95%
90%
85%
80%
75%
Percentage of Strength
0
7
14
21
28
35
42
49
56
63
70
77
84
91
98
Age of Testing

CHAPTER SIX
CONCLUSIONS AND RECOMMENDATIONS

6.1 INTRODUCTION

The analyses and discussions on the properties of concretes produced using the five cement types which are made based on the literature survey on cement and test results of the five cements and their concrete compressive strength test results in the previous chapter are the bases for conclusions and recommendations.

6.2 CONCLUSIONS

In all classes of concrete considered, mixing was made with the same conditions except varying the cement type. Hence, the variation on the concrete compressive strength test result mainly attributes to the characteristic of the cement used.

The concrete strength proposed using the cement test results analysis and concrete strength obtained from the compressive strength test results are similar. This has of course created confidence on the reliability of other concrete properties proposed using the cement test results.

There are three mix proportions that were conducted to compare the rate of strength development, the difference in compressive strength values with age and to see the effect of curing on compressive strength development on the three classes of concrete produced using Mugher OPC & PPC, Messebo OPC & PPC and Diredawa PPC. They were made with cement content of 370kg/m^3, 450kg/m^3 and 550 kg/m^3, water/cement ratio of 0.5, 0.4 and 0.27, maximum aggregate size of 25, 20 and 12.5mm, and chemical admixture of 0, 6.75 and 16.5 litres/m^3 respectively for the normal, intermediate and high strength concretes. The samples were moist cured for 3 and 7 days then indoor and outdoor air cured up to testing date.

For the above mentioned mix proportions and conditions, the following conclusions are drawn:

1. At the age of 91 days mean compressive strength of: 26.0, 25.8, 27.0, 33.0 & 35 MPa for Normal Strength concrete (NSC), 40.8, 40.5, 46.4, 55.4 & 59.9 MPa for Intermediate Strength concrete (ISC) and 75.0, 72.8, 76.1, 82.2, & 91.2 MPa for High Strength concrete (HSC) have been produced using Mugher PPC, Diredawa

PPC, Messebo PPC, Mugher OPC, and Messebo OPC respectively. Therefore, at all ages and classes of concrete, Messebo OPC has produced the highest compressive strength concrete, followed by Mugher OPC, Messebo PPC, Mugher PPC and Diredawa PPC, in descending order.

2. Between the 91 and 28 days strengths, the highest 20% increment is attained by Diredawa PPC and the least 4% by Messebo OPC. Generally, at later ages the PPCs have shown larger strength increment as compared to the OPCs.

3. Though the strength differences show a decreasing trend with age, it is highly unlikely that the concrete produced using the PPCs can narrow and reach the strength of the concretes made of the OPCs. Hence, keeping every condition the same, the PPCs can not produce a concrete strength as high as the OPCs do at the age of three months.

4. The pozzolanas used in production of the three PPCs are volcanic materials which are less pozzolanic, and the ultimate strength achieved from these pozzolanas cannot be as high as what could be achieved from active pozzolanas. Besides, the hydration of C_2S in clinker and the silicate in the pozzolana require long moist curing; but in this research, moist curing is made only for 3 and 7 days. These are, therefore, the reasons believed to cause the ultimate strength of the PPCs' concretes to be lower than that of the OPCs' at the age of three months.

5. At the age of 28 days, concretes made of Mugher PPC and Diredawa PPC respectively attain to the average 94% and 87% the compressive strength of concrete made of Messebo PPC.

6. At the age of 28 days concrete made of Mugher OPC attains to the average 90% of the compressive strength developed by concrete made of Messebo OPC.

7. 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; besides, due to short moist curing the contribution of C_2S in ultimate strength may not be that much significant. Therefore, it is its high C_3S content that gives concrete made of Messebo OPC the highest strength at all ages.

8. At the 91 days strength, the difference in strength is significant that nearly a 10% increase in strength is shown on samples water cured for 7 days over the samples water cured for 3 days

6.3 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. Hence, in the production of such concretes, the OPCs in general and Messebo OPC in particular are recommended.

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, the OPCs in general and Messebo OPC in particular are better recommended than the PPCs to be used in colder areas.

b. This is susceptible to early age thermal shrinkage and thus the OPCs in general and Messebo OPC in particular are not recommended in hot area concreting, in mass concreting and in works with high surface area exposed to air, like finishing works.

c. In the production of high strength concrete, both OPCs in general and Messebo OPC in particular are best recommended. However, out of the five cements, the OPCs in general and Messebo OPC in particular release the highest 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. In the building of large dams , mass structures and concreting in hot areas 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, the PPCs in general and Mugher PPC and Diredawa PPC in particular are best recommended cements in the production of concrete.

4. When moderate early strength and chemical attack resistant concrete is desired at the same time, Messebo PPC is preferable.

5. When water tight concrete is required, the PPCs are recommended. But on top of other qualities common to all the PPCs, Mugher PPC has remarkably the highest specific surface area and is most preferable in such concrete production.

6. At the 91 days strength, the difference in strength is significant that nearly a 10% increase in strength is shown on samples water cured for 7 days over the samples water cured for 3 days. Therefore, as much as possible, longer early age moist curing is recommended for all concretes, especially for concretes produced using the PPCs.

7. 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.

8. The traditional mix proportioning commonly used by the small scale contractors dictates the mix proportioning ratios of cement, sand and aggregate with out mentioning any thing 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.

9. The construction industry in our country is in its infant stage. For instance, if we take material specifically cement, the available cement types, PPC and OPC, are too small to produce concretes and other cement products that fit to different purposes. Furthermore, little is known on the availability of different cement types and in some cases lack the information on the difference among the locally produced cement types. In relevant to this research, the following are recommended:

    a. There are too small cement types to produce concretes and other cement products that fit to different purposes. For instance, OPC may not be economical and suitable for ordinary brick laying, masonry and pipe works. Therefore, producers should do researches based on market need and be able to produced different cement types to fit different purposes and then should promote their products.

b. Producing excellent mix design in laboratory cannot guarantee for the quality of structures constructed on site. As a result, parties in the construction industry should strive so that laboratory tests should be carried out considering the prevailing site conditions and concrete construction and concrete materials handling on site must be done strictly in compliance with laboratory results and specifications so that the desired quality structure can be constructed.

c. Besides, better technology should be used and training of staffs ranging from the professionals to semi – skilled laborers should be done to acquire them with the basic knowledge and skills and to make them conscious of quality.

6.4 Areas of Further Studies

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

1. Laboratory tests on concrete made of the five cements in determining the amount of the four cements required to produce concrete characteristic strength equivalent to the fifth one so that cost – benefit analysis on the concretes made of Mugher PPC and OPC, Messebo PPC and OPC and Diredawa PPC.

2. Longer and continuous moist curing, different curing conditions and long term compressive strength test for further comparison among the concretes produced using Mugher PPC and OPC, Messebo PPC and OPC and Diredawa PPC.

3. Laboratory tests on the durability of concretes made of Mugher PPC and OPC, Messebo PPC and OPC and Diredawa PPC.

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APPENDIX – I

Sieve Analysis Results of the Sand and the Aggregates

Table A-1 Sieve analysis of Sand

Sieve Opening [mm]	*Mass of Sieve [gm]*	*Mass of Sieve + aggregate [gm]*	*Mass of retaining Aggregate [gm]*	*Percentage Retained*	*Percentage Coarser*	*Percentage Passing*
9.5	595	595	0	0.0%	0.0%	100.0%
4.75	567.1	595.3	28.2	3.7%	3.7%	96.3%
2.36	529.3	593.5	64.2	8.5%	12.2%	87.8%
1.18	535.7	656.2	120.5	15.9%	28.1%	71.9%
0.6	514.6	746.9	232.3	30.7%	58.7%	41.3%
0.3	486.1	718.7	232.6	30.7%	89.4%	10.6%
0.15	469.4	520.9	51.5	6.8%	96.2%	3.8%
Pan	422.7	451.2	28.5	3.8%	100.0%	0.0%
Fineness Modulus					**2.88**	

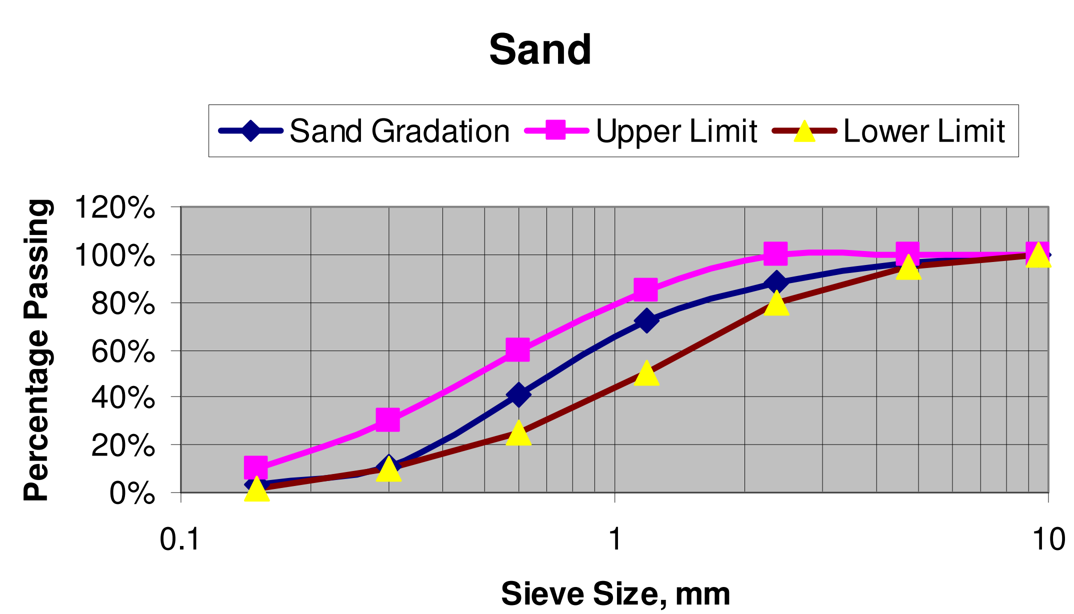

Fig. A-1 Gradation Curve for Sand

Table A-2 Proportion of aggregate blended for the normal strength concrete

Sieve Opening[mm]	Mass of retaining Aggregate	Percentage Retained	Percentage Coarser	Percentage Passing
25	0	0%	0%	100%
19.5	20.5	39%	39%	61%
12.5	14.1	27%	66%	34%
9.5	12.1	23%	89%	11%
4.75	5.7	11%	100%	0%

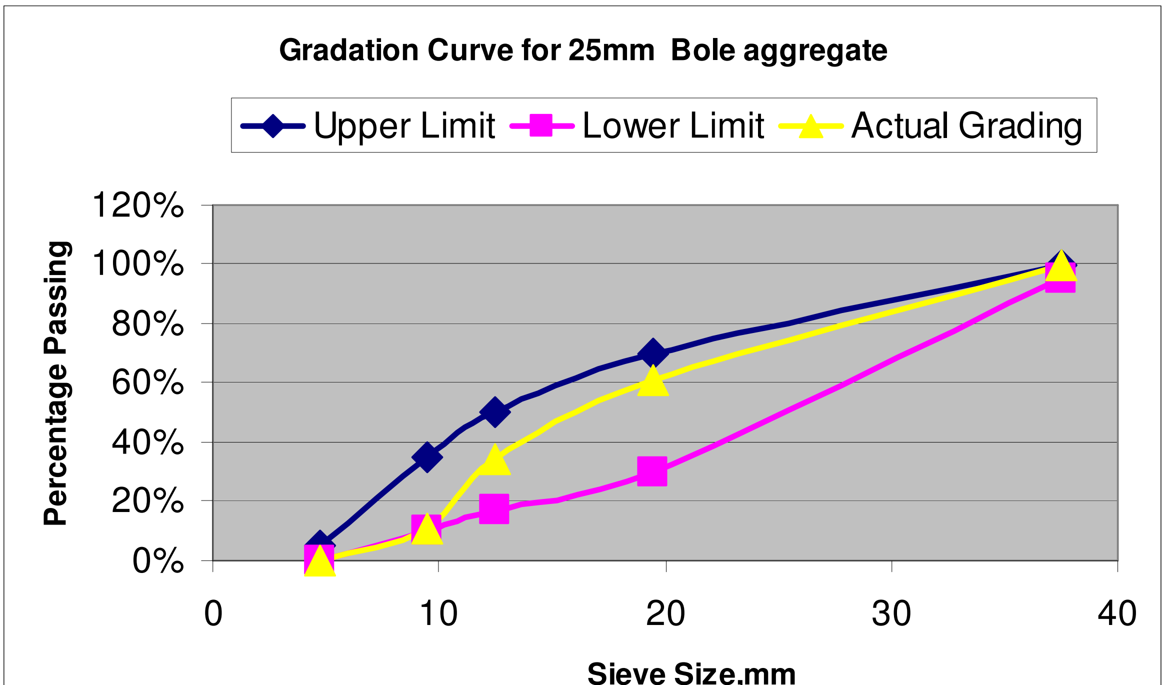

Fig. A-2 25mm Bole Aggragate used for Normal Strength Concrete

Table A -3 Aggregate blended proportion for the Intermediate strength concrete

Sieve Opening[mm]	Mass of retaining Aggregate	Percentage Retained	Percentage Coarser	Percentage Passing
19.5	0	0%	0%	100%
12.5	22	34%	34%	66%
9.5	25	38%	72%	28%
4.75	18	28%	100%	0%

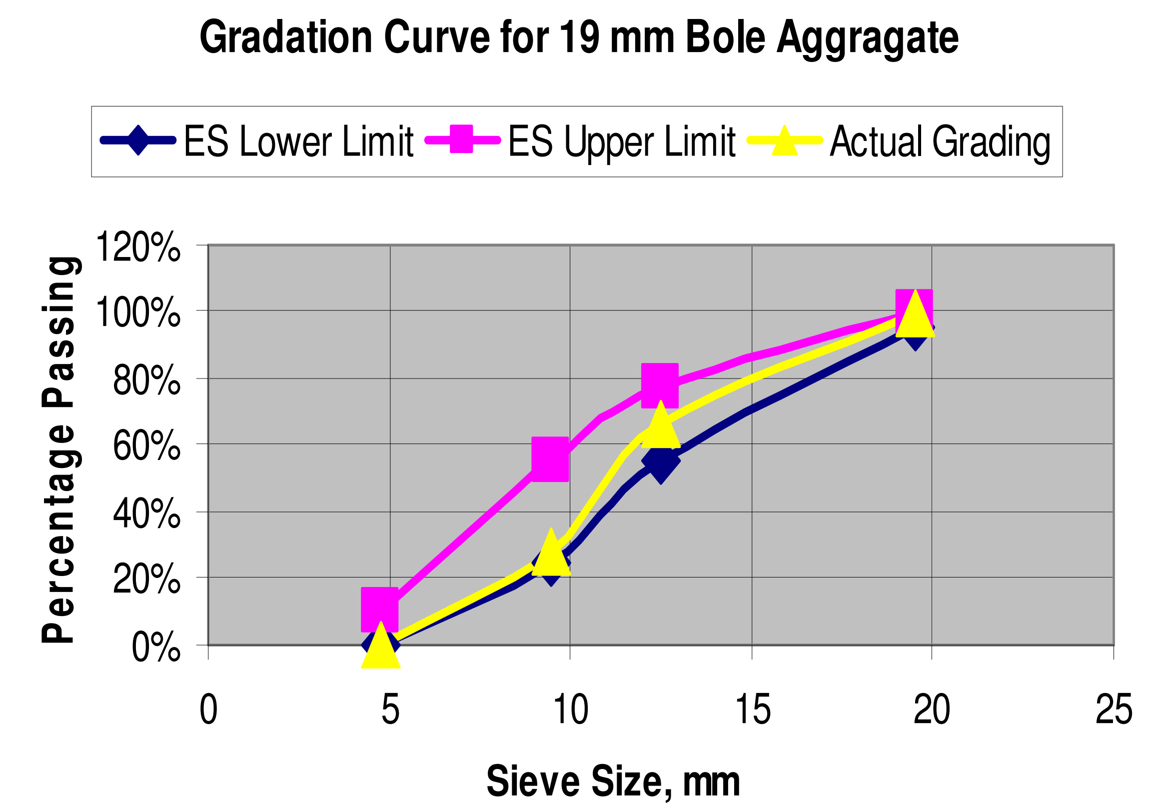

Figure A-3 19mm Bole Aggragate used for Intermediate Strength Concrete

Table A-4 Sieve analysis of blended Aggregate for the High strength concrete

Sieve Opening [mm]	Mass of Sieve[gm]	Mass of Sieve + aggregate [gm]	Mass of retaining Aggregate [gm]	Percentage Retained	Percentage Coarser	Percentage Passing
12.5	584	595.5	11.5	0.5%	0.5%	99.5%
9.5	595	1045	450	18.3%	18.8%	81.2%
4.75	568	2326.5	1758.5	71.7%	90.5%	9.5%
2.56	530	724	194	7.9%	98.4%	1.6%
1.18	536	564	28	1.1%	99.6%	0.4%
Pan	423	433.5	10.5	0.4%	100.0%	0.0%

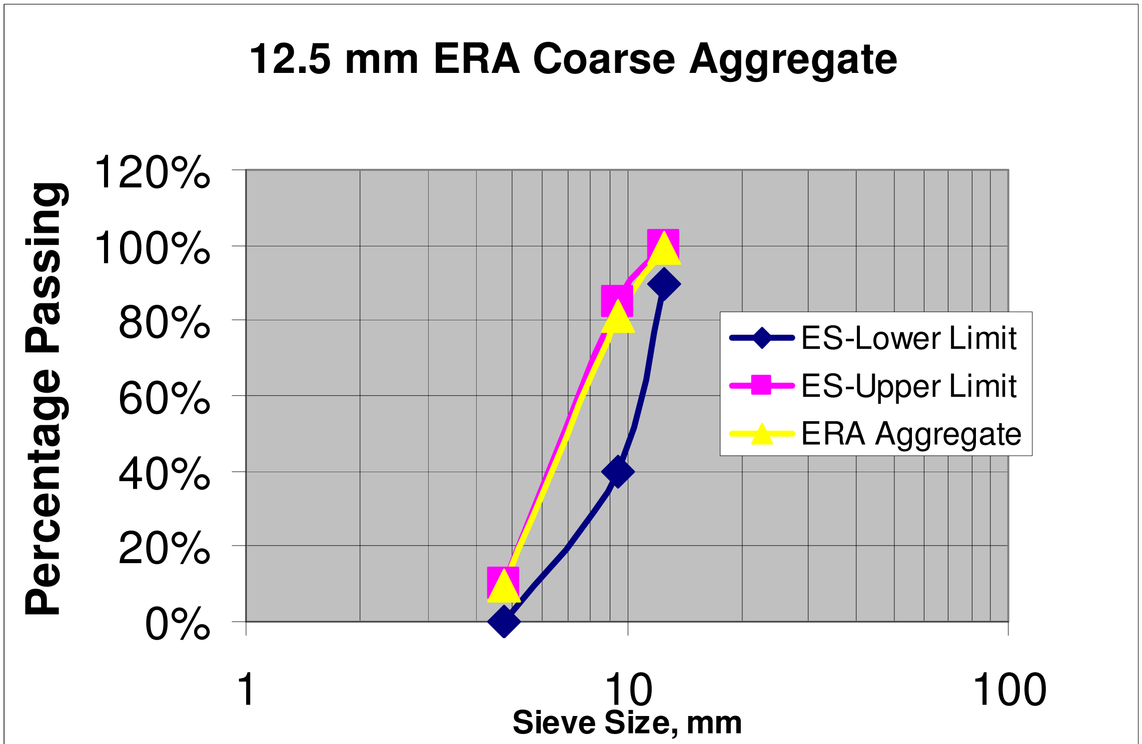

Fig A-4Gradation Curve for ERA Coarse Aggregate used for high strngth concrete

APPENDIX – II

Cube Compressive Strength Results [Raw Data] of Normal to High Strength concrete

Normal Strength Concrete											
Cement Type	**I.N.**	**Age [days]**	**Dimension[cm]**			**Weight[gm]**	**Load[KN]**	**Density [Kg/M^3]**	**Average Density [Kg/M3]**	**Compressive Strength[MPa]**	**Average Strength [MPa]**
			L	**W**	**H**						
Mugher PPC	1	3	15.2	15.1	15.2	8082	202.2	2.32	2.33	8.81	9.42
	2	3	15.2	15.1	15.2	8175	217.6	2.34		9.48	
	3	3	15	14.9	15	7834	222.6	2.34		9.96	
Diredawa PPC	1	3	15	15	15	7672	180.3	2.27	2.32	8.01	7.82
	2	3	15.1	15.2	15	8167	182	2.37		7.93	
	3	3	14.9	14.9	15	7724	167	2.32		7.52	
Messebo PPC	1	3	15	15	15	7805	235	2.31	2.23	10.44	9.96
	2	3	15	15	15	7325	223.7	2.17		9.94	
	3	3	15	15	15	7461	213.9	2.21		9.51	
Mugher OPC	1	3	15	15	15	7880	271.6	2.33	2.35	12.07	11.83
	2	3	15.2	15.2	15.2	8321	271	2.37		11.73	
	3	3	15	14.9	14.9	7854	261	2.36		11.68	
Messebo OPC	1	3	14.9	14.9	15	7902	315	2.37	2.34	14.19	15.09
	2	3	15	15	15	7804	326	2.31		14.49	
	3	3	15	14.9	14.9	7753	371	2.33		16.60	

Intermediate Strength Concrete

Cement Type	I.N.	Age [days]	Dimension[cm] L	W	H	Weight[gm]	Load[KN]	Density [Kg/M^3]	Average Density [Kg/M3]	Compressive Strength [MPa]	Average Strength [MPa]
Mugher PPC	1	3	15	15	15	7859	389.6	2.33	2.33	17.32	17.61
	2	3	14.9	14.9	15	7823	395.8	2.35		17.83	
	3	3	15	14.9	15	7793	395.3	2.32		17.69	
Diredawa PPC	1	3	14.9	14.9	15	7812	367.7	2.35	2.33	16.56	15.69
	2	3	14.9	15	15	7787	333.7	2.32		14.93	
	3	3	14.9	15	15	7798	348.1	2.33		15.57	
Messebo PPC	1	3	14.9	14.9	14.9	7838	519.5	2.37	2.36	23.40	22.78
	2	3	15	14.9	15	7911	490.5	2.36		21.95	
	3	3	14.9	15	14.9	7784	513.6	2.34		22.98	
Mugher OPC	1	3	15	14.9	15	7995	628.8	2.38	2.39	28.13	27.94
	2	3	15	14.9	15	7991	632.8	2.38		28.31	
	3	3	15.2	15.2	15.2	8385	632.3	2.39		27.37	
Messebo OPC	1	3	15	14.9	15	7900	722.7	2.36	2.36	32.34	31.87
	2	3	15	15	15	7990	706.7	2.37		31.41	
	3	3									

High Strength Concrete

Cement Type	I.N.	Age [days]	Dimension[cm]			Weight[gm]	Load[KN]	Density [Kg/M3]	Average Density [Kg/M3]	Compressive Strength [MPa]	Average Strength [MPa]
			L	W	H						
Mugher PPC	1	3	15	15	15	8206	798	2.43	2.44	35.47	37.78
	2	3	15	15	15	8243	887.2	2.44		39.43	
	3	3	15	14.8	15	8157	853.2	2.45		38.43	
Diredawa PPC	1	3	14.9	14.9	15	8152	762.4	2.45	2.45	34.34	33.10
	2	3	15	15	15	8198	718.6	2.43		31.94	
	3	3	14.9	15	14.8	8167	738.3	2.47		33.03	
Messebo PPC	1	3	15.2	15.2	15.2	8779	928	2.50	2.48	40.17	40.55
	2	3	15	15	15	8365	922.6	2.48		41.00	
	3	3	15	15	15	8342	910.8	2.47		40.48	
Mugher OPC	1	3	15	14.9	15	8316	1010	2.48	2.51	45.19	44.84
	2	3	15	14.9	15	8423	980.7	2.51		43.88	
	3	3	15	14.9	15	8481	1016	2.53		45.46	
Messebo OPC	1	3	15	15	15	8350	1098	2.47	2.48	48.80	51.31
	2	3	15	15	15	8392	1211	2.49		53.82	
	3	3									

Normal Strength Concrete

Cement Type	I.N.	Age [days]	Dimension[cm]			Weight [gm]	Load [KN]	Density [Kg/M^3]	Average Density [Kg/M3]	Compressive Strength [MPa]	Average Strength [MPa]
			L	W	H						
Mugher PPC in Water	1	7	15	14.9	15	7644	324.2	2.28	2.30	14.51	13.97
	2	7	14.9	14.9	15	7768	315.4	2.33		14.21	
	3	7	15	15	15	7726	296.8	2.29		13.19	
Mugher PPC Indoor	1	7	15	14.9	15	7612	327.2	2.27	2.25	14.64	14.94
	2	7	15	14.9	14.9	7524	360	2.26		16.11	
	3	7	14.9	14.9	15	7418	312.2	2.23		14.06	
Mugher PPC Outdoor	1	7	15	14.9	15	7597	361.6	2.27	2.28	16.18	15.43
	2	7	15	15	15	7699	354.8	2.28		15.77	
	3	7	15	15	14.9	7677	322.7	2.29		14.34	
Diredawa PPC in Water	1	7	15	15	15	7847	276.7	2.33	2.33	12.30	12.51
	2	7	15	14.9	15	7751	294.3	2.31		13.17	
	3	7	15	14.9	14.9	7813	269.9	2.35		12.08	
Diredawa PPC Indoor	1	7	15	15	15	7651	322.1	2.27	2.27	14.32	13.74
	2	7	14.9	15	15	7585	285.4	2.26		12.77	
	3	7	15	14.9	15	7601	316	2.27		14.14	
Diredawa PPC Outdoor	1	7	15	14.9	15	7470	324	2.23	2.25	14.50	14.51
	2	7	14.9	14.9	14.9	7521	331.2	2.27		14.92	
	3	7	15	15	15	7602	317.7	2.25		14.12	
Messebo PPC in Water	1	7	15	14.9	14.9	7822	348	2.35	2.33	15.57	15.61
	2	7	15.2	15.2	15.2	8176	363.6	2.33		15.74	
	3	7	14.9	15	15	7803	346.8	2.33		15.52	
Messebo PPC Indoor	1	7	14.9	14.9	14.9	7590	351.3	2.29	2.29	15.82	16.22
	2	7	15	14.9	15	7675	368.9	2.29		16.51	
	3	7	15	15	15	7750	367.3	2.30		16.32	

Normal Strength Concrete(continued)

Cement Type	I.N.	Age [days]	Dimension[cm]			Weight [gm]	Load[KN]	Density [Kg/M^3]	Average Density [Kg/M3]	Compressive Strength [MPa]	Average Strength [MPa]
			L	W	H						
Messebo PPC Outdoor	1	7	15	15.1	14.9	7644	355.2	2.26	2.27	15.68	15.97
	2	7	15	15	15	7684	361.9	2.28		16.08	
	3	7	15	15	15	7631	363	2.26		16.13	
Mugher OPC in Water	1	7	15	15	15.2	8015	490.1	2.34	2.34	21.78	18.91
	2	7	15	14.9	15	7837	397.7	2.34		17.79	
	3	7	15	15	15	7931	385.7	2.35		17.14	
Mugher OPC Indoor	1	7	14.8	15	15	7650	409.2	2.30	2.30	18.43	18.63
	2	7	14.9	14.9	14.9	7653	404.6	2.31		18.22	
	3	7	15	15	15	7698	432.8	2.28		19.24	
Mugher OPC Outdoor	1	7	15.2	15.2	15.2	8207	422	2.34	2.32	18.27	18.50
	2	7	15.2	15.2	15.2	8057	415.1	2.29		17.97	
	3	7	15	14.9	14.9	7769	430.5	2.33		19.26	
Messebo OPC in Water	1	7	15.2	15.2	15.2	8163	494	2.32	2.33	21.38	20.66
	2	7	15	15	15	7863	450.8	2.33		20.04	
	3	7	15	15	15	7871	463	2.33		20.58	
Messebo OPC Indoor	1	7	15	15	15	7929	520	2.35	2.33	23.11	22.86
	2	7	15.1	15.1	15.2	8097	516.4	2.34		22.65	
	3	7	14.9	15	15	7682	510	2.29		22.82	
Messebo OPC Outdoor	1	7	14.9	15	15	7742	475	2.31	2.30	21.25	20.67
	2	7	15	15	15	7715	452	2.29		20.09	
	3	7	15	15	14.9	7744	465	2.31		20.67	

Intermediate Strength Concrete												
Cement Type	**I.N.**	**Age [days]**	**Dimension[cm]**			**Weight[gm]**	**Load[KN]**	**Density [Kg/M^3]**	**Average Density [Kg/M3]**	**Compressive Strength [MPa]**	**Average Strength [MPa]**
			L	**W**	**H**						
Mugher PPC Outdoor	1	7	15	14.9	15	7812	524.5	2.33	2.33	23.47	23.22
	2	7	15	15	14.9	7824	535.9	2.33		23.82	
	3	7	15	14.8	15	7766	497	2.33		22.39	
Mugher PPC Indoor	1	7	15	14.9	15	7664	600.4	2.29	2.29	26.86	26.50
	2	7	15	15	15	7669	591.2	2.27		26.28	
	3	7	15.2	15.1	15.2	8081	604.9	2.32		26.36	
Mugher PPC in Water	1	7	15	14.9	15	7798	542.4	2.33	2.34	24.27	23.96
	2	7	14.9	15	14.9	7797	520.6	2.34		23.29	
	3	7	15.2	15.1	15.2	8216	558.2	2.36		24.32	
Diredawa PPC Outdoor	1	7	14.9	14.9	15	7822	513	2.35	2.32	23.11	22.73
	2	7	15	15	15	7757	504.3	2.30		22.41	
	3	7	15	15	15	7849	510.2	2.33		22.68	
Diredawa PPC Indoor	1	7	15	14.9	15	7672	553.1	2.29	2.29	24.75	24.51
	2	7	15	14.8	15	7657	539.5	2.30		24.30	
	3	7	15	14.9	15	7652	547.2	2.28		24.48	
Diredawa PPC in Water	1	7	15	15	15	7819	519.5	2.32	2.33	23.09	22.63
	2	7	15.2	15.1	15.2	8210	511.8	2.35		22.30	
	3	7	15	15	15	7808	506	2.31		22.49	
Messebo PPC Outdoor	1	7	15	14.9	15	7838	684.2	2.34	2.34	30.61	31.21
	2	7	15	15	15	7866	715.9	2.33		31.82	
	3	7	14.9	14.9	15	7825	692.9	2.35		31.21	
Messebo PPC Indoor	1	7	15	15	15	7804	702.9	2.31	2.34	31.24	31.16
	2	7	15.2	15.1	15.2	8224	730.3	2.36		31.82	
	3	7	15.2	15.2	15.2	8233	703.2	2.34		30.44	

Intermediate Strength Concrete(continued)

Cement Type	I.N.	Age [days]	Dimension[cm]			Weight[gm]	Load[KN]	Density [Kg/M^3]	Average Density [Kg/M3]	Compressive Strength [MPa]	Average Strength [MPa]
			L	W	H						
Messebo PPC in Water	1	7	15	15	15	7964	713.9	2.36	2.35	31.73	30.81
	2	7	15	14.9	15	7851	681.3	2.34		30.48	
	3	7	15	15	15	7933	679.9	2.35		30.22	
Mugher OPC Outdoor	1	7	15.2	15.2	15.2	8374	803.9	2.38	2.37	34.79	36.06
	2	7	15	14.9	15	7928	844.9	2.36		37.80	
	3	7	15	14.9	15	7890	795.3	2.35		35.58	
Mugher OPC Indoor	1	7	15	15	15	7828	811.8	2.32	2.34	36.08	36.94
	2	7	15	14.9	15	7854	824.5	2.34		36.89	
	3	7	15	15	14.9	7867	851.6	2.35		37.85	
Mugher OPC in Water	1	7	15	14.9	15	7975	862.6	2.38	2.38	38.60	34.72
	2	7	14.9	14.9	15	7909	744.1	2.37		33.52	
	3	7	15	15	15	8006	720.8	2.37		32.04	
Messebo OPC Outdoor	1	7	15.2	15.2	15.2	8299	948.9	2.36	2.35	41.07	42.03
	2	7	15	14.9	15	7944	950.3	2.37		42.52	
	3	7	15	14.9	15	7762	949.7	2.32		42.49	
Messebo OPC Indoor	1	7	15	15	15	7910	1050	2.34	2.34	46.67	46.13
	2	7	15	14.9	15	7905	1018	2.36		45.55	
	3	7	15	15	14.9	7781	1039	2.32		46.18	
Messebo OPC in Water	1	7	15	15.2	15	8004	998	2.34	2.36	43.77	43.89
	2	7	15	15	15	7930	936.8	2.35		41.64	
	3	7	15	14.9	15	7964	1034	2.38		46.26	

High Strength Concrete

Cement Type	I.N.	Age [days]	Dimension[cm]			Weight[gm]	Load[KN]	Density [Kg/M^3]	Average Density[Kg/M3]	Compressive Strength [MPa]	Average Strength [MPa]
			L	W	H						
Mugher PPC in Water	1	7	15	14.9	15	8289	1063	2.47	2.47	47.56	49.49
	2	7	15	14.9	14.9	8201	1147	2.46		51.32	
	3	7	15	14.9	14.9	8225	1108	2.47		49.57	
Mugher PPC Indoor	1	7	15	15	15	8182	1095	2.42	2.43	48.67	48.82
	2	7	15	15	15	8183	1040	2.42		46.22	
	3	7	15	15.1	15	8316	1168	2.45		51.57	
Mugher PPC Outdoor	1	7	15	14.9	15	8118	1054	2.42	2.45	47.16	48.42
	2	7	15	15	15	8219	1115	2.44		49.56	
	3	7	15.1	15.1	15.2	8598	1107	2.48		48.55	
Diredawa PPC in Water	1	7	15	14.9	15	8156	958.4	2.43	2.44	42.88	44.57
	2	7	15	14.9	15	8235	1034	2.46		46.26	
	3	7	15	14.9	14.9						
Diredawa PPC Indoor	1	7	14.9	15	14.9	8131	1080	2.44	2.44	48.32	46.02
	2	7	15	14.9	15	8125	990.7	2.42		44.33	
	3	7	14.9	14.9	15	8126	1008	2.44		45.40	
Diredawa PPC Outdoor	1	7	15	14.9	15	8115	990.4	2.42	2.42	44.31	45.26
	2	7	15	14.9	15	8123	1048	2.42		46.89	
	3	7	15	15	15	8165	1003	2.42		44.58	
Messebo PPC in Water	1	7	15	15	15	8398	1220	2.49	2.47	54.22	54.29
	2	7	15	14.8	15	8219	1217	2.47		54.82	
	3	7	15	15.1	15.1	8430	1219	2.46		53.82	
Messebo PPC Indoor	1	7	15	15	15	8253	1200	2.45	2.46	53.33	54.71
	2	7	14.8	15.2	15	8392	1243	2.49		55.25	
	3	7	15	15	15	8299	1250	2.46		55.56	

High Strength Concrete (continued)

Cement Type	I.N.	Age [days]	Dimension[cm]			Weight[gm]	Load[KN]	Density [Kg/M^3]	Average Density [Kg/M3]	Compressive Strength [MPa]	Average Strength [MPa]
			L	W	H						
Messebo PPC Outdoor	1	7	14.9	14.9	15	8192	1126	2.46	2.46	50.72	51.30
	2	7	15	15	15	8271	1147	2.45		50.98	
	3	7	15	15.2	15	8395	1190	2.45		52.19	
Mugher OPC in Water	1	7	15	15	15	8350	1316	2.47	2.48	58.49	58.89
	2	7	14.9	15	15	8363	1325	2.49		59.28	
	3	7	15	15	15						
Mugher OPC Indoor	1	7	15	15	15	8300	1378	2.46	2.50	61.24	59.50
	2	7	15.2	15.2	15.2	8779	1335	2.50		57.78	
	3	7	15.2	15.2	15.2	8912	1374	2.54		59.47	
Mugher OPC Outdoor	1	7	15.2	15.2	15.2	8793	1293	2.50	2.50	55.96	56.90
	2	7	15.2	15	15	8477	1284	2.48		56.32	
	3	7	15	14.9	14.9	8428	1306	2.53		58.43	
Messebo OPC in Water	1	7	15	14.9	15	8321	1550	2.48	2.48	69.35	70.45
	2	7	15	15	15	8383	1601	2.48		71.16	
	3	7	15	15	15	8391	1594	2.49		70.84	
Messebo OPC Indoor	1	7	15.2	15.2	15.2	8801	1671	2.51	2.48	72.33	72.36
	2	7	15	15	14.9	8300	1595	2.48		70.89	
	3	7	15	15	15	8302	1662	2.46		73.87	
Messebo OPC Outdoor	1	7	15	15	15	8308	1570	2.46	2.46	69.78	69.12
	2	7	15	15	15	8331	1561	2.47		69.38	
	3	7	15.2	15.2	15.2	8635	1576	2.46		68.21	

Normal Strength Concrete

Cement Type	I.N.	Age [days]	Dimension[cm]			Weight [gm]	Load [KN]	Density $[Kg/M^3]$	Avg. Density Kg/M3]	Strength [MPa]	Avg. Strength [MPa]
			L	W	H						
Mugher PPC 3 days in Water then Out Door	1	28	15	15	15	7723	528.3	2.29	2.29	23.48	23.10
	2	28	15	15	15	7700	513.2	2.28		22.81	
	3	28	15	14.9	15	7739	514.5	2.31		23.02	
Mugher PPC 3 days In Water then Indoor	1	28	15.2	15.2	15.2	7937	499.7	2.26	2.24	21.63	21.71
	2	28	15	15	15	7473	493.6	2.21		21.94	
	3	28	15.2	15.2	15.2	7888	498.5	2.25		21.58	
Mugher PPC 7 days In Water then Outdoor	1	28	15	15	15	7823	546.6	2.32	2.30	24.29	25.12
	2	28	15	14.9	15	7660	560.2	2.28		25.06	
	3	28	15	15	15	7773	584.9	2.30		26.00	
Mugher PPC 7 days In Water then Indoor	1	28	15	15	15	7465	565	2.21	2.20	25.11	24.49
	2	28	15	15	15	7399	538.8	2.19		23.95	
	3	28	15	14.9	15	7377	545.9	2.20		24.43	
Diredawa PPC 3 days in Water then Out Door	1	28	15.2	15.2	15.2	8056	479.7	2.29	2.27	20.76	20.81
	2	28	15	15	15	7602	467.2	2.25		20.76	
	3	28	15	15	15	7613	470.1	2.26		20.89	
Diredawa PPC 3 days In Water then Indoor	1	28	15	14.8	15	7439	448	2.23	2.21	20.18	20.58
	2	28	15	15	15	7415	465.7	2.20		20.70	
	3	28	15	15	15	7399	469.2	2.19		20.85	
Diredawa PPC 7 days In Water then Outdoor	1	28	15	15	15	7713	499.8	2.29	2.30	22.21	22.23
	2	28	15.2	15.2	15.2	8081	502.3	2.30		21.74	
	3	28	15	15	15	7804	511.4	2.31		22.73	
Diredawa PPC 7 days In Water then Indoor	1	28	15	15	15	7391	501.7	2.19	2.20	22.30	22.47
	2	28	15	15	15	7455	524.5	2.21		23.31	
	3	28	15	15	15	7398	490.8	2.19		21.81	
Messebo PPC 3 days in Water then Out Door	1	28	15	15	15	7868	518.5	2.33	2.32	23.04	23.22
	2	28	15	14.8	15	7641	527.4	2.29		23.76	
	3	28	15.2	15.2	15.2	8179	528	2.33		22.85	
Messebo PPC 3 days In Water then Indoor	1	28	15.2	15.2	15.2	8018	565.6	2.28	2.26	24.48	24.74
	2	28	15	15	15	7628	549.1	2.26		24.40	
	3	28	15	15	15	7521	570.2	2.23		25.34	

Normal Strength Concrete(Continued)

Cement Type	I.N.	Age [days]	Dimension[cm] L	W	H	Weight [gm]	Load [KN]	Density [Kg/M^3]	Avg. Density Kg/M3]	Strength [MPa]	Avg. Strength [MPa]
Messebo PPC 7 days In Water then Outdoor	1	28	15	15	15	7673	551.5	2.27	2.29	24.51	24.68
	2	28	15	15	15	7769	553.1	2.30		24.58	
	3	28	15	15	15	7747	561.6	2.30		24.96	
Messebo PPC 7 days In Water then Indoor	1	28	15	15	15	7612	569.4	2.26	2.27	25.31	25.29
	2	28	15	14.9	14.9	7554	570.1	2.27		25.51	
	3	28	15.2	15.1	15.2	7960	575	2.28		25.05	
Mugher OPC 3 days in Water then Out Door	1	28	15	15	15	7761	651.6	2.30	2.31	28.96	30.15
	2	28	15	15	15	7727	672.1	2.29		29.87	
	3	28	15	14.9	15	7824	706.6	2.33		31.62	
Mugher OPC 3 days In Water then Indoor	1	28	15	15	15	7649	689.5	2.27	2.27	30.64	30.84
	2	28	15	15	15	7738	697.1	2.29		30.98	
	3	28	15	15	15	7646	695.3	2.27		30.90	
Mugher OPC 7 days In Water then Outdoor	1	28	15	15	15	7871	709.9	2.33	2.33	31.55	31.76
	2	28	15	15	15	7886	743.8	2.34		33.06	
	3	28	15.2	15.2	15.2	8138	708.8	2.32		30.68	
Mugher OPC 7 days In Water then Indoor	1	28	15	14.9	15	7663	711.2	2.29	2.27	31.82	31.50
	2	28	15	14.9	14.9	7536	693.5	2.26		31.03	
	3	28	15	15	15	7643	712.3	2.26		31.66	
Messebo OPC 3 days in Water then Out Door	1	28	15	15	15	7862	725.7	2.33	2.31	32.25	32.43
	2	28	15	15	15	7714	722.9	2.29		32.13	
	3	28	15	15	15	7809	740.6	2.31		32.91	
Messebo OPC 3 days In Water then Indoor	1	28	14.9	14.9	15	7554	727.9	2.27	2.26	32.79	33.51
	2	28	15	15	15	7630	727.3	2.26		32.32	
	3	28	15	15	14.9	7550	796.7	2.25		35.41	
Messebo OPC 7 days In Water then Outdoors	1	28	15	14.9	15	7687	759.6	2.29	2.31	33.99	33.21
	2	28	15.2	15.1	15.2	8118	738.6	2.33		32.18	
	3	28	15	14.9	15	7742	748.0	2.31		33.47	
Messebo OPC 7 days In Water then Indoor	1	28	15	15	15	7643	801.2	2.26	2.27	35.61	35.15
	2	28	15	14.8	15	7562	790.7	2.27		35.62	
	3	28	15	14.9	15	7611	765.1	2.27		34.23	

Intermediate Strength Concrete

Cement Type	I.N.	Age [days]	Dimension[cm]			Weight [gm]	Load [KN]	Density [Kg/M^3]	Avg. Density [Kg/M3]	Strength [MPa]	Avg. Strength [MPa]
			L	W	H						
Mugher PPC 3 days in Water then Out Door	1	28	14.9	14.9	15	7764	847.3	2.33	2.33	38.16	35.39
	2	28	14.9	14.9	15	7817	769.8	2.35		34.67	
	3	28	15	15	15	7816	749.7	2.32		33.32	
Mugher PPC 3 days In Water then Indoors	1	28	14.9	14.9	15	7544	893.4	2.27	2.27	40.24	39.84
	2	28	15	14.9	15	7620	883.1	2.27		39.51	
	3	28	15	14.9	15	7660	888.5	2.28		39.75	
Mugher PPC days In Water then Outdoor	1	28	15	14.9	15	7766	861.3	2.32	2.32	38.54	38.19
	2	28	15	14.9	15	7737	851.8	2.31		38.11	
	3	28	15	14.9	15	7804	847.8	2.33		37.93	
Mugher PPC 7 days In Water then Indoor	1	28	15	15	15	7773	820.8	2.30	2.27	36.48	36.87
	2	28	15	14.9	15	7560	821.9	2.26		36.77	
	3	28	15	15	14.9	7593	840.5	2.26		37.36	
Diredawa PPC 3 days in Water then Out Door	1	28	15	15	15	7716	818.4	2.29	2.31	36.37	35.86
	2	28	15	15	15	7755	833.5	2.30		37.04	
	3	28	15.2	15.2	15.1	8194	789.4	2.35		34.17	
Diredawa PPC 3 days In Water then Indoor	1	28	14.9	14.9	15	7561	752.2	2.27	2.27	33.88	34.46
	2	28	15	15	15	7620	787.7	2.26		35.01	
	3	28	15	14.9	15	7612	770.6	2.27		34.48	
Diredawa PPC 7 days In Water then Outdoor	1	28	14.9	14.8	14.9	7658	750.1	2.33	2.31	34.02	34.43
	2	28	15	14.9	15	7733	772.2	2.31		34.55	
	3	28	15	15	15	7750	781.2	2.30		34.72	
Diredawa PPC 7 days In Water then Indoor	1	28	15.2	15.2	15.2	7980	843.3	2.27	2.28	36.50	37.25
	2	28	15	14.9	15	7603	844.9	2.27		37.80	
	3	28	15	14.9	14.8	7580	837.1	2.29		37.45	
Messebo PPC 3 days in Water then Out Door	1	28	15	14.9	15	7850	915	2.34	2.34	40.94	40.54
	2	28	15	15	15	7910	902.9	2.34		40.13	
	3	28	15	15	15	7840	912.4	2.32		40.55	
Messebo PPC 3 days In Water then Indoor	1	28	15	15	15	7680	948.2	2.28	2.31	42.14	41.04
	2	28	15.2	15.2	15.2	8200	923.6	2.33		39.98	
	3	28	15	15	15	7800	922.6	2.31		41.00	

Intermediate Strength Concrete(continued)

Cement Type	I.N.	Age [days]	Dimension[cm] L	W	H	Weight [gm]	Load [KN]	Density [Kg/M3]	Avg. Density [Kg/M3]	Strength [MPa]	Avg. Strength [MPa]
Messebo PPC 7 days In Water then Outdoor	1	28	15	14.9	15	7840	976.1	2.34	2.36	43.67	42.54
	2	28	15	15	15	7960	918.4	2.36		40.82	
	3	28	15	14.9	15	7970	963.9	2.38		43.13	
Messebo PPC 7 days In Water then Indoor	1	28	15	14.9	15	7733	1021	2.31	2.31	45.68	45.35
	2	28	15	14.9	15	7735	1005	2.31		44.97	
	3	28	14.9	14.9	15	7725	1008	2.32		45.40	
Mugher OPC 3 days in Water then Out Door	1	28	15	15	15	7881	1121	2.34	2.34	49.82	48.81
	2	28	15	14.9	15	7823	1156	2.33		51.72	
	3	28	15.2	15.2	15.2	8273	1037	2.36		44.88	
Mugher OPC 3 days In Water then Indoor	1	28	15	15	15	7818	1140	2.32	2.32	50.67	48.65
	2	28	15	15	15	7803	1086	2.31		48.27	
	3	28	15	14.9	14.9	7772	1051	2.33		47.02	
Mugher OP 7 days In Water then Outdoor	1	28	15	15	15	7867	1119	2.33	2.33	49.73	48.47
	2	28	15	15	14.9	7822	1048	2.33		46.58	
	3	28	15	15	15	7858	1105	2.33		49.11	
Mugher OPC 7 days In Water then Indoor	1	28	15.2	15.2	15.2	8319	1158	2.37	2.33	50.12	51.39
	2	28	15	15	15	7750	1138	2.30		50.58	
	3	28	15	15	15	7812	1203	2.31		53.47	
Messebo OPC 3 days in Water then Out Door	1	28	15.2	15.2	15.2	8246	1248	2.35	2.34	54.02	55.07
	2	28	15	14.9	15	7831	1294	2.34		57.90	
	3	28	15	15	15	7855	1199	2.33		53.29	
Messebo OPC 3 days In Water then Indoor	1	28	15	14.9	15	7865	1332	2.35	2.31	59.60	56.95
	2	28	15	15	15	7751	1232	2.30		54.76	
	3	28	15	15	15	7707	1271	2.28		56.49	
Messebo OPC days In Water then Outdoor	1	28	15	14.9	15	7931	1312	2.37	2.35	58.70	57.78
	2	28	15.2	15.2	15.2	8232	1321	2.34		57.18	
	3	28	15	15	15	7884	1293	2.34		57.47	
Messebo OPC 7 days In Water then Indoor	1	28	15.1	15	15	7926	1334	2.33	2.32	58.90	58.24
	2	28	15	15	15	7815	1248	2.32		55.47	
	3	28	15	15	15	7783	1358	2.31		60.36	

High Strength Concrete

Cement Type	I.N.	Age [days]	Dimension[cm]			Weight [gm]	Load [KN]	Density [Kg/M^3]	Avg. Density [Kg/M3]	Strength [MPa]	Avg. Strength [MPa]
			L	W	H						
Mugher PPC 3 days in Water then Out Door	1	28	15	15	15	8217	1448	2.43	2.45	64.36	68.12
	2	28	15	14.9	15	8266	1565	2.47		70.02	
	3	28	15	14.9	15	8230	1564	2.45		69.98	
Mugher PPC 3 days In Water then Indoors	1	28	15	14.9	15	8107	1536	2.42	2.44	68.72	68.25
	2	28	15	15	15	8192	1473	2.43		65.47	
	3	28	14.8	14.9	14.8	8090	1556	2.48		70.56	
Mugher PPC days In Water then Outdoor	1	28	15.2	15.2	15.2	8663	1474	2.47	2.45	63.80	68.89
	2	28	15	14.9	14.9	8093	1561	2.43		69.84	
	3	28	15	14.8	15	8163	1621	2.45		73.02	
Mugher PPC 7 days In Water then Indoor	1	28	15.2	15.1	15.2	8513	1654	2.44	2.44	72.06	70.20
	2	28	15	14.9	15	8138	1634	2.43		73.11	
	3	28	15.2	15.1	15.2	8561	1502	2.45		65.44	
Diredawa PPC 3 days in Water then Out Door	1	28	15	15	14.9	8184	1423	2.44	2.47	63.24	62.78
	2	28	15.1	15.1	15.2	8590	1425	2.48		62.50	
	3	28	15.1	15.1	15.2	8581	1427	2.48		62.58	
Diredawa PPC 3 days In Water then Indoor	1	28	15	14.9	15	8075	1338	2.41	2.41	59.87	61.15
	2	28	15	14.9	15	8024	1361	2.39		60.89	
	3	28	15	14.9	15	8093	1401	2.41		62.68	
Diredawa PPC 7 days In Water then Outdoor	1	28	15	15	15	8258	1389	2.45	2.44	61.73	64.80
	2	28	15	14.9	15	8188	1451	2.44		64.92	
	3	28	15	15	15	8231	1524	2.44		67.73	
Diredawa PPC 7 days In Water then Indoor	1	28	15	15	15	8216	1544	2.43	2.44	68.62	65.01
	2	28	15	14.9	15	8255	1439	2.46		64.38	
	3	28	14.9	14.9	15	8025	1377	2.41		62.02	
Messebo PPC 3 days in Water then Out Door	1	28	15.2	15.2	15.2	8770	1621	2.50	2.47	70.16	69.35
	2	28	14.9	14.9	14.8	8105	1543	2.47		69.50	
	3	28	15.2	15.2	15.2	8620	1580	2.45		68.39	
Messebo PPC 3 days In Water then Indoor	1	28	15	14.9	15	8205	1578	2.45	2.47	70.60	70.03
	2	28	15	14.8	15	8225	1529	2.47		68.87	
	3	28	15	14.9	15	8365	1578	2.50		70.60	

High Strength Concrete(continued)

Cement Type & Curing	I.N.	Age [days]	Dimension[cm] L	W	H	Weight [gm]	Load [KN]	Density [Kg/M^3]	Avg. Density [Kg/M3]	Strength [MPa]	Avg. Strength [MPa]
Messebo PPC 7 days In Water then Outdoor	1	28	15	14.8	15	8340	1645	2.50	2.48	74.10	73.01
	2	28	15	14.9	15	8275	1592	2.47		71.23	
	3	28	15	15	15	8315	1658	2.46		73.69	
Messebo PPC 7 days In Water then Indoor	1	28	14.9	14.9	15	8240	1585	2.47	2.49	71.39	72.17
	2	28	14.9	14.9	15	8275	1629	2.48		73.38	
	3	28	15.23	15.1	15.2	8740	1650	2.50		71.75	
Mugher OPC 3 days in Water then Out Door	1	28	15	14.9	15	8262	1682	2.46	2.48	75.26	75.15
	2	28	15.2	15.2	15.2	8785	1713	2.50		74.14	
	3	28	15	14.9	15	8285	1700	2.47		76.06	
Mugher OPC 3 days In Water then Indoor	1	28	14.9	14.9	15	8198	1674	2.46	2.49	75.40	75.70
	2	28	15	14.9	15	8321	1725	2.48		77.18	
	3	28	14.8	14.9	15	8330	1643	2.52		74.51	
Mugher OP 7 days In Water then Outdoor	1	28	15	15	15	8262	1795	2.45	2.47	79.78	78.15
	2	28	15	15	15	8305	1796	2.46		79.82	
	3	28	15.2	15.2	15.2	8736	1729	2.49		74.84	
Mugher OPC 7 days In Water then Indoor	1	28	15	15	15	8298	1736	2.46	2.46	77.16	78.19
	2	28	15	15	15	8275	1810	2.45		80.44	
	3	28	15	15	15	8287	1732	2.46		76.98	
Messebo OPC 3 days in Water then Out Door	1	28	14.9	14.9	15	8320	1819	2.50	2.50	81.93	86.66
	2	28	14.9	14.9	15	8325	2003	2.50		90.22	
	3	28	15.2	15.2	15.2	8770	2029	2.50		87.82	
Messebo OPC 3 days In Water then Indoor	1	28	15	14.9	15	8265	1782	2.47	2.48	79.73	83.04
	2	28	15	15	15	8455	1989	2.51		88.40	
	3	28	15	14.9	14.9	8260	1810	2.48		80.98	
Messebo OPC days In Water then Outdoor	1	28	14.9	14.8	15	8260	1990	2.50	2.49	90.24	86.38
	2	28	15	15	15	8345	1860	2.47		82.67	
	3	28	15	14.9	15	8360	1927	2.49		86.22	
Messebo OPC 7 days In Water then Indoor	1	28	15.2	15.2	15.2	8800	1913	2.51	2.48	82.80	85.50
	2	28	15	14.9	15	8270	1956	2.47		87.52	
	3	28	15	14.9	15	8300	1926	2.48		86.17	

Normal Strength Concrete

Cement Type & Curing	I.N.	Age [days]	Dimension[cm] L	W	H	Weight [gm]	Load [KN]	Density [Kg/M^3]	Avg. Density [Kg/M3]	Strength [MPa]	Avg. Strength [MPa]
Mugher PPC 3 days in Water & indoor	1	91	15	14.9	15	7244	547	2.16	2.19	24.47	24.71
	2	91	15	15	15	7442	582.9	2.21		25.91	
	3	91	15	14.9	15	7365	530.5	2.20		23.74	
Mugher PPC 7 days in water & Indoor	1	91	15	14.9	15	7425	612.7	2.21	2.20	27.41	27.26
	2	91	15	14.9	15	7363	611.2	2.20		27.35	
	3	91	15	14.9	15	7385	603.9	2.20		27.02	
Diredawa PPC 3 days in Water & Indoor	1	91	15	15	15	7422		2.20	2.18		24.54
	2	91	15	15	15	7393	564.1	2.19		25.07	
	3	91	15	15	15	7306	540.1	2.16		24.00	
Diredawa PPC 7 Days in water & Indoor	1	91	15.2	15.2	15.2	7847	599.2	2.23	2.21	25.93	27.01
	2	91	15	15	15	7395	625.9	2.19		27.82	
	3	91	15	15	15	7454	613.9	2.21		27.28	
Messebo PPC 3 Days in Water & Indoor	1	91	15	15	15	7483	577.5	2.22	2.22	25.67	25.68
	2	91	15	15	15	7462	582.1	2.21		25.87	
	3	91	15	15	15	7530	573.7	2.23		25.50	
Messebo PPC 7 Days in water & Indoor	1	91	15	15	15	7492	657.0	2.22	2.20	29.20	28.23
	2	91	15.2	15.2	15.2	7496	630.9	2.13		27.31	
	3	91	15	15	15	7537	633.8	2.23		28.17	
Mugher OPC 3 Days in Water & Indoor	1	91	15	15	15	7557	737.8	2.24	2.23	32.79	31.49
	2	91	15	15	15	7548	679.4	2.24		30.20	
	3	91	15	15	15	7478	633.6	2.22			
Mugher OPC 7 Days in water & Indoor	1	91	14.8	15	15	7657	791.1	2.30	2.27	35.64	34.53
	2	91	14.9	14.9	14.9	7544	747.9	2.28		33.69	
	3	91	15	15	15	7524	771.2	2.23		34.28	
Messebo OPC 3 Days in Water & Indoor	1	91	15	15	15	7538	745.3	2.23	2.23	33.12	33.01
	2	91	15	14.9	15	7495	739.6	2.24		33.09	
	3	91	15	14.8	15	7430	728.8	2.23		32.83	
Messebo OPC 7 Days in water & Indoor	1	91	15	15	15	7593	811.5	2.25	2.25	36.07	36.91
	2	91	15	14.9	15	7521	830.3	2.24		37.15	
	3	91	15.2	15.2	15.2	7965	866.9	2.27		37.52	

Intermediate Strength Concrete

Cement Type & Curing	I.N.	Age [days]	Dimension[cm]			Weight [gm]	Load [KN]	Density [Kg/M^3]	Avg. Density [Kg/M3]	Strength [MPa]	Avg. Strength [MPa]
			L	W	H						
Mugher PPC 3 days in Water & indoor	1	91	15	15	15	7561	860.8	2.24	2.24	38.26	38.81
	2	91	15.2	15.2	15.2	7896	925.1	2.25		40.04	
	3	91	15.2	15.2	15.2	7827	880.7	2.23		38.12	
Mugher PPC 7 days in water & Indoor	1	91	15	14.8	15	7632	952.4	2.29	2.26	42.90	42.88
	2	91	15	15	15	7563	987.7	2.24		43.90	
	3	91	15	15	15	7616	941.6	2.26		41.85	
Diredawa PPC 3 days in Water & Indoor	1	91	15	14.9	15	7566	847.9	2.26	2.24	37.94	38.43
	2	91	15	15	15	7474	857.6	2.21		38.12	
	3	91	15	14.9	15	7566	877.1	2.26		39.24	
Diredawa PPC 7 Days in water & Indoor	1	91	15	15	15	7589	937.9	2.25	2.26	41.68	42.53
	2	91	15.2	15.2	15.2	7960	972.1	2.27		42.07	
	3	91	15	14.9	15	7573	979.5	2.26		43.83	
Messebo PPC 3 Days in Water & Indoor	1	91	15	15	15	7638	1006	2.26	2.28	44.71	45.30
	2	91	15	15	15	7708	1031	2.28		45.82	
	3	91	15.2	15.2	15.2	8062	1048	2.30		45.36	
Messebo PPC 7 Days in water & Indoor	1	91	15	15	15	7705	1093	2.28	2.30	48.58	47.59
	2	91	15	15	15	7763	1047	2.30		46.53	
	3	91	15	15	15	7825	1072	2.32		47.64	
Mugher OPC 3 Days in Water & Indoor	1	91	15	15	15	7906	1164	2.34	2.31	51.73	53.59
	2	91	15	15	15	7761	1231	2.30		54.71	
	3	91	15	15	15	7746	1222	2.30		54.31	
Mugher OPC 7 Days in water & Indoor	1	91	15	15	15	7732	1207	2.29	2.30	53.64	57.21
	2	91	15	15	15	7830	1329	2.32		59.07	
	3	91	15	15	15	7769	1326	2.30		58.93	
Messebo OPC3 Days in Water & Indoor	1	91	15	15	15	7787	1339	2.31	2.30	59.51	58.01
	2	91	15	15	15	7743	1244	2.29		55.29	
	3	91	15	15	15	7729	1333	2.29		59.24	
Messebo OPC 7 Days in water & Indoor	1	91	15	15	15	7787	1413	2.31	2.31	62.80	61.69
	2	91	15.2	15.2	15.2	8145	1344	2.32		58.17	
	3	91	15	15	15	7793	1442	2.31		64.09	

High Strength Concrete

Cement Type & Curing	I.N.	Age [days]	Dimension[cm] L	W	H	Weight [gm]	Load [KN]	Density [Kg/M^3]	Avg. Density [Kg/M3]	Strength [MPa]	Avg. Strength [MPa]
Mugher PPC 3 days in Water & indoor	1	91	15	15	15	8079	1657	2.39	2.40	73.64	73.84
	2	91	15	15	15	8146	1673	2.41		74.36	
	3	91	15	15	15	8125	1654	2.41		73.51	
Mugher PPC 7 days in water & Indoor	1	91	15	15	15	8129	1760	2.41	2.41	78.22	76.07
	2	91	15	15	15	8068	1671	2.39		74.27	
	3	91	15	15	15	8161	1704	2.42		75.73	
Diredawa PPC 3 days in Water & Indoor	1	91	15	15	15	8075	1504	2.39	2.41	66.84	69.52
	2	91	15.2	15.2	15.2	8533	1665	2.43		72.07	
	3	91	15	15	15	8138	1567	2.41		69.64	
Diredawa PPC 7 Days in water & Indoor	1	91	15	14.9	15	8100	1582	2.42	2.43		75.99
	2	91	15	15	15	8184	1731	2.42		76.93	
	3	91	15.2	15.2	15.2	8603	1734	2.45		75.05	
Messebo PPC 3 Days in Water & Indoor	1	91	15	15	15	8148	1669	2.41	2.42	74.18	74.21
	2	91	15	15	15	8144	1697	2.41		75.42	
	3	91	15	15	15	8233	1643	2.44		73.02	
Messebo PPC 7 Days in water & Indoor	1	91	15	15	15	8256	1726	2.45	2.44	76.71	78.06
	2	91	15	15	15	8236	1772	2.44		78.76	
	3	91	15	15	15	8212	1771	2.43		78.71	
Mugher OPC 3 Days in Water & Indoor	1	91	15.2	15.2	15.2	8706	1837	2.48	2.45	79.51	82.02
	2	91	15	15	15	8237	1876	2.44		83.38	
	3	91	15	14.9	15	8156	1859	2.43		83.18	
Mugher OPC 7 Days in water & Indoor	1	91	15.2	15.2	15.2	8665	1912	2.47	2.48	82.76	82.29
	2	91	15	14.7	15	8151	1788	2.46		81.09	
	3	91	15.2	15.2	15.2	8779	1918	2.50		83.02	
Messebo OPC3 Days in Water & Indoor	1	91	15.2	15.2	15.2	8692	2135	2.48	2.46	92.41	90.93
	2	91	15	14.9	15	8276	2049	2.47		91.68	
	3	91	15	15	15	8202	1996	2.43		88.71	
Messebo OPC 7 Days in water & Indoor	1	91	15	15	15	8360	2186	2.48	2.46	97.16	91.39
	2	91	15	15	15	8288	1995	2.46		88.67	
	3	91	15	15	15	8302	1988	2.46		88.36	

APPENDIX – III

Test Results of the Five Cements

Declaration

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

Name:	Nigus G/Egziabher
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Place:	Faculty of Technology, AAU
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