Addis Ababa University

Addis Ababa Institute of Technology

School of Civil and Environmental Engineering

Feasibility of Using Selected Addis Ababa Basaltic Crusher Dust as Partial Cement Replacement Material in Concrete Production

A Thesis Submitted to School of Graduate Studies in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering (Construction Technology and Management)

By: - Hamid Ebrahim

Advisor: - Prof. (Dr.–Ing.) Abebe Dinku

January 2018

Feasibility of Using Selected Addis Ababa Basaltic Crusher Dust as a Partial Cement Replacement Material in Concrete Production

Hamid Ebrahim

A Thesis Submitted to

The School of Civil and Environmental Engineering

Presented in Partial Fulfillment of the Requirement for the Degree of Masters of Science

(Construction Technology and Management)

Addis Ababa University

Addis Ababa, Ethiopia

January 2018

Addis Ababa University

Addis Ababa Institute of Technology

School of Civil and Environmental Engineering

This is to certify that the thesis prepared by Hamid Ebrahim, entitled: Feasibility of Using Selected Addis Ababa Basaltic Crusher Dust as a Partial Cement Replacement Material in Concrete Production and submitted in partial fulfillment of the requirement for the degree of Masters of Science (Construction Technology and management) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

Signature by the Examining Committee:

Internal Examiner Ephraim Senbetta Signature Ephraim Senbetta Date 29/12/2017

External Examiner Denamo Addisie Signature ______ Date 01.01.2018

Advisor Prof Dr. -Ing Abebe Dinku Signature Abebe Dinku Date 05-01-2018

Dr. Agizew Nigussie
Dean, School of Civil &
Environmental Engineering

School or Center Chair Person

ACKNOWLEDGMENTS

Primarily I would like to thank the Almighty for giving me the strength to do this thesis work. Next I would like to acknowledge my Advisor ***Prof. (Dr. -Ing)*** **Abebe Dinku** for his guidance, support and valuable comments at all stages of the research work.

In addition, I want to acknowledge Addis Ababa University, Addis Ababa Institute of Technology, school of Civil and Environmental Engineering for providing all technical and financial assistance and for giving me the chance to study in the MSc Program.

I also want to express my sincere gratitude to the aggregate production companies found in and around Akaki Kality Worku Sefer area, who have helped me to collect crusher dust samples and giving me access to do pre-thesis investigations.

Finally, I want to express my heartfelt gratitude to my family and friends for their endless patience, encouragement, continuous support and help during my postgraduate study.

ABSTRACT

The production of coarse aggregates generates up to 25% Crusher by-product. Crusher by-product contains 15% to 25% fine materials called crusher dust. In most of aggregate production plants found in Ethiopia, dry screening to separate the excess fines from crusher by-product is not adopted. Hence crusher by-product containing high amount of fines becomes controversial to be used as manufactured sand, on the other hand there are economic and environmental issues speculated in relation to the use of River sand and Portland cement products.

Consequently Efforts have been made in the concrete industry to use crusher dust as partial replacement of fine aggregates and cement. This research work examines the feasibility of using raw basaltic crusher dusts as a partial replacement of OPC and PPC cement in concrete production. Here OPC and PPC were partially replaced by Basaltic Crusher Dust as 5%, 10%, 15% and 20% to prepare blended cements and produce commonly used C-25 and C-30concretes. Then tests were performed to examine the effects of basaltic crusher dust replacements on consistency and setting time of cement paste; compressive strength of cement mortar; workability of fresh concrete and compressive strength and water permeability of hardened concretes. Additionally it was attempted to survey the possible economic and environmental advantages derived from using basaltic crusher dust as a partial cement replacement material.

From the results obtained, it was noticed that basaltic crusher dust can replace 5% of PPC and 10% of OPC with comparable concrete compressive strength and water penetration resistance. However, basaltic crusher dust containing up to 20% clay shows higher loss in compressive strength of cement mortar and concrete compressive strength. Furthermore it was observed that partial replacement of basaltic crusher dust with OPC or PPC is more favorable in C-25 than C-30 concrete. Replacing crusher dust were also found to reduce environmental and related problems created in lesser use of crusher by-product and crusher dust produced during aggregate production. Finally it was able to observe that using basaltic crusher dust as partial cement replacement material by 5% and 10% results in saving 2.7% to 6.4% cost of concretes with comparable properties.

Key Words: Basaltic crusher dust, Blended cement, Crusher By-product, Concrete

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ACI	American Concrete Institute
ASTM	American Society for Testing Materials
BS	British Standard
Bnt/y	Billion ton per year
C-25	25MPa specified compressive strength of concrete
C-30	30MPa specified compressive strength of concrete
BCD1	Basaltic Crusher Dust Sample 1
BCD2	Basaltic Crusher Dust Sample 2
CH	Calcium Hydroxide
CSH	Calcium Silicate Hydrate
EBCS 2	Ethiopian Building Code of Standards 2
ES	Ethiopian Standard
EN	Euro Norm
f_{cr}	Required concrete compressive strength
f'_c	Specified concrete compressive strength
f'_{cm}	Expected mean strength
I.R	Insoluble Residue
LOI	Loss on Ignition
QDFP	Quarry Dust Fine Powder
SAI	Strength Activity Index
w/c	Water to cement ratio
w/cm	Water to cementitious material ratio
XRF	X-ray Fluorescence

CHAPTER ONE

INTRODUCTION

1.1. General

Concrete is a mixture of binding material, coarse aggregate, fine aggregates and water. It is a versatile construction material due to its reasonable cost and easy availability of its constituents. Owing to increasing urbanization and other development activities in different sectors its consumption is increasing day-by-day. Increase in construction activities requires production of more and more quantity of concrete, which needs more and more Portland cement, natural river sand and coarse aggregate [1].

The mechanized production of coarse aggregates generates crusher dust as a byproduct. Crusher dusts are by-products that are produced as a result of the crushing operation, containing a large amount of fine material that passes the 150μm sieve. Crusher dust fines may be dry screenings collected from below the last screen deck in a dry or semi dry state or pond screenings, obtained from washing aggregates, collected from settling ponds. The amount of fines generated varies from one crushing plant to another and may include up to 25% of the production depending on quarry nature, type of rock crushed, and type and size of aggregates produced. Most of the specifications for construction use of fine aggregates do not accept any material with more than 10% passing 150μm sieve. Currently these fine grained materials are used on a limited basis and their proper disposal is a growing concern of the stone industry [2].

Cement is one of the oldest binding materials widely used in construction industry around the world which is considered as one of the primary producer of carbon dioxide, contributing about 5-8 percent to the overall carbon dioxide production in the world. As in the production of one ton of Portland cement about one ton of carbon dioxide is released into the environment. It is estimated that cement production is responsible for about 3% of the global greenhouse gas emission. About 50% of the CO_2 released during cement production is related to the decomposition of limestone during burning. As a result mixing of clinker with supplementary materials (called blending) is considered as a very effective way to reduce CO_2 emission [3, 4].

Most common blending materials used in cement production or concrete production are industrial wastes. This is due to the fact that recycling of industrial wastes as blending materials has technical, economic and environmental benefits besides the reduction of CO_2 emission from cement production [4]. Fly ash, blast furnace slag and silica fume are most widely used industrial wastes in place of cement for concrete production attributed to their reactivity nature called pozzolanic behavior.

Other agricultural and industrial by-products have been used in concrete and mortar production as pozzolanic or inert filler for similar reasons. Among these, crusher dust which is a by-product of aggregate crushing was studied by some researchers for its use in concrete and mortar production as sand and/or cement replacing material. Most of the researches showed positive results and indicate that crusher dust could have pozzolanic properties. However as the by-product differs in its property depending on the rocks used for aggregate production which depends on the locality and other factors, it is necessary to conduct an indicative experimental investigation to examine, the impact of replacing Portland cement partially with crusher dust, on the mechanical and physical properties of cement paste, mortar and concrete.

1.2. Problem Statement

Due to the development in the construction industry the need for construction materials is increasing. One of the materials which involve increment in demand is coarse aggregate, so that aggregate production companies are emerging and increasing their production capacities. As it happen crusher by-product which is a byproduct of coarse aggregate production is also increasing. This by-product material is difficult to market (to be used as manufactured sand) because it contains 15 - 25% fines passing 150µm sieve, which is basically pulverized rock. Meanwhile there are some economic and environmental issues raised on crusher by-product and crusher dust disposal as well as production and use of Portland cement and river sand.

Additionally basaltic crusher dust can be discovered in a separated form which is collected naturally by wind around the crusher site. The basaltic crusher dust found in this way is generally considered as waste material. Even though it is difficult to determine the amount production, currently the amount of loss as waste is increasing as more companies joined the industry. So disposal of this waste material gets concerns since it might cause the following environmental problems:

a) If the waste is disposed on soils, the permeability of topsoil will be reduced, water ponding will be created and land use problems will be raised.

b) When the waste is dumped and dried out, the fine basaltic crusher dust suspends in the air and slowly spread out through wind to the nearby area.

c) When dumped along a catchment area of natural river or rainwater, it results in contamination of over ground water reservoir and surface water.

The other problem arises from the general observation that shows the most widely used fine aggregate type in Ethiopian construction industry is natural river sand but there is a huge production and collection of crusher by-product (traditionally called “zero zero” or “fino”) which accounts about 25% of coarse aggregate production and can be used as a full or partial replacement of fine aggregate as proven by Shwaferaw Dinku (2006) [5], however the main hindering factor in using this material as a fine aggregate is its excess fine content. Most of contractors and consultants in Ethiopian construction industry believed that crusher dust contained in the crusher by-product could take the place of cement in concrete and mortar, so that it can affect different properties of cement and concrete such as consistency, setting time, workability, compressive strength and water permeability.

According to the estimation made, depending on the coarse aggregate demand of governmental building construction projects from the report organized by ministry of urban development, housing and construction in 2014/15[9], the average annual crusher dust produced and contained in crusher by-product due to production of coarse aggregate for building construction projects conducted under the government were more than 125,000 m^3. This can be considered as an indicator for a high potential production of crusher dust due to coarse aggregate production for all construction projects going on all over the country. Thus, In order to verify the above cases and to find an alternative way to use such an abundant material it is better to test it for its feasibility to be used as partial cement replacement material in concrete production.

1.3. Research Questions

- Can raw basaltic crusher dust be used as cement fillers?
- Could basaltic crusher dust be used as pozzolanic material?
- What will be the effect of replacing cement partially by basaltic crusher dust in 5%, 10%, 15% and 20% on consistency and setting time of cement paste and strength development of cement mortar?
- What will be the effect of replacing cement partially by basaltic crusher dust in 5%, 10%, 15% and 20% on workability of fresh concrete and compressive strength and water permeability of hardened concrete?
- Does using crusher dust as a partial cement replacement material have economic and environmental advantages?

1.4. Objectives of the Research

The general objective of this research work is:

- To study the feasibility of using Basaltic Crusher Dust as a partial cement replacement material.

The specific objectives of this research are:

- To find the feasible contents of Basaltic Crusher Dust to be used as a partial Portland cement replacement material in concrete production.
- To investigate the effect of partial replacement of Basaltic Crusher Dust on consistency, setting time and strength development of blended cement.
- To assess the effects of partial cement replacement with Basaltic Crusher Dust on workability, compressive strength and water permeability of concrete.
- Investigate economic and environmental advantages of using Basaltic Crusher Dust as a partial cement replacement material.

1.5. Methodology

The methodology used to achieve the objectives of the research is illustrated figuratively as shown in Figure 1-1.

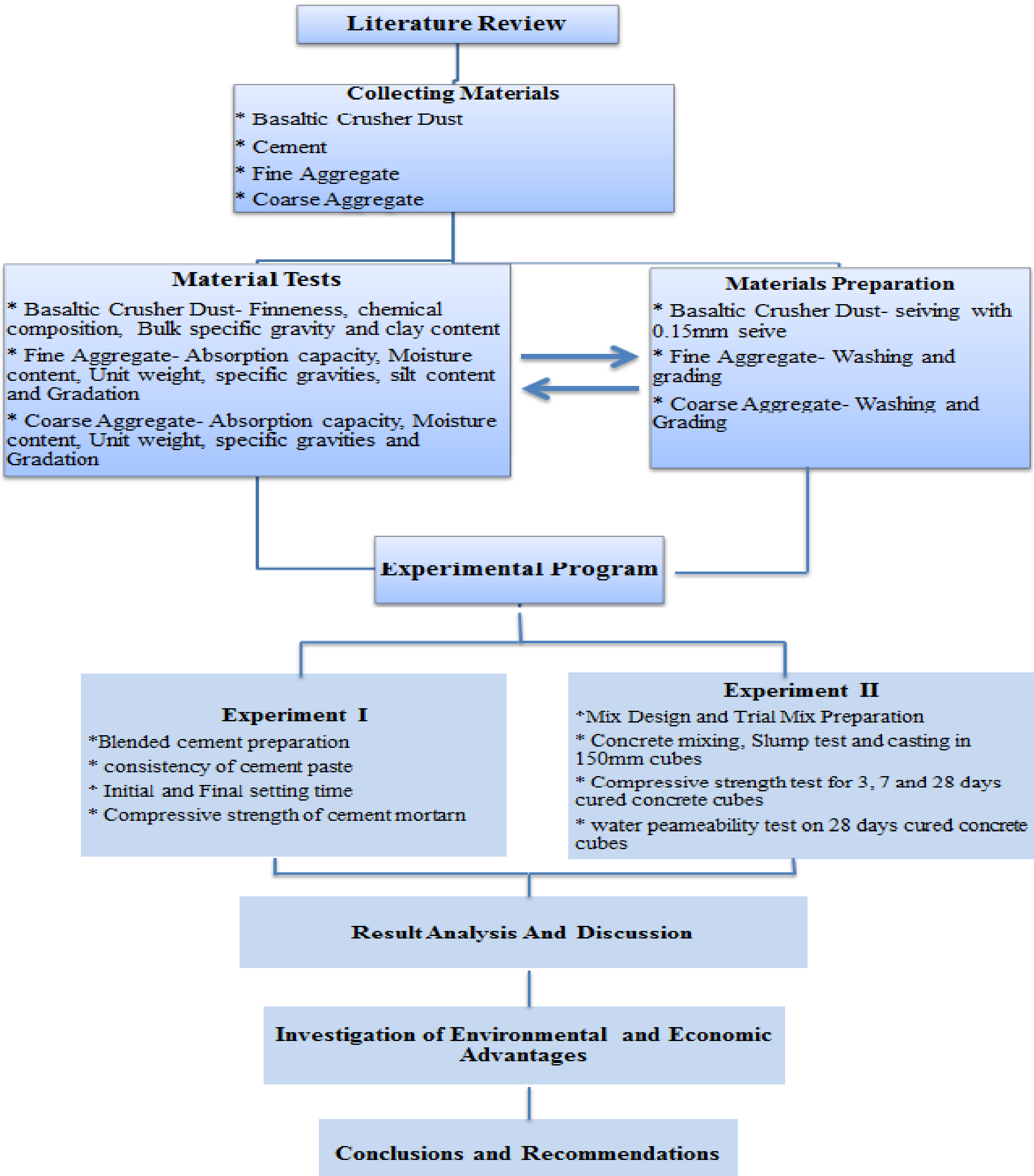


Figure 1-1 Summary of Research Methodology

1.6. Research Significance

As a binding material, cement performs a significant role in civil engineering constructions around the world. However, the production of cement releases carbon dioxide (CO_2) in the atmosphere both directly and indirectly which contributes to the global warming. Using crusher dust as partial replacement of Portland cement in concrete production could be alternative and reasonable approach to create friendly environment.

The result of this research could also inspire construction contractors and ready mix concrete producers to use crusher by-product which contains high amount of fines as both river sand and cement replacing material simultaneously, so that environmental impact due to production of crusher by-product, crusher dust and river sand could reduce and the overall cost of concrete could be minimized because of the reduced quantity of cement.

1.7. Scope of the Research

In this research it is attempted to classify basaltic crusher dusts based on their clay content which is entrapped due to the condition of scalping prior to crushing operation. According to the preliminary observation made in different crushing plants, degree of rock scalping mostly depend on the location of crusher plant relative to the quarry site. Even though the clay content of basaltic crusher dust differs with the degree of scalping made in each one of the aggregate production sites, two sample basaltic crusher dusts with 0% and 20% clay contents were selected from two different basaltic coarse aggregate production sites which are believed to represent the best and the worst case in scalping the parent rock before crushing in order to remove impurities. Then the selected basaltic crusher dusts have been examined for their feasibility to be used as a partial cement replacing material in concrete production.

1.8. Limitation of the research

Due to time and resource limitation the research does not consider the effect of partial cement replacement by basaltic crusher dust on compressive strength of cement mortar and compressive strength of concrete beyond 28 curing days.

CHAPTER TWO
LITERATURE REVIEW

2.1. Introduction

The cement and concrete technology has shown various advancements during the past years. One of the best advancements is the use of by-product materials as a cement and sand replacement to alleviate environmental and economic impact of cement and river sand production as well as the disposal of those industrial and agricultural by-products. Cement replacing materials such as fly ash, blast furnace slag, natural Pozzolanas and other industrial wastes were reported to improve different properties of mortar and concrete [6].

Crusher dust is one of these by-product materials found from aggregate production plants. Recently it has been studied for its feasibility as a cement replacing material in some parts of the world and has been found to have economic, environmental and technical advantages, if it is used in mortar and concrete. The performance of mortar and concrete is assessed by different tests on both fresh and hardened state. This includes physical and chemical properties of blended cements and workability, compressive strength and water permeability of concrete made with blended cements.

This chapter is dedicated in discussing some topics related to this research work such as properties of cement, concrete, pozzolans, filler, stone wastes and review of related researches.

2.2. Stone Processing By-product Powder/Dust

The use of different cement replacing materials has become a common practice in the construction industry. Most of these cement replacement materials are by-products of different industries and agricultural wastes. Blast furnace slag, silica fume, fly ash and rice husk can be sited as an example. Stone by-product powder/dust which is a by-product of crushing, cutting or polishing different types of stones for different purposes have been found to be used as natural Pozzolana or as filler while producing concrete. Marble dust, granite dust and limestone powder are mostly tested stone processing by-product materials for their properties to be used as cement replacing materials. Among all stone processing industries Crusher dust produced during aggregate production is common and widely produced stone by-product.

2.2.1. Crusher Dust

Crusher dusts are fines passing 150µm sieve which are produced during aggregate production. The properties and quantity of produced dust could be different with the type and properties of parent rock used for aggregate production (such as basalt, granite, ignimbrite, pumice, scoria or trachyte) and the type of crusher used for crushing operation.

Releasing such by-product material directly into environment can cause different environmental problems and incur additional cost of storage and disposal. To reduce the impact of crusher dust on the environment and eradicate additional storage and disposal costs, it has to be used to produce new products; so that, the natural resources are used efficiently [7].

2.2.1.1. How are Crusher Dust (Fines) Produced

Crusher dust or fines are products that are produced as a result of the crushing operation, containing a large amount of fine material that passes the 150 µm and 75 µm sieve. The fines may be dry screenings collected from below the last screen deck in a dry or semi dry state or pond screenings, obtained from washing aggregates and collected from settling ponds. The amount of by product generated varies from one crushing plant to another and may include up to 15 to 25% of the production depending on quarry nature, type of rock crushed, and type and size of aggregates produced. The production of fines in more advanced quarry site is illustrated in Figure 2-1.

Mined boulders and blast rock are loaded and hauled to a crusher bin. The quarried rocks are fed through primary and secondary crushers for processing and are subsequently screened to produce aggregates of sizes determined by demand.

Primary crushing is often done at or near the pit, usually by jaw or gyratory crushers, but impact and other special types of crushers are also used. In-pit movable crushers are also increasingly being used. Cone crushers and gyratory crushers are the most common types of secondary crushers used. Impact crushers, including hammer mills and roll crushers are also used as secondary crushers. Screening is most commonly done by using inclined vibratory screens. For screening large sizes of crushed stone, grizzly bars, rod decks and heavy punched steel or plastic plates are used [2].

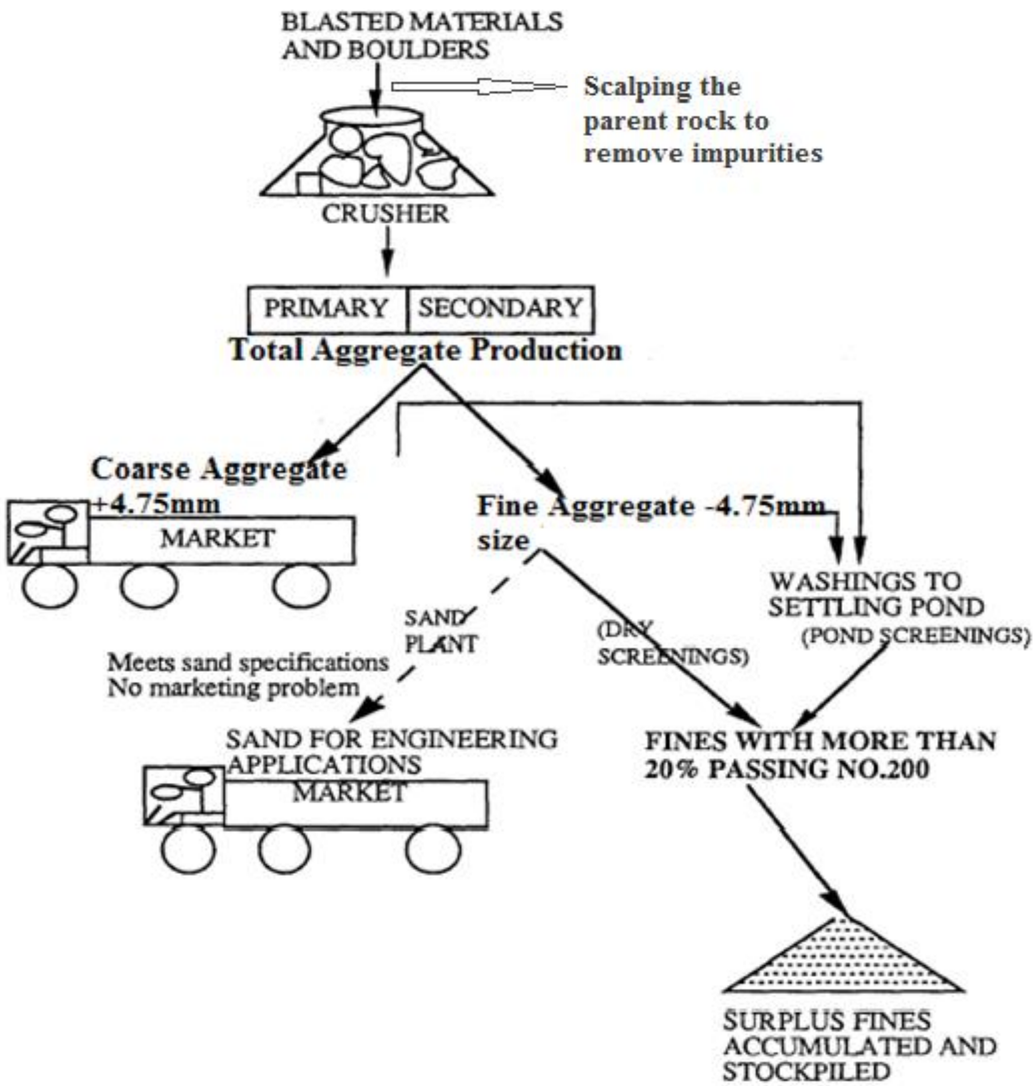


Figure 2-1 Advanced production of Aggregate and crusher fines [2]

2.2.1.2. Crusher By-products in Ethiopia

In Ethiopia, Production of aggregate and crusher fines is not as advanced as the process shown in the above Figure 2-1. Jaw and impact or cone crushers are mostly used crusher types for primary and secondary crushing of basalt rock. Dry screening of crusher by-product passing 4.75mm and washing coarse aggregates to eliminate fines are not adopted, so crusher dust/ fines and potential manufactured sand materials are blended and stored together as crusher by-product as shown in Figure 2-2 which is atypical example of crusher by product storage in aggregate production plants. Additionally some of the crusher dust/fines are extracted naturally by wind and collected around crusher, screens and spreads over crushing site.

Figure 2-2 Crusher by-product collection in a typical Aggregate production plant (found in Addis Ababa, Akaki Kality area)

Coarse aggregate can be produced from different rock types. In Ethiopian the most commonly available local coarse aggregates are obtained from normal weight crushed basaltic stone and lightweight volcanic ash, which are a member of a family of igneous rock (scoria or pumice) [8]. So basaltic coarse aggregate is widely used coarse aggregate type for concrete production in most part of Ethiopia.

The production of coarse aggregate results up to 25% pulverized rocks passing 4.75mm and containing 15 to 25% of fines passing 150μm. The amount of by-product and fines produced could be different based on size of aggregate to be produced, rock type and type of primary and secondary crusher. The total coarse aggregate and crusher by product production of Ethiopia is not studied as a whole, however, the generalized report organized by ministry of urban development, housing and construction in 2014/15 indicates demand of construction materials for building construction projects conducted by the government [9]. The coarse aggregate demand, estimated crusher byproduct and crusher dust production are illustrated under Table 2-1.

Table 2- 1 Coarse aggregate demand and estimated Crusher dust production for governmental construction projects [9]

Year in EC. (GC.)	02 Aggregate demand (m^3)	Expected crusher by-product (Passing 4.75 mm sieve) (m^3)	Expected Crusher dust production (Passing 150µm sieve) (m^3)
2005(2012/2013)	577,370.88	192,456.96	38,491.39
2006(2013/2014)	1,715,388.00	571,796.00	114,359.20
2007(2014/2015)	2,532,583.00	844,194.33	168,838.87
2008(2015/2016)	2,684,648.00	894,882.67	178,976.53

The Table shows that coarse aggregate demand is increasing every year, so that the corresponding by-products productions are also increasing. According to the report the average annual crusher dust produced due to production of coarse aggregate for construction projects conducted under the government were more than 125,000 m^3. This can be considered as an indicator for a high potential production of crusher dust due to coarse aggregate production for all construction projects going on all over the country.

When it is tried to consider the capital Addis Ababa where construction industry and related construction materials production industries are booming, the commonly found aggregate rocks are basalt, trachyte, and ignimbrite. Basalt rock is most dominantly available and used for coarse aggregate production. Karstaedt analyzed the chemical composition of basaltic stone by taking samples from a quarry in the vicinity of Addis Ababa Bole International Airport. The quarry was planned for a supply of aggregate for the construction of Addis Ababa International Airport in 1995G.C. and the chemical composition was summarized as shown in Table 2-2 [8]:

Table 2- 2 Chemical composition (%) of Addis Ababa Basalt, Bole area [8]

Oxides	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	H_2O	LoI	TiO_2	MnO
Contents %	49	16.1	13.74	8.2	5.4	3.3	0.9	0.8	0.7	2.4	0.2

According to the information of Addis Ababa housing development and construction bureau the total coarse aggregate production of Addis Ababa is not recorded. However, in order to show how much crusher dust have been produced during aggregate production, “the main construction materials distribution report” prepared by Addis Ababa Housing Development Office [10] is summarized in Table 2-2 and the corresponding crusher by-product and dust productions are also estimated.

Table 2- 3 Coarse aggregate production and estimated crusher dust production for Addis Ababa housing projects [10]

Year in EC. (GC.)	02 Aggregate supply (m^3)	Expected by product (Passing 4.75 mm sieve) (m^3)	Crusher dust (Passing 150µm sieve) (m^3)
2005(2010/11)	50,202.00	16,734.00	3,346.8
2005(2011/12)	379,336.00	126,445.33	25,289.07
2005(2012/13)	929,010.00	309,670.00	61,934.00
2006(2013/14)	344,028.00	114,676.00	22,935.20
2007(2014/15)	544,245.00	181,415.00	36,283.00
2008(2015/16)	785,293.00	261,764.33	52,352.87
2009(2016/17)	316,849.00	105,616.33	21,123.27
Estimated Average Crusher dust			**31,894.89**

The calculation based on the reported annual 02 aggregate distribution for housing projects shows the average annual crusher dust production for the recorded seven years were more than 31,000m^3. As a result, crusher by-product dust/fines which is basically composed of basalt with such an enormous amount of annual production and oxide composition can possibly be used as a cement replacement material in concrete production in order to eradicate environmental problems, to reduce cost of concrete and encourage the use of manufactured sand which contains relatively higher amount of fines passing 0.15mm sieve.

2.3. Studies on Using Crusher Dust as a Partial Cement Replacement

Sairam Kumar et al. in India in 2013 conducted an “experimental study on partial replacement of cement with quarry dust” which is a by-product of crusher unit’s that accounts 25% of the final product. In this study the researcher collected the dust from two different stone crushing units. The dust used was a powder which passed 90 µm sieve and having a specific gravity of 2.5. The dust was used for replacement of cement up to 40 percent and concretes with 20MPa, 30MPa and 40MPa compressive strength were produced.

The result shows that marginal (insignificant) decreases in compressive strength of concretes were observed up to 25% cement replaced with quarry dust. But considerable (significant) decreases in compressive strength of concretes were observed beyond 25% cement replacement with quarry dust. So the researchers concluded that cement can be replaced with 25% of quarry dust in concrete without excessive loss in compressive strength of concrete [7].

El-Didamony H. et al. in Egypt in 2015 conducted research on “Basalt powder as Pozzolana and Filler in Ordinary Portland Cement” which was aimed to investigate the influence of basalt powder up to 20% replacement on water of consistency, initial and final setting times, bulk density as well as total porosity and compressive strength of cement pastes. The basalt powder used was ground to pass 90 µm sieves and the chemical composition of the powder is shown in Table 2-4 [11]:

Table 2- 4 Chemical composition (%) of basalt powder used [11]

Oxides	Content %	Oxides	Content %
CaO	9.68	K_2O	6.24
SiO_2	59.74	SO_3	_
Al_2O_3	15.39	LIO	1.52
Fe_2O_3	11.4		
MgO	1.87		
Na_2O	0.06		

The results of the experimental study revealed that the water requirement of cement increases with increase in basalt powder content, whereas the setting time was slightly elongated. Free lime content of OPC and basalt filled hardened cement pastes (which were cured for 3, 7, 28 and 90 days) decreases with increase in curing age which shows that, basalt powder has low pozzolanic property at earlier ages, however, increases slightly with curing age.

Compressive strength of hardened cement paste decreases with increase in the replacement amount of basalt powder up to 15% by weight of cement. But the addition of 20 % basalt gives the higher compressive strength of hardened cement pastes in comparison to OPC and hardened cement pastes containing 5, 10 and 15 % basalt at all curing ages. This indicates that the pozzolanic activity of basalt powder was higher at 20% replacement than the lower replacement percentages. So the researchers concluded that Basalt Powder up to 20% by weight of Portland cement can be used as filled-pozzolanic material [11]:

Kartini, K. et al. in Malaysia in 2004 conducted a research on “quarry dust fine powder (QDFP) as substitute for ordinary Portland cement in concrete mix”. The research evaluates mechanical properties and durability index on concrete composed of various w/cm ratios (0.3, 0.4, 0.5 and 0.6) for replacement level of 3%, 5%, 10% and 15% with the inclusion of super-plasticizer to enhance the workability of concrete. The researchers first determines the oxide composition of QDFP by X-ray Fluorescence (XRF) test as shown in Table 2-5 and fineness of cement blended with QDFP using 90 µm sieve[12].

Table 2- 5 Chemical composition of Quarry dust powder used in the research [12]

Oxides	Content %	Oxides	Content %
CaO	1.84	K_2O	8.12
SiO_2	69.96	SO_3	0.2
Al_2O_3	12.81	P_2O_5	0.2
Fe_2O_3	4.28	MnO	0.1
MgO	0.44	Tio_2	0.22
Na_2O	0.51		

Based on the finding of the research OPC is much finer than the quarry dust. The chemical composition of quarry dust is found to be with in the acceptable limit ASTM C 618: 2003 with the total composition of those three compounds 87.05% > 70% as indicated by X-ray Fluorescence test. The loss of ignition (LOI) for OPC and QDFP is obtained as 1.33% and 1.32% respectively. Thus, QDFP satisfies the requirement of ASTM C 618: 2003.The research founds that with higher replacement level of OPC with QDFP, the workability in terms of slump was improved and this is because of the coarseness of QDFP which makes it to consume less water than much finer OPC [12].

The research measures performance of concrete at 7, 28, 60, 90 and 120 days of ages and shows that the compressive strength of the concrete with super plasticizer and QDFP reduces as the percentage of QDFP replacement increases from 3% to 15% as compared with control OPC concrete, simultaneously due to the reduction in the cement content. The research indicates that the difference of strength between OPC and the QDFP concrete were higher at the earlier age, however as the period of curing prolong, the relative difference were smaller. This clearly shows that the development of strength of QDFP as pozzolanic material at the earlier age was slow but it develops through time. The research also shows that replacement of QDFP in higher proportion and increasing the w/cm ratio from 0.3 to 0.6 increases the coefficient of permeability and water absorption of the resulted concrete specimens and it is concluded that, “however, the QDFP concrete still can be considered as low water permeability and good quality concrete.” [12].

2.4. Cement

According to Neville A.M, definition, cement, in the general sense of the word, can be described as a material with adhesive and cohesive properties which make it capable of bonding mineral fragments into a compact whole. For constructional purposes, the meaning of the term ‘cement’ is restricted to the bonding materials used with stones, sand, bricks, building blocks, etc. The use of cementing materials is very old. It begins with the ancient Egyptians who used calcined impure gypsum. Then Greeks and the Romans used calcined limestone and later learned to add sand and crushed stone or brick and broken tiles to lime and water mixture and this was the first concrete in history [13]. Since Lime mortar does not harden under water, for construction under water the Romans ground lime and a volcanic ash or finely ground burnt clay tiles together. The active silica and alumina in the ash and the tiles combined with the lime to produce what became known as pozzolanic cement from the name of the village of Pozzuoli, near Vesuvius, Italy where the volcanic ash was first found. The name ‘pozzolanic cement’ is used to this day to describe cements obtained simply by the grinding of natural materials at normal temperature [13].

The sign to the discoveries and manufacture of all modern cements is undoubtedly the investigations carried out by John Smeaton. Smeaton, while building the third Eddy stone house (1759AD) of the cost of Cornwall in southern England found that, a mix of lime clay and crushed slag from iron making, produced a mortar which hardened under water. Then after Joseph Aspdin took out patent in 1824 for “Portland cement” a material he produced by firing finely grounded limestone until the limestone was calcined [13]. While the use of cement in concrete has a very long history, the industrial production of cements started in the middle of the 19th century, at first with shaft kilns and later on replaced by rotary kilns as standard equipment worldwide. Knowadays global cement production has reached 2.8Bnt/yr and is expected to increase to around 4Bnt/yr. Major growth is forecast in countries like China and India as well as the Middle East and Africa[3]. At the same time, the cement industry is facing challenges such as increased energy costs, requirements to reduce CO_2 emissions and problems of sourcing raw material of sufficient quality and quantity. The use of alternative materials, like slag, fly ash, natural pozzolanas or other potential industrial and agricultural by-products are becoming the important advancements in the current cement industry in order to minimize those challenges.

2.5. Portland cement

Portland cement, whose name was originated from the resemblance of the color and quality of the hardened cement to Portland stone - a limestone quarried in Dorset, England -, is described as a hydraulic cement produced by pulverizing clinker consisting essentially of hydraulic calcium silicates, usually containing one or more of the forms of calcium sulphate as an inter-ground addition [14]. Such method of making cement has been improved upon since the time of Aspdin but the basic process has remained the same. Modern Portland cement is made from materials which must contain the proper proportions of lime (CaO), silica (SiO_2), alumina (Al_2O_3), iron ($Fe_2 0_3$) with minor amounts of magnesia and sulfur trioxide [6].

2.5.1. Classification of Portland cement

There are different standards for classification of Portland cement. The two major standards are the ASTM C150 standard, used primarily in the U.S., and European EN-197 standard [4].

American standard: - Eight types of cement are covered in ASTM C 150 standard. These types and descriptions of their uses are listed in Table 2-.6 below [4].

Table 2- 6 Portland cement types and their uses as ASTM C 150 [3]

Cement type	Use
I	General purpose cement, when there are no extenuating conditions
II	Aids in providing moderate resistance to sulfate attack
III	When high-early strength is required
IV	When a low heat of hydration is desired
V	When high sulfate resistance is required
IA	A type I cement containing an integral air-entraining agent
IIA	A type II cement containing an integral air-entraining agent
IIIA	A type III cement containing an integral air-entraining agent

Beyond this ASTM C 595 specifies five classes of blended hydraulic cements for both general and special applications, using either slag or pozzolans, or both, with Portland cement or Portland cement clinker or slag with lime.

Type IS-Portland blast-furnace slag cement,

Type IP-Portland-Pozzolana cement,

Type P-Portland-Pozzolana cement,

Type I (PM)-Pozzolana-modified Portland cement,

Type I(SM)-Slag-modified Portland cement: are the five classes of blended hydraulic cement. According to this classification blending potential industrial and agricultural by-products with Portland cement can be considered as Type I (PM) Pozzolana modified Portland cement.

European standard: - EN 197-1 defines 5 classes of common cement that comprise Portland cement as a main constituent. These classes differ from the ASTM classes as shown in the following Table 2-7 [4].

Table 2- 7 Classes of common cement comprising Portland cement as EN 197-1 [4]

Type	Name	Description
I	Portland cement:	Comprising Portland cement and up to 5% of minor additional constituents
II	Portland composite cement:	Portland cement and up to 35% of other single constituents
III	Blast furnace cement:	Portland cement and higher percentages of blast furnace slag
IV	Pozzolanic cement:	Portland cement and up to 55% of pozzolanic constituents
V	Composite cement:	Portland cement, blast furnace slag and Pozzolana or fly ash

2.5.2. Chemical Properties of cement

2.3.2.1. Chemical Composition

The primary constituents of Portland cement are iron, silica, lime and alumina oxides. The interaction of these oxides results in the formation of four compounds as shown on Table 2-8 [13]. The different types of cement we have nowadays are produced by varying the proportions of the various compounds. Table 2-9 illustrates the oxide composition limits of Portland cement.

Table 2- 8 Main compounds of Portland cement [13]

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

Table 2- 9 Oxide composition of Portland cement [13]

Oxides	Content (%)
CaO	60-67
SiO_2	17-25
Al_2O_3	3-8
Fe_2O_3	0.5-6.0
MgO	0.5-4.0
Alkalis (as Na_2O)	0.3-1.2
SO_3	2.0-3.5

The various compounds affect the strength of cement in different ways. The two silicates (C_3S and C_2S) are responsible for the strength gain of hydrated cement paste. While C_3S influences strength development during the early days (usually the first 4 weeks), C_2S contribute to strength gain afterwards. The other compounds also play key role in strength development. C_3A contributes to strength development from 1 - 3 days and even longer. It must be noted however that at longer days, C_3A has retrogressive effect on strength especially for cements with high C_3A or (C_3A + C_4AF) content [15].

2.3.2.2. Loss on Ignition

Loss on ignition is calculated by heating up a cement sample to 900 – 1000 ^{0}C until a constant weight is obtained. The weight loss of the sample due to heating is then determined. A high loss on ignition can indicate pre-hydration and carbonation, which may be caused by improper and prolonged storage or adulteration during transport or transfer. Maximum loss on ignition permitted by BS 12:1991 and ASTM C150-94 is 3% and 4% respectively. But with cement containing calcareous filler, 5% of the mass of the cement nucleus is allowed by EN 197-1992 and ASTM C618 recommends maximum of 10% for cements containing natural pozzolans. The standard loss on ignition test is contained in EN 196-2 No.7:1994 Standard Test Methods for Determination of Loss on Ignition in European standard and AASHTO T 105 and ASTM C 114: Chemical Analysis of Hydraulic Cement in American standard [6]. According to the Ethiopian standard the loss in mass on ignition shall not exceed 4% for Portland cement [16].

2.3.2.3. Insoluble Residue

The insoluble residue which is determined by treating the cement with hydrochloric acid is a measure of adulteration of cement largely arising from impurities in gypsum. The standard insoluble residue test is contained in ASTM C 114: Standard Test Methods for Chemical Analysis of Hydraulic Cement [8]. BS 12 1991 limits the insoluble residue to 1.5% content of a filler, the standard insoluble residue test is contained in EN 196-2 no,9;1994 standard test methods for determination of insoluble residue and EN 196-2 No 10, 1994 standard test methods for determination of insoluble residue [4].

2.5.3. Physical Properties of Portland cement

An understanding of the significance of some of the physical properties of cement is helpful in interpreting results of cement tests. Tests of the physical properties of the cements should be used to evaluate the properties of the cement, rather than the concrete.

2.5.3.1. Fineness

Fineness is a measure of particle size of cement. There are several methods to measure cement fineness [8]:

- ASTM C 115: Standard Test Method for Fineness of Portland cement by the Turbidimeter
- ASTM C 786: Standard Test Method for Fineness of Hydraulic Cement and Raw Materials by the 300-µm (No. 50), 150-µm (No.100), and 75-µm (No. 200) Sieves by Wet Methods
- ASTM C 204: Standard Test Method for Fineness of Hydraulic Cement by Air Permeability Apparatus
- ASTM C 430: Standard Test Method for Fineness of Hydraulic Cement by 45-µm (No. 325) Sieve

Fineness of Portland cement has great effects on hydration rate and thus setting time, and the rate of strength gain. As an example, the smaller is the particle size, the greater the surface area-to-volume ratio. This causes more area available for water-cement interaction. The finer particles mainly affect the early strength of the cement (2 days) while the larger particles dominate the strength after this time. The effects of greater fineness on strength are generally seen during the first seven or twenty eight days. Fineness of pozzolans to be added in blended cements has a greater effect on the strength and durability properties of blended cements [4].

According to the Ethiopian standard ordinary Portland cement shall have a specific surface area not less than 2250 cm^2/g [16], whereas the ASTM C 150 standard recommends a minimum fineness of 2800 cm^2/g [4].

2.5.3.2. Consistency of Cement Paste

Many of the properties of concrete are affected by its water content. The physical requirements of cement paste like setting and soundness depends on the water content of the neat cement paste. Therefore it is necessary to define and study the water content. This is defined in terms of the normal consistency of the paste which is measured according to ASTM C 187 and the European standard for consistency test is indicated on EN 196-3, No.5, 1994. [4] The amount of water required to achieve a normal consistency as defined by a penetration of 10 ± 1 mm of the Vicat plunger (ASTM C 187) is expressed as a percentage by weight of the dry cement, the usual range being about 26% to 33% [4]. The effect of natural pozzolans on water requirement of cement is mainly dependent on the fineness of natural pozzolans to be added relative to the fineness of Portland cement to be replaced partially.

2.5.3.3. Setting Time

The stiffening of the cement paste (cement + water) is called setting. The time starting from the mixing of cement and water until the cement paste sets is called the setting time. There are two types of setting time i.e. initial and final setting times. The initial setting time indicates the time at which the paste begins to stiffen considerably and can no longer be molded; while the final setting time indicates the time at which the paste has hardened to the point at which it can sustain some load. [6, 14].

The cement paste is only shapeable during setting time. Thus, the initial setting time must be long enough, and the final setting time must be short enough. The standard setting time tests are [14]:

- ASTM C 191: Standard Test Method for Time of Setting of Hydraulic Cement by Vicat Needle
- ASTM C 266: Standard Test Method for Time of Setting of Hydraulic-Cement Paste by Gillmore Needles

Ethiopian standard recommends that the initial setting time for cement not to be less than 45 minutes and the final setting time not to exceed 10 hours [16].

2.5.3.4. Soundness

When referring to Portland cement, "soundness" refers to the ability of a hardened cement paste to retain its volume after setting without delayed destructive expansion. Soundness can also be defined as a property by which the cement does not undergo any appreciable expansion or change in volume after it has set, thus eliminating any chance of disrupting the hardened cement paste. The destructive expansion is caused by excessive amounts of free lime (CaO) or magnesia (MgO) [4, 13].

The standard test for soundness of cement paste is: ASTM C 151: Standard Test Method for Autoclave Expansion of Portland Cement which specifies a maximum autoclave expansion of 0.80 percent for all Portland cement types [4, 14]. Another soundness test is Le Chatelier Test, which is also described in IS 4031(Part 3). According to the Ethiopian standard which uses the Le Chatelier's test, the expansion of Portland cement shall not exceed 10mm.If this is not satisfied, an additional test shall be made using aerated portion of the same sample. The maximum expansion of such aerated sub sample shall not exceed 5mm [16].

2.5.3.5. Strength

The strength of cement mortar is typically defined in three ways: compressive, tensile and flexural. There are several factors affecting these strengths including: water-cement ratio, cement-fine aggregate ratio, type and grading of fine aggregate, method of mixing and molding specimens, curing conditions, size and shape of specimen, moisture content during the time of test, loading conditions and age. Since cement gains strength over time, the time at which strength test is to be conducted must be specified. Typically times are 1 day (for high early strength cement), 3 days, 7 days, 28 days and 90 days (for low heat of hydration cement) [4,14].

A. Compressive Strength test: - is the most common strength test. According to ASTM standards, the test is carried out on a 50 mm cement mortar test specimen that is subjected to a compressive load until failure. The maximum load must be reached in not less than 20 seconds and no more than 80 seconds. The standard cement mortar compressive strength test is: ASTM C 109: Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens) [14].

B. Tensile strength test: - the direct tension test does not provide any useful insight into the concrete-making properties of cements. However, it was still specified by ASTM C 190,"Method of Test for Tensile Strength of Hydraulic Cement Mortars," until 1990 mainly due to being used as the most common test in the early years of cement since it was difficult to find machines that could compress a cement sample to failure [14].

C. Flexural strength: - (a measure of tensile strength in bending) is carried out on cement mortar beam that is loaded at its center point until failure. The standard cement mortar flexural strength test is described in: ASTM C 348: Flexural Strength of Hydraulic Cement Mortars in American standard and EN 196-1, No4.7: Standard Test Method for Flexural Strength of Cement Mortars in European standard [4].

2.5.3.6. Specific Gravity

The specific gravity of Portland cement is generally around 3.15. The specific gravities of Portland-blast-furnace-slag and Portland-Pozzolana cements may be as low as 2.90. The standard specific gravity test is: ASTM C 188: Standard Test Method for Density of Hydraulic Cement [14].

2.5.3.7. Hydration of Cement

When water and Portland cement are mixed, the constituent compounds of the cement and water undergo a chemical reaction resulting in hardening of the concrete. This chemical reaction of cement and water is called hydration, and it results in new compounds called hydration products. Both C_3S and C_2S react with water to produce an amorphous calcium silicate hydrate known as

C–S–H gel which is the main glue that binds the sand and coarse aggregate particles together in concrete [6].

Each of the compounds found in the cement react with water, but the rate at which they react is different. The order of reaction is $C_3A > C_3S > C_4AF > C_2S$. But the rate of hydration of these compounds differs from cement to cement depending on the fineness and other factors like presence of impurities and other cement compounds [6].

2.6. Pozzolana

Pozzolana can be defined as a material which in itself possesses little or no cementing property, but in the presence of moisture reacts with calcium hydroxide to form compounds which has binding characteristics. Pozzolana's main function in concrete is to enhance durability and strength of hardened concrete, whereas the fineness of Pozzolana determines their effect on workability of fresh concrete. These purposes allow the concrete manufacturer to design the best concrete mixture to suit desired conditions. Pozzolanas and supplementary cementations materials either natural or artificial are often used as cement replacement or as an improvement in concrete. Physical or chemical properties of the material determine their pozzolanic or cementation properties [15]. Generally, pozzolans can be grouped into natural and artificial Pozzolana.

Natural pozzolans are naturally occurring volcanic origin materials such as some diatomaceous earths; opaline cherts and shales; tuffs and volcanic ashes or pumicites, any of which may or may not be processed by calcination; and various materials requiring calcinations to induce satisfactory properties, such as some clays and shales.

The latter type is the artificial pozzolans that are obtained as industrial by-products. Fly ashes (fine solid particles of ashes carried out from burning coal in power plants), silica fumes (finely divided by-products obtained in manufacturing of silicon metal or silicon alloys), and granulated blast furnace slags (by-products generated by the rapid cooling of non-ferrous substances in iron ores that are separated from the hot metal in a blast furnace) are the most common examples of artificial pozzolans [14, 15, 13].

2.6.1. Pozzolanic Reaction

The hydration of tri-calcium silicate and di-calcium silicate with water gives calcium silicate hydrate and calcium hydroxide. The first compound have very low solubility in water while the later one is very much soluble in water and has no cementations value and is found as a free lime in the concrete, resulting in porosity of the concrete, which in turn results in durability problems. The siliceous and aluminous compounds found in the Pozzolana in a finely divided form react with the calcium hydroxide to form highly stable cementations substances of complex composition involving water, calcium and silica. Finely divided pozzolans and amorphous silicates result a better pozzolanic reaction. The principal reaction taking place can be shown as

Pozzolana (reactive silica) + Calcium Hydroxide + water $\longrightarrow$ Calcium Silicate Hydrate (gel)

$$SiO_2 + CH + H \longrightarrow C\text{-}S\text{-}H \quad \text{[Eq-2.1]}$$

The C-S-H formed in this reaction is not very different from that formed in the regular reaction, except the slightly lower ratio of Calcium to Silicate (C/S), which is the case for most of the pozzolans. The normal C/S ratio is believed to be around 2 [6].

2.6.2. Benefits of Pozzolana

According to American Concrete Institute (ACI 2000), Pozzolans are not only strengthens the concrete, but they have the following benefits as well:

I. Economical: For all other things being equal, concrete produced from pozzolans less costly than ordinary Portland cement.
II. Concrete produced from pozzolans continues to gain increasing strength with time
III. Low Permeability: Pozzolana decreases the permeability of concrete.
IV. Pozzolana concrete has the ability to resist the attack by aggressive compounds and hence increases concrete durability.
V. Besides the above, Pozzolana has other benefits such as reduction in shrinkage, low heat production, improve workability etc.

2.7. Fillers

Filler is a very finely-ground material, of about the same fineness as Portland cement, which, owing to its physical properties, has a beneficial effect on some properties of concrete, such as workability, density, permeability, capillarity, bleeding, or cracking tendency. Fillers are usually chemically inert but there is no disadvantage if they have some hydraulic properties or if they enter into harmless reactions with the products of hydration in the hydrated cement paste [13].

Fillers can be naturally occurring materials or processed inorganic mineral materials. What is essential is that they have uniform properties, and especially fineness. They must not increase the water demand when used in concrete, unless used with a water-reducing admixture, or adversely affect the resistance of concrete to weathering or the protection against corrosion which concrete provides to the reinforcement. Fillers can be used for concrete are such as lime, steel dust, quartz filler and other similar materials [13, 15].

2.8. Concrete

Concrete is the most commonly used modern construction materials. It forms the basis of the modern construction system. Concrete is mainly composed of cement, aggregate and water. Cementations materials, pozzolanic materials, filler materials, chemical admixtures, and some other additives may also be the constituents of concrete depending on the need and their availability. All the constituents have their own purpose in the concrete.

If a concrete is to be suitable for a particular purpose, it is necessary to select the constituent materials and combine them in such a manner as to develop the special qualities required as economical as possible. Therefore the selection of constituents of concrete depends on the quality and economy of the particular concrete required.

2.8.1. Workability of Concrete

Workability is the measure of how easy or difficult it is to place, consolidate and finish concrete. It contains in it different aspects like consistency, flow-ability, mobility, compact-ability, finish-ability, and harshness. This property of concrete is affected by a number of factors like: water content of the mix, mix proportions, aggregate properties, time, temperature, characteristics of the cement and admixtures.

Water content is the most important factor affecting the workability of concrete. Increasing the amount of water will increase the workability of the concrete. However the increase in water content of the mix will decrease the strength and also result in segregation and bleeding.

The amount of aggregate, the proportion of coarse and fine aggregate and the shape and texture of the aggregate particles affect the workability of concrete. Keeping the water content and cement content constant increasing the amount of aggregate reduces the workability of concrete. Spherical and smooth aggregate result in a more workable mix, whereas flat, elongated and rough aggregate particles will result in reduction of workability.

The cement content and cement replacing materials also affect the workability. Higher cement content reduces workability. The effect of cement replacing materials depends on their nature. Finer materials result in reduction of workability while spherical materials increase workability.

Workability is generally a relative property in which a concrete workable under one condition might not be workable under the other. To date there is unfortunately no direct method to measure the workability and consistency of fresh concrete, however there are approximate methods such as slump test ASTM C143-10, flow test ASTM C124-39 and compaction factor test BS 1881-103 and ACI 211.3-75 [6,13,17].

2.8.2. Strength of Concrete

Strength of concrete is commonly considered its most valuable property, although in many practical cases other characteristics, such as durability and permeability, may in fact be more important. Nevertheless, strength usually gives an overall picture of the quality of concrete because it is directly related to the structure of the hardened cement paste [6].

The strength of concrete is dependent on many things. The hydration reaction, water to Cement ratio, aggregate type, amount and size, water content, cement content, curing condition, cement type, compaction method used etc. have an effect on the strength of concrete.

Strength at any W/C ratio depends on the degree of hydration of the cement and its physical and chemical properties. The decrease in the water content of the concrete results in a higher strength of the concrete. The water required for the hydration reaction is less than that of the mixing water; the extra water provided is used to make the concrete more workable.

The compaction of the fresh concrete reduces the amount of entrapped air and therefore increases the strength of the concrete. It is found that for each 1 % of air entrapped there will be a 5 to 6 % loss on strength. Curing temperature affects the hydration of cement and hence the duration of strength gains [6, 17]. Different pozzolanic materials have different effect on strength. But most of them have been found to improve the strength of concrete especially at latter days due to the secondary reaction.

2.8.3. Permeability of Concrete

Permeability is the movement of fluids across a porous medium as a result of pressure gradient. Thus concrete permeability refers to its ability to transmit fluids through it caused by pressure head; it applies to the transport of both gases and liquids.

The w/c (or w/cm) ratio of concrete has major influence on the permeability of concrete. As the w/c ratio decreases the porosity of the paste decrease and the concrete becomes more impermeable. This variation of permeability with w/c ratio is largely due to large capillary porosity rather than gel pores.

Most pozzolanic materials were found to decrease the permeability of concrete due to the pozzolanic reaction and their higher fineness. The pozzolanic reaction consumes the free lime in the concrete and the higher fineness of the pozzolans fills pores in the concrete both resulting in a lower permeability.

Many test methods have been developed to measure the resistance of concrete to the movement or penetration of fluids (such as water, oxygen or carbon dioxide) or aggressive species (such as chlorides or sulfates). Some of these tests involve the measure of fluid flow in response to a hydraulic pressure gradient or moisture gradient, or they involve the measure of ionic movement in response to a concentration gradient, whereas other tests measure another property, such as electrical conductivity or resistivity, and relate this parameter to penetration resistance. Regardless of the test method applied, it is generally considered that the durability of concrete will be improved with its ability to resist the movement of fluids and ionic species [4, 6].

The impermeability of concrete can be determined in the laboratory by applying water under controlled pressure to the surface of concrete and measuring the penetration of water in to the specimen called water permeability test. As water represents the most important liquid among those penetrating through concrete, improvement in impermeability of concrete to water implies improvement in durability of concrete [4].

2.9. Literature Summary and Gap Identification

Stone processing for different applications yields by product materials. Among this marble dust and granite powder from marble and granite rock cutting and polishing industries and crusher dust produced during coarse aggregate production are commonly found by-products.

Crusher by-product is a material passing 4.75mm sieve which amounts up to 25% of the total crushed rock depending on the crushed rock type and type of crusher used. Crusher by-product contains 15% to 25% crusher dust passing 150µm sieve which makes it difficult to be used as manufactured sand. The annual crusher dust production of Ethiopia is not estimated. However, the estimation of annual crusher dust production driven from available aggregate production records indicates that an average of 125,000m^3 of crusher dust due to coarse aggregate production for governmental construction projects and 31,000m^3 of crusher dust due to coarse aggregate production for Addis Ababa housing projects.

Research conducted on the use of crusher dust as a partial cement replacement material shows the effect of crusher dust on different properties of cement and concrete and also initiates different effective replacement ranges. Sairam Kumar N., et al. in India in 2013 shows that cement can be replaced with 25% of quarry dust (crusher dust which accounts 25% of final product) in concrete without excessive loss in compressive strength of concrete. El-Didamony H., et al. in Egypt in 2015 revealed that water of consistency of blended cements increases and setting time was slightly elongated with increase in basalt powder content. Additionally the study shows that replacing OPC with 20% basalt powder can improve the strength of cement and can be used as filled-pozzolanic material. Literatures on the related subjects shows that chemical and physical properties of cement such as chemical composition, loss on ignition, fineness, consistency, setting time and strength of cement could be altered due to basaltic crusher dust replacement. Moreover, using filler materials or natural Pozzolanas as a partial cement replacement material in concrete production, has been found to show different effects on fresh and hardened properties of concrete; essentially on workability, compressive strength and water permeability of concrete.

The reviewed researches conducted in different countries uses different types of crusher dust provided with extra processing such as grinding to increase fineness and removing impurities to get pure pulverized rock powder; and shows different results and percentage replacement limits. This is because of the difference in physical properties of crusher dust and chemical composition of parent rocks used for aggregate production.

Even so there is immense amount of crusher dust production there is no literatures or studies exist to explain the effect of replacing basaltic crusher dust partially with OPC or PPC on the properties of cement and concrete which is conducted in Ethiopia. Based on these gaps, the current study is designed to identify the chemical composition of raw basaltic crusher dusts; to observe the effects on the properties of basaltic crusher dust blended cement and to study the workability, compressive strength and water permeability of concretes made with basaltic crusher dust blended cements.

CHAPTER THREE

MATERIALS USED FOR THE RESEARCH

3.1. Introduction

In this section materials used for the experimental study are described alongside to their physical and chemical properties. Laboratory investigations on the Properties of fine and coarse aggregates, specific gravities of crusher dust and cement pastes, mortars and concretes are conducted in Addis Ababa University, Civil Engineering Department, construction materials laboratory; whereas the test for fineness of cement and crusher dust is carried out in Addis Ababa University Chemical Engineering laboratory; and test for the chemical properties of the Crusher dust are conducted in Ethiopian Geological Survey, Center of Ethiopia Geoscience Laboratory.

3.2. Materials used for the research

3.2.1. Basaltic Crusher Dust

Throughout the experiment, crusher dusts produced from aggregate production plants found in Addis Ababa city were used. Since there are more than three hundred aggregate production plants available in the city and the crusher dust produced from each different quarries could be different in its chemical composition, clay content and fineness based on the type of rock to be crushed, the location of crushing site and the type of crusher used. It is tried to select the sample crusher dust by considering the geological map of the city and the population of production plants with in the capable areas.

The geological map of Addis Ababa and study done by Abebe Dinku (2005)[8] indicates that most commonly found aggregate rock in and around Addis Ababa, Ethiopia area are basalt, trachyte, and ignimbrite. According to preliminary observation and information gained from construction companies it is indicated that most of the aggregate production plants and their quarries found in Bole Bulbula and Akaki kality areas following Akaki River [18]. Since basaltic rock is the most widely available and used rock type for aggregate production in Ethiopia, Basaltic Crusher Dust from basalt aggregate crushing plant were selected.

From the preliminary overview conducted, it is tried to understand that dust produced in different arrangements of crusher plant and crushing process used results in different clay contents.

Crushing plants installed beside rock quarries or directly feed from the quarry (without need of trucks for material transportation) are susceptible for high clay and organic content because there is no or poor scalping process performed to remove clay lumps and other impurities. On the hand crusher plant installed in a distance that needs trucks for transportation of rocks involves the process of scalping to separate rocks from organic matters and clay lumps for the ease of transport, in this case the crusher dust produced have been found to be relatively pure rock powder (basalt powder). Hence Two samples of Basaltic Crusher Dusts, namely Basaltic Crusher Dust containing 0% clay (pure basalt powder) and 20% clay relatively, were selected based on the location of crusher plant in order to consider the effects of partial replacements on properties of OPC and PPC cement and C-25 and C-30 concretes.

I. Summary of basaltic crusher dust samples selection

- In Addis Ababa there are more than three hundred coarse aggregate production sites which commonly produce basaltic crushed stone aggregate.
- Most of the aggregate production sites are found in Akaki kality sub city with more than 180 quarry owners and a total quarry area of 5,136,443.91 m^2 [18].
- The quality of rock scalping process implemented by each of aggregate production sites prior to crushing operation determines the impurity of basaltic crusher dust basically in terms of clay content.
- The best and the worst case in scalping of rock before crushing operation were considered.
    - ✓ Best case – Basaltic rock crushing sites which adopts a very good scalping process to remove impurities such as organic matters (tree roots, leafs, etc.), clay lumps and other soft rocks (such as sand stone) before feeding the rock to primary crusher. This crusher sites are mostly located in some distance from the quarry and they need to transport the quarried rock from quarry to crushing site. (Appendix I-1)
    - ✓ Worst case – Basaltic rock crushing sites which doesn't implement scalping process to remove impurities such as organic matters (tree roots, leafs, etc.), clay lumps and other soft rocks (such as sand stone). This crusher sites are mostly located in or near the quarry in which they have no need to transport quarried rock rather uses loaders to feed the crushers directly from the quarry. (Appendix I-2)

II. Collecting Sample Basaltic crusher dusts

Basaltic Crusher dust produced in Addis Ababa is not separated by dry or wet screening unless the separation of dust by natural wind. This means that dust is blended with crusher by-product (traditionally called "zero zero" or "fino") which can potentially be used as manufactured sand. Crusher by-product contains 15% to 25% basaltic crusher dust as it was investigated through performing sieve analysis for ten basalt crushing sites (Appendix A). So in this research the by-product were sieved by traditional sieve having approximately 0.6mm (600µm) opening at the crusher sites for the ease of transport and the dust were separated by sieving through 0.15mm (150µm) sieve at Addis Ababa University Construction Materials Laboratory and used to prepare blended cements.

III. Tests done on Basaltic crusher dust samples

For the ease of mix codding and description of mix codes in result analysis and discussion section the samples are nominated as BCD1 and BCD2. BCD1 is a basaltic crusher dust sample from Akaki Kality area containing 20% clay and specific gravity of 2.58 and BCD2 is basaltic crusher dust with 0% clay and specific gravity of 2.81 from Akaki Kality area. Since there is no direct method to test the clay content either in Ethiopian geological survey or in any of Addis Ababa university laboratories indirect method ASTM D854 have been used to determine the clay content of crusher dust sample. The indirect method used for determination of clay content is by determining the specific gravity of clay from the quarry area and the pure basalt powder and blending those materials in different percentages until it reaches the specific gravity of BCD1. The results of all tests conducted on basaltic crusher dust are summarized under Table 3-1.

Table 3- 1 Summary of test results on basaltic crusher dust

<table>
<tr><th>No</th><th colspan="2">Test description</th><th>BCD1</th><th>BCD2</th></tr>
<tr><td>1</td><td colspan="2">Clay content</td><td>20%</td><td>0%</td></tr>
<tr><td rowspan="2">2</td><td rowspan="2">Unit weight(kg/m³)</td><td>Loose unit weight</td><td>1425.40</td><td>1504.86</td></tr>
<tr><td>Compacted unit weight</td><td>1513.63</td><td>1598.05</td></tr>
<tr><td>3</td><td colspan="2">Bulk Specific gravity</td><td>2.58</td><td>2.81</td></tr>
</table>

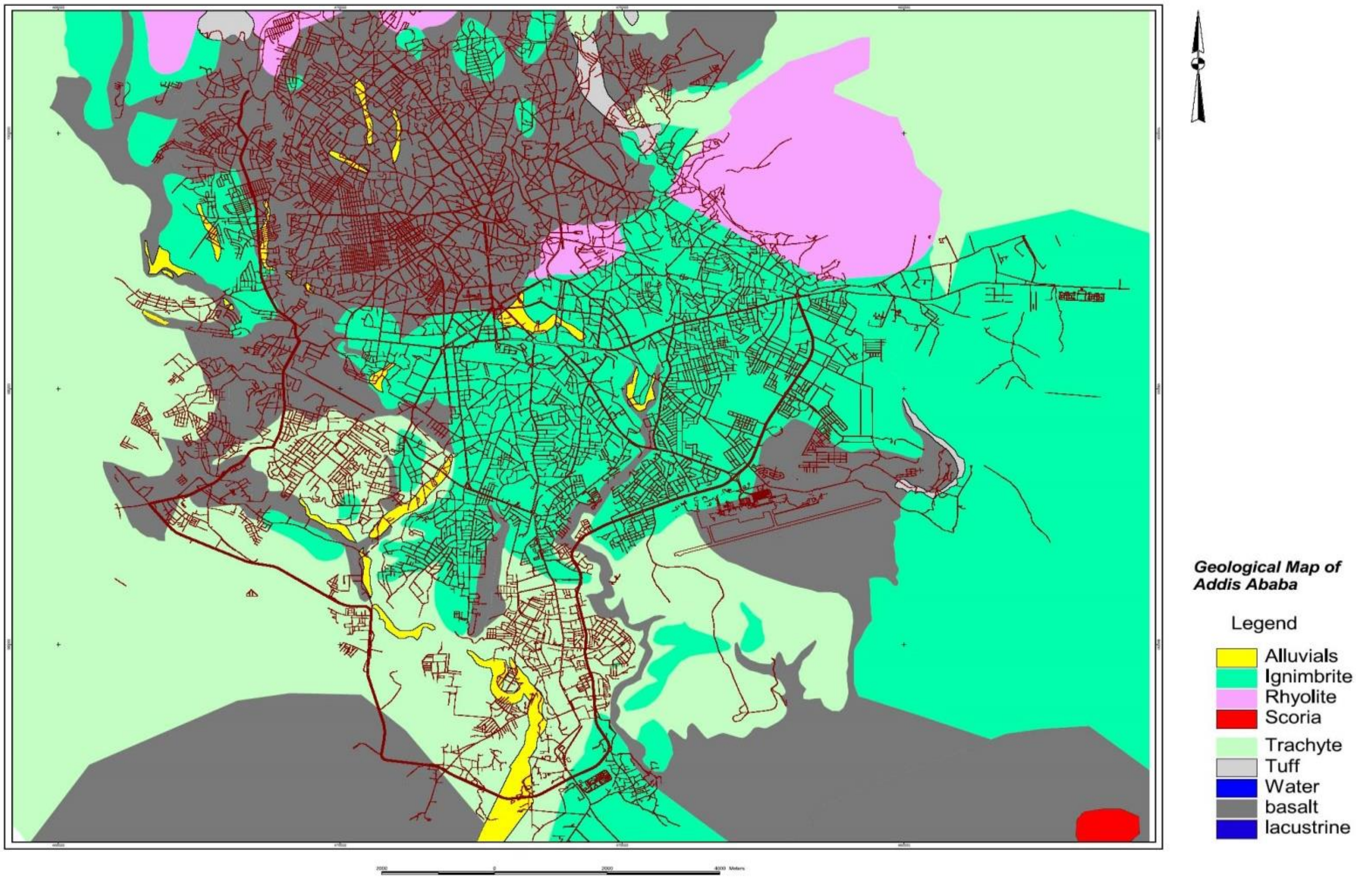


Figure 3-1 Geological map of Addis Ababa [19]

Figure 3-2 Crusher Dust Samples (BCD1 and BCD2)

The fineness of BCD1 and BCD2 were measured in Addis Ababa University Chemical Engineering Laboratory by using Blain air permeability meter according to the test procedure recommended by ASTM C 204 and procedures of laboratory manual. The result indicates that BCD1 has a fineness of 3030.45 cm^2/g and BCD2 has a fineness of 2874.17 cm^2/g (Appendix B)

The chemical compositions (complete silicate analysis) of the two samples were determined in Ethiopian Geological Survey Geoscience Laboratory and it is shown in Table 3.2.

Table 3- 2 Chemical composition of BCD1 and BCD2

Chemical Oxides		CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
Oxides composition (%)	**BCD1**	4.89	55.27	15.9	7.71	2.38	5.78	2.28	0.4	0.74	0.62	2.09	2.06
	BCD2	8.26	51.22	16.92	8.22	4.44	5.98	1.6	0.3	0.52	0.72	1.15	1.5

3.2.2. Cement

While studying the effects of basaltic crusher dust on the properties of cement and concrete, Mugher OPC 42.5 and PPC 32.5 were used for all mortar and concrete specimens casted for the experimental study. Mugher 42.5 OPC and 32.5 PPC are manufactured to satisfy Ethiopian standard CES 28-2013 and European standard EN-197-1-2000. Typical chemical and mineralogical compositions and specific gravities of both cement types are shown under Tables 3-3 and 3-4.

Table 3- 3 Contents of PPC and specific gravities of OPC and PPC [20]

Mean of Pozzolana included in PPC (%)	Mean gypsum content in cement (%)	Pozzolana type	Cement type produced	Specific gravity
28.3	4 - 5	Pumice	OPC	3.15
			PPC	2.91

Table 3- 4 Chemical composition of Mugher OPC and Pozzolana used to produce PPC [20]

Chemical Composition	Mean Chemical Oxides of OPC (%)	Mean Chemical Oxides of Pozzolana (%)
CaO	63.38	4.04
SlO_2	21.36	64.58
Al_2O_3	4.89	2.27
Fe_2O_3	3.92	0.97
MgO	1.27	15.17
SO_3	2.54	-
LOI	-	-

The fineness of Mugher OPC and PPC cements were measured in Addis Ababa University Chemical Engineering Laboratory by using Blain air permeability meter according to the test procedure recommended by ASTM C 204 and procedures of laboratory manual [21]. The result indicates that Mugher OPC 42.5 has a fineness of 4006.78 cm^2/g and Mugher PPC 32.5 has a fineness of 3820.32 cm^2/g (Appendix B).

3.2.3. Standard Sand

The sand used in the study to determine the strength of cement was from Ziway area which is washed until all the silt was removed and clear water came out. This sand is used because of standard Ottawa or other standard sands were not available in the market unless cement companies imported such sand for their laboratories. So this relatively good quality sand was used for the study by satisfying the grading requirement of ASTM C 778 as shown in Table 3-5.

Table 3- 5 Standard sand gradation [22]

Sieve size (mm)	**ASTM C 778 Specification (% passing)**	**Prepared sand (% retained)**
1.18	100	0
0.6	96-100	4
0.425	65-75	31
0.3	20-30	45
0.15	0-4	20

Figure 3-3 Sand prepared and used for determination of cement strength

3.2.4. Aggregates

Throughout the experiment, river sand as a fine aggregate and basaltic crushed stone as a coarse aggregate which are available from local market were used, by studying their properties based on ASTM standards.

3.2.4.1. Fine Aggregate

Among the available Natural River sands in local market the sand produced from Meki area was believed to have a good quality and selected to be used as a fine aggregate throughout this experimental study. The properties of this sand such as silt content, gradation, unit weight, specific gravity, moisture content and absorption capacity are performed and corrective measures are taken in order to satisfy ASTM and Ethiopian standards for fine aggregate.

Test for silt content of sand was conducted as per ASTM standard to determine materials finer than No.200 sieve. The silt content of sand was 9.67% which is above the recommendation of ASTM and Ethiopian standards that specifies the maximum silt content of sand to be 5 and 6%. So to use this sand for this experimental study the silt content was reduced by washing the sand using metal cart as a washing basin and to 4.16%.

Sieve analysis is performed to determine the grain size distribution and to calculate fineness modulus of the selected sand after the silt content was reduced this test is performed according to ASTM C163. The fineness modulus of used sand was calculated as 2.93 which is between 2.25 to 3.25 (specified fineness modulus range for graded sand according to ASTM). The gradation table and curve are shown under Table 3-6 and Figure 3-4.

Table 3- 6 Fine Aggregate gradation

Sieve size (mm)	Cumulative Retained (%)	Cumulative Passing (%)	(ES C.D3.201) Specification
9.5	0	100	100
4.75	1.4	98.6	95-100
2.36	14.3	85.7	80-100
1.18	45	55	50-85
0.6	52.3	47.7	25-60
0.3	84.6	15.4	10-30
0.15	95.2	4.8	2-10
pan	100	0	

$$Fineness\ modulus = \frac{\sum commulative\ retained\ (\%)}{100} = \frac{292.8}{100} = 2.928 \approx 2.93$$

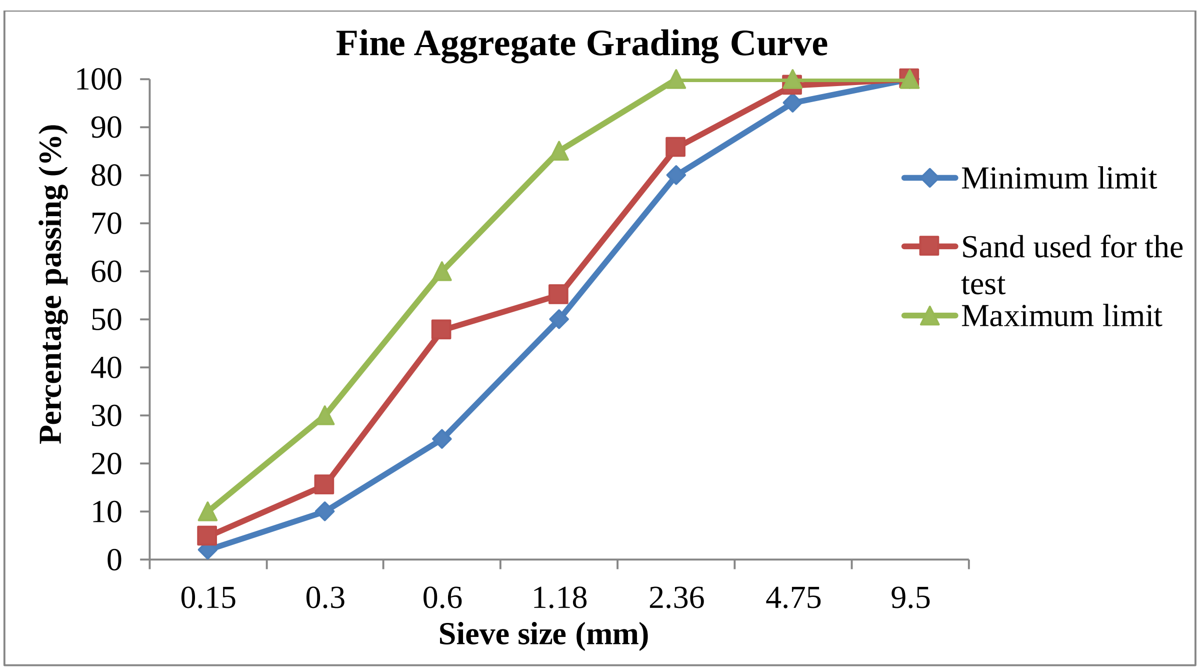


Figure 3-4 Fine aggregate gradation curves

Generally Specific gravity can be defined as ratio between the weight of the aggregate and that of the same volume of water. It is an expression of the density of an aggregate which depends on whether the pores available in aggregates are included in the measurement or not. Specific gravity of aggregate can be measured as bulk or apparent. Apparent specific gravity of an aggregate refers to the solid materials excluding the pores and bulk specific gravity refers to total volume i.e. including pores of the aggregate. Absorption capacity of fine aggregate was also determined simultaneously with specific gravity determination according to ASTM C 127 test method.

Unit weight effectively measures the volume that the graded aggregate will occupy in concrete and includes both the solid aggregate particles and the voids between them. The test were conducted is as per ASTM C29 test method.

Moisture content test determines the moisture available in the aggregate. Since the moisture available with in the aggregate can affect water cement ratio which determines workability, strength and permeability of concrete moisture content of aggregates should be measured to assist adjustments in water cement ratio during mix design. Table 3-7 shows summary of test results on fine aggregate.

Table 3- 7 Summary of test results on fine aggregate properties

<table>
<tr><th>No</th><th colspan="2">Test Description</th><th>Test results</th></tr>
<tr><td>1</td><td colspan="2">Silt content (%)</td><td>4.16</td></tr>
<tr><td rowspan="2">2</td><td rowspan="2">Unit weight kg/m^3</td><td>Loose unit weight</td><td>1408.52</td></tr>
<tr><td>Compacted unit weight</td><td>1596.78</td></tr>
<tr><td>3</td><td colspan="2">Moisture content (%)</td><td>2.46</td></tr>
<tr><td rowspan="3">4</td><td rowspan="3">Specific gravity</td><td>Bulk Specific gravity</td><td>2.45</td></tr>
<tr><td>Bulk Specific gravity(SSD)</td><td>2.58</td></tr>
<tr><td>Apparent Specific gravity</td><td>2.88</td></tr>
<tr><td>5</td><td colspan="2">Absorption capacity (%)</td><td>6.73</td></tr>
</table>

3.2.4.2. Coarse Aggregate

Crushed basaltic rock is used as coarse aggregate in this research work. Basaltic aggregate traditionally called 02 and 01 was purchased from local market and blended until it satisfies the grading requirements of coarse aggregate. Since the aggregate contains clayey dust it was washed so that such materials are removed. A maximum aggregate size of 19 mm was used in all the concrete work. The gradation of coarse aggregate used for the study is summarized under Table 3-8 and Figure 3-5.

Table 3- 8 Coarse Aggregate gradation

Sieve size (mm)	Cumulative Retained (%)	Cumulative Passing (%)	(ES C. D3. 201) Specification (%)
37.5	0	100	1
19	3.6	96.4	95-100
9.5	54.85	45.15	25-55
4.75	99.05	0.95	0-10
pan	100		

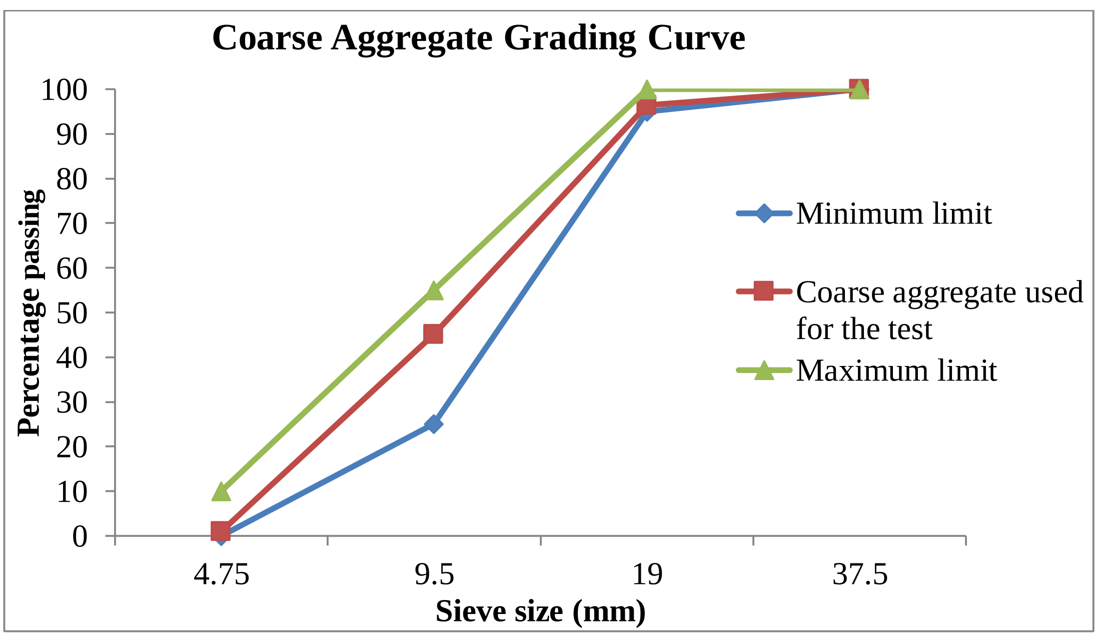


Figure 3-5 Coarse aggregate gradation curves

The coarse aggregate grading curve shown in Figure 3.5 was made to satisfy the specification of Ethiopian standard by continuous blending of 02 aggregate (maximum size of 20mm) with 01 aggregate (maximum size of 10mm aggregate).

As unit weight, moisture content, specific gravity and absorption capacity affect the type and quality of concrete and as such parameters are essential for mix designing, these parameters were determined for coarse aggregate According to ASTM C29, ASTM C127 and ASTM C128 test method. The results of the tests are summarized under Table 3-9.

Table 3- 9 Summary of test results on coarse aggregate properties

No	Test Description		Test results
1	Maximum size(mm)		**19.00**
2	Unit weight kg/m^3	Loose unit weight	**1477.60**
		Compacted unit weight	**1657.08**
3	Moisture content (%)		**1.06**
4	Specific gravity	Bulk Specific gravity	**2.79**
		Bulk Specific gravity(SSD)	**2.84**
		Apparent Specific gravity	**2.95**
5	Absorption capacity (%)		**1.95**

3.2.5. Mixing and Curing Water

Throughout the laboratory investigation, tap water supplied for drinking consumption at Addis Ababa Institute of Technology Construction Materials Laboratory was used for paste, mortar and concrete mixing and curing.

3.2.6. Environmental issues

To identify the environmental issues related to using basaltic crusher dust as a partial cement replacement material, visual observations and photographs collected from different aggregate crushing sites found in and around the study area were used.

CHAPTER FOUR
EXPERIMENTAL PROGRAM

4.1. Introduction

The main objective of the test program is to study the feasibility of using the selected basaltic crusher dusts as a partial cement replacing material in concrete production. These include studying properties of paste, and concrete by replacing part of Portland cement with Basaltic Crusher Dust powder in 0%, 5%, 10%, 15% and 20%. All the testes made in the research are summarized in Table 4-1.

Two sets of tests were conducted in order to achieve the objectives of the research. The first set of experiment includes; testing chemical composition of basaltic crusher dust; fineness of cement and crusher dust, normal consistency, setting time and compressive strength of blended paste. The second sets of experiment were made on concretes with 25MPa and 30MPa specified compressive strength which are produced using 42.5 OPC, 32.5 PPC and Basaltic Crusher Dust blended cements. These tests are used to investigate the effect of Basaltic Crusher Dust on the performance of concrete such as workability, compressive strength and permeability.

Table 4- 1 Summary of tests to be conducted

Sets of Experiment	Tests to be Conducted
Experiment 1	Chemical composition, specific gravity and clay content of basaltic crusher dusts
	Fineness of Cements and basaltic crusher dusts
	Consistency of cement pastes
	Setting time of cement pastes
	Compressive strength of hardened cement mortars
Experiment 2	Mix design and Trial mix preparation for concretes with 25MPa and 30MPa specified compressive strength made by OPC and PPC cement replaced partially with 0, 5, 10, 15 and 20% BCD1 and BCD2
	Slump tests for workability of fresh concretes
	Compressive strength of concretes on 3, 7 and 28 days cured 150mm concrete cubes
	Water Permeability of concrete on 28 days cured 150mm concrete cubes

4.2. Experiment I

4.2.1. Chemical Composition, Specific Gravity and Clay Content of Crusher Dust

The samples collected from two different basalt aggregate crushing sites around Akaki kality area were tested in Ethiopian geological survey geoscience laboratory for their chemical compositions (complete silicate analysis). Since the differences between the two samples were their clay content and specific gravity, it was tried to determine the specific gravity and clay contents indirectly using ASTM D 854 standard test method for specific gravity of soils.

4.2.2. Fineness

The fineness of crusher dust and cement were determined by the blain air permeability (ASTM C 204) method in AAIT Chemical Laboratory. The blain air method of determining the specific surface area is based on the relationship between the surface area of the particles in a porous bed and the rate of fluid flow through the bed. It is expressed as total surface area in square centimeters per gram, or square meters per kilogram, of cement.

4.2.3. Consistency of Cement

According to ASTM C 595 recommendation normal consistency for both hydraulic cements and blended cement were done using ASTM C 187 test method. This test was done to determine the effect of partial replacement of cement with basaltic crusher dust on water requirement of blended cement for a constant consistency of cement paste [21]. The test was done for the control mix and for all blended cements with 5%, 10%, 15% and 20% cement replacement by codding each of the samples as shown in Table 4-2 and 4-3.

Table 4- 2 Labels of test samples for OPC/BCD1 and PPC/BCD1 pastes

Crusher dust Sample 1							
		Proportion by weight (%)				**Proportion by weight (%)**	
S. No.	**Code**	**C.D1**	**Cement (OPC)**	**S. No.**	**Code**	**C.D1**	**Cement (PPC)**
1	OPC	0	100	6	PPC	0	100
2	O-1(5%)	5	95	7	P-1(5%)	5	95
3	O-1(10%)	10	90	8	P-1(10%)	10	90
4	O-1(15%)	15	85	9	P-1(15%)	15	85
5	O-1(20%)	20	80	10	P-1(20%)	20	80

Table 4- 3 Labels of test samples for OPC/BCD2 and PPC/BCD2 pastes

Crusher dust Sample 2							
		Proportion by weight (%)				**Proportion by weight (%)**	
S. No.	**Code**	**C.D2**	**Cement (OPC)**	**S. No.**	**Code**	**C.D2**	**Cement (PPC)**
11	O-2(5%)	5	95	15	P-2(5%)	5	95
12	O-2(10%)	10	90	16	P-2(10%)	10	90
13	O-2(15%)	15	85	17	P-2(15%)	15	85
14	O-2(20%)	20	80	18	P-2(20%)	20	80

In all blended mixes in this research replacement by weight of cement and crusher dust is applied, i.e. 1kg of crusher dust replaces 1kg of crusher dust.

4.2.4. Setting Time

In this study ASTM C 191 method of measuring initial and final setting time were used for both type of hydraulic cement (OPC and PPC) and blended cement in each replacement percentages. In this method initial and final setting time were determined by a means of vicat needle. The codding of samples were the same as that of consistency test as shown in Table 4.2 and 4.3.

4.2.5. Compressive Strength of Hardened Cement Mortars

In this study different mortar mixes were prepared with different percentage of crusher dust replacing the cement. Two types of cements OPC and PPC were used with BCD1 and BCD2 replacing 5- 20% in 5% range. The mix proportion and tests were performed according to ASTM C109 Standard Test Method for Compressive Strength of Hydraulic Cement Mortars Using 50mm Cube Specimens. The mix proportions used to prepare mortar specimens are described in the Table 4.4 and Table 4.5.

Table 4- 4 Mix Proportion of OPC/BCD1 and PPC/BCD1

Mix code	Cement (gm)	Crusher dust (BCD1) (gm)	Water (gm)	Sand (gm)	W/C	W/(C+CM)	(C+CM)/ Sand
OPC	500	0	242	1375	0.484	0.484	2.750
O-1(5%)	475	25	242	1375	0.509	0.484	2.750
O-1(10%)	450	50	242	1375	0.538	0.484	2.750
O-1(15%)	425	75	242	1375	0.569	0.484	2.750
O-1(20%)	400	100	242	1375	0.605	0.484	2.750
PPC	500	0	242	1375	0.484	0.484	2.750
P-1(5%)	475	25	242	1375	0.509	0.484	2.750
P-1(10%)	450	50	242	1375	0.538	0.484	2.750
P-1(15%)	425	75	242	1375	0.569	0.484	2.750
P-1(20%)	400	100	242	1375	0.605	0.484	2.750

Table 4- 5 Mix Proportion of OPC/BCD2 and PPC/BCD2

Mix code	Cement (gm)	Crusher dust (BCD2) (gm)	Water (gm)	Sand (gm)	W/C	W/(C+CM)	(C+CM)/ Sand
OPC	500	0	242	1375	0.484	0.484	2.750
O-2(5%)	475	25	242	1375	0.509	0.484	2.750
O-2(10%)	450	50	242	1375	0.538	0.484	2.750
O-2(15%)	425	75	242	1375	0.569	0.484	2.750
O-2(20%)	400	100	242	1375	0.605	0.484	2.750
PPC	500	0	242	1375	0.484	0.484	2.750
P-2(5%)	475	25	242	1375	0.509	0.484	2.750
P-2(10%)	450	50	242	1375	0.538	0.484	2.750
P-2(15%)	425	75	242	1375	0.569	0.484	2.750
P-2(20%)	400	100	242	1375	0.605	0.484	2.750

Where:-

OPC- control mix with 100% OPC

O-1(5%)- OPC with 5% BCD1 replacement

O-1(10%)- OPC with 10% BCD1 replacement

O-1(15%)- OPC with 15% BCD1 replacement

O-1(20%)- OPC with 20% BCD1 replacement

PPC- control mix with 100% PPC

P-1(5%)- PPC with 5% BCD1 replacement

P-1(10%)- PPC with 10% BCD1 replacement

P-1(15%)- PPC with 15% BCD1 replacement

P-1(20%)- PPC with 20% BCD1 replacement

O-2(5%)- OPC with 5% BCD2 replacement	P-2(5%)- PPC with 5% BCD2 replacement
O-2(10%)- OPC with 10% BCD2 replacement	P-2(10%)- PPC with 10% BCD2 replacement
O-2(15%)- OPC with 15% BCD2 replacement	P-2(15%)- PPC with 15% BCD2 replacement
O-2(20%)- OPC with 20% BCD2 replacement	P-2(20%)- PPC with 20% BCD2 replacement

The mixing procedure followed to prepare each mix were first weighing each materials and dry mixing until blended color have been achieved, then adding the prepared mixing water and mixing it for about 5 minutes, filling the mortar in to 50mm cubic molds which are painted with releaser oil and vibrating for about 2 minutes in a small table vibrator and finally finishing the surface and covering it with towel in order to keep it’s moisture. A total of one hundred eight 50mm size mortar cubes were prepared to be tested after 3, 7 and 28 curing days.

4.3. Experiment II

This set of experiments consists of determination of mix designing, concrete specimens preparation and tests of fresh and hardened concrete. It was designed to determine the effects of replacing part of cement with crusher dust on performance of concrete.

4.3.1. Mix Design and Trial Mix Preparation

Concrete mix designs were prepared according to ACI 211.1 Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete for both C-25 and C-30 concretes[23].

Before a concrete mixture were proportioned, mixture characteristics were selected based on the intended use of concrete, the exposure conditions, the size and shape of building elements, and the physical properties of the concrete required for the intended purposes.

In this research there are four control mixes and thirty two test mixes. First mix proportions were prepared for the control mixes C-25 OPC mix, C-25 PPC mix, C-30 OPC mix and C-30 PPC mix and designated as 25MPa-O, 25MPa-P, 30MPa-O and 30MPa-P for the simplicity during result analysis and discussion. The mix designs were done by defining a slump between 75 to 100mm according to ACI 211.1and required compressive strength of 33.5MPa and 38.5MPa according to ACI 301 specification for structural concrete [24]. The proportion of trial control mixes and their test results are shown in the following Table 4.6.

Table 4- 6 Mix proportions and slump results for trial mixes

No	Mix Codes	Cement (kg)	Crusher dust (kg)	Coarse aggregate (kg)	Fine aggregate (kg)	Water (kg)	W/(C+CM)	Slump (mm)
1	25MPa-O	14.1	0	35.95	24.02	8.22	0.49	85
2	25MPa-P	14.1	0	35.95	24.02	8.22	0.49	95
3	30MPa-O	15.58	0	35.87	22.5	8.17	0.44	75
4	30MPa-P	15.58	0	35.87	22.5	8.17	0.44	90

According to the result obtained from the trial mix the slumps and 3 day compressive strength of the control mixes were within the acceptable limit. So the other test mixes were prepared according to the control mix by replacing each crusher dust samples from 5% to 20% in 5% range. The proportions of all concrete mixes are shown on Appendix D.

4.3.2. Workability of Concrete

In order to assess the effects of replacement on workability of the fresh concrete, slump test were conducted for each of concrete mixes using slump cone. The tests were conducted according to ASTM C 143. Mix codes for each of concrete mixes are shown in Table 4.7 and 4.8.

4.3.3. Compressive strength of concrete

The compressive strength test of concrete is the most common test type for the hardened concrete. The reasons for these are; many codes and design manuals are based on compressive strength of concrete and other properties are dependent on compressive strength.

The mix designs are prepared according to ACI 211.1 which recommends 300mm x 150mm cylindrical molds for compressive strength testing, but in this research 150x150x150mm cube samples were used for compressive strength testing because of reliability of cylindrical molds (the cylindrical molds available in Addis Ababa University construction materials laboratory are deformed in a way that could have impact during compressive strength test) and the higher quantity of concrete needed if cylindrical mold is used.

In this study more than three hundred twenty four 150mm x 150mm x150m size cube samples were prepared for C-25 and C-30 concrete made with OPC, PPC and crusher dust blended cements for testing compressive strength after 3, 7 and 28 curing days. In order to compare the results with the specifications of ACI 209 and ACI 301; the results were changed from cube strength to cylindrical strength by using conversion factor recommended by EBCS 2 [25].

The compressive strength of each of the concrete was determined by testing the cubes in a compression machine. For each of the mixes the average values of two samples were taken as their three days compressive strength result and average of three samples as seven and twenty eight days compressive strength. The mix codes and descriptions are shown in Table 4.7 and 4.8.

Table 4- 7 Mix codes description for C-25 concrete

No.	Mix codes	Cement (%)	Crusher dust (%)	Test days	Total samples	Remark
1	25MPa-O	100	0	3, 7 & 28	9	C 25 control mix with OPC
2	25MPa-O-1(5%)	95	5	"	9	C 25 using OPC & BCD1 (C-25 OPC/BCD1 concretes)
3	25MPa-O-1(10%)	90	10	"	9	
4	25MPa-O-1(15%)	85	15	"	9	
5	25MPa-O-1(20%)	80	20	"	9	
6	25MPa-O-2(5%)	95	5	"	9	C 25 using OPC & BCD 2 (C-25 OPC/BCD2 concretes)
7	25MPa-O-2(10%)	90	10	"	9	
8	25MPa-O-2(15%)	85	15	"	9	
9	25MPa-O-2(20%)	80	20	"	9	
10	25MPa-P	100	0	3, 7 & 28	9	C 25 control mix with PPC
11	25MPa-P-1(5%)	95	5	"	9	C 25 using PPC & BCD1(C-25 PPC/BCD1 concretes)
12	25MPa-P-1(10%)	90	10	"	9	
13	25MPa-P-1(15%)	85	15	"	9	
14	25MPa-P-1(20%)	80	20	"	9	
15	25MPa-P-2(5%)	95	5	"	9	C 25 using PPC & BCD2(C-25 PPC/BCD2 concretes)
16	25MPa-P-2(10%)	90	10	"	9	
17	25MPa-P-2(15%)	85	15	"	9	
18	25MPa-P-2(20%)	80	20	"	9	

Table 4- 8 Mix codes description for C-30 concrete

No	Mix codes	Cement (%)	Crusher dust (%)	Test days	Total samples	Remark
19	30MPa-O	100	0	3, 7 & 28	9	C 30 control mix with OPC
20	30MPa-O-1(5%)	95	5	"	9	C 30 using OPC & BCD1(C-30 OPC/BCD1 concretes)
21	30MPa-O-1(10%)	90	10	"	9	
22	30MPa-O-1(15%)	85	15	"	9	
23	30MPa-O-1(20%)	80	20	"	9	
24	30MPa-O-2(5%)	95	5	"	9	C 30 using OPC & BCD2(C-30 OPC/BCD2 concretes)
25	30MPa-O-2(10%)	90	10	"	9	
26	30MPa-O-2(15%)	85	15	"	9	
27	30MPa-O-2(20%)	80	20	"	9	
28	30MPa-P	100	0	3, 7 & 28	9	C 30 control mix with PPC
29	30MPa-P-1(5%)	95	5	"	9	C 30 using PPC & BCD1(C-30 PPC/BCD1 concretes)
30	30MPa-P-1(10%)	90	10	"	9	
31	30MPa-P-1(15%)	85	15	"	9	
32	30MPa-P-1(20%)	80	20	"	9	
33	30MPa-P-2(5%)	95	5	"	9	C 30 using PPC & BCD2(C-30 PPC/BCD2 concretes)
34	30MPa-P-2(10%)	90	10	"	9	
35	30MPa-P-2(15%)	85	15	"	9	
36	30MPa-P-2(20%)	80	20	"	9	

All Cubes were casted for determination of compressive strength and water permeability of concretes. After 24 hours the molds were de-molded and subjected to water curing for 3, 7 and 28 days. Before testing, the cubes were air dried for 2 hours. Crushing loads were noted and average compressive strength of specimens is determined at 3days, 7 days and 28 days.

4.3.4. Water Permeability of Concrete

For assessing performance changes related to durability due to the replacement of crusher dust in different percentage in concrete production, non-steady water permeability were conducted on concrete of 150mm x 150mm x 150mm cubes. The non-steady state permeability was selected because of the large number of sample involved in the study and the long duration required in conducting steady state water permeability test. Due to problem encountered on the permeability testing apparatus and time constraint only single sample were tested for C-25 mix categories. Thus three samples of different kind were tested simultaneously. According to the above restrictions the test were conducted for 18 cube samples.

Non steady state water permeability of concrete test was carried out at 28 days cured 150mm concrete cubes. The steps followed for conducting water permeability test are shown as follows.

- The concrete cube samples are dried in oven for 24 hours, in order to save the time needed to dry the concrete samples naturally.
- The test samples were assembled in the Permeability apparatus and 3 bar (0.3 MPa) pressure was applied for the first 24 hours. (Figure shown in Appendix I-14)
- Then 5 bar (0.5MPa) water pressure were applied for the next 24 hours and
- The water pressure was increased to 7 bar (0.7 MPa) for the third 24 hours to be total of 72 hours under water pressure.
- At the end of the 72 hours period, the concrete cubes were removed from the permeability rig and split in to two.
- Using visual examination, the portion of the specimen into which water has penetrated appears darker than the rest, so this zone was marked and measurements were taken by dividing the width of the sample in to 10 sections and the average water penetration depth were calculated for each sample. Additionally the maximum water penetration depth of samples was recorded. (Figure shown in Appendix I-15)

CHAPTER FIVE
TEST RESULTS AND DISCUSSIONS

5.1. Introduction

In this chapter test results are described with the help of tables and graphs and discussed briefly by comparing results with each other and with standard specifications and related research works. The tests were performed in two sets of experiments (section 4.2. and 4.3) and discussed here orderly as a single unit.

5.2. Chemical Composition

The chemical analysis of crusher dust samples were carried out in order to identify their chemical properties such as oxide composition, lose on ignition, alkali content and moisture content of the samples. The chemical compositions of BCD1 and BCD2 are shown in Table 3.2 of chapter three and Appendix J.

5.2.1. Major oxide composition

The result of major oxides composition resembles the chemical composition of basalt rock with relatively higher SiO_2 and lower Fe_2O_3 contents. The oxide composition shows that SiO_2 content of BCD1 is 55.27% and that of BCD2 is 51.22% which is lower than the SiO_2 content of Pozzolana used in production of Mugher PPC.

$SiO_2 + Al_2O_3 + Fe_2O_3 = 55.27 + 15.9 + 7.71 = 78.88\%$ for BCD1
$SiO_2 + Al_2O_3 + Fe_2O_3 = 51.22 + 16.92 + 8.22 = 76.36\%$ for BCD2

The $SiO_2 + Al_2O_3 + Fe_2O_3$ content of BCD1 is 78.9% and that of BCD2 is 76.36% which is greater than the $SiO_2 + Al_2O_3 + Fe_2O_3$ content of Pozzolana used for production of Mugher PPC. ASTM C618 (Standard specification for coal fly ash and row or calcined natural Pozzolana for use as a mineral admixture in concrete) recommends that materials to be classified as Class N Pozzolana $SiO_2 + Al_2O_3 + Fe_2O_3$ content should be greater than 70% [26]. Considering this specification, BCD1 and BCD2 can satisfy the requirement and can be classified as row Class N Pozzolana based on their chemical composition. The test result for major oxides compositions are shown in Appendix J.

5.2.2. Moisture and Alkali Content

Alkali contained within natural Pozzolanas could lead to alkali silica reactions which are potentially harmful only when they produce significant expansion and hence cracking of concrete, leading to loss of strength. To control formation of such reactions ASTM C 618 specifies the maximum content of alkalis in terms of equivalent Na_2O % to be 1.5% [26]. Equivalent Na_2O content of natural Pozzolana is calculated according to ASTM C 311.

Equivalent Na_2O, % = Na_2O, % + 0.658 x K_2O, % [27]……..[Eq. 5.1]

In this study the Na_2O and K_2O content of BCD1 are 5.78% and 2.28% and that of BCD2 are 5.98% and 1.6%. From the results equivalent Na_2O was calculated to be 7.2% for BCD1 and 7.03% for BCD2. The results show that both samples have more alkali content than specified by ASTM C 618. According to Neville A.M. Higher alkalis K_2O and Na_2O could increase the early strength development and reduce the long term strength.

Equivalent Na_2O, % for BCD1 = 5.78% + 0.658 x 2.28 % = **7.2%**

Equivalent Na_2O, % for BCD2 = 5.98 % + 0.658 x 1.6 % = **7.03%**

Moisture content of natural Pozzolana is specified by ASTM C 618 to be Maximum 3% by mass of natural Pozzolanas. In this study the moisture content of BCD1 and BCD2 was tested and found to be 2.08% and 1.15% which are less than the maximum specified content.

5.2.3. Lose on Ignition

The loss on ignition (LOI) of BCD1 and BCD2 were conducted to show the amount of carbon in the sample and hydration of free lime and free magnesia due to the atmosphere exposure, if it has binding properties by itself. The maximum LOI of cement at 1000^{o}C permitted by ASTM C150 is and 3%, while for pozzolanic material, the recommended maximum content for class N pozzolans is 10%. In this study the LOI for BCD1 and BCD2 obtained was 2.06% and 1.5% respectively as shown in Table 3.2 of third chapter. Thus, BCD1 and BCD2 satisfy the requirement of ASTM C 618; however it was visible that LOI of BCD1 was higher than LOI of BCD2. The reason for this could be the clay content of BCD1 which accounts 20% by mass of the total basaltic crusher dust.

5.3. Fineness and Specific Gravity of Cement and Crusher Dust

Basaltic crusher dust samples taken from crushing sites by sieving through traditional sieve (about 600µm size) were sieved through 150 µm sieve to be used as cement replacement material. Then the fineness of BCD1 and BCD2 were tested by Blaine air permeability apparatus according to ASTM C204. BCD1 was found to have Blaine fineness of 3030.45cm^2/gm and BCD2 appears to have blain fineness of 2874.17cm^2/gm.

Fineness by air permeability test was also done for Mugher OPC and PPC and found to be 4006.78cm^2/gm and 3820.32cm^2/gm. This finding clearly shows that both crusher dust samples are coarser than both cement types, which indicates that raw Basaltic Crusher Dust passing150 µm sieve cannot be used as a filler of cement unless further processing is made to increase the fineness of Basaltic Crusher Dusts. When it is tried to compare the fineness of BCD1 and BCD2, BCD1 which contains 20 % clay is found to be 5.44% finer than BCD2 and this is probably because of the availability of clay which can be grinded finer than the parent basalt rock used for aggregate production.

The specific gravity of BCD1 and BCD2 were done according to ASTM D854 standard test method for specific gravity of soils. The result shows that BCD1 has a specific gravity of 2.58 and BCD2 has specific gravity of 2.81. The difference in specific gravities of the two samples originated from the clay content, generated due to the production process followed by the crusher plants where the samples were collected as described in research materials section of the study. Specific gravity test were also used to indicate the clay content of BCD1 indirectly by replacing clay from the same area to pure basalt powder in different percentages until it becomes approximately equal to the original specific gravity of BCD1 which is 2.58. The test results of specific gravity and fineness of cement and crusher dust are shown in Appendix B.

5.4. Normal Consistency of Portland and Blended Cements

Normal consistencies for blended cement were performed according to ASTM C187 and the results are described to the nearest 0.5mm [26] as shown in Table 5-1. Figure 5-1 shows the changes in water requirement of blended pastes through replacement percentage.

Table 5- 1 Normal consistencies of cements and blended cements

Mix codes	Water requirement %	Mix codes	Water requiremen t %	Mix codes	Water requirement %	Mix codes	Water requirement %
OPC	29.5	OPC	29.5	PPC	28.0	PPC	28.0
O-1(5%)	29.5	O-2(5%)	29.5	P-1(5%)	28.0	P-2(5%)	28.0
O-1(10%)	30.0	O-2(10%)	29.5	P-1(10%)	28.5	P-2(10%)	27.5
O-1(15%)	30.0	O-2(15%)	29.5	P-1(15%)	29.0	P-2(15%)	27.5
O-1(20%)	30.0	O-2(20%)	29.0	P-1(20%)	29.0	P-2(20%)	27.0

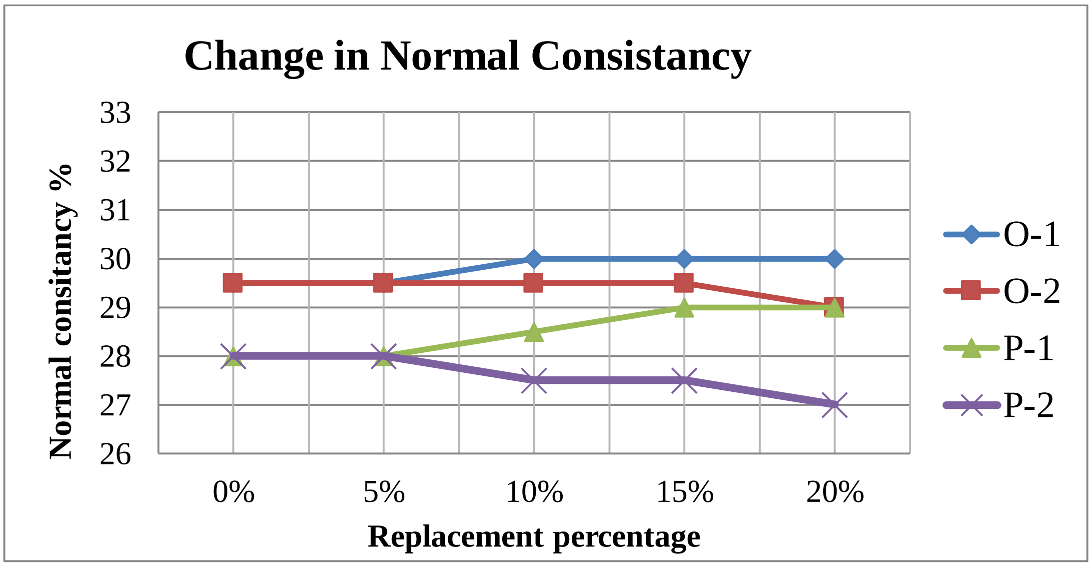


Figure 5-1 Change in Water requirement through % replacement

As shown in the graph plotted using the result of normal consistency tests one can understand that replacing crusher dust containing 20% clay (BCD1) increases the requirement of water for normal consistency from 29.5% to 30% for OPC/BCD1 and from 28% to 29% for PPC/BCD1 replacement blended cement pastes, even so BCD1 was coarser than OPC and PPC as shown previously by fineness test results. When it is tried to identify the cause of such property, it is able to found that nature of clay i.e. to take or absorb more water than the pure basalt powder or Portland cements (OPC and PPC) could be the possible reason for OPC/BCD1 and PPC/BCD1 blended cements to behave this way.

Blended OPC/BCD2 and PPC/BCD2 behave differently from the first group of blended cements as they reduce the water requirement through replacement percentages from 29.5% to 29% for OPC/BCD2 and from 28% to 27% for PPC/BCD2 replacement.

El-Diadasmony H. et al. [11] shows that water requirement of blended cement increases with increase in basalt content, on the other hand, Kartini K. et al. [12] indicates that the coarseness of Quarry dust makes the blended cement to consume more and more water with increase in quarry dust content. Even though the results of the researchers differs, the reason for their conclusions were derived from the fineness of the material used for the research, but here in this research, it is also noticed that in addition to the fineness of raw natural Pozzolanas the water of consistency could be affected by the availability of clay with in raw natural Pozzolanas.

ASTM C 618 specifies the maximum water requirement for Class N Pozzolana blended cement relative to the controls to be 115% [26]. For all replacement percentages of OPC/BCD2 and PPC/BCD2 pastes made in this study the percentage of water requirement relative to the controls were below the maximum percentage recommended by ASTM C618.

5.5. Initial and Final Setting Time

Tests for Setting time of OPC/BCD1&2 and PPC/BCD1&2 blended cements were performed according to ASTM C191 using Vicat Needle and the results are shown in Table 5-2 below and the changes in initial and final setting times of blended pastes through replacement percentage are illustrated using graphs in Figure 5.2 and 5.3.

The Ethiopian standard limits setting time for Portland Pozzolana cement (ES C.D5.202, section 4.2.4) to be 45 minutes as a minimum initial setting time and 600 minutes as a maximum final setting time respectively. ASTM C 150 limits the initial and final setting time tasted using Vicant apparatus to be 45 and 375 minutes.

Table 5- 2 Initial and final setting times

S.No	Labels of samples	Initial setting time (minute)	Final setting time (minute)
1	OPC	233	375
2	O-1(5%)	234	390
3	O-1(10%)	242	390
4	O-1(15%)	246	400
5	O-1(20%)	250	405
6	O-2(5%)	235	390
7	O-2(10%)	245	405
8	O-2(15%)	248	405
9	O-2(20%)	255	420
10	PPC	266	405
11	P-1(5%)	268	405
12	P-1(10%)	270	420
13	P-1(15%)	274	420
14	P-1(20%)	295	435
15	P-2(5%)	270	405
v16	P-2(10%)	274	420
17	P-2(15%)	295	435
18	P-2(20%)	320	480

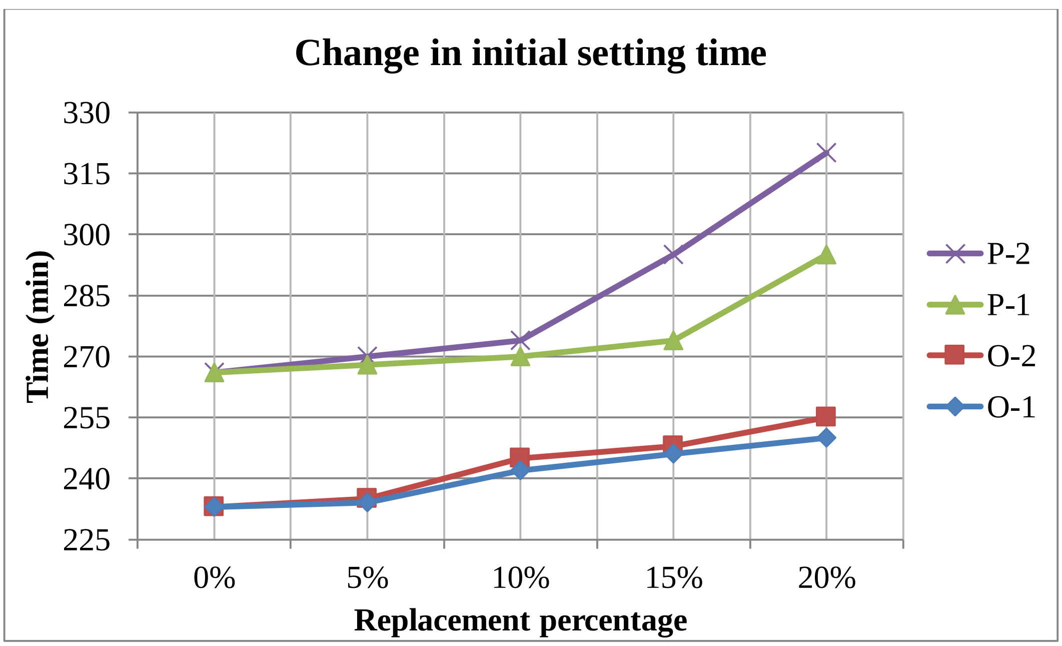


Figure 5-2 Change in initial setting time through % replacement

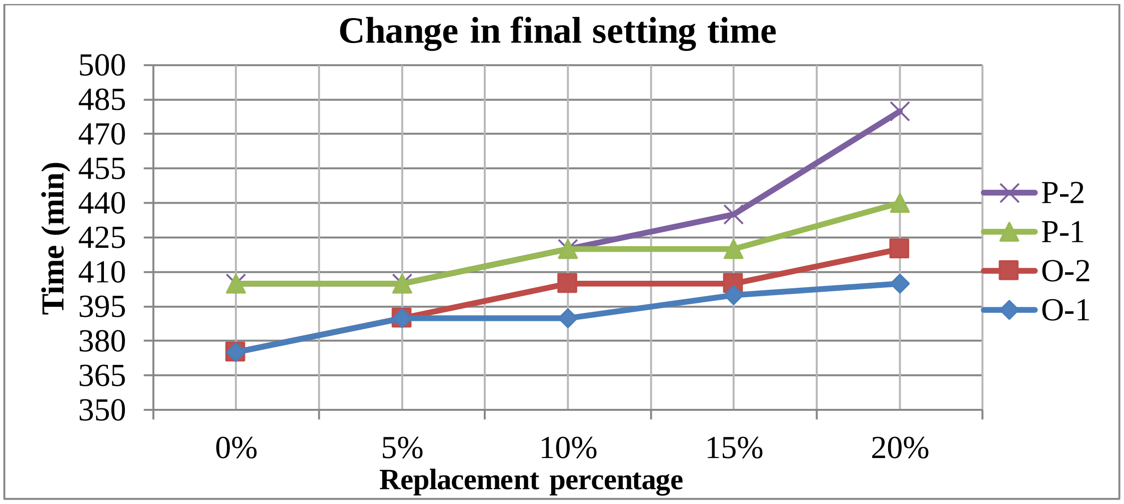


Figure 5-3 Change in final setting time through % replacement

The initial setting time of OPC/BCD1 paste increases by 17minutes which is 7.3% from the control at 20% replacement while OPC/BCD2 paste increases initial setting time by22 minutes which is 9.44% more than the initial setting time needed for the control paste. PPC/BCD1 paste shows less increase in initial setting time up to 15% replacement; beyond this the initial setting time increases by 29 minutes which is 11% more than the time needed by control paste. Whereas PPC/BCD2 paste shows less increase in initial setting time up to 10% replacement but beyond that initial setting time increases by 54 minutes which is 20% more than the time needed by the control paste.

Final setting time of OPC/BCD1 and OPC/BCD2 pastes increases 15 to 25minutes (which is 4%-8% more than the time needed for the setting of control paste) and 15 to 45minutes (4% - 12% more than the time needed for the setting of control paste) through 5% to 20% replacement, whereas PPC/BCD1 and PPC/BCD2 pastes shows an increment in final setting time up to 30 and 75 minutes (which is 7.4% and 18.5% more than the time needed by the control paste to set).

Even though, both the initial and final setting time are observed to increase with increase in replacement percentage; it is also possible observe that crusher dust containing 20 % clay increases initial and final setting time in relatively less percentage than the pure basalt powder do. This is probably because of the property of clay contained in BCD1, which is relatively soft than pulverized basalt, to lose absorbed water rapidly. Additionally the result shows that replacing crusher dust by PPC has higher effect in increasing initial and final setting times than

OPC/BCD1 and BCD2 replacements and this could be because the fact that the pozzolans contained in PPC doesn't involve in the initial hydration of cement.

Other researchers [11, 12] had also conformed to the elongation of initial and final setting time of basalt powder blended pastes. According to El-Didamony et al. the initial and final setting time of basalt filled cement pastes elongate linearly with the basalt content and it is mainly due to the low hydraulic properties of basalt as compared with Portland cement. The basalt powder does not involve in the initial hydration as Portland cement do. Therefore, as the cement content decreases the setting times are elongated, i.e., the dilution of cement with basalt leads to delaying the reaction.

The initial and final setting times of all blended cements produced in this research are within the limit specified by Ethiopian standard. Except 15% PPC/BCD2 and 20% PPC/BCD1 and BCD2 replacements all of blended cement pastes prepared in this study satisfies the requirement of ASTM C 595 (which is maximum of 420 minutes) for final setting time, whereas all pastes can satisfy the requirement of ASTM C 595 for initial setting time.

5.6. Compressive Strength of Hardened Cement Mortars

Compressive strength testing was designed to follow ASTM C109/C109M Standard Test Method for Compressive Strength of Hydraulic Cement Mortars as closely as possible under the available materials and laboratory conditions. The average compressive strength results are shown in Tables 5.3 and 5.4 and strength development graphs are demonstrated in Figure 5.4 and 5.5. All compressive strength test results, which carried out in the study are also shown under Appendix-C.

The compliance criteria for different mortar mixes used in this research was the specification of ASTM C 618, which require a minimum of 75% strength of the control to classify the replaced material as Class N Pozzolana. To compare the results with the compliance criteria, strength activity index were calculated for each mortar mixes through replacement percentages and curing dates as shown in Tables 5.3 and 5.4.

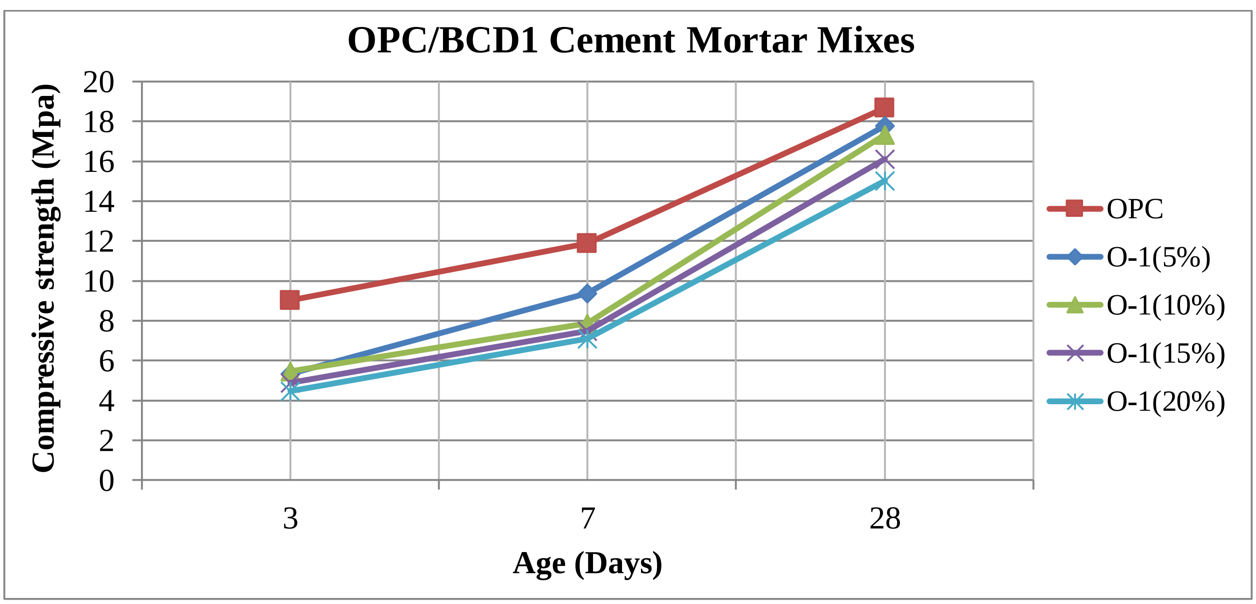
$$\text{Strength Activity Index(SAI) \%} = \frac{Strength\ of\ blended\ mortar\ (B)}{strength\ of\ control\ mortar(A)}\ x\ 100[27]$$

……… [Eq. 5.2]

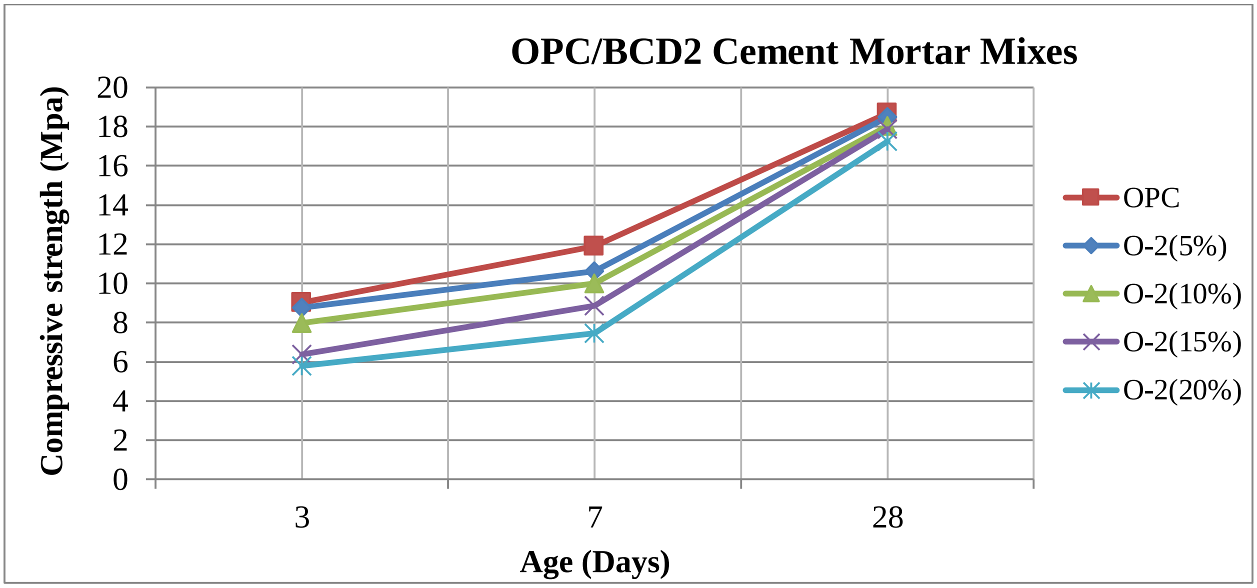
The test for compressive strength of cement mortar and strength activity index is used to determine whether a mineral admixture results in an acceptable level of strength development when used with hydraulic cement in concrete. Since the test is performed with mortar, the results may not provide a direct correlation of how the mineral admixture will contribute to strength in concrete [27]. So the compressive strength of cement mortar is used as an indicator for the pozzolanic activity of basaltic crusher dust at each replacement percentages corresponding to the specification of ASTM C618.

Table 5- 3 Average strength and strength activity index of OPC/BCD1 & BCD2 Cement Mortars

Mix code	3 days		7 days		28 days	
	Compressive strength (MPa)	Strength activity index (%)	Compressive strength (MPa)	Strength activity index (%)	Compressive strength (MPa)	Strength activity index (%)
OPC	**11.02**	**100.00**	**11.89**	**100.00**	**18.70**	**100.00**
O-1(5%)	5.32	48.28	9.38	**78.85**	17.79	**95.16**
O-1(10%)	5.48	49.73	7.89	66.32	17.35	**92.81**
O-1(15%)	4.88	44.24	7.50	63.04	16.11	**86.17**
O-1(20%)	4.47	40.52	7.09	59.63	15.04	**80.45**
O-2(5%)	8.77	**79.58**	10.64	**89.44**	18.05	**96.55**
O-2(10%)	7.98	72.37	9.99	**84.02**	18.03	**96.44**
O-2(15%)	6.38	57.85	8.86	74.52	17.88	**95.64**
O-2(20%)	5.79	52.50	7.46	62.70	17.24	**92.22**



a)



b)

Figure 5-4 Compressive strength of a) OPC/BCD1 & b) OPC/BCD2 Cement Mortars

As it can be seen in Table 5-3 and illustrations of the graphs plotted in Figure 5-4, replacing OPC with BCD1 and BCD2 affects the strength of cement in different degrees at different ages. At 3 days 5% BCD1 blended cement results in reduction of cement compressive strength by more than 50% whereas 5% and 10% BCD2 blended cements decreases 20.42% and 27.63% strength of the control OPC mix. After 7 curing days 5% BCD1 blended cement shows 21% reduction in cement strength and 5% and 10% BCD2 blended cements shows much lower strength reduction than 5% BCD1blended cement. The strength activity index (SAI) indicates 78.85% for 5% BCD1 blended cements and 89.44% and 84.02% at 5% and 10% BCD2 blended cements. After seven curing days 5% OPC/BCD1 and 10% OPC/BCD2 blended cements satisfies the 75% minimum requirement of ASTM C 618. The reason for higher amount of compressive strength loss in the early day compressive strengths of blended cement mortars could be due to the weak pozzolanic activity of basaltic crusher dust at early ages which is relatively common behavior of all types of pozzolanic or blended cements.

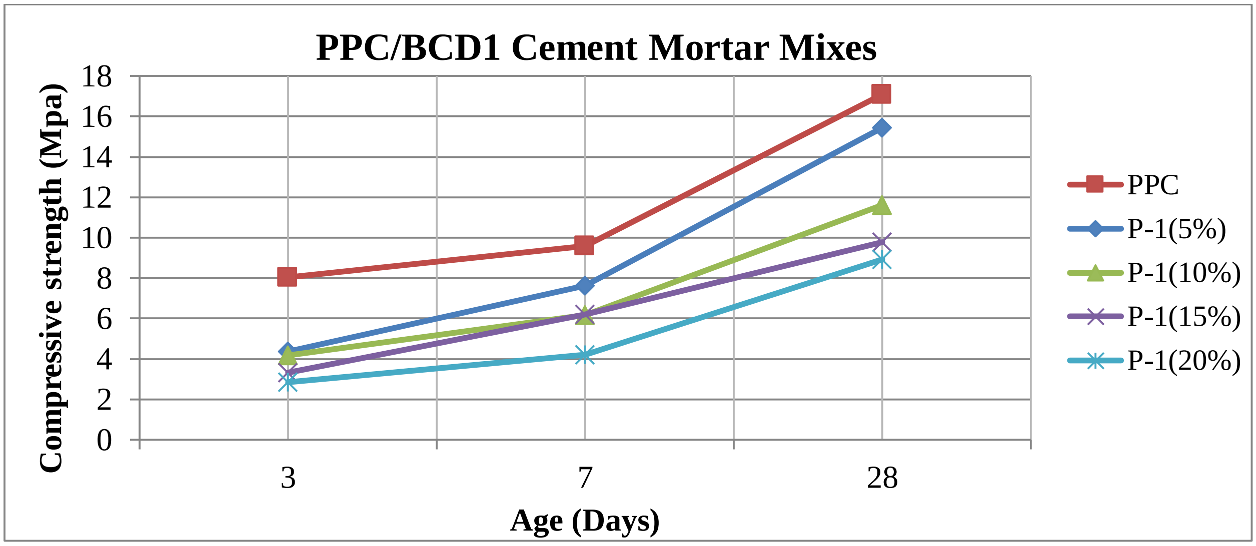
After 28 curing days 5% to 20% BCD1 and BCD2 blended cements shows 4.84% to 19.55% and 3.45% to 7.78% reduction in cement compressive strength through replacement percentages relative to the control mix, however strength activity index of both BCD1 and BCD2 blended cements satisfy the compliance criteria of ASTM C618. Blended cement made with 20% BCD1 shows excessive reduction of compressive strength than BCD2 blended cement does.

Even so, it was able to observe that compressive strength of cement decreases with increase in basaltic crusher dust content, basaltic crusher dust containing up to 20% clay can be used to replace OPC, since the 28 days compressive strength results of blended cements satisfies the requirement to be classified as natural Pozzolana. It is also distinguished that compressive strength of basaltic crusher dust blended cement decreases with an increase in clay content of basaltic crusher dust.

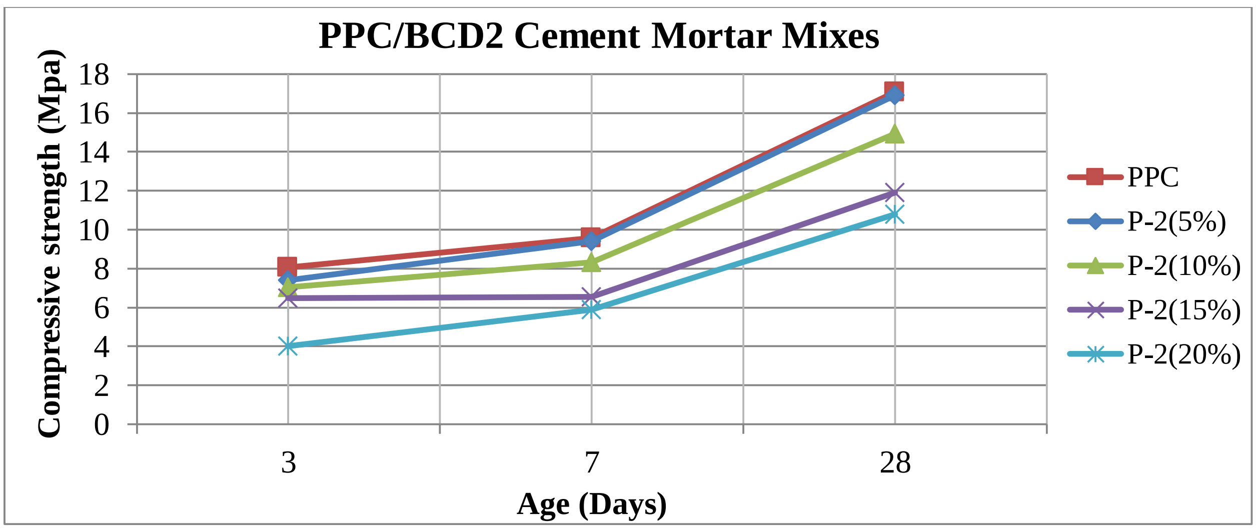
The strength activity index had shown a general pattern of increasing for most of OPC/BCD1 and OPC/BCD2 blended cements with age at 3, 7 and 28 days respectively. Such an increase in strength activity index with age can partly show the pozzolanic nature of basaltic crusher dust in ordinary Portland cement, since pozzolanic reactions are slower and dependent on the hydration of the cement.

Table 5- 4 Average strength and strength activity index of PPC/BCD1 & BCD2 Cement Mortars

Mix code	**3 days**		**7 days**		**28 days**	
	Compressive strength (MPa)	**Strength activity index (%)**	**Compressive strength (MPa)**	**Strength activity index (%)**	**Compressive strength (MPa)**	**Strength activity index (%)**
PPC	8.05	100.00	9.58	100.00	17.08	100.00
P-1(5%)	4.38	54.35	7.62	**79.49**	15.45	**90.48**
P-1(10%)	4.17	51.74	6.18	64.51	11.61	67.99
P-1(15%)	3.31	41.12	6.19	64.61	9.78	57.25
P-1(20%)	2.86	35.53	4.22	44.00	8.94	52.33
P-2(5%)	7.39	**91.80**	9.43	**98.38**	16.91	**99.03**
P-2(10%)	7.05	**87.52**	8.32	**86.85**	14.95	**87.55**
P-2(15%)	6.48	**80.43**	6.56	68.48	11.91	69.75
P-2(20%)	4.01	49.75	5.88	61.33	10.78	63.13



a)



b)

Figure 5-5 Compressive strength of a) PPC/BCD1 & b) PPC/BCD2 Cement Mortars

As it is shown in the Table 5-4 and illustrated in graphs plotted under Figure 5-5 replacing PPC with BCD1 or BCD2 affects the strength of cement in different degrees at different ages as well. At 3 days 5% - 20% BCD1 replacement results in reduction of cement strength by about 45% to 65 % through 5% replacement range, whereas BCD2 replacement decreases 9% - 20% strength of the control PPC mix at 5%, 10% and 15% replacement but at 20% PPC/BCD2 replacement higher strength loss (50%) were recorded. After 7 curing days 5% BCD1 replacement 20.5% reduction in cement strength were recorded which shows slower strength development effect of

20% clay containing basaltic crusher dust. At this test day replacing BCD1 beyond 5% results in 35% to 56% strength loss. 5% and 10% PPC/BCD2 replacement shows much lower strength reduction (1.6% and 13.15%) than PPC/BCD1blended mixes does, but at 15 and 20% replacement the strength loss increases to 31.5% and 38.7%, but still lower reduction in cement strength than PPC/BCD1 mixes behave at the same percentage replacement. The strength activity index (SAI) indicates 79.49% for 5% BCD1 replacement and 98.38% and 86.85% at 5% and 10% BCD2 replacements. Here it can be noticed that 5% PPC/BCD1 and 10% PPC/BCD2 blended mixes can satisfies the 75% minimum relative strength requirement of ASTM C 618 for Class N Pozzolana. The probable reason for the relatively higher compressive strength loss in early age could be the weak pozzolanic activity of basaltic crusher dust and the 28% by weight pozzolanic materials content of Mugher PPC at early ages which is relatively common behavior of all types of pozzolanic or blended cements.

At the age of 28 days 5% BCD1 and BCD2 blended cements shows 9.52% and 0.97% reduction in compressive strength relative to the control, which are not significant compressive strength losses since strength activity index of both blends satisfy the compliance criteria of ASTM C618. Blended cement made with 10% BCD1 shows excessive reduction of compressive strength whereas 10% BCD2 blended cement gives comparable compressive strength with strength activity index of 87.55% which is greater than 75%.

From the results discussed above it was able to understand that basaltic crusher dust containing about 20% clay (BCD1) could only replace PPC at 5% (SAI = 90.48%) with relatively higher cement compressive strength loss (21.33%) than pure basalt powder (BCD2). Whereas BCD2 can replace 10% of Portland Pozzolana cement with comparable strength activity index (87.55% > 75%) and lower strength loss (12.5%) than 5% BCD1 blended cement.

Figures 5-4 and 5-5 (a & b) indicates that the strength records of PPC/BCD1 blends were relatively more outlying from the control in all of the results of test dates, however PPC/BCD2 blends were relatively closer to the control mortars specially at 5% and 10% replacements. Even so, BCD1 was finer than BCD2 (3030.45cm2/g and 2874.17cm2/g), its strength development throughout testing days and replacement percentages were slower than that of BCD2 in both OPC and PPC replacements. Excessive reductions in Strength activity index were observed beyond 5% PPC /BCD1 and 10% PPC/BCD2 blended mixes with increasing in percentage replacement which indicates that, increasing crusher dust replacement results in excessive reduction in compressive strength of cement. This is probably because of the fact that Mugher PPC is composed of 28% Pozzolana which can undergo a secondary chemical reaction by itself.

5.7. Workability of Concrete

In this study slump were determined for each fresh concrete mixes according to ASTM C 143 standard test method for slump of hydraulic cement concrete at the end of mixing and prior to casting of concrete. The results are reported to the nearest 5mm [29] as shown in Table 5-5. The comparison of slump through replacement percentages for the two different grades of concrete are illustrated using graphs as shown in Figure 5-6 and 5-7.

Table 5- 5 Recorded slumps of C-25 and C-30 concrete

Mix codes	slump (mm)	Mix codes	slump (mm)	Mix codes	slump (mm)	Mix codes	slump (mm)
25MPa-O	85	AO	85	30MPa-O	75	30MPa-O	75
25MPa-O-1 (5%)	85	25MPa-O-2 (5%)	85	30MPa-O-1 (5%)	80	30MPa-O-2 (5%)	75
25MPa-O-1 (10%)	90	25MPa-O-2 (10%)	85	30MPa-O-1 (10%)	85	30MPa-O-2 (10%)	80
25MPa-O-1 (15%)	95	25MPa-O-2 (15%)	95	30MPa-O-1 (15%)	95	30MPa-O-2 (15%)	80
25MPa-O-1 (20%)	120	25MPa-O-2 (20%)	110	30MPa-O-1 (20%)	110	30MPa-O-2 (20%)	90
25MPa-P	95	25MPa-P	95	30MPa-P	90	30MPa-P	90
25MPa-P-1 (5%)	95	25MPa-P-2 (5%)	95	30MPa-P-1 (5%)	90	30MPa-P-2 (5%)	90
25MPa-P-1 (10%)	100	25MPa-P-2 (10%)	95	30MPa-P-1 (10%)	100	30MPa-P-2 (10%)	95
25MPa-P-1 (15%)	120	25MPa-P-2 (15%)	110	30MPa-P-1 (15%)	110	30MPa-P-2 (15%)	100
25MPa-P-1 (20%)	135	25MPa-P-2 (20%)	120	30MPa-P-1 (20%)	115	30MPa-P-2 (20%)	105

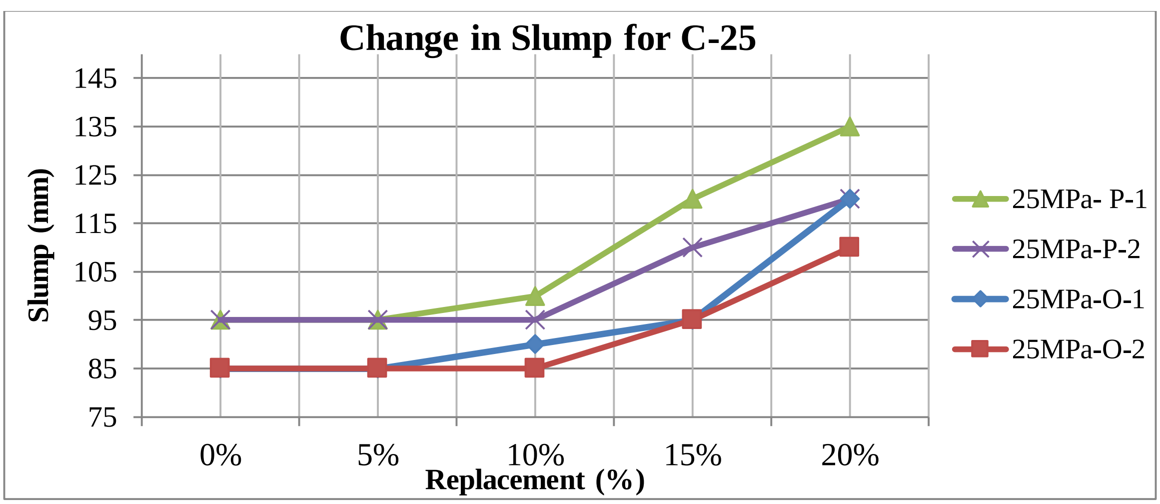


Figure 5-6 Change in slump for C-25 concretes

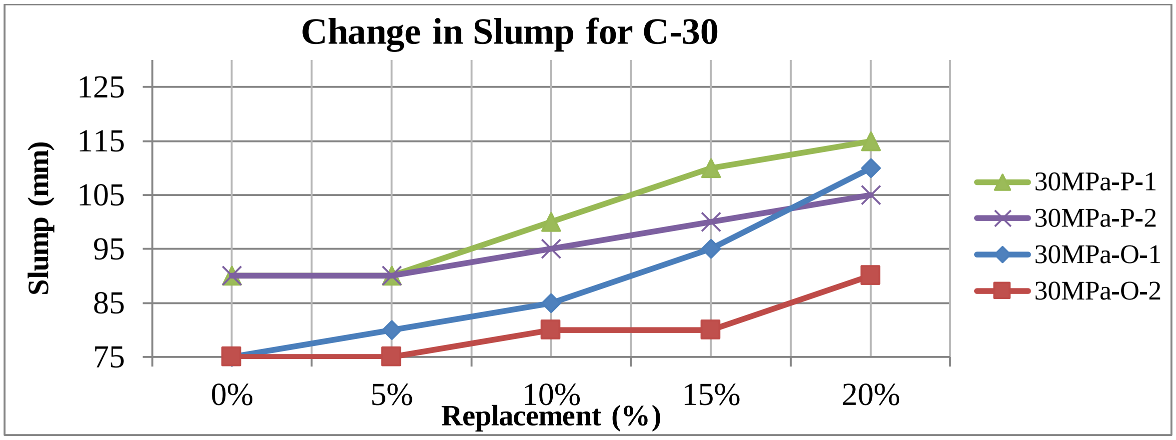


Figure 5-7 Change in slump for C-30 concretes

The results shown under Table 5-5 and Figures 5-6 and 5-7 generally illustrates that the slump of both C-25 and C-30 concretes increases with increasing percentages of both types of crusher dust used. This happens because of two different reasons the first is due to lower fineness of basaltic crusher dusts which requires less water than OPC and PPC cements which have relatively higher fineness (more surface area to absorb water) for OPC or PPC/BCD2 replacements and the second reason is for OPC or PPC/BCD1replacements might be the behavior of clay contained in BCD1 which can probably reduce the cohesion of cement paste with aggregate particles that could result a weaker bond between the interface of aggregate particles and the cement paste during the compaction for slump test.

When it is tried to see the effects separately, 25MPa-O-2 and 25MPa-O-2 (C-25, OPC & PPC/ BCD2 replacement) concretes shows a constant slump up to 10% replacement, beyond 10% the slump increases by 26% and 29% from the control mixes. 30MPa-O-2 and 30MPa-P-2 (C-30, OPC & PPC/ BCD2 replacement) concretes shows the same slump up to 5% replacement and beyond that an increase of slump up to 17% and 20% were recorded. This can indicate that, in order to get a certain slump, concretes made with OPC or PPC needs relatively higher water content than concretes made with basaltic crusher dust blended cements. The probable reason for this may be the lower specific surface area of the basaltic crusher dust, resulting in lower water demand. Additionally it is able to notice that BCD1 replacement has a tendency to increase the slump of concrete than BCD2. The possible reason for such type of tendency is that 20% clay contained within BCD1. As it is known clay is soft materials relative to basalt powder, so that, it reduces the cohesion between concrete materials and makes the concrete to slide easily.

5.8. Compressive Strength of Concrete

Tests on compressive strength of concrete were carried out after the cube samples are fully immersed in water for 3, 7 and 28 days. The mix design was prepared for C-25 and C-30 cylindrical compressive strength testing according to ACI 211.1 mix design method, but the tests were performed on 150x150x150mm cubes due to reliability and shortage of the available 300x150mm cylindrical molds.

Even if, ACI have no specifications to convert cylinder strength to cube strength or vice versa, the researches related to ACI founds a conversion factor of 1.15 to 1.25 to convert 150x150x150mm cube strength to 300x150mm cylindrical strength. Whereas, EBCS 2 recommends a conversion factor of 1.25 in order to convert 150mm cube strength to cylindrical strength [25]. All of the 150x150x150mm cube compressive strength test results obtained at 3, 7 and 28 days are reported in Appendix E. Whereas the summarized mean compressive strength results and failure load of cubic samples and converted cylindrical compressive strength results are shown in Appendix F and Appendix G. In this section mean cylindrical compressive strength results and percentages which compare loss of strength due to partial cement replacements are shown under Tables 5-6 to 5-9. Figures 5-8 and 5-9 demonstrate the relationship between compressive strength and replacement percentages for all concrete mixes.

In this study ACI 301 specification for structural concrete and ACI 209 are used as a compliance criteria to check the feasibility of using basaltic crusher dust as a partial replacement of cement in concrete production. ACI 301 states that "the strength level of concrete will be considered satisfactory when: the averages of all sets of three consecutive compressive strength test results molded and cured in accordance with the requirements of ASTM C 31M equal or exceed fc′; and no individual strength test result falls below fc′ by more than 3.5 MPa when fc′ is 35 MPa or less, or by more than 0.1times fc′ when fc′ is more than 35 MPa." [24].

$f'cm \geq f'c$ and……………………………………………………………........[Eq.5.1]

$fc_i > (f'c - 3.5)$ for $f'c \leq 35$ MPa………………………………………………..[Eq.5.2]

$fc_i > (f'c - (0.1*f'c))$ for $f'c \geq 35$ MPa……………………………………….,[Eq.5.3]

For early day strength of moist cured concrete ACI 209 gives a formula to calculate the expected compressive strength at specified dates [30].

$$f'cm(t) = f'c * \left(\frac{t}{4+0.85t}\right) \quad \text{......} \quad [Eq. 5.4]$$

Where: - f'cm(t) – Expected mean strength at specified curing date t
f'c - Specified strength

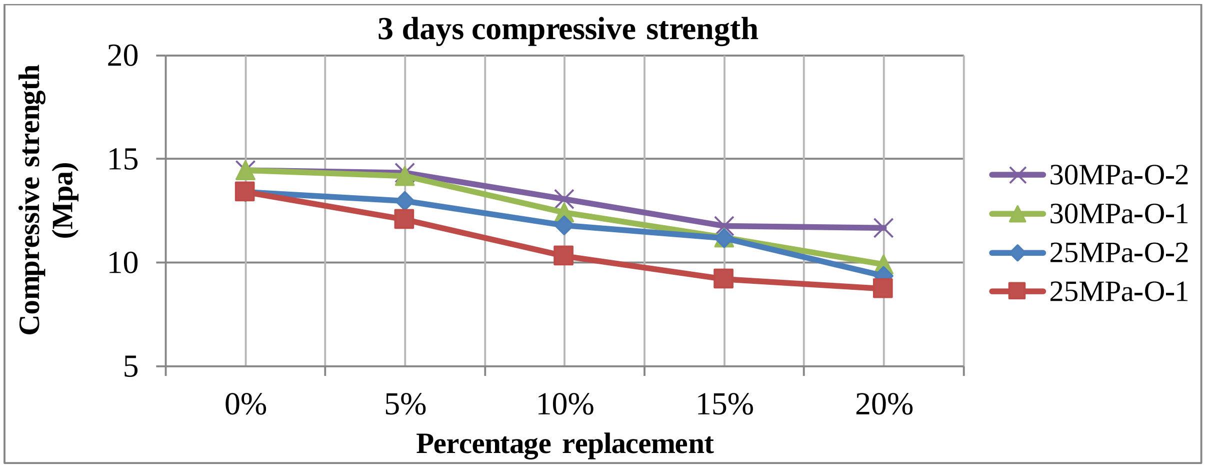
According to Eq. 5.4 C-25 concretes made for this study are expected to attain 11.45MPa after 3 days and 17.58 MPa after 7 days of curing. For C-30 concretes the expectations are 13.74MPa and 21.09 MPa after 3 and 7 days of curing.

Table 5- 6 Average cylindrical compressive strength results of C-25 OPC/BCD1 & BCD2 concretes

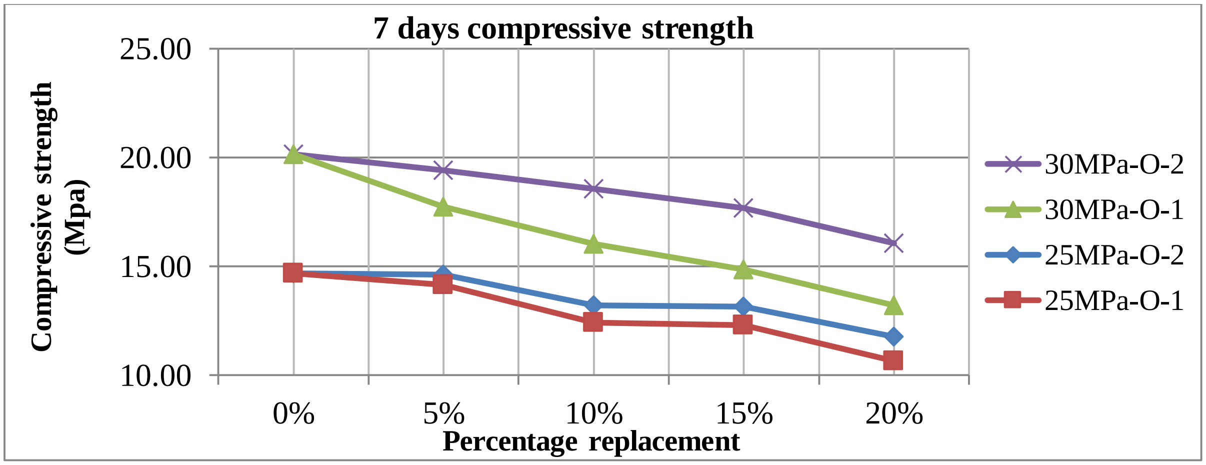
Mix code	3 days		7 days		28 days	
	Compressive strength (MPa)	**% Reduction in strength**	**Compressive strength (MPa)**	**% Reduction in strength**	**Compressive strength (MPa)**	**% Reduction in strength**
25MPa-O	**13.42**	**0.00**	**14.67**	**0.00**	**26.88**	**0.00**
25MPa-O-1(5%)	12.06	10.08	14.14	3.60	**25.50**	5.12
25MPa-O-1(10%)	10.32	23.11	12.43	15.29	23.95	10.91
25MPa-O-1(15%)	9.20	31.43	12.30	16.14	22.13	17.68
25MPa-O-1(20%)	8.72	34.97	10.65	27.44	19.17	28.70
25MPa-O-2(5%)	12.96	3.40	14.61	0.40	**26.51**	1.38
25MPa-O-2(10%)	11.81	11.99	13.22	9.87	**25.70**	4.39
25MPa-O-2(15%)	11.17	16.73	13.15	10.34	22.84	15.02
25MPa-O-2(20%)	9.37	30.17	11.77	19.81	21.23	21.02

Table 5- 7 Average cylindrical compressive strength results of C-30 OPC/BCD1 & BCD2 concretes

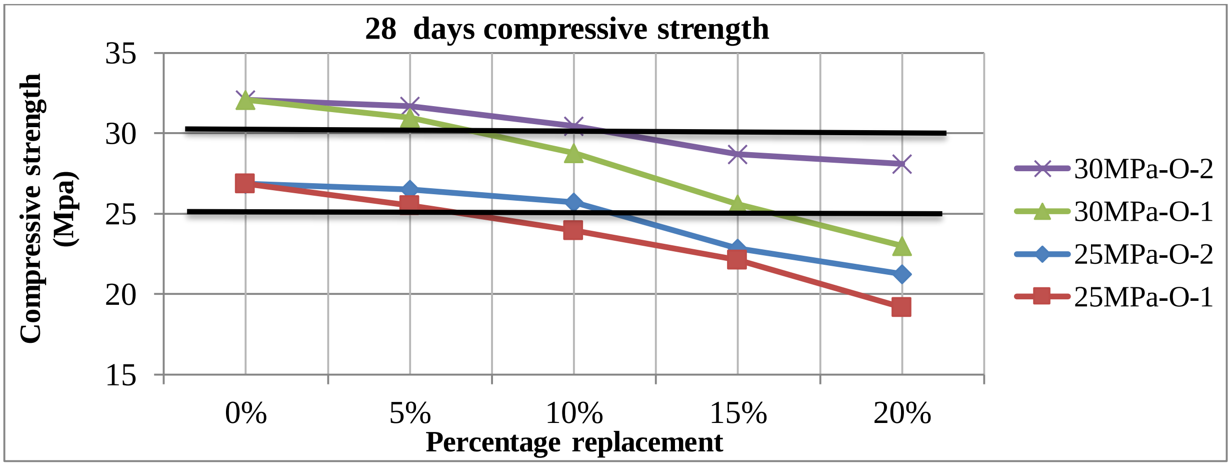
Mix code	3 days		7 days		28 days	
	Compressive strength (MPa)	**% Reduction in strength**	**Compressive strength (MPa)**	**% Reduction in strength**	**Compressive strength (MPa)**	**% Reduction in strength**
30MPa-O	**14.46**	**0.00**	**20.16**	**0.00**	**32.08**	**0.00**
30MPa-O-1(5%)	14.18	1.96	17.74	12.02	**30.98**	3.44
30MPa-O-1(10%)	12.42	14.13	16.02	20.52	28.75	10.37
30MPa-O-1(15%)	11.22	22.46	14.87	26.23	25.57	20.30
30MPa-O-1(20%)	9.92	31.42	13.21	34.50	23.02	28.25
30MPa-O-2(5%)	14.32	1.00	19.41	3.73	**31.67**	1.26
30MPa-O-2(10%)	13.07	9.62	18.57	7.90	**30.44**	5.11
30MPa-O-2(15%)	11.76	18.69	17.69	12.26	28.67	10.62
30MPa-O-2(20%)	11.67	19.30	16.06	20.32	28.09	12.43



a)



b)



c)

Figure 5-8 Effect of replacement on a) 3 days b) 7 days and c) 28 days compressive strength of C25 & C30 OPC/BCD1 & BCD2 concretes

As shown in the tables and graphs above 25MPa-O-1 concretes (C-25 OPC/BCD1) shows reduction in compressive strength between 10%-35% after 3 curing days and 3.6% to 27.4% after 7 curing days through 5% - 20% BCD1 replacement. The 28 days strength also shows reduction from 5.1% to 28.2% through replacement percentage. Only 5% BCD1 replacement satisfies compliance criteria of ACI 209 at 3 days whereas at 7 days slower strength developments were observed. At 28 days the compressive strength of concrete with 5% BCD1 replacement satisfies compliance criteria of ACI 301 by being 25.5MPa which is greater than the specified 25MPa compressive strength.

C-25 concretes made with OPC/BCD2 replacement (25MPa-O-2) shows reduction in compressive strength from 3.4% to 30.1%, 0.4% to 19.8% and 1.3% to 21% after 3, 7 and 28 curing days with corresponding percentage replacements. Concretes replaced with 5% and 10% BCD2 achieves compliance criteria of ACI 209 at 3 days while at 7 days slower strength development was observed similarly as BCD1 replaced concretes. At 28 days the compressive strength of concretes with 5% and 10% BCD2 replacement satisfies compliance criteria of ACI 301 (26.5MPa and 25.7MPa which is greater than the specified 25MPa compressive strength).

When it is tried to compare OPC/BCD1 and BCD2 replacement in C-25 concretes, it was able to understand that the early and initial strength developments of both categories were slower relative to the control mix, however, at 28 days concretes with 5% BCD1 replacement gives a positive result whereas concretes replaced with BCD2 shows better results up to 10% replacement. This can show that crusher dust can replace as high as 10% by weight of Ordinary Portland Cement, if it is free from clay (pure basalt powder in this case) with maximum of 4.4% strength loss from compressive strength of concrete made with OPC. Whereas crusher dust containing clay up to 20% by weight of basalt powder can replace cement up to 5% by weight of cement with 5.1% loss of compressive strength relative to control concrete mix.

30MPa-O-1 concretes (C-30 OPC/BCD1) shows reduction in compressive strength between 1.9%-31.4% after 3 curing days and 12% to 34.5% after 7 curing days through 5% - 20% BCD1 replacement. The 28 days strength also shows reduction from 3.4% to 28.7% through replacement percentage. Only 5% BCD1 replacement satisfies compliance criteria of ACI 209 at 3 days, but at 7 days slower strength development were observed. At 28 days the compressive strength of 5% BCD1 replacement archives the compliance criteria of ACI 301 (30.98MPa which is greater than the specified 30MPa compressive strength).

C-30 concretes made with OPC/BCD2 replacement (30MPa-O-2) shows reduction in compressive strength from 1% to 19.3%, 3.7% to 20.32% and 1.2% to 12.4% after 3, 7 and 28 curing days through replacement percentages. C-30 concretes replaced with 5% BCD2 satisfy compliance criteria of ACI 209 at 3 days whereas at 7 days slower strength development were observed and the concretes in this category doesn't satisfy ACI 209 requirement. At 28 days the compressive strength of 5% and 10% BCD2 replacement satisfies compliance criteria of ACI 301 by being 31.67MPa and 30.44MPa which are greater than the specified 30MPa compressive strength.

When it is tried to compare OPC/BCD1 and BCD2 replacement in C-30 concretes it was able to know that early and initial strength developments of both categories were also slower relative to the control mix, however at 28 days 5% BCD1 replacement gives a positive result and BCD2 replacement shows better result up to 10% replacement. This can show that crusher dust is capable to replace Ordinary Portland Cement up to 10% for C-30 concrete, if it is free from clay (pure basalt powder in this case) with maximum of 5.1% strength loss from the control C-30 concrete made with OPC. Whereas crusher dust containing clay up to 20% by weight of basalt powder can replace cement up to 5% by weight of cement with 3.4% loss of compressive strength from the control concrete.

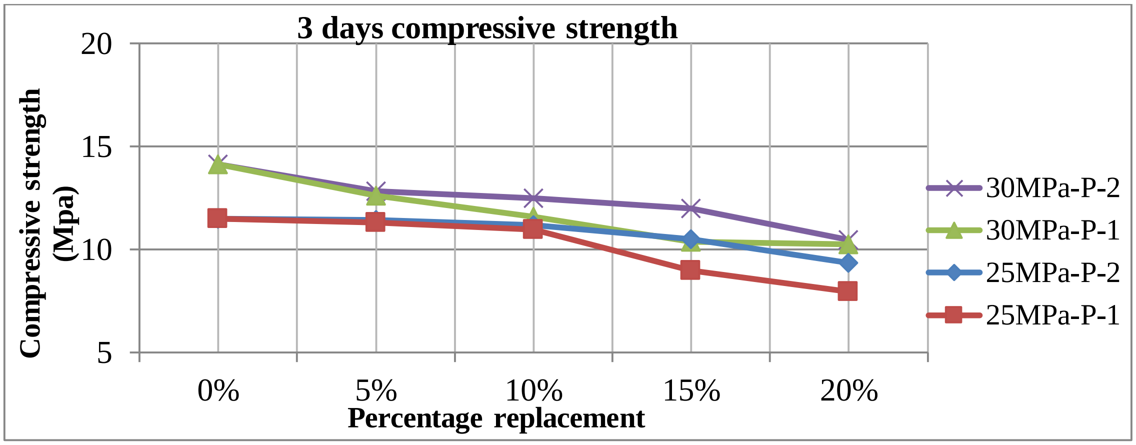
Comparison of crusher dust replacement through concrete grade generally indicates that 5% OPC/BCD1 (25MPa-O-1 and 30MPa-O-1) and 10 % for OPC/BCD2 (25MPa-O-2 and 30MPa-O-2) concretes has positive results as discussed above but higher strength loss have been observed while replacing BCD1 and BCD2 in C-30 (30MPa-O-1 and 30MPa-O-2) concretes than C-25 concretes do. Despite the irregularities of the results, it becomes noticeable that crusher dust replacement is more favorable or promising in lower grade concretes.

Table 5- 8 Average cylindrical compressive strength results of C-25 PPC/BCD1 & BCD2 concretes

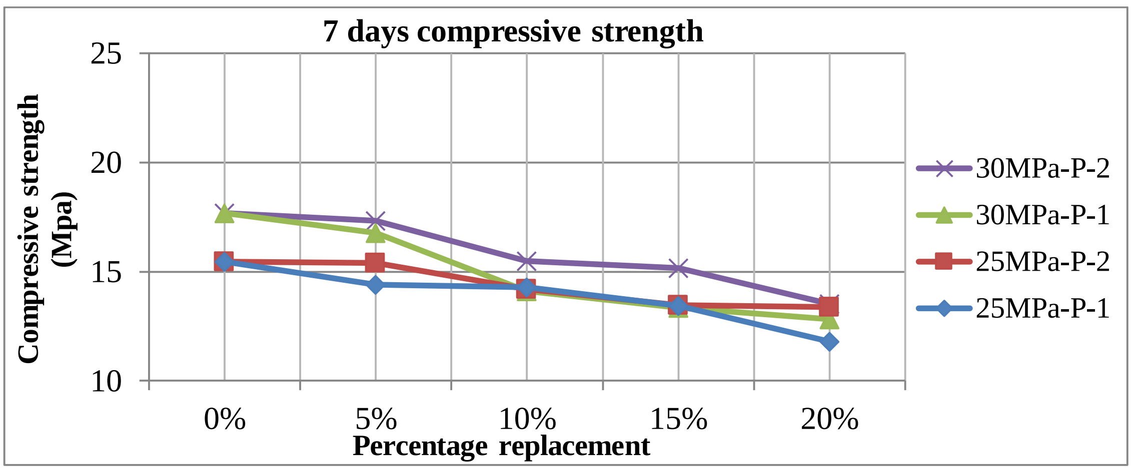
Mix code	3 days		7 days		28 days	
	Compressive strength (MPa)	**% Reduction in strength**	**Compressive strength (MPa)**	**% Reduction in strength**	**Compressive strength (MPa)**	**% Reduction in strength**
25MPa-P	**11.50**	**0.00**	**15.44**	**0.00**	**25.71**	**0.00**
25MPa-P-1(5%)	11.32	1.53	14.39	6.79	23.76	7.59
25MPa-P-1(10%)	10.96	4.66	14.30	7.41	21.31	17.11
25MPa-P-1(15%)	8.99	21.78	13.44	12.95	19.41	24.53
25MPa-P-1(20%)	7.97	30.69	11.80	23.56	17.74	30.99
25MPa-P-2(5%)	11.45	0.42	15.41	0.21	**25.46**	0.97
25MPa-P-2(10%)	11.19	2.64	14.19	8.07	23.11	10.13
25MPa-P-2(15%)	10.50	8.63	13.46	12.80	22.05	14.25
25MPa-P-2(20%)	9.36	18.55	13.37	13.42	20.79	19.12

Table 5- 9 Average cylindrical compressive strength results of C-30 PPC/BCD1 & BCD2 concretes

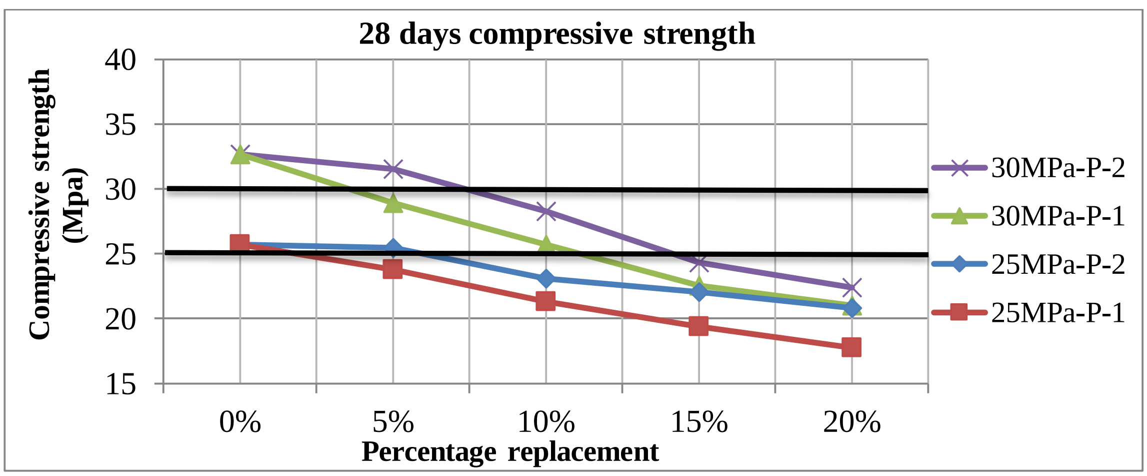
Mix code	3 days		7 days		28 days	
	Compressive strength (MPa)	**% Reduction in strength**	**Compressive strength (MPa)**	**% Reduction in strength**	**Compressive strength (MPa)**	**% Reduction in strength**
30MPa-P	**14.14**	**0.00**	**17.66**	**0.00**	**32.66**	**0.00**
30MPa-P-1(5%)	12.63	10.64	16.76	5.12	28.91	11.46
30MPa-P-1(10%)	11.58	18.05	14.10	20.18	25.69	21.34
30MPa-P-1(15%)	10.39	26.49	13.33	24.52	22.55	30.95
30MPa-P-1(20%)	10.26	27.42	12.82	27.42	21.01	35.67
30MPa-P-2(5%)	12.84	9.20	17.34	1.86	**31.54**	3.42
30MPa-P-2(10%)	12.50	11.54	15.49	12.32	28.29	13.36
30MPa-P-2(15%)	11.98	15.22	15.17	14.10	24.34	25.47
30MPa-P-2(20%)	10.46	25.98	13.53	23.40	22.38	31.48



a)



b)



c)

Figure 5-9 Effect of replacement on a) 3 days b) 7 days and c) 28 days compressive strength of C25 & C30 PPC/BCD1 & BCD2 concretes

As shown in the tables and graphs above 25MPa-P-1 concretes shows reduction in compressive strength between 1.5% to 30.6% after 3 curing days and 6.7% to 23.56% after 7 curing days through 5% to 20% BCD1 replacement. The 28 days strength also shows reduction from 7.5% to 30.9% through 5 to 20% replacement range. None of the concretes in this category satisfies compliance criteria of ACI 209 and ACI 301 at all ages. This expresses that crusher dust containing 20% clay could not be used to replace PPC cement at any percentages.

C-25 concretes made with OPC/BCD2 replacement (25MPa-P-2) shows reduction in compressive strength from 0.4% to 18.5%, 0.2% to 13.4% and 0.97% to 19.1% after 3, 7 and 28 curing days through replacement percentages. 5% PPC/BCD2 replacement satisfies compliance criteria of ACI 209 at 3 days whereas at 7 days slower strength developments were observed. At 28 days the compressive strength of 5% BCD2 replacement satisfies compliance criteria of ACI 301 (25.46MPa which is greater than the specified 25MPa compressive strength).

When it is tried to compare PPC/BCD1 and PPC/BCD2 replacement in C-25 concretes it was able to realize that the early and initial strength developments of both categories are slower relative to the control PPC mix, however at 28 days 5% BCD2 replacement gives a positive result and BCD1 replacement shows excessive loss in compressive strength. This can show that BCD2 can replace as high as 5% by weight of PPC, if it is free from clay (pure basalt powder in this case) with 0.97% strength loss from compressive strength of concrete made with PPC. Whereas crushers dust containing clay up to 20% by weight of basalt powder is proved to be ineffective in replacing PPC.

30MPa-P-1 concretes shows reduction in compressive strength between 10.6% - 27.4% after 3 curing days and 5.1% to 27.4% after 7 curing days through 5% - 20% BCD1 replacement. At 28 days higher reduction of compressive strength from 11.4% to 35.6% through replacement percentage were observed. At all test days and all replacement percentages slower strength development were observed and all the concretes in this category doesn’t satisfy ACI 209 and ACI 301 requirements. C-30 concretes made with PPC/BCD2 replacement (30MPa-P-2) shows decline in compressive strength from 9.2% to 25.9%, 1.8% to 23.4% and 3.4% to 31.4% after 3, 7 and 28 curing days through replacement percentages. At 3 and 7 day’s slower strength development were observed so that concretes in this category doesn’t satisfy ACI 209 requirement. At 28 days the compressive strength of concrete with 5% BCD2 replacement satisfies compliance criteria of ACI 301 (31.54 MPa which is greater than the specified 30MPa compressive strength).This shows that strength development of concretes replaced with 5% BCD2 were increased with time i.e.at this replacement percentage crusher dust could have pozzolanic reaction with free lime liberated due to hydration of PPC.

When it is tried to compare PPC/BCD1 and BCD2 replacement in C-30 concretes it was able to understand that early and initial strength developments of both categories are slower relative to the control mix, however at 28 days 5% BCD2 replacement gives a positive result and BCD1 replacement shows a continuous decrease in compressive strength. This can display that crusher dust is capable of replacing up to 5% by weight of Portland Pozzolana cement, if it is free from clay (pure basalt powder in this case) with maximum of 3.4% strength loss from the control C-30 concrete made with PPC. Whereas crushers dust containing clay up to 20% by weight of basalt powder cannot be used as PPC replacement.

Generally it was found that, if the crusher dust used for cement replacement is clay free basalt powder, it will be capable of replacing 5% of PPC and 10% of OPC while producing C-25 and C-30 concretes. The reason for relatively lower PPC/BCD2 replacement is that, PPC contains 28% pozzolanic materials by itself; therefore, free lime liberated during hydration of PPC may be consumed by the pozzolans contained in PPC which are composed of more reactive silica than crusher dust basalt powder. Basaltic crusher dust containing 20% clay cannot be used to replace PPC since it results a significant loss in compressive strength of concretes due to less involvement of clay in early and late age hydration reaction. On the other hand, replacing BCD1 by 5% of OPC results inconsiderable reduction in compressive strength of concrete so that it can be considered as a feasible replacement percentage.

The probable reason for lower feasible replacement percentages could be reduction in the hydration reaction due to reducing cement content to replace it with relatively less reactive basaltic crusher dusts. The other reason could be the higher water requirement of BCD1 due to its clay content, by making the water unavailable for the hydration of the cement and by creating a weak bond between aggregate particles and cement paste. Even so OPC have no Pozzolans by itself, the effective BCD2 replacement shows only 10% by weight of OPC which is not far from PPC replacement; and this could be because of the less reactivity and coarseness of basaltic crusher dust used.

Even though pure basaltic crusher dust shows pozzolanic property up to 20% replacement by weight of OPC in hardened cement mortar compressive strength tests, the feasible replacement percentages of OPC with pure basaltic crusher dust for C-25 and C-30 concrete productions were observed to be up to 10%. This is because of that the test for compressive strength of cement mortar and strength activity index is used to determine whether a mineral admixture results in an acceptable level of strength development when used with hydraulic cement in concrete and the results may not provide a direct correlation of how the mineral admixture will contribute to strength in concrete [27]. So the feasible replacement percentages to be used in concrete production are decided based on compressive strength of concretes made with blended cements.

5.9. Water Permeability of Concrete

The maximum and average water penetration readings made on 28 days cured concrete are given in Table 5-10 and the changes in permeability through percentage replacements are demonstrated using graph as shown in Figure 5-10.

Table 5- 10 Water penetration depth for C-25 concretes

Mix code	Penetration depth(mm)	
	Maximum	**Average(mm)**
25MPa-O	14	13.5
25MPa-O-1(5%)	32	21.5
25MPa-O-1(10%)	65	41.5
25MPa-O-1(15%)	73	59
25MPa-O-1(20%)	86	70
25MPa-O-2(5%)	27	19.5
25MPa-O-2(10%)	43	35
25MPa-O-2(15%)	64	46
25MPa-O-2(20%)	71	56.5
25MPa-O	33	25.5
25MPa-P-1(5%)	64	55
25MPa-P-1(10%)	85	68
25MPa-P-1(15%)	110	99
25MPa-P-1(20%)	93	86.5
25MPa-P-2(5%)	42	33
25MPa-P-2(10%)	58	47.5
25MPa-P-2(15%)	89	62.5
25MPa-P-2(20%)	96	69

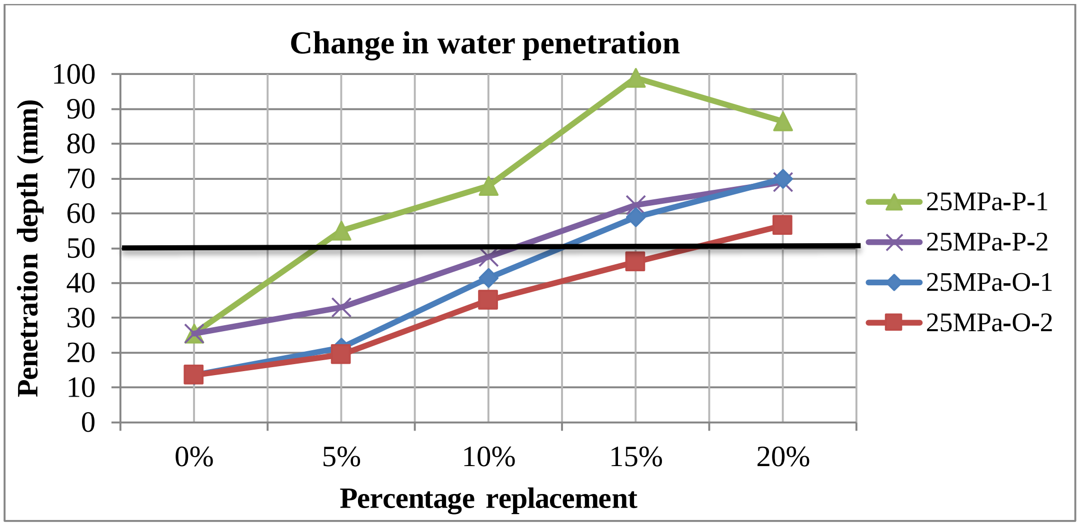


Figure 5-10 Effect of crusher dust replacement on water permeability of C-25 concrete

As shown in Figure 5-10 crusher dust replacement has been observed to have significant effect on water permeability of concrete. Increase in percentage replacement of crusher dust results in increase in water penetration depth for both types of crusher dusts and both cement types. This might be because of the relatively less pozzolanic activity of basaltic crusher dust to react with all the free lime liberated in hydration reaction due to the coarseness of the replaced basaltic crusher dusts than OPC and PPC. It was also observed that water penetration increment was higher in BCD1 replacement than BCD2 replacement for all replacement percentages and both cement types. According to Neville A.M., (1995), a depth less than 50mm classifies the concrete as impermeable; and depth less than 30mm, as impermeable under aggressive conditions [6].

CHAPTER SIX

ENVIRONMENTAL ISSUES AND FINANCIAL ANALYSIS

6.1. Introduction

Using by-products from aggregate production industry in concrete production has environmental and economic advantages for both the producers and the users of the by-product. Here the environmental issues could be discussed in to two different ways. The first attention could be the problems created by wasting the by-product and the second consideration is environmental advantages to be grown out of the effective use of crusher by-product fine. The economic advantages of using crusher dust in concrete production are also considered based on the effective replacement percentages.

6.2. Environmental Issus

The major environmental problems created due to less consumption of crusher by-product because of its high fine content (dust) are spotted from different aggregate production sites. The spotted environmental problems are discussed with the help of photographs shown under Figures 6-1 to 6-3 taken from different sites.

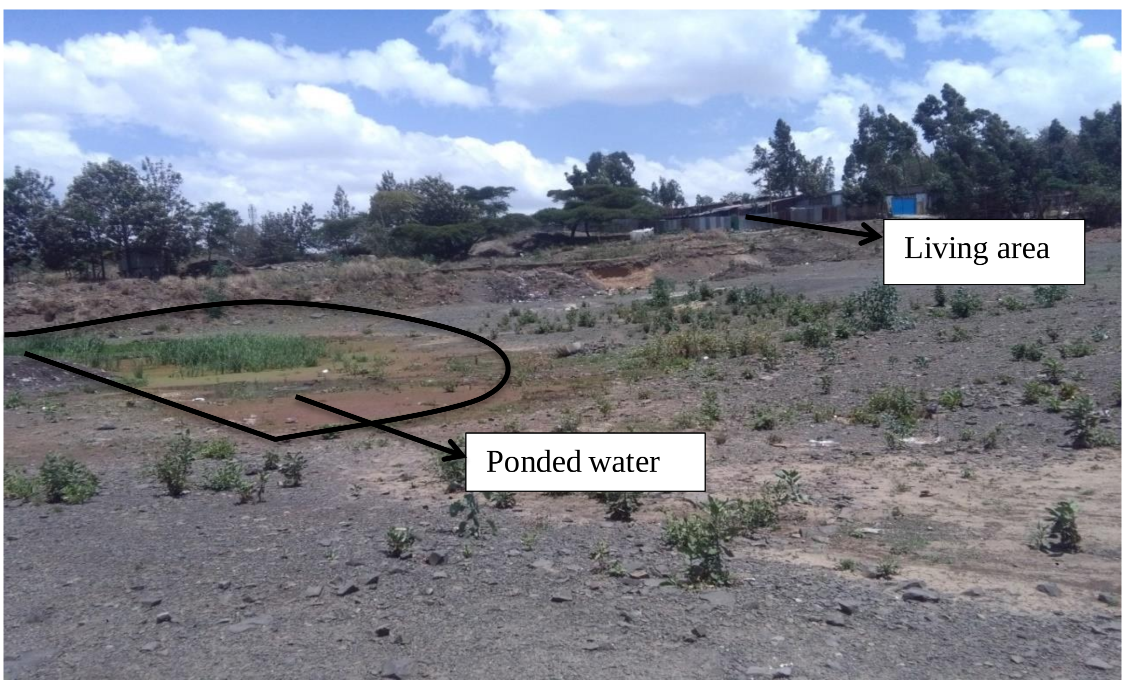


Figure 6-1 Water ponding in abandoned crushing sites around Akaki Kality area

Collection of crusher by-product were spread and left in abandoned aggregate production sites have been observed to cause water ponding as shown in Figure 6-1, this is because crusher by product creates impervious layer on the top surface of such areas. This could have negative impact on health of adjoining inhabitants by becoming a breeding ground for harm full insects such as malaria and it could create allergies if contact is made with such unprotected water.

Figure 6-2 Dumping of crusher by-product to adjoining river (aggregate production sites around Akaki River)

The less consumption of crusher by-product raised out of its high fines content makes the aggregate production companies to provide less care on this material, as spotted in Figure 6-2, so that the company removes the crusher by-product and the fines (which are separated and collected naturally by wind) to the adjoining river.

Figure 6-3 Collection of crusher by-product tightening working and storage area (Aggregate production site found in Addis Ababa Akaki Kality sub city)

Currently in Ethiopia Crusher by-product is used in less quantity as filler or bedding material for walkways and cobble stone road works and this consumption does not comply with the production of this material, on the other hand this by-product material which passes 4.75mm sieve has not been utilized widely as alternative to river sand because of its high fines content, So huge collections of crusher by-product were observed in most of aggregate production companies explored in this study. These collections were detected and reported by the companies to create tightening of storage and working area, so that they are forced to remove this material as indicated in the Figure 6-2.

Using crusher dust in concrete production as a cement replacement material could have other environmental advantages in addition to eradicating the above problems. The additional environmental advantages which contributed indirectly are reduction of carbon dioxide emission due to cement production and environmental effects of river sand production by creating awareness on contractors and ready mix concrete producers to use crusher by-product and its fines as a river sand and Portland cement replacement material simultaneously. Furthermore making aware of the feasibility of crusher dust as a partial cement replacement material could make aggregate production companies to adopt dust control mechanisms.

6.3. Financial Analysis

In this research work, it is tried to prepare cost break down and cost comparisons of concretes made with and without crusher dust replacement. Two cases were considered for the cost of basaltic crusher dust depending on the addition cost of scraping.

Case-1- The cost of scalping parent rock from impurities does not increase the cost of Crusher by- product and basaltic crusher dust. (This is the actual case based on the current market)

During the cost analysis the following considerations are taken as the major elements of cost breakdown and comparisons.

- Scalping the parent basalt rock to remove impurities is considered as one of the basic processes of coarse aggregate production, so the scalping cost is considered in the cost of coarse aggregate and has no implication on the cost of crusher by product and crusher dust.
- Crusher dust (fines passing 150µm sieve) used is the dust blended with crusher by-product (materials passing 4.75mm sieve).
- According to the aggregate crusher companies and survey made 15-25% of crusher by-products composed of fines passing 150µm sieve having a cost of 200birr/m^3 i.e. 0.136birr/kg (Appendix-H-1 to H-4).
- Transport cost of crusher dust is considered to be equal to transport cost of coarse aggregate as 3.28birr per m^3 per km as calculated by ministry of urban development, housing and construction [9] for distance of 20.1km to 40km. The total cost of crusher dust for the longest transport is calculated to be 0.226 birr per 1kg.

Table 6- 1 Summarized cost comparison of concretes for Case 1

Concrete type	**25MPa-P**	**25MPa-P(5%)**	**25MPa-P(10%)**	**25MPa-O**	**25MPa-O(5%)**	**25MPa-O(10%)**
Calculated cost of concrete (birr/m3)	1451.11	1409.09	1366.15	1657.16	1604.99	1551.7
Cost saved (%)		**2.9%**	**5.9%**		**3.1%**	**6.4%**
Concrete type	**30MPa-P**	**30MPa-P(5%)**	**30MPa-P(10%)**	**30MPa-O**	**30MPa-O(5%)**	**30MPa-P(10%)**
Calculated cost of concrete (birr/m3)	1537.69	1489.97	1442.25	1766.69	1707.47	1648.25
Cost saved (%)		**3.1%**	**6.2%**		**3.4%**	**6.7%**

The cost breakdown shown in Appendix H-1 to H-4 and summarized under Table 6-1 indicates that 5% and 10% crusher dust replacement with PPC cement could save 2.9 % and 5.9% cost of C-25 concrete. OPC replacement has also 3.1% and 6.4% saving in C-25 concrete. For C-30 concretes the saving was increased to 3.1% and 6.2 % for PPC and 3.4% to 6.7% at 5 and 10% crusher dust replacements.

Case-2- If the cost of scalping parent rock from impurities does considered in the cost of Crusher by- product and basaltic crusher dust. (This is theoretical case which is not adopted in the current market)

During the cost analysis the following considerations are taken:

The scalping cost is considered in the cost of crusher by product and crusher dust. The scalping cost is calculated using the information of crushing sites. The information is that they pay 400 to 500birr for one team of daily laborer (four daily laborers) for loading a truck with a capacity of 12m^3 and one team can load three trucks in a day. (Appendix H-5)

- Crusher dust (fines passing 150µm sieve) used is the dust blended with crusher by-product (materials passing 4.75mm sieve). The cost of basaltic crusher dust including cost of scalping is calculated as 288.7birr/m^3 (Appendix-H-6 to H-9).
- Transport cost of crusher dust is considered to be equal to transport cost of coarse aggregate as 3.28birr per m^3 per km as calculated by ministry of urban development, housing and construction [9] for distance of 20.1km to 40km. The total cost of basaltic crusher dust for the longest transport distance is calculated to be 0.36 birr per 1kg.

Table 6- 2 Summarized cost comparison of concretes for Case 2

Concrete type	**25MPa-P**	**25MPa-P(5%)**	**25MPa-P(10%)**	**25MPa-O**	**25MPa-O(5%)**	**25MPa-O(10%)**
Calculated cost of concrete (birr/m3)	1451.11	1411.86	1371.69	1657.16	1607.76	1557.24
Cost saved (%)		**2.7%**	**5.5%**		**3.0%**	**6.0%**

Concrete type	**30MPa-P**	**30MPa-P(5%)**	**30MPa-P(10%)**	**30MPa-P**	**30MPa-O(5%)**	**30MPa-O(10%)**
Calculated cost of concrete (birr/m3)	1537.69	1493.04	1448.39	1766.69	1710.54	1654.39
Cost saved (%)		**2.9%**	**5.8%**		**3.2%**	**6.4%**

The cost breakdown shown in Appendix H-5 to H-9 and summarized under Table 6-2 indicates that 5% and 10% crusher dust replacement with PPC cement could save 2.7 % and 5.5% cost of C-25 concrete. OPC replacement has also 3.0% and 6.0% saving in C-25 concrete. For C-30 concretes the saving was increased to 2.9% and 5.8 % for PPC and 3.2% to 6.4% at 5 and 10% basaltic crusher dust replacements.

In both cases considered above the cost of concretes made with 5% and 10% feasible replacement percentages were observed to be lower than concrete made with Portland cements. When it is tried to compare the cost reduction of the two cases we can observe that adding the cost of scalping on the cost of basaltic crusher dust has insignificant difference with the cost reduction made by neglecting the cost of scalping from the cost of basaltic crusher dust.

Generally it was found that at 5% and 10% partial replacement of cement with pure basaltic crusher dust results in saving 2.7% to 6.4% cost of concretes respectively with comparable characteristics in strength, water permeability and workability.

CHAPTER SEVEN

CONCLUSION AND RECOMMENDATIONS

7.1. Conclusions

Based on the conducted experimental studies and economic and environmental investigations the following conclusions are drawn.

1. Raw basaltic crusher dusts are coarser than OPC and PPC, so that basaltic crusher dust cannot be used as cement filler since a mineral admixture is required to have equal or more fineness(in cm^2/gm.) to be considered as cement filler. The chemical composition test reveals that both basaltic crusher dust samples with 0% and 20% clay can be categorized as class N Pozzolana, According to ASTM C 618 specification, i.e. SiO_2+ Al_2O_3+ Fe_2O_3 greater than 70%.

2. Higher replacements of OPC and PPC with pure basaltic crusher dust resulted in lower water requirement whereas the basaltic crusher dust containing 20% clay results an increase in water requirement of blended cements by absorbing more water than pure basalt powder or the replaced cement do. Initial and final setting times of blended cements are increased with increase in percentage replacement of basaltic crusher dusts.

3. Replacement of OPC and PPC with crusher dust generally shows reduction in cement strength with increase in percentage replacement. Basaltic crusher dust shows pozzolanic property up to 10% by weight of PPC and 20% by weight of OPC and this can be considered as feasible replacement percentages for cement mortar since strength activity index (SAI) of those blended cement mortar mixes were greater than 75%.

4. It was observed that replacing crusher dust containing 20% clay make the blended cement to loss more strength than pure basalt powder does. So clay content of crusher dust appears to be an influential factor to use basaltic crusher dust as a partial cement replacement material. Hence the clay contained within basaltic crusher dust should be removed by adopting proper scalping process prior to crushing process before feeding the quarried basalt rock to the primary crusher.

5. The study revealed that replacing cement with crusher dust increases the slump of concrete mixes with increase in replacement percentage. Furthermore it was noticed that basaltic crusher dust containing clay has a tendency to increase slump of concrete more than pure basalt powder does without increasing the water content.

6. Generally replacing cement with crusher dust reduces compressive strength of concretes at 3, 7 and 28 curing days, however compressive strength loss of concretes were observed to reduce as the age of concrete increases which shows that the pozzolanic property of basaltic crusher dust increases with time. The effective basaltic crusher dust partial replacement percentages are identified to be 5% for PPC and 10% for OPC during production of C-25 and C-30 concretes by achieving compliance criteria of ACI 301 at later age. On the other hand crusher dust containing 20% clay shows lower effective replacement ranges with higher compressive strength loss. Additionally it was observed that partial replacement of crusher dust with OPC or PPC is more favorable or promising for lower strength concretes.

7. Increasing crusher dust replacement range increases water penetration depth of concrete specimens. It was also observed that the clay content of crusher dust makes the concretes permeable than concretes made with pure basaltic crusher dust blended cements. However it can be concluded that the feasible replacement percentages (5% and 10%) can be considered as durable concretes since their maximum water penetration depth is below 50mm.

8. Replacing crusher dust has found to avoid environmental and related problems created in lesser use of crusher by-product and crusher dust produced during aggregate production. Using pure basaltic crusher dust as partial cement replacement material by 5% and 10% results in saving 2.7% to 6.4% cost of concretes respectively with comparable characteristics in strength, water permeability and workability.

7.2. Recommendations

Based on the conducted study the following recommendations are forwarded.

1. Since the clay content of crusher dust has been found to have negative effect on its capacity to be used as a partial cement replacement material, aggregate production companies could work on reducing the clay content of this by-product material by adopting proper scalping process to separate parent rock from clay lumps and organic materials.

2. Even if the feasible replacement percentages with comparable water penetration resistance were determined, durability of concretes made with partial replacement of basaltic crusher dust can still be a challenge for application in structural concretes. So it is advisable to limit the use of basaltic crusher dust as a partial replacement of cement in concretes where has durability is less concern.

3. Crusher dust as investigated in this research work can be used as a partial cement replacement material by 5 and 10%, therefore concerned bodies like aggregate production companies, construction contractors and ready mix concrete producers should be aware of this potential, so that they can drop their controversial ideas about use of crusher by-product as a fine aggregate because of its high fines/dust content and consider using this material as both cement and sand replacement material.

7.3. Recommendation for Further Studies

Further study areas as forwarded as follows:

- Alternatively studies shall be made on use of crusher dust as fine aggregate filler in concrete production and comparison should be made with the results of this study.
- Since only crusher dust from basalt crushing plant were considered in this study, crusher dust produced from crushing of other parent rocks such as ignimbrite, trachyte or limestone should be tested for partial replacement of Portland cement and compared with the results of this study.
- Studies should be done to optimize the use of crusher by-product as both sand and cement replacement material in concrete production.

REFERENCES

[1] Sandeep K. S., Vikas S., Agarwal V.C., Rakesh K. and Mehta P.K.. (2014). An Experimental Investigation On Stone Dust As Partial Replacement Of Fine Aggregate In Concrete. Motilal Nehru National Institute of Technology, India.

[2] Doraiswamy S.K. and Hudson W. R. (1992). Use of Quarry Fines for Engineering and Environmental Applications. The University of Texas, Austin.

[3] Martin S. and Verein D. (2011, March 02). New cement technologies. Retrieved from http://www.globalcement.com

[4] Abrar Awol. (2011). Using marble waste powder in cement and concrete production, MSc Thesis, Addis Ababa University School Of Graduate Studies, Addis Ababa

[5] Shewaferaw Dinku. (2006). The Use of Manufactured Sand in Concrete Production: Test Results and Cost Comparison, MSc Thesis, Addis Ababa University School Of Graduate Studies, Addis Ababa, Ethiopia.

[6] Biruk Hailu. (2011). Bagasse ash as a cement replacing material, MSc Thesis, Addis Ababa University School of Graduate Studies, Addis Ababa, Ethiopia.

[7] Venkata S. K.., Panduranga R., Krishna S. (2013). Experimental study on partial replacement of cement with quarry dust. International Journal of Advanced Engineering Research and Studies.

[8] Abebe Dinku, (2005). The need for standardization of aggregates for concrete production in Ethiopian construction industry. Civil Engineering Department. Addis Ababa University, Ethiopia. www/http adinku@tech.aau.edu.et

[9] ከ/ል/ቤ/ኮ/ሚ/ር, (ሰኔ / 2007 ዓ.ም), በ2008 በጀት ዓመት በመንግሥት ለሚገነቡ ፕሮጀክቶች የአካባቢ ግብዓቶች ፍላጎት እና አቅርቦት ጥናት. በመኖሪያ ቤቶች ልማትና የመንግሥት ህንጻዎች ኮንስትራክሽን ቢሮ. አዲስ አበባ.

[10] በጥናት ዕቅድና በጀት ደ/የሥራ ሂደት የተዘጋጀ, (ነሀሴ 2009), የተቀናጀ ቤቶች ልማት ፕሮግራም የዋና ዋና ግቦች አፈጻጸምና ውጤት አመልካች መረጃዎች (1996-2009), የአዲስ አበባ ቤቶች ልማት ፕሮጀክት ጽ/ቤት. አዲስ አበባ.

[11] El-Didamony H., Helmy I.M., Randa M. Osman and Habboud A.M. (2015). Basalt as Pozzolana and Filler in Ordinary Portland Cement, Faculty of science, Zagazig University, Zagazig, Egypt.

[12] Kartini K., Hamidah M. S., Norhana A. R., Nur Hanani A. R. (2004). Quarry dust fine powder as substitute for ordinary Portland cement in concrete mix, Faculty of Civil Engineering, University of Technology MARA, Malaysia.

[13] Neville A.M. (1995). Properties of Concrete, 4th Edition, Longman Group Limited, England, UK.

[14] Meral C.. (2004). Use of perlite as a pozzolanic addition in blended cement production. The Graduate School of Natural and Applied Sciences of Middle East Technical University, Turkey.

[15] Wondimu Gadiss. (2010). The Use of Limestone powder as an alternative cement replacement material: an experimental study, MSc Thesis, Addis Ababa University School of Graduate studies, Addis Ababa.

[16] Ethiopian standards. (1990), Cement and cement products.

[17] Mikiyas Abayneh. (1987). Construction materials. AAU Printing press, Addis Ababa.

[18] Semere Mulatu. (2013). Environmental Impacts of Coarse Aggregate Production in and Around Addis Ababa, MSc Thesis, Addis Ababa University School Of Graduate Studies, Addis Ababa

[19] Geological map of Addis Ababa. <http// www.oocities.org/ geological map of Addis Ababa> on August 21,2016

[20] Birhanu Bogale. (2007). Comparison of Concrete Durability as Produced by Various Cements Manufactured in Ethiopia, MSc Thesis, Addis Ababa University School Of Graduate Studies, Addis Ababa, Ethiopia.

[21] Abebe Dinku. (2003). Construction Materials Laboratory Manual. Addis Ababa University Printing Press, Addis Ababa, Ethiopia.

[22] ASTM Standard C778. (1998). Standard Specification for Standard Sand, ASTM International, West Conshohocken, PA, United States.

[23] ACI Committee 211. (2002). ACI 211.1 Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete. American Concrete Institute, Farmington Hills, Michigan, USA.

[24] ACI Committee 301. (2002). ACI 301Specification for structural concrete. American Concrete Institute, Farmington Hills, Michigan, USA.

[25] EBCS-2. (1995). Structural Use of Concrete, Ethiopian Ministry of Works and Urban Development.

[26] ASTM Standards C618. (2003). Specification for Coal, Fly Ash and Raw or Calcined Natural Pozzolana for Use as a Mineral Admixture in Portland cements Concrete , ASTM International, West Conshohocken, PA, United States.

[27] ASTM Standards C311. (2003). Standard Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete, , ASTM International, West Conshohocken, PA, United States.

[28] ASTM Standards C187. (2003). Standard Test Method for Normal Consistency of Hydraulic Cement, ASTM International, West Conshohocken, PA, United States.

[29] ASTM Standards C143. (2003). Standard Test Method for Slump of Hydraulic-Cement Concrete, ASTM International, West Conshohocken, PA, United States.

[30] ACI Committee. (1998). ACI 209 Prediction of Creep, Shrinkage, and Temperature effect in concrete structures. American concrete institute, Farmington Hills, Michigan, USA.

APPENDIX A

SIEVE ANALYSIS RESULT OF SAMPLE CRUSHER BY-PRODUCTS

Sieve size (mm)	Sample No.									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	Cumulative % Passing									
9.50	100.00	100.00	99.80	100.00	100.00	100.00	100.00	100.00	100.00	100.00
4.50	98.40	97.80	98.60	100.00	99.40	99.60	99.60	100.00	99.00	98.40
2.36	90.20	87.20	79.20	85.00	84.60	91.80	88.60	88.20	92.40	90.20
1.18	63.00	63.00	68.80	57.80	62.20	67.00	63.80	63.20	68.20	69.60
0.60	44.20	44.20	42.80	39.00	40.80	50.00	43.60	38.80	46.20	48.00
0.30	27.40	32.60	27.20	26.20	24.60	38.80	31.20	28.60	33.60	31.80
0.15	**19.00**	**24.20**	**20.80**	**18.60**	**15.60**	**22.20**	**16.20**	**16.60**	**24.60**	**24.60**
Pan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

APPENDIX B

FINENESS AND SPECIFIC GRAVITY OF CEMENT AND CRUSHER DUST SAMPLES

S-1 Test for Fineness of cement, BCD1 and BCD2

Trials	Time recorded (s) (T)	Standard specific gravity (Ss)	Standard time (Ts)	Calculated specific gravity of sample (cm2/g) (S)= Ss (√T)/(√Ts)
Mugher OPC				
1	33.72	3774	29.77	4016.55
2	33.11	3774	29.77	3980.08
3	33.84	3774	29.77	4023.72
Average Finness				**4006.78**
Mugher PPC				
1	30.66	3774	29.77	3829.99
2	29.52	3774	29.77	3758.12
3	31.35	3774	29.77	3872.85
Average Finness				**3820.32**
Crusher dust sample 1(CDS1)				
1	19.68	3774	29.77	3068.49
2	19.03	3774	29.77	3017.39
3	18.88	3774	29.77	3005.47
Average Finness				**3030.45**
Crusher dust sample 2 (CDS2)				
1	17.87	3774	29.77	2923.98
2	16.95	3774	29.77	2822.4
3	17.29	3774	29.77	2876.14
Average Finness				**2874.17**

S-2 Test for specific gravity of BCD1 and BCD2

Trials	Weight of sample	Weight of water & pycnometer	Weight of sample, water & pycnometer	Calculated Specific gravity	Temprature (0C)	Temprature coefficient (K)	Corrected specific gravity (G)
Crusher dust sample 1(CD1)							
1	20	707.56	720.05	2.66	16	1.00074	2.67
2	20	707.72	719.52	2.44	16	1.00074	2.44
3	20	707.41	719.84	2.64	16	1.00074	2.64
Average specific gravity							**2.58**
Crusher dust sample 2 (CD2)							
1	20	707.75	720.62	2.81	16	1.00074	2.81
2	20	707.41	720.25	2.79	16	1.00074	2.80
3	20	707.62	720.54	2.82	16	1.00074	2.83
Average specific gravity							**2.81**

APPENDIX C

COMPRESSIVE STRENGTH OF HARDENED CEMENT MORTARS

C-1 Three Days Compressive strength of cement mortars

No	Test age days	Dimensions (mm) L	W	H	Weight (gm)	Weight (gm)	Failure load (KN)	Comp. Strength (MPa)	Unit Weight (gm/cm3)
OPC									
1	3	51.11	51.26	50.02	131.047	271	23.06	9.23	2.07
2		51.16	50.84	50.08	130.257	273	22.03	8.81	2.10
Mean							**22.55**	**9.02**	**2.08**
O-1(5%)									
1	3	50.64	50.11	51.2	129.924	268	12.58	5.14	2.06
2		50.58	50	50.26	127.108	265	13.76	5.5	2.08
Mean							**13.17**	**5.32**	**2.07**
O-1(10%)									
1	3	51.46	50.94	50.2	131.593	269	13.99	5.6	2.04
2		50.9	50.44	50.21	128.909	263	13.39	5.36	2.04
Mean							**13.69**	**5.48**	**2.04**
O-1(15%)									
1	3	51.44	50.21	50.09	129.373	268	11.8	4.72	2.07
2		50.25	49.8	50.01	125.148	263	12.57	5.03	2.10
Mean							**12.19**	**4.88**	**2.09**
O-1(20%)									
1	3	50.23	50.65	50.6	128.734	260	10.7	4.28	2.02
2		50.02	51.22	50.95	130.535	262	11.62	4.65	2.01
50.65							**11.16**	**4.47**	**2.01**
O-2(5%)									
1	3	50.82	50.57	51.68	132.816	272	21.24	8.5	2.05
2		50.97	50.24	50.71	129.855	271	22.6	9.04	2.09
Mean							**21.92**	**8.77**	**2.07**
O-2(10%)									
1	3	51.72	50.69	50.02	131.137	271	19.36	7.75	2.07
2		50.21	50.98	50.66	129.675	265	20.51	8.2	2.04
Mean							**19.94**	**7.98**	**2.06**
O-2(15%)									
1	3	51.73	50.85	50.23	132.129	269	16.24	6.5	2.04
2		51.2	51.21	50.79	133.169	269	15.62	6.25	2.02
Mean							**15.93**	**6.38**	**2.03**
O-2(20%)									
1	3	49.68	51.64	51.23	131.429	265	13.74	5.5	2.02
2		50.04	51.42	50.44	129.785	267	15.17	6.07	2.06
Mean							**14.46**	**5.79**	**2.04**

No	Test age days	Dimensions (cm) L	W	H	Weight (gm)	Volume (cm3)	Failure load (KN)	Comp. Strength (Mpa)	Unit Weight (gm/cm3)
PPC									
1	3	51.18	50.86	51.53	271	134.1334	20.73	8.29	2.02
2		51.57	50.31	50.09	270	129.9578	19.54	7.81	2.08
Mean							**20.14**	**8.05**	**2.05**
P-1(5%)									
1	3	49.91	51.08	51.13	268	130.351	10.44	4.18	2.06
2		50.02	52.01	51.21	270	133.2249	11.43	4.57	2.03
Mean							**10.94**	**4.38**	**2.04**
P-1(10%)									
1	3	50.85	51.41	50.22	267	131.285	11.41	4.56	2.03
2		50.2	50.38	50.85	265	128.6035	9.43	3.77	2.06
Mean							**10.42**	**4.17**	**2.05**
P-1(15%)									
1	3	51.22	50.32	50.6	268	130.416	8.73	3.48	2.05
2		50.22	49.93	50.44	266	126.4775	7.85	3.14	2.10
Mean							**8.29**	**3.31**	**2.08**
P-1(20%)									
1	3	50.62	50.9	50.01	266	128.8537	7.35	2.94	2.06
2		50.17	49.92	50.68	262	126.9274	7	2.78	2.06
Mean							**7.18**	**2.86**	**2.06**
P-2(5%)									
1	3	50.22	51.52	51.11	270	132.2387	18.38	7.35	2.04
2		51.24	50.53	51.19	271	132.539	18.55	7.42	2.04
Mean							**18.47**	**7.39**	**2.04**
P-2(10%)									
1	3	51.94	51.21	50.26	272	133.6839	18.24	7.3	2.03
2		50.19	50.2	50.05	267	126.1029	16.96	6.79	2.12
Mean							**17.60**	**7.05**	**2.08**
P-2(15%)									
1	3	51.27	51.35	50.33	270	132.5045	16.74	6.7	2.04
2		49.96	50.14	50.08	264	125.4501	15.62	6.25	2.10
Mean							**16.18**	**6.48**	**2.07**
P-2(20%)									
1	3	51	50.28	51.6	269	132.3168	10.44	4.18	2.03
2		51.04	50.83	51.24	267	132.9352	9.57	3.83	2.01
Mean							**10.01**	**4.01**	**2.02**

C-2 Seven Days Compressive strength of cement mortars

No	Test age days	Dimensions (cm) L	W	H	Weight (gm)	Volume (cm3)	Failure load (KN)	Comp. Strength (Mpa)	Unit Weight (gm/cm3)
OPC									
1	7	50.26	51.28	50.11	271	129.1501	29.06	11.62	2.10
2		50.6	51.49	50.01	270	130.2958	30.39	12.16	2.07
Mean							**29.73**	**11.89**	**2.09**
O-1(5%)									
1	7	50.44	51.09	50.64	269	130.4982	22.9	9.16	2.06
2		50.43	51.28	50.17	269	129.7421	23.97	9.59	2.07
Mean							**23.44**	**9.38**	**2.07**
O-1(10%)									
1	7	50.54	50.5	50.68	267	129.349	20.05	8.02	2.06
2		51.08	50.23	51.04	268	130.9558	18.92	7.75	2.05
Mean							**19.49**	**7.89**	**2.06**
O-1(15%)									
1	7	50.32	50.6	51.09	265	130.0849	20.03	8.01	2.04
2		50.64	50.84	49.92	262	128.5209	17.44	6.98	2.04
Mean							**18.74**	**7.50**	**2.04**
O-1(20%)									
1	7	50.4	50.58	50.26	262	128.1244	18.84	7.54	2.04
2		51.11	50.28	50.88	265	130.752	16.59	6.64	2.03
Mean							**17.72**	**7.09**	**2.04**
O-2(5%)									
1	7	51.54	50.21	50.58	270	130.8921	25.78	10.31	2.06
2		50.02	50.55	51.15	268	129.3333	27.4	10.96	2.07
Mean							**26.59**	**10.64**	**2.07**
O-2(10%)									
1	7	50.27	51.92	50	270	130.5009	23.99	9.6	2.07
2		51.67	50.62	50.37	268	131.7445	25.7	10.38	2.03
Mean							**24.85**	**9.99**	**2.05**
O-2(15%)									
1	7	50.98	51.2	50.42	268	131.6051	22.5	9.01	2.04
2		50.46	51.14	50.27	267	129.723	21.77	8.71	2.06
Mean							**22.14**	**8.86**	**2.05**
O-2(20%)									
1	7	51.24	50.29	51.63	271	133.0433	18.58	7.43	2.04
2		50.3	51.04	50.7	266	130.1627	18.71	7.48	2.04
Mean							**18.65**	**7.46**	**2.04**

No	Test age days	Dimensions (cm) L	W	H	Weight (gm)	Volume (cm3)	Failure load (KN)	Comp. Strength (Mpa)	Unit Weight (gm/cm3)
PPC									
1	7	50.21	50.53	51.19	268	129.8747	23.98	9.58	2.06
2		50.97	51.24	50.71	269	132.4394	23.95	9.58	2.03
Mean							**23.97**	**9.58**	**2.05**
P-1(5%)									
1	7	50.5	50.85	50.54	268	129.7829	19.14	7.66	2.06
2		50.23	49.99	51.32	262	128.8644	18.92	7.57	2.03
Mean							**19.03**	**7.62**	**2.05**
P-1(10%)									
1	7	50.27	49.98	50.69	261	127.3584	15.67	6.27	2.05
2		51.03	50.03	50.51	265	128.9536	15.23	6.09	2.06
Mean							**15.45**	**6.18**	**2.05**
P-1(15%)									
1	7	51.2	49.97	50.09	259	128.1535	15.6	6.24	2.02
2		50.94	50.02	50.66	262	129.0826	15.35	6.14	2.03
Mean							**15.48**	**6.19**	**2.03**
P-1(20%)									
1	7	50.25	50.02	49.97	252	125.5998	10.35	4.14	2.01
2		50.96	51.27	50.24	263	131.263	10.72	4.29	2.00
Mean							**10.54**	**4.22**	**2.00**
P-2(5%)									
1	7	49.88	50.07	50.22	260	125.424	22.91	9.16	2.07
2		50.19	51.41	51.63	270	133.2192	24.23	9.69	2.03
Mean							**23.57**	**9.43**	**2.05**
P-2(10%)									
1	7	50	50.08	50.68	264	126.9027	21.81	8.72	2.08
2		51.05	51.64	50.44	266	132.971	19.8	7.92	2.00
Mean							**20.81**	**8.32**	**2.04**
P-2(15%)									
1	7	51.23	50.68	50.39	267	130.8294	15.3	6.12	2.04
2		50.99	51.11	50.18	263	130.774	17.5	7	2.01
Mean							**16.40**	**6.56**	**2.03**
P-2(20%)									
1	7	50.99	51.11	50.96	266	132.8068	14.18	5.67	2.00
2		50.21	50.91	50.03	264	127.8862	15.21	6.08	2.06
Mean							**14.70**	**5.88**	**2.03**

C-3 Twenty eight Days Compressive strength of cement mortars

No	Test age days	Dimensions (cm) L	W	H	Weight (gm)	Volume (cm3)	Failure load (KN)	Comp. Strength (MPa)	Unit Weight (gm/cm3)
OPC									
1	28	51.08	52.13	50.08	275	133.353	47.62	19.05	2.06
2		50.57	52.31	50.09	278	132.5039	45.86	18.34	2.10
Mean							**46.74**	**18.70**	**2.08**
O-1(5%)									
1	28	51.13	52.42	50	273	134.0117	44.63	17.86	2.04
2		51.12	51.01	49.91	272	130.1469	44.29	17.72	2.09
Mean							**44.46**	**17.79**	**2.06**
O-1(10%)									
1	28	51.5	50.21	50.7	270	131.1008	42.77	17.11	2.06
2		50.75	51.66	50.6	271	132.6603	43.96	17.59	2.04
Mean							**43.37**	**17.35**	**2.05**
O-1(15%)									
1	28	51.8	50.41	50.77	269	132.5726	40.06	16.02	2.03
2		51.09	50.87	50.97	272	132.4684	40.50	16.2	2.05
Mean							**40.28**	**16.11**	**2.04**
O-1(20%)									
1	28	50.52	50.99	51.15	269	131.7632	38.01	15.21	2.04
2		51.52	50.55	51.11	272	133.1076	38.93	15.58	2.04
Mean							**38.47**	**15.40**	**2.04**
O-2(5%)									
1	28	51.44	50.55	50.65	274	131.7048	46.47	18.59	2.08
2		50.83	51.18	51.14	274	133.0397	46.00	18.40	2.06
Mean							**46.24**	**18.50**	**2.07**
O-2(10%)									
1	28	51.23	51.08	51.21	273	134.0078	45.54	18.22	2.04
2		50.02	50.95	50.23	269	128.0121	46.13	17.84	2.10
Mean							**45.84**	**18.03**	**2.07**
O-2(15%)									
1	28	51.69	50.85	50.99	274	134.024	45.43	17.77	2.04
2		50.35	50.2	51.26	266	129.5632	44.94	17.98	2.05
Mean							**45.19**	**17.88**	**2.05**
O-2(20%)									
1	28	51.54	50.02	50.55	268	130.3195	42.04	16.82	2.06
2		51.32	49.95	50.4	265	129.1971	44.17	17.66	2.05
Mean							**43.11**	**17.24**	**2.05**

No	Test age days	Dimensions (mm)			Weight (gm)	Volume (cm3)	Failure load (KN)	Comp. Strength (MPa)	Unit Weight (gm/cm3)
		L	W	H					
PPC									
1	28	50.32	50.75	51.68	269	131.9773	44.73	17.29	2.04
2		50.97	51.24	50.7	276	132.4133	42.16	16.86	2.08
Mean							**43.45**	**17.08**	**2.06**
P-1(5%)									
1	28	50.74	50.31	51.66	270	131.874	38.16	15.28	2.05
2		50.11	50.89	51.02	267	130.106	39.01	15.62	2.05
Mean							**38.59**	**15.45**	**2.05**
P-1(10%)									
1	28	50.73	49.85	51.23	267	129.5551	30.51	12.2	2.06
2		50.2	51.21	51.79	267	133.1387	27.51	11.02	2.01
Mean							**29.01**	**11.61**	**2.03**
P-1(15%)									
1	28	50.76	49.9	51.35	267	130.0656	24.69	9.88	2.05
2		50.24	51.1	50.67	262	130.0833	24.39	9.67	2.01
Mean							**24.54**	**9.78**	**2.03**
P-1(20%)									
1	28	50.28	49.88	51.72	265	129.712	22.56	9.02	2.04
2		51.5	50.06	51.1	264	131.7404	22.12	8.85	2.00
Mean							**22.34**	**8.94**	**2.02**
P-2(5%)									
1	28	50.96	50.03	51.94	272	132.4225	43.96	17.58	2.05
2		51.84	50.58	50.26	271	131.7851	40.56	16.24	2.06
Mean							**42.26**	**16.91**	**2.06**
P-2(10%)									
1	28	51.22	50.47	51.43	269	132.9503	37.61	15.04	2.02
2		50.68	50.39	51.29	267	130.9826	37.15	14.86	2.04
Mean							**37.38**	**14.95**	**2.03**
P-2(15%)									
1	28	51.11	51.18	50.88	266	133.0924	29.94	11.98	2.00
2		50.91	50.93	50.87	266	131.8981	29.59	11.84	2.02
Mean							**29.77**	**11.91**	**2.01**
P-2(20%)									
1	28	50.75	50.21	51.58	265	131.434	28.57	11.43	2.02
2		51.23	49.96	50.93	261	130.3528	25.32	10.13	2.00
Mean							**26.95**	**10.78**	**2.01**

APPENDIX D

PROPORTIONS OF CONCRETE MIXES

S.No	Code	Cement (kg)	Crusher dust (kg)	Coarse aggregate (kg)	Fine aggregate (kg)	Water (kg)	W/(C+P)
1	25MPa-O	413.4	0	1027.8	706.48	241.8	0.49
2	25MPa-O-1(5%)	392.73	20.67	1027.8	706.48	241.8	0.49
3	25MPa-O-1(10%)	372.06	41.34	1027.8	706.48	241.8	0.49
4	25MPa-O-1(15%)	351.39	62.01	1027.8	706.48	241.8	0.49
5	25MPa-O-1(20%)	330.72	82.68	1027.8	706.48	241.8	0.49
6	25MPa-O-2(5%)	392.73	20.67	1027.8	706.48	241.8	0.49
7	25MPa-O-2(10%)	372.06	41.34	1027.8	706.48	241.8	0.49
8	25MPa-O-2(15%)	351.39	62.01	1027.8	706.48	241.8	0.49
9	25MPa-O-2(20%)	330.72	82.68	1027.8	706.48	241.8	0.49
10	25MPa-P	413.4	0	1027.8	706.48	241.8	0.49
11	25MPa-P-1(5%)	392.73	20.67	1027.8	706.48	241.8	0.49
12	25MPa-P-1(10%)	372.06	41.34	1027.8	706.48	241.8	0.49
13	25MPa-P-1(15%)	351.39	62.01	1027.8	706.48	241.8	0.49
14	25MPa-P-1(20%)	330.72	82.68	1027.8	706.48	241.8	0.49
15	25MPa-P-2(5%)	392.73	20.67	1027.8	706.48	241.8	0.49
16	25MPa-P-2(10%)	372.06	41.34	1027.8	706.48	241.8	0.49
17	25MPa-P-2(15%)	351.39	62.01	1027.8	706.48	241.8	0.49
18	25MPa-P-2(20%)	330.72	82.68	1027.8	706.48	241.8	0.49
19	30MPa-O	458.24	0	1025.72	661.68	240.3	0.44
20	30MPa-O-1(5%)	435.33	22.91	1025.72	661.68	240.3	0.44
21	30MPa-O-1(10%)	412.42	45.82	1025.72	661.68	240.3	0.44
22	30MPa-O-1(15%)	389.50	68.74	1025.72	661.68	240.3	0.44
23	30MPa-O-1(20%)	366.59	91.65	1025.72	661.68	240.3	0.44
24	30MPa-O-2(5%)	435.33	0	1025.72	661.68	240.3	0.44
25	30MPa-O-2(10%)	412.42	22.91	1025.72	661.68	240.3	0.44
26	30MPa-O-2(15%)	389.50	45.82	1025.72	661.68	240.3	0.44
27	30MPa-O-2(20%)	366.59	68.74	1025.72	661.68	240.3	0.44
28	30MPa-P	458.24	0.00	1025.72	661.68	240.3	0.44
29	30MPa-P-1(5%)	435.33	22.91	1025.72	661.68	240.3	0.44
30	30MPa-P-1(10%)	412.42	45.82	1025.72	661.68	240.3	0.44
31	30MPa-P-1(15%)	389.50	68.74	1025.72	661.68	240.3	0.44
32	30MPa-P-1(20%)	366.59	91.65	1025.72	661.68	240.3	0.44
33	30MPa-P-2(5%)	435.33	22.91	1025.72	661.68	240.3	0.44
34	30MPa-P-2(10%)	412.42	45.82	1025.72	661.68	240.3	0.44
35	30MPa-P-2(15%)	389.50	68.74	1025.72	661.68	240.3	0.44
36	30MPa-P-2(20%)	366.59	91.65	1025.72	661.68	240.3	0.44

APPENDIX E

COMPRESSIVE STRENGTH OF C-25 and C-30 CONCRETE CUBES

E-1 Three Days Compressive strength of Concretes

No	Test age days	Dimensions (cm)			Weight (gm)	Volume (cm3)	Failure load (KN)	Comp. Strength (Mpa)	Unit Weight (gm/cm3)
		L	W	H					
25MPa-O									
1	3	15.08	15.01	15.25	7974	3451.85	376.3	16.72	2.31
2		15.02	15.03	15.22	7988	3435.92	378.7	16.83	2.32
Mean							**377.5**	**16.77**	**2.32**
25MPa-O-1(5%)									
1	3	15	15.2	15.3	7981	3488.4	334.6	14.87	2.29
2		15	15.1	15.1	7993	3420.15	344.1	15.29	2.34
Mean							**339.35**	**15.08**	**2.31**
25MPa-O-1(10%)									
1	3	15.02	15.2	15.1	7983	3447.3904	287.7	12.79	2.32
2		15	15.1	15.34	7985	3474.51	292.4	13	2.30
Mean							**290.05**	**12.90**	**2.31**
25MPa-O-1(15%)									
1	3	15	15	15.3	7922	3442.5	261	11.6	2.30
2		15	15	15.35	8037	3453.75	256.6	11.4	2.33
Mean							**258.8**	**11.50**	**2.31**
25MPa-O-1(20%)									
1	3	15.02	15	15.6	7979	3514.68	249.5	11.09	2.27
2		15.05	15.01	15.31	7848	3458.536655	241.1	10.72	2.27
Mean							**245.3**	**10.91**	**2.27**
25MPa-O-2(5%)									
1	3	15.01	15.05	15.1	7928	3411.09755	368.3	16.37	2.32
2		15.02	15	15.1	7883	3402.03	361	16.04	2.32
Mean							**364.65**	**16.20**	**2.32**
25MPa-O-2(10%)									
1	3	15	15.02	15.2	7931	3424.56	341.7	15.19	2.32
2		15.02	15	15.21	7903	3426.813	322.4	14.33	2.31
Mean							**332.05**	**14.76**	**2.31**
25MPa-O-2(15%)									
1	3	15	15	15.42	7955	3469.5	309.9	13.77	2.29
2		15.01	15.04	15.2	7988	3431.40608	318.6	14.16	2.33
Mean							**314.25**	**13.97**	**2.31**
25MPa-O-2(20%)									
1	3	15.01	15.01	15.25	7917	3435.826525	268.5	11.93	2.30
2		15	15.02	15.1	7906	3402.03	258.6	11.49	2.32
Mean							**263.55**	**11.71**	**2.31**

No	Test age days	Dimensions (cm)			Weight (gm)	Volume (cm3)	Failure load (KN)	Comp. Strength (Mpa)	Unit Weight (gm/cm3)
		L	W	H					
30MPa-O									
1	3	15	15.01	15.1	8081	3399.77	428.1	19.02	2.38
2		14.99	15	15.06	8061	3386.24	385.7	17.14	2.38
Mean							**406.9**	**18.08**	**2.38**
30MPa-O-1(5%)									
1	3	15.01	15	15.33	8069	3451.5495	414.1	18.41	2.34
2		15.04	15.01	15.21	8141	3433.66358	383.4	17.04	2.37
Mean							**398.75**	**17.73**	**2.35**
30MPa-O-1(10%)									
1	3	15.02	15	15.21	7981	3426.813	354.4	15.75	2.33
2		15.02	15.02	15.33	8029	3458.45413	344.2	15.3	2.32
Mean							**349.3**	**15.53**	**2.33**
30MPa-O-1(15%)									
1	3	15	15	15.42	7993	3469.5	317.4	14.11	2.30
2		15.02	15.01	15.05	7968	3393.02551	313.5	13.93	2.35
Mean							**315.45**	**14.02**	**2.33**
30MPa-O-1(20%)									
1	3	15	15	15.1	7938	3397.5	279	12.4	2.34
2		15	15	15.1	7926	3397.5	279	12.4	2.33
Mean							**279**	**12.40**	**2.33**
30MPa-O-2(5%)									
1	3	15.01	15	15.11	7967	3402.0165	432.7	19.23	2.34
2		15	15.01	15.1	7995	3399.765	372.7	16.56	2.35
Mean							**402.7**	**17.90**	**2.35**
30MPa-O-2(10%)									
1	3	15.02	15	15.31	7981	3449.343	361.1	16.05	2.31
2		15.03	15.03	15.45	8029	3490.16891	374.2	16.63	2.30
Mean							**367.65**	**16.34**	**2.31**
30MPa-O-2(15%)									
1	3	15.02	15	15.04	7969	3388.512	328.4	14.6	2.35
2		15.01	15.01	15.24	7981	3433.57352	328.8	14.8	2.32
Mean							**328.6**	**14.70**	**2.34**
30MPa-O-2(20%)									
1	3	15.01	15	15.25	7964	3433.5375	338.1	15.02	2.32
2		15	15.01	15.2	7962	3422.28	318.6	14.16	2.33
Mean							**328.35**	**14.59**	**2.32**

No	Test age days	Dimensions (cm)			Weight (gm)	Volume (cm3)	Failure load (KN)	Comp. Strength (Mpa)	Unit Weight (gm/cm3)
		L	W	H					
25MPa-P									
1	3	15	15.2	14.94	7963	3406.32	334.9	14.87	2.34
2		15.01	15	15.08	7941	3395.26	312.4	13.88	2.34
Mean							**323.67**	**14.37**	**2.34**
25MPa-P-1(5%)									
1	3	15.01	15	15.1	7908	3399.765	326.5	14.51	2.33
2		15	15	15.2	7954	3420	314.4	13.79	2.33
Mean							**320.45**	**14.15**	**2.33**
25MPa-P-1(10%)									
1	3	15.03	15.01	15.11	7941	3408.8205	306.1	13.61	2.33
2		15.02	15.03	15.16	7978	3422.3791	310.4	13.79	2.33
Mean							**308.25**	**13.70**	**2.33**
25MPa-P-1(15%)									
1	3	15.02	15.01	15.1	7920	3404.298	260.6	11.58	2.33
2		15	15.03	15.28	7955	3444.876	245.2	10.9	2.31
Mean							**252.9**	**11.24**	**2.32**
25MPa-P-1(20%)									
1	3	15	15.01	15.14	7938	3408.771	231.4	10.28	2.33
2		15.02	15.02	15.27	7929	3444.9181	217	9.64	2.30
Mean							**224.2**	**9.96**	**2.32**
25MPa-P-2(5%)									
1	3	15	15.02	15.15	7998	3413.295	320.7	14.25	2.34
2		15	14.93	15.18	7970	3399.561	323.2	14.37	2.34
Mean							**321.95**	**14.31**	**2.34**
25MPa-P-2(10%)									
1	3	15.02	15	15.25	7930	3435.825	298.8	13.28	2.31
2		15.01	15	15.2	7999	3422.28	330.4	14.69	2.34
Mean							**314.6**	**13.99**	**2.32**
25MPa-P-2(15%)									
1	3	15.02	15	14.98	7933	3374.994	293.1	13.03	2.35
2		15	15.02	15.19	7931	3422.307	297.9	13.24	2.32
Mean							**295.5**	**13.13**	**2.33**
25MPa-P-2(20%)									
1	3	15	15	15	7922	3375	249.3	11.08	2.35
2		15.02	15	15.45	8010	3480.885	277.4	12.33	2.30
Mean							**263.35**	**11.71**	**2.32**

No	Test age days	Dimensions (cm)			Weight (gm)	Volume (cm3)	Failure load (KN)	Comp. Strength (Mpa)	Unit Weight (gm/cm3)
		L	W	H					
30MPa-P									
1	3	15.02	15	15	7964	3379.50	387.9	17.24	2.36
2		15	15.05	15.22	8029	3435.92	407.3	18.1	2.34
Mean							**397.6**	**17.67**	**2.35**
30MPa-P-1(5%)									
1	3	15	15	15.01	7958	3377.25	370	16.44	2.36
2		15.01	15.01	15.14	8013	3411.0435	340.5	15.13	2.35
Mean							**355.25**	**15.79**	**2.35**
30MPa-P-1(10%)									
1	3	15	15	15.1	7980	3397.5	321.8	14.3	2.35
2		15	15.05	15.28	8020	3449.46	329.9	14.66	2.33
Mean							**325.85**	**14.48**	**2.34**
30MPa-P-1(15%)									
1	3	15.01	15.02	15.28	7988	3444.8791	280.1	12.45	2.32
2		15	15	15.11	7927	3399.75	304.5	13.53	2.33
Mean							**292.3**	**12.99**	**2.33**
30MPa-P-1(20%)									
1	3	15	15.02	15.15	7905	3413.295	286.4	12.73	2.32
2		15.05	15	15.02	7920	3390.765	290.7	12.92	2.34
Mean							**288.55**	**12.83**	**2.33**
30MPa-P-2(5%)									
1	3	15	15	15	7916	3375	365.1	16.22	2.35
2		15.01	15	15.04	7946	3386.256	357.2	15.87	2.35
Mean							**361.15**	**16.05**	**2.35**
30MPa-P-2(10%)									
1	3	15	15.02	15.08	7988	3397.524	333	14.8	2.35
2		15.02	15.02	15.2	7998	3429.1261	370.4	16.46	2.33
Mean							**351.7**	**15.63**	**2.34**
30MPa-P-2(15%)									
1	3	15.01	15	15.06	7933	3390.759	348.9	15.51	2.34
2		15	15.02	15	7913	3379.5	325.2	14.45	2.34
Mean							**337.05**	**14.98**	**2.34**
30MPa-P-2(20%)									
1	3	15	15.03	15.15	7968	3415.5675	289.7	12.87	2.33
2		15.02	15	15.13	7930	3408.789	299.2	13.3	2.33
Mean							**294.4**	**13.08**	**2.33**

E-2 Seven Days Compressive Strength of Concretes

No	Test age days	Dimensions (cm) L	W	H	Weight (gm)	Volume (cm3)	Failure load (KN)	Comp. Strength (Mpa)	Unit Weight (gm/cm3)
25MPa-O									
1	7	15.06	14.9	15.23	8023	3417.5206	422.4	18.77	2.35
2		15.03	15.02	15.14	8043	3417.8641	406.1	18.04	2.35
3		15.1	15.09	15.22	7986	3468.014	409.7	18.21	2.30
Mean							**412.73**	**18.34**	**2.33**
25MPa-O-1(5%)									
1	7	15	15	15.2	7953	3420	410.5	18.24	2.33
2		15	15.1	15.1	8008	3420.15	365.6	16.25	2.34
3		15	15.01	15.1	7945	3399.765	417.5	18.55	2.34
Mean							**397.87**	**17.68**	**2.33**
25MPa-O-1(10%)									
1	7	15.05	15	15.3	8000	3453.975	353.2	15.7	2.32
2		15	15.05	15.2	7995	3431.4	349	15.51	2.33
3		15.11	15	15.2	7992	3445.08	346.5	15.4	2.32
Mean							**349.57**	**15.54**	**2.32**
25MPa-O-1(15%)									
1	7	15.02	15.02	15.2	7915	3429.1261	339.3	15.08	2.31
2		15	15.06	15.3	8012	3456.27	353.4	15.71	2.32
3		15.01	15.01	15	7911	3379.5015	345.4	15.35	2.34
Mean							**346.03**	**15.38**	**2.32**
25MPa-O-1(20%)									
1	7	15.08	15.08	15.2	7816	3456.5773	287.7	12.79	2.26
2		15	15	15.4	7934	3465	277.7	12.34	2.29
3		15.06	15.01	15.41	8043	3483.4397	331.7	14.79	2.31
Mean							**299.03**	**13.31**	**2.29**
25MPa-O-2(5%)									
1	7	15	15	15.3	8005	3442.5	391.7	17.41	2.33
2		15	15.02	15.21	7995	3426.813	415.1	18.45	2.33
3		15.02	15	15.17	7968	3417.801	426.2	18.94	2.33
Mean							**411**	**18.27**	**2.33**
25MPa-O-2(10%)									
1	7	15.02	15	15.1	7966	3402.03	344.1	15.29	2.34
2		15.05	15.01	15.2	7958	3433.6876	384.5	17.09	2.32
3		15.01	15	15.1	7961	3399.765	387.1	17.21	2.34
Mean							**371.9**	**16.53**	**2.33**
25MPa-O-2(15%)									
1	7	15	15.02	15.1	7973	3402.03	370.4	16.46	2.34
2		15.03	15	15.13	7960	3411.0585	380.8	16.93	2.33
3		15	15	15.23	7963	3426.75	358.7	15.94	2.32
Mean							**369.97**	**16.44**	**2.33**
25MPa-O-2(20%)									
1	7	15.04	15	15.1	7919	3406.56	325.9	14.49	2.32
2		15.02	15.01	15.06	7928	3395.28	334.9	14.88	2.34
3		15	15	15.24	7920	3429	331.8	14.75	2.31
Mean							**330.87**	**14.71**	**2.32**

No	Test age days	Dimensions (cm) L	W	H	Weight (gm)	Volume (cm3)	Failure load (KN)	Comp. Strength (Mpa)	Unit Weight (gm/cm3)
30MPa-O									
1	7	15	15.04	15.26	8064	3442.66	549.7	24.43	2.34
2		15.02	15	15.13	8012	3408.79	578.2	25.7	2.35
3		15	15.03	15.08	8046	3399.79	573.1	25.47	2.37
Mean							**567**	**25.2**	**2.35**
30MPa-O-1(5%)									
1	7	15.02	15	15.15	8053	3413.30	502.8	22.35	2.36
2		15	15.01	15.2	8042	3422.28	506.6	22.52	2.35
3		15	15	15.1	7926	3397.50	486.7	21.63	2.33
Mean							**498.7**	**22.17**	**2.35**
30MPa-O-1(10%)									
1	7	15.01	15.01	15.3	7994	3447.092	461.4	20.51	2.32
2		15	15.05	15.26	8045	3444.945	440.9	19.6	2.34
3		15.02	15.05	15.23	8022	3442.757	449.5	19.98	2.33
Mean							**450.60**	**20.03**	**2.33**
30MPa-O-1(15%)									
1	7	15.02	15.01	15.2	8065	3426.84	416.1	18.49	2.35
2		15.01	15	15.36	8026	3458.30	423.6	18.83	2.32
3		15	15.01	15.55	8091	3501.08	415.5	18.46	2.31
Mean							**418.40**	**18.59**	**2.33**
30MPa-O-1(20%)									
1	7	15.02	15.01	15	7924	3381.753	371.9	16.53	2.34
2		15	15.04	15.2	7948	3429.12	395.6	17.58	2.32
3		15	15	15.43	8017	3471.75	346.6	15.41	2.31
Mean							**371.37**	**16.51**	**2.32**
30MPa-O-2(5%)									
1	7	15	15.01	15.2	8025	3422.28	556.1	24.72	2.34
2		15.04	15.01	15.2	8065	3431.41	533.9	23.73	2.35
3		15	15	15.23	7961	3426.75	547.3	24.33	2.32
Mean							**545.8**	**24.26**	**2.34**
30MPa-O-2(10%)									
1	7	15.03	15	15.22	7994	3431.349	521.3	23.17	2.33
2		15	15.01	15.13	7945	3406.5195	528.0	23.47	2.33
3		15	15	14.98	7922	3370.5	517.0	22.98	2.35
Mean							**522.10**	**23.21**	**2.34**
30MPa-O-2(15%)									
1	7	15	15	14.89	7907	3350.25	511.3	22.72	2.36
2		15	15.01	15.19	7940	3420.0285	484.5	21.53	2.32
3		15.01	15	15	7921	3377.25	496.8	22.08	2.35
Mean							**497.5**	**22.11**	**2.34**
30MPa-O-2(20%)									
1	7	15	15.01	15.1	7924	3399.765	460.4	20.44	2.33
2		15	15.02	15.28	8022	3442.584	444.9	19.77	2.33
3		15	15.04	15.17	8017	3422.352	450.7	20.03	2.34
Mean							**452**	**20.08**	**2.33**

No	Test age days	Dimensions (cm) L	W	H	Weight (gm)	Volume (cm3)	Failure load (KN)	Comp. Strength (Mpa)	Unit Weight (gm/cm3)
25MPa-P									
1	7	15	15	15.1	7992	3397.5	410.6	18.25	2.35
2		15	15.08	15.2	8047	3438.24	434.7	19.32	2.34
3		15.04	15.01	15.06	7988	3399.80	459.7	20.43	2.35
Mean							**433.13**	**19.3**	**2.35**
25MPa-P-1(5%)									
1	7	15.06	15.00	15.16	7971.00	3424.64	404.10	17.96	2.33
2		15.00	15.02	15.14	7966.00	3411.04	399.70	17.76	2.34
3		15.01	15.01	15.13	7978.00	3408.79	410.50	18.25	2.34
Mean							**404.7**	**17.99**	**2.33**
25MPa-P-1(10%)									
1	7	15.00	15.06	15.10	7943.00	3411.09	410.90	18.26	2.33
2		15.00	15.04	15.38	8023.00	3469.73	402.00	17.87	2.31
3		15.01	15.02	15.13	7943.00	3411.06	393.30	17.48	2.33
Mean							**402**	**17.87**	**2.32**
25MPa-P-1(15%)									
1	7	15.00	15.02	15.35	7936.00	3458.36	377.40	16.77	2.29
2		15.02	15.03	15.16	7977.00	3422.38	369.90	16.44	2.33
3		15.01	15.00	15.18	7959.00	3417.78	387.00	17.20	2.33
Mean							**378.1**	**16.80**	**2.32**
25MPa-P-1(20%)									
1	7	15.01	15.04	15.05	7917.00	3397.54	344.00	15.29	2.33
2		15.00	15.03	15.09	7866.00	3402.04	324.90	14.44	2.31
3		15.00	15.01	15.11	7921.00	3402.02	327.00	14.53	2.33
Mean							**331.97**	**14.75**	**2.32**
25MPa-P-2(5%)									
1	7	15.01	15.02	15.10	7878.00	3404.30	442.20	19.63	2.31
2		15.01	15.00	15.23	7976.00	3429.03	415.10	18.45	2.33
3		15.00	15.03	15.11	8007.00	3406.55	443.20	19.70	2.35
Mean							**433.5**	**19.26**	**2.33**
25MPa-P-2(10%)									
1	7	15.00	15.03	15.15	8016.00	3415.57	416.50	18.51	2.35
2		15.00	15.00	15.04	7942.00	3384.00	400.60	17.80	2.35
3		15.00	15.01	15.20	7981.00	3422.28	380.70	16.92	2.33
Mean							**399.27**	**17.74**	**2.34**
25MPa-P-2(15%)									
1	7	15.01	15.00	15.14	8003.00	3408.77	401.00	17.82	2.35
2		15.03	15.00	15.38	8080.00	3467.42	372.40	16.55	2.33
3		15.00	15.01	15.06	7959.00	3390.76	362.60	16.12	2.35
Mean							**378.7**	**16.83**	**2.34**
25MPa-P-2(20%)									
1	7	15.00	15.02	15.21	7978.00	3426.81	370.70	16.47	2.33
2		15.01	15.01	15.10	7956.00	3402.03	380.80	16.92	2.34
3		15.00	15.00	15.14	7952.00	3406.50	376.40	16.73	2.33
Mean							**375.9**	**16.71**	**2.33**

No	Test age days	Dimensions (cm) L	W	H	Weight (gm)	Volume (cm3)	Failure load (KN)	Comp. Strength (Mpa)	Unit Weight (gm/cm3)
30MPa-P									
1	7	15.04	15.01	15.31	8100.00	3456.24	481.10	21.38	2.34
2		15.02	15.03	15.05	8004.00	3397.55	505.00	22.45	2.36
3		15.00	15.00	14.89	7932.00	3350.25	504.20	22.41	2.37
Mean							**496.77**	**22.08**	**2.36**
30MPa-P-1(5%)									
1	7	15.02	15.02	15.10	8027.00	3406.57	473.00	21.03	2.36
2		15.00	15.04	15.14	8032.00	3415.58	450.90	20.04	2.35
3		15.01	15.00	15.20	8042.00	3422.28	489.80	21.77	2.35
Mean							**471.23**	**20.95**	**2.35**
30MPa-P-1(10%)									
1	7	15.00	15.00	15.11	7978.00	3399.75	387.60	17.23	2.35
2		15.00	15.01	15.01	7948.00	3379.50	372.20	16.54	2.35
3		15.04	15.06	15.35	8098.00	3476.81	429.70	19.10	2.33
Mean							**396.5**	**17.62**	**2.34**
30MPa-P-1(15%)									
1	7	15.00	15.02	15.41	8059.00	3471.87	378.00	16.80	2.32
2		15.01	15.00	15.10	7934.00	3399.77	345.70	15.36	2.33
3		15.00	15.01	15.05	7942.00	3388.51	401.40	17.84	2.34
Mean							**375.03**	**16.67**	**2.33**
30MPa-P-1(20%)									
1	7	15.01	15.00	15.04	7908.00	3386.26	357.70	15.90	2.34
2		15.00	15.01	15.16	7911.00	3413.27	368.30	16.37	2.32
3		15.02	15.01	15.20	7928.00	3426.84	355.70	15.81	2.31
Mean							**360.57**	**16.03**	**2.32**
30MPa-P-2(5%)									
1	7	15.01	15.00	15.11	8065.00	3402.02	495.80	22.04	2.37
2		15.02	15.02	15.24	8087.00	3438.15	437.00	19.42	2.35
3		15.00	15.01	15.08	8052.00	3395.26	529.70	23.54	2.37
Mean							**487.50**	**21.67**	**2.36**
30MPa-P-2(10%)									
1	7	15.01	15.01	15.00	7992.00	3379.50	446.80	19.86	2.36
2		15.02	15.03	15.08	8044.00	3404.32	425.80	18.92	2.36
3		15.01	15.00	14.98	7961.00	3372.75	434.30	19.30	2.36
Mean							**435.63**	**19.36**	**2.36**
30MPa-P-2(15%)									
1	7	15.00	15.00	15.10	7980.00	3397.50	431.90	19.20	2.35
2		15.00	15.08	15.20	7920.00	3438.24	436.30	19.39	2.30
3		15.04	15.01	15.40	8056.00	3476.56	411.90	18.31	2.32
Mean							**426.7**	**18.97**	**2.32**
30MPa-P-2(20%)									
1	7	15.00	15.03	15.12	7919.00	3408.80	371.90	16.53	2.32
2		15.01	15.04	15.18	7956.00	3426.89	395.60	17.58	2.32
3		15.00	15.02	15.14	7947.00	3411.04	374.10	16.63	2.33
Mean							**380.53**	**16.91**	**2.32**

E-3 Twenty Eight Days Compressive strength of Concretes

No	Test age days	Dimensions (cm) L	W	H	Weight (gm)	Volume (cm3)	Failure load (KN)	Comp. Strength (Mpa)	Unit Weight (gm/cm3)
25MPa-O									
1	28	15.05	15	15.21	8049	3433.6575	775.8	34.48	2.34
2		15	15	15.13	8020	3404.25	750.2	33.34	2.36
3		15	15	15.1	7988	3397.5	740.1	32.99	2.35
						Mean	**755.37**	**33.60**	**2.35**
25MPa-O-1(5%)									
1	28	15.1	15.1	15.1	8080	3442.951	715.2	31.79	2.35
2		15	15.1	15.1	8017	3420.15	764.4	33.17	2.34
3		15	15.2	15.1	8027	3442.8	690.7	30.7	2.33
						Mean	**723.43**	**31.89**	**2.34**
25MPa-O-1(10%)									
1	28	15	15	15.3	8015	3442.5	675.6	30.03	2.33
2		15	15	15.2	7992	3420	657.2	29.21	2.34
3		15	15	15.1	8011	3397.5	687.6	30.56	2.36
						Mean	**673.47**	**29.93**	**2.34**
25MPa-O-1(15%)									
1	28	15.1	15	15.25	8036	3454.125	652.8	29.01	2.33
2		15	15.07	15.16	7997	3426.918	619.5	27.53	2.33
3		15	15.02	15.3	8012	3447.09	594.9	26.44	2.32
						Mean	**622.40**	**27.66**	**2.33**
25MPa-O-1(20%)									
1	28	15.00	15.01	15.30	7966.00	3444.80	551.20	24.50	2.31
2		15.07	15.00	15.32	8003.00	3463.09	519.50	23.09	2.31
3		15.05	15.02	15.15	7916.00	3424.67	546.20	24.28	2.31
						Mean	**538.97**	**23.96**	**2.31**
25MPa-O-2(5%)									
1	28	15.00	15.00	15.10	8004.00	3397.50	754.40	33.53	2.36
2		15.00	15.03	15.00	7930.00	3381.75	747.20	33.21	2.34
3		15.00	15.00	15.20	8023.00	3420.00	735.10	32.67	2.35
						Mean	**745.57**	**33.14**	**2.35**
25MPa-O-2(10%)									
1	28	15.02	15	15.1	7970	3402.03	710.9	31.6	2.34
2		15.01	15.02	15.2	8001	3426.843	726.9	32.31	2.33
3		15	15	15	7915	3375	730.3	32.46	2.35
						Mean	**722.70**	**32.12**	**2.34**
25MPa-O-2(15%)									
1	28	15	15	15.35	8031	3453.75	618.3	27.48	2.33
2		15	15.03	15.31	7992	3451.6395	647.6	28.78	2.32
3		15.01	15	14.93	7969	3361.4895	661.5	29.4	2.37
						Mean	**642.47**	**28.55**	**2.34**
25MPa-O-2(20%)									
1	28	15	15	15.08	7978	3393	612.5	27.22	2.35
2		15	15	15.1	7970	3397.5	570.8	25.37	2.35
3		15	15.01	15.11	7939	3402.0165	608.1	27.02	2.33
						Mean	**597.13**	**26.54**	**2.34**

No	Test age days	Dimensions (cm) L	W	H	Weight (gm)	Volume (cm3)	Failure load (KN)	Comp. Strength (Mpa)	Unit Weight (gm/cm3)
30MPa-O									
1	28	15.00	15.01	15.06	8052.00	3390.76	923.30	41.03	2.37
2		15.02	15.00	15.24	8078.00	3433.57	885.00	39.24	2.35
3		15.00	15.00	15.20	8055.00	3420.00	900.80	40.04	2.36
						Mean	**903.03**	**40.10**	**2.36**
30MPa-O-1(5%)									
1	28	15.00	15.01	15.06	8027.00	3390.76	870.80	38.70	2.37
2		15.02	15.00	15.10	7997.00	3402.03	871.80	38.74	2.35
3		15.04	15.00	15.20	8024.00	3429.12	871.30	38.72	2.34
						Mean	**871.30**	**38.72**	**2.35**
30MPa-O-1(10%)									
1	28	15.04	15.02	15.42	8081.00	3483.39	796.70	35.41	2.32
2		15.00	15.00	15.20	7959.00	3420.00	791.50	35.18	2.33
3		15.01	15.01	14.98	7974.00	3375.00	838.00	37.24	2.36
						Mean	**808.73**	**35.94**	**2.34**
30MPa-O-1(15%)									
1	28	15.00	15.02	15.08	7975.00	3397.52	726.40	32.29	2.35
2		15.00	15.00	15.12	7952.00	3402.00	701.30	31.17	2.34
3		15.01	15.02	15.23	8011.00	3433.61	729.40	32.42	2.33
						Mean	**719.03**	**31.96**	**2.34**
30MPa-O-1(20%)									
1	28	15.00	15.01	15.48	8017.00	3485.32	649.00	28.84	2.30
2		15.00	15.04	15.10	7990.00	3406.56	678.80	30.17	2.35
3		15.01	15.00	14.99	7919.00	3375.00	614.10	27.30	2.35
						Mean	**647.30**	**28.77**	**2.33**
30MPa-O-2(5%)									
1	28	15.00	15.01	15.13	8053.00	3406.52	872.50	38.77	2.36
2		15.01	15.02	15.04	8024.00	3390.77	886.80	39.43	2.37
3		15.03	15.02	15.52	8096.00	3503.65	913.00	40.58	2.31
						Mean	**890.77**	**39.59**	**2.35**
30MPa-O-2(10%)									
1	28	15.02	15.00	15.20	8044.00	3424.56	895.30	39.79	2.35
2		15.02	15.01	15.24	8031.00	3435.86	854.80	37.99	2.34
3		15.04	15.00	15.36	8072.00	3465.22	816.00	36.37	2.33
						Mean	**855.37**	**38.05**	**2.34**
30MPa-O-2(15%)									
1	28	15.00	15.00	15.31	8030.00	3444.75	831.40	36.95	2.33
2		15.03	15.03	15.40	8062.00	3478.87	814.90	36.22	2.32
3		15.00	15.01	15.00	7977.00	3377.25	773.20	34.36	2.36
						Mean	**806.50**	**35.84**	**2.34**
30MPa-O-2(20%)									
1	28	15.03	15.00	15.10	7990.00	3404.30	813.00	36.13	2.35
2		15.00	15.02	15.42	8050.00	3474.13	770.50	34.23	2.32
3		15.01	15.01	15.05	7969.00	3390.77	787.30	34.99	2.35
						Mean	**790.27**	**35.12**	**2.34**

No	Test age days	Dimensions (cm)			Weight (gm)	Volume (cm3)	Failure load (KN)	Comp. Strength (Mpa)	Unit Weight (gm/cm3)
		L	W	H					
25MPa-P									
1	28	15.01	15.02	15.28	8045.00	3444.88	750.20	33.34	2.34
2		15.00	15.02	15.19	7999.00	3422.31	675.50	29.22	2.34
3		15.07	15.00	15.12	8084.00	3417.88	761.90	33.86	2.37
Mean							**729.20**	**32.14**	**2.35**
25MPa-P-1(5%)									
1	28	15.08	15.00	15.29	8080.00	3458.60	678.30	30.14	2.34
2		15.01	15.01	15.16	7952.00	3415.55	634.40	28.20	2.33
3		15.01	15.02	15.09	7975.00	3402.04	692.30	30.77	2.34
Mean							**668.33**	**29.70**	**2.34**
25MPa-P-1(10%)									
1	28	15.00	15.00	15.10	8022.00	3397.50	569.20	25.30	2.36
2		15.01	15.01	15.14	7958.00	3411.04	644.20	29.52	2.33
3		15.00	15.03	15.50	8035.00	3494.48	564.70	25.10	2.30
Mean							**592.70**	**26.64**	**2.33**
25MPa-P-1(15%)									
1	28	15.02	15.01	15.00	7931.00	3381.75	555.50	24.69	2.35
2		15.00	15.03	15.35	7983.00	3460.66	534.30	23.75	2.31
3		15.00	15.00	15.11	7949.00	3399.75	548.30	24.33	2.34
Mean							**546.03**	**24.26**	**2.33**
25MPa-P-1(20%)									
1	28	15.01	15.00	15.21	7892.00	3424.53	504.70	22.43	2.30
2		15.03	15.00	15.14	7963.00	3413.31	496.40	22.06	2.33
3		15.01	15.01	15.10	7876.00	3402.03	496.10	22.05	2.32
Mean							**499.07**	**22.18**	**2.32**
25MPa-P-2(5%)									
1	28	15.06	15.00	15.25	7935.00	3444.98	712.80	31.46	2.30
2		15.01	15.01	14.97	7936.00	3372.74	732.60	32.56	2.35
3		15.02	15.03	15.00	7986.00	3386.26	707.90	31.46	2.36
Mean							**717.77**	**31.83**	**2.34**
25MPa-P-2(10%)									
1	28	15.01	15.01	15.21	7996.00	3426.81	667.30	29.66	2.33
2		15.00	15.00	15.10	8005.00	3397.50	649.00	28.84	2.36
3		15.00	15.03	15.35	8042.00	3460.66	633.50	28.15	2.32
Mean							**649.93**	**28.88**	**2.34**
25MPa-P-2(15%)									
1	28	15.02	15.00	15.00	7960.00	3379.50	616.10	27.38	2.36
2		15.00	15.04	15.33	7944.00	3458.45	603.70	26.83	2.30
3		15.00	15.02	15.01	7974.00	3381.75	640.50	28.47	2.36
Mean							**620.10**	**27.56**	**2.34**
25MPa-P-2(20%)									
1	28	15.02	15.00	15.11	7938.00	3404.28	614.00	27.28	2.33
2		15.03	15.02	15.23	7998.00	3438.18	565.40	25.13	2.33
3		15.00	15.00	15.14	7988.00	3406.50	573.30	25.57	2.34
Mean							**584.23**	**25.99**	**2.33**

No	Test age days	Dimensions (cm) L	W	H	Weight (gm)	Volume (cm3)	Failure load (KN)	Comp. Strength (MPa)	Unit Weight (gm/cm3)
30MPa-P									
1	28	15.01	15.01	15.10	7976.00	3402.03	950.20	42.23	2.34
2		15.00	15.00	15.07	8040.00	3390.75	877.40	38.99	2.37
3		15.02	15.00	15.14	8059.00	3411.04	928.30	41.26	2.36
						Mean	**918.63**	**40.83**	**2.36**
30MPa-P-1(5%)									
1	28	15.00	15.01	15.12	7992.00	3404.27	806.10	35.82	2.35
2		15.06	15.02	15.18	8084.00	3433.73	833.70	37.05	2.35
3		15.02	15.00	15.06	8006.00	3393.02	800.01	35.55	2.36
						Mean	**813.27**	**36.14**	**2.35**
30MPa-P-1(10%)									
1	1	15.02	15.01	15.26	8001.00	3440.37	705.40	31.35	2.33
2		15.02	15.02	15.00	7955.00	3384.01	743.50	33.04	2.35
3		15.04	15.00	15.29	8035.00	3449.42	718.70	31.94	2.33
						Mean	**722.53**	**32.11**	**2.34**
30MPa-P-1(15%)									
1	28	15.02	15.01	15.27	8015.00	3442.62	688.40	30.59	2.33
2		15.00	15.00	15.05	7930.00	3386.25	623.90	27.53	2.34
3		15.01	15.01	15.05	7922.00	3390.77	595.00	26.44	2.34
						Mean	**635.77**	**28.19**	**2.34**
30MPa-P-1(20%)									
1	28	15.02	15.00	15.19	7909.00	3422.31	582.00	25.86	2.31
2		15.01	15.00	15.10	7935.00	3399.77	613.70	27.28	2.33
3		15.01	15.01	15.12	7918.00	3406.54	577.10	25.64	2.32
						Mean	**590.93**	**26.26**	**2.32**
30MPa-P-2(5%)									
1	28	15.00	15.02	15.13	7981.00	3408.79	908.60	40.38	2.34
2		15.01	15.00	15.30	8063.00	3444.80	864.50	38.42	2.34
3		15.02	15.00	15.26	8016.00	3438.08	887.90	39.47	2.33
						Mean	**887.00**	**39.42**	**2.34**
30MPa-P-2(10%)									
1	28	15.01	15.00	15.11	7953.00	3402.02	793.40	35.26	2.34
2		15.00	15.02	15.04	7996.00	3388.51	782.80	34.80	2.36
3		15.04	15.00	15.23	8024.00	3435.89	811.20	36.04	2.34
						Mean	**795.80**	**35.37**	**2.34**
30MPa-P-2(15%)									
1	28	15.01	15.00	15.20	7974.00	3422.28	663.10	29.46	2.33
2		14.98	15.01	15.07	7967.00	3388.49	704.20	31.30	2.35
3		15.00	15.00	14.96	8004.00	3366.00	686.20	30.51	2.38
						Mean	**684.50**	**30.42**	**2.35**
30MPa-P-2(20%)									
1	28	15.01	15.02	14.95	7908.00	3370.48	616.60	27.40	2.35
2		15.00	15.00	15.04	7974.00	3384.00	615.70	27.37	2.36
3		15.00	15.01	15.17	7953.00	3415.53	655.60	29.14	2.33
						Mean	**629.30**	**27.97**	**2.34**

APPENDIX F

SUMMARY OF MEAN COMPRESSIVE STRENGTH RESULTS OF 150X150X150mm CONCRETE CUBES

Mix code	3 days		7 days		28 days	
	Failure load(KN)	Compressive strength (Mpa)	Failure load(KN)	Compressive strength (Mpa)	Failure load(KN)	Compressive strength (Mpa)
25MPa-O	406.90	16.77	412.73	18.34	755.37	33.60
25MPa-O-1(5%)	402.70	15.08	397.87	17.68	723.43	31.88
25MPa-O-1(10%)	367.65	12.90	349.57	15.54	673.47	29.93
25MPa-O-1(15%)	315.45	11.50	346.03	15.38	622.40	27.66
25MPa-O-1(20%)	279.00	10.91	299.03	13.31	538.97	23.96
25MPa-O	406.90	16.77	412.73	18.34	755.37	33.60
25MPa-O-2(5%)	398.75	16.20	411.00	18.27	745.57	33.14
25MPa-O-2(10%)	349.30	14.76	371.90	16.53	722.70	32.12
25MPa-O-2(15%)	328.60	13.97	369.97	16.44	642.47	28.55
25MPa-O-2(20%)	328.35	11.71	330.87	14.71	597.13	26.54
30MPa-O	406.90	18.08	567.00	25.20	903.03	40.10
30MPa-O-1(5%)	398.75	17.73	498.70	22.17	871.30	38.72
30MPa-O-1(10%)	349.30	15.53	450.60	20.03	808.73	35.94
30MPa-O-1(15%)	315.45	14.02	418.40	18.59	719.03	31.96
30MPa-O-1(20%)	279.00	12.40	371.37	16.51	647.30	28.77
30MPa-O	406.90	18.08	567.00	25.20	903.03	40.10
30MPa-O-2(5%)	402.70	17.90	545.77	24.26	890.77	39.59
30MPa-O-2(10%)	367.65	16.34	522.10	23.21	856.04	38.05
30MPa-O-2(15%)	328.60	14.70	497.50	22.11	806.50	35.84
30MPa-O-2(20%)	328.35	14.59	452.00	20.08	790.27	35.12
25MPa-P	323.67	14.37	433.13	19.30	729.20	32.14
25MPa-P-1(5%)	320.45	14.15	404.70	17.99	668.33	29.70
25MPa-P-1(10%)	308.25	13.70	402.00	17.87	592.70	26.64
25MPa-P-1(15%)	252.90	11.24	378.10	16.80	546.03	24.26
25MPa-P-1(20%)	224.20	9.96	331.97	14.75	499.07	22.18
25MPa-P	323.67	14.37	433.13	19.30	729.20	32.14
25MPa-P-2(5%)	321.95	14.31	433.50	19.26	717.77	31.83
25MPa-P-2(10%)	314.60	13.99	399.27	17.74	649.93	28.88
25MPa-P-2(15%)	295.50	13.13	378.70	16.83	620.10	27.56
25MPa-P-2(20%)	263.35	11.71	375.90	16.71	584.23	25.99
30MPa-P	397.60	17.67	496.77	22.08	918.63	40.82
30MPa-P-1(5%)	355.25	15.79	471.23	20.95	813.27	36.14
30MPa-P-1(10%)	325.85	14.48	396.50	17.62	722.53	32.11
30MPa-P-1(15%)	292.30	12.99	375.03	16.67	635.77	28.19
30MPa-P-1(20%)	288.55	12.83	360.57	16.03	590.93	26.26
30MPa-P	397.60	17.67	496.77	22.08	918.63	40.82
30MPa-P-2(5%)	361.15	16.05	478.50	21.67	887.00	39.42
30MPa-P-2(10%)	351.70	15.63	435.63	19.36	795.80	35.37
30MPa-P-2(15%)	337.05	14.98	426.70	18.97	684.50	30.42
30MPa-P-2(20%)	294.40	13.08	380.53	16.91	629.30	27.97

APPENDIX G

MEAN COMPRESSIVE STRENGTH RESULTS CONVERTED TO 300mm X 150mm CONCRETE CYLINDER

Mix code	3 days		7 days		28 days	
	Failure load(KN)	Compressive strength (MPa)	Failure load(KN)	Compressive strength (MPa)	Failure load(KN)	Compressive strength (MPa)
25MPa-O	325.52	13.42	330.19	14.67	604.29	26.88
25MPa-O-1(5%)	322.16	12.06	318.29	14.14	578.75	25.50
25MPa-O-1(10%)	294.12	10.32	279.65	12.43	538.77	23.95
25MPa-O-1(15%)	252.36	9.20	276.83	12.30	497.92	22.13
25MPa-O-1(20%)	223.20	8.72	239.23	10.65	431.17	19.17
25MPa-O	325.52	13.42	330.19	14.67	604.29	26.88
25MPa-O-2(5%)	319.00	12.96	328.80	14.61	596.45	26.51
25MPa-O-2(10%)	279.44	11.81	297.52	13.22	578.16	25.70
25MPa-O-2(15%)	262.88	11.17	295.97	13.15	513.97	22.84
25MPa-O-2(20%)	262.68	9.37	264.69	11.77	477.71	21.23
30MPa-O	325.52	14.46	453.60	20.16	722.43	32.08
30MPa-O-1(5%)	319.00	14.18	398.96	17.74	697.04	30.98
30MPa-O-1(10%)	279.44	12.42	360.48	16.02	646.99	28.75
30MPa-O-1(15%)	252.36	11.22	334.72	14.87	575.23	25.57
30MPa-O-1(20%)	223.20	9.92	297.09	13.21	517.84	23.02
30MPa-O	325.52	14.46	453.60	20.16	722.43	32.08
30MPa-O-2(5%)	322.16	14.32	436.61	19.41	712.61	31.67
30MPa-O-2(10%)	294.12	13.07	417.68	18.57	684.83	30.44
30MPa-O-2(15%)	262.88	11.76	398.00	17.69	645.20	28.67
30MPa-O-2(20%)	262.68	11.67	361.60	16.06	632.21	28.09
25MPa-P	258.94	11.50	346.50	15.44	583.36	25.71
25MPa-P-1(5%)	256.36	11.32	323.76	14.39	534.67	23.76
25MPa-P-1(10%)	246.60	10.96	321.60	14.30	474.16	21.31
25MPa-P-1(15%)	202.32	8.99	302.48	13.44	436.83	19.41
25MPa-P-1(20%)	179.36	7.97	265.57	11.80	399.25	17.74
25MPa-P	258.94	11.50	346.50	15.44	583.36	25.71
25MPa-P-2(5%)	257.56	11.45	346.80	15.41	574.21	25.46
25MPa-P-2(10%)	251.68	11.19	319.41	14.19	519.95	23.11
25MPa-P-2(15%)	236.40	10.50	302.96	13.46	496.08	22.05
25MPa-P-2(20%)	210.68	9.36	300.72	13.37	467.39	20.79
30MPa-P	318.08	14.14	397.41	17.66	734.91	32.66
30MPa-P-1(5%)	284.20	12.63	376.98	16.76	650.62	28.91
30MPa-P-1(10%)	260.68	11.58	317.20	14.10	578.03	25.69
30MPa-P-1(15%)	233.84	10.39	300.03	13.33	508.61	22.55
30MPa-P-1(20%)	230.84	10.26	288.45	12.82	472.75	21.01
30MPa-P	318.08	14.14	397.41	17.66	734.91	32.66
30MPa-P-2(5%)	288.92	12.84	382.80	17.34	709.60	31.54
30MPa-P-2(10%)	281.36	12.50	348.51	15.49	636.64	28.29
30MPa-P-2(15%)	269.64	11.98	341.36	15.17	547.60	24.34
30MPa-P-2(20%)	235.52	10.46	304.43	13.53	503.44	22.38

APPENDIX H

COST BREAK DOWN FOR DIFFERENT CONCRETES

H-1 Cost breakdown for C25 PPC/BCD concretes Case 1

Item : ***CONCRETE***				
TYPE	**25MPa-P**			
TOTAL QUANTITY OF ITEM:	1 m3			
Type of Material	**Unit**	**Qty ***	**Rate (birr)**	**Cost per Unit(birr)**
Cement	Qnt.	4.13	230.00	949.90
Sand	m3	0.44	500.00	221.00
C.Aggregate	m^3	0.62	450.00	279.00
Water	m^3	0.24	5.00	1.21
Crusher dust	kg		0.23	0.00
Total				1451.105

TYPE	**25MPa-P(5%)**			
TOTAL QUANTITY OF ITEM:	1 m3			
Type of Material	**Unit**	**Qty ***	**Rate (birr)**	**Cost per Unit(birr)**
Cement	Qnt.	3.93	230.00	903.21
Sand	m3	0.44	500.00	221.00
C.Aggregate	m^3	0.62	450.00	279.00
Water	m^3	0.24	5.00	1.21
Crusher dust	kg	20.67	0.23	4.67
Total				1409.087
Total cost saved due to 5% basaltic crusher dust replacement (%)				**2.9**

TYPE	**25MPa-P(10%)**			
TOTAL QUANTITY OF ITEM:	1 m3			
Type of Material	**Unit**	**Qty ***	**Rate (birr)**	**Cost per Unit(birr)**
Cement	Qnt.	3.72	230.00	855.60
Sand	m3	0.44	500.00	221.00
C.Aggregate	m^3	0.62	450.00	279.00
Water	m^3	0.24	5.00	1.21
Crusher dust	kg	41.34	0.23	9.34
Total				1366.15
Total cost saved due to 10% basaltic crusher dust replacement (%)				**5.9**

H-2 Cost breakdown for C25 OPC/BCD concretes Case 1

Item : ***CONCRETE***				
TYPE	**25MPa-O**			
TOTAL QUANTITY OF ITEM:	1 m3			
Type of Material	**Unit**	**Qty ***	**Rate (birr)**	**Cost per Unit(birr)**
Cement	Qnt.	4.13	280.00	1156.40
Sand	m3	0.44	500.00	221.00
C.Aggregate	m^3	0.62	450.00	278.55
Water	m^3	0.24	5.00	1.21
Crusher dust	kg		0.23	0.00
Total (1:-01)				1657.155
TYPE	**25MPa-O(5%)**			
TOTAL QUANTITY OF ITEM:	1 m3			
Type of Material	**Unit**	**Qty ***	**Rate (birr)**	**Cost per Unit(birr)**
Cement	Qnt.	3.93	280.00	1099.56
Sand	m3	0.44	500.00	221.00
C.Aggregate	m^3	0.62	450.00	278.55
Water	m^3	0.24	5.00	1.21
Crusher dust	kg	20.67	0.23	4.67
Total				1604.987
Total cost saved due to 5% basaltic crusher dust replacement (%)				**3.1**
TYPE	**25MPa-P(10%)**			
TOTAL QUANTITY OF ITEM:	1 m3			
Type of Material	**Unit**	**Qty ***	**Rate (birr)**	**Cost per Unit(birr)**
Cement	Qnt.	3.72	280.00	1041.60
Sand	m3	0.44	500.00	221.00
C.Aggregate	m^3	0.62	450.00	278.55
Water	m^3	0.24	5.00	1.21
Crusher dust	kg	41.34	0.23	9.34
Total				1551.699
Total cost saved due to 10% basaltic crusher dust replacement (%)				**6.4**

H-3 Cost breakdown for C30 PPC/BCD concretes Case 1

Item : ***CONCRETE***				
TYPE	**30MPa-P**			
TOTAL QUANTITY OF ITEM:	1 m3			
Type of Material	**Unit**	**Qty ***	**Rate (birr)**	**Cost per Unit(birr)**
Cement	Qnt.	4.58	230.00	1053.40
Sand	m3	0.41	500.00	205.00
C.Aggregate	m^3	0.62	450.00	278.10
Water	m^3	0.24	5.00	1.19
Crusher dust	kg		0.23	0.00
Total				1537.69
TYPE	**30MPa-P(5%)**			
TOTAL QUANTITY OF ITEM:	1 m3			
Type of Material	**Unit**	**Qty ***	**Rate (birr)**	**Cost per Unit(birr)**
Cement	Qnt.	4.35	230.00	1000.50
Sand	m3	0.41	500.00	205.00
C.Aggregate	m^3	0.62	450.00	278.10
Water	m^3	0.24	5.00	1.19
Crusher dust	kg	22.91	0.23	5.18
Total				1489.97
Total cost saved due to 5% basaltic crusher dust replacement (%)				**3.1**
TYPE	**30MPa-P(10%)**			
TOTAL QUANTITY OF ITEM:	1 m3			
Type of Material	**Unit**	**Qty ***	**Rate (birr)**	**Cost per Unit(birr)**
Cement	Qnt.	4.12	230.00	947.60
Sand	m3	0.41	500.00	205.00
C.Aggregate	m^3	0.62	450.00	278.10
Water	m^3	0.24	5.00	1.19
Crusher dust	kg	45.82	0.23	10.36
Total				1442.25
Total cost saved due to 10% basaltic crusher dust replacement (%)				**6.2**

H-4 Cost breakdown for C30 OPC/BCD concretes Case 1

Item : ***CONCRETE***				
TYPE	**30MPa-O**			
TOTAL QUANTITY OF ITEM:	1 m3			
Type of Material	**Unit**	**Qty ***	**Rate (birr)**	**Cost per Unit(birr)**
Cement	Qnt.	4.58	280.00	1282.40
Sand	m3	0.41	500.00	205.00
C.Aggregate	m^3	0.62	450.00	278.10
Water	m^3	0.24	5.00	1.19
Crusher dust	kg		0.23	0.00
Total				1766.69

TYPE	**30MPa-O(5%)**			
TOTAL QUANTITY OF ITEM:	1 m3			
Type of Material	**Unit**	**Qty ***	**Rate (birr)**	**Cost per Unit(birr)**
Cement	Qnt.	4.35	280.00	1218.00
Sand	m3	0.41	500.00	205.00
C.Aggregate	m^3	0.62	450.00	278.10
Water	m^3	0.24	5.00	1.19
Crusher dust	kg	22.91	0.23	5.18
Total				1707.468
Total cost saved due to 5% basaltic crusher dust replacement (%)				**3.4**

TYPE	**30MPa-O(10%)**			
TOTAL QUANTITY OF ITEM:	1 m3			
Type of Material	**Unit**	**Qty ***	**Rate (birr)**	**Cost per Unit(birr)**
Cement	Qnt.	4.12	280.00	1153.60
Sand	m3	0.41	500.00	205.00
C.Aggregate	m^3	0.62	450.00	278.10
Water	m^3	0.24	5.00	1.19
Crusher dust	kg	45.82	0.23	10.36
Total				1648.246
Total cost saved due to 10% basaltic crusher dust replacement (%)				**6.7**

H-5 Cost breakdown for cost of scalping to be added on price of crusher by-product

No	Scalped rock in m3	Total cost of scalping by labors (birr)	Cost of scalping in (birr/ m3)	Cost to be added on price of crusher by-product (birr/m3)
1	14.50	300	20.68	82.75
2	12	250	20.83	83.33
3	12	300	25	100.0
Average cost of scalping to be added on cost of crusher by product (birr/m3)				**88.7**

H-6 Cost breakdown for C25 PPC/BCD concretes Case 2

Item : ***CONCRETE***				
TYPE	**25MPa-P**			
TOTAL QUANTITY OF ITEM:	1 m3			
Type of Material	**Unit**	**Qty ***	**Rate**	**Cost per**
Cement	Qnt.	4.13	230.00	949.90
Sand	m3	0.44	500.00	221.00
C.Aggregate	m^3	0.62	450.00	279.00
Water	m^3	0.24	5.00	1.21
Crusher dust	kg		0.36	0.00
Total				1451.11
TYPE	**25MPa-P(5%)**			
TOTAL QUANTITY OF ITEM:	1 m3			
Type of Material	**Unit**	**Qty ***	**Rate**	**Cost per**
Cement	Qnt.	3.93	230.00	903.21
Sand	m3	0.44	500.00	221.00
C.Aggregate	m^3	0.62	450.00	279.00
Water	m^3	0.24	5.00	1.21
Crusher dust	kg	20.67	0.36	7.44
Total				1411.86
Total cost saved due to 5% basaltic crusher dust replacement (%)				**2.7**
TYPE	**25MPa-P(10%)**			
TOTAL QUANTITY OF ITEM:	1 m3			
Type of Material	**Unit**	**Qty ***	**Rate**	**Cost per**
Cement	Qnt.	3.72	230.00	855.60
Sand	m3	0.44	500.00	221.00
C.Aggregate	m^3	0.62	450.00	279.00
Water	m^3	0.24	5.00	1.21
Crusher dust	kg	41.34	0.36	14.88
Total				1371.69
Total cost saved due to 10% basaltic crusher dust replacement (%)				**5.5**

H-7 Cost breakdown for C25 OPC/BCD concretes Case 2

Item : ***CONCRETE***				
TYPE	**25MPa-O**			
TOTAL QUANTITY OF ITEM:	1 m3			
Type of Material	**Unit**	**Qty ***	**Rate**	**Cost per**
Cement	Qnt.	4.13	280.00	1156.40
Sand	m3	0.44	500.00	221.00
C.Aggregate	m^3	0.62	450.00	278.55
Water	m^3	0.24	5.00	1.21
Crusher dust	kg		0.36	0.00
Total (1:-01)				1657.16
TYPE	**25MPa-O(5%)**			
TOTAL QUANTITY OF ITEM:	1 m3			
Type of Material	**Unit**	**Qty ***	**Rate**	**Cost per**
Cement	Qnt.	3.93	280.00	1099.56
Sand	m3	0.44	500.00	221.00
C.Aggregate	m^3	0.62	450.00	278.55
Water	m^3	0.24	5.00	1.21
Crusher dust	kg	20.67	0.36	7.44
Total				1607.76
Total cost saved due to 5% basaltic crusher dust replacement (%)				**3.0**
TYPE	**25MPa-P(10%)**			
TOTAL QUANTITY OF ITEM:	1 m3			
Type of Material	**Unit**	**Qty ***	**Rate**	**Cost per**
Cement	Qnt.	3.72	280.00	1041.60
Sand	m3	0.44	500.00	221.00
C.Aggregate	m^3	0.62	450.00	278.55
Water	m^3	0.24	5.00	1.21
Crusher dust	kg	41.34	0.36	14.88
Total				1557.24
Total cost saved due to 10% basaltic crusher dust replacement (%)				**6.0**

..

H-8 Cost breakdown for C30 PPC/BCD concretes Case 2

Item : ***CONCRETE***				
TYPE	**30MPa-P**			
TOTAL QUANTITY OF ITEM:	1 m3			
Type of Material	**Unit**	**Qty ***	**Rate**	**Cost per**
Cement	Qnt.	4.58	230.00	1053.40
Sand	m3	0.41	500.00	205.00
C.Aggregate	m^3	0.62	450.00	278.10
Water	m^3	0.24	5.00	1.19
Crusher dust	kg		0.36	0.00
Total				1537.69

TYPE	**30MPa-P(5%)**			
TOTAL QUANTITY OF ITEM:	1 m3			
Type of Material	**Unit**	**Qty ***	**Rate**	**Cost per Unit**
Cement	Qnt.	4.35	230.00	1000.50
Sand	m3	0.41	500.00	205.00
C.Aggregate	m^3	0.62	450.00	278.10
Water	m^3	0.24	5.00	1.19
Crusher dust	kg	22.91	0.36	8.25
Total				1493.04
Total cost saved due to 5% basaltic crusher dust replacement (%)				**2.9**

TYPE	**30MPa-P(10%)**			
TOTAL QUANTITY OF ITEM:	1 m3			
Type of Material	**Unit**	**Qty ***	**Rate**	**Cost per Unit**
Cement	Qnt.	4.12	230.00	947.60
Sand	m3	0.41	500.00	205.00
C.Aggregate	m^3	0.62	450.00	278.10
Water	m^3	0.24	5.00	1.19
Crusher dust	kg	45.82	0.36	16.50
Total				1448.39
Total cost saved due to 10% basaltic crusher dust replacement (%)				**5.8**

H-9 Cost breakdown for C30 OPC/BCD concretes Case 2

Item : ***CONCRETE***				
TYPE	**30MPa-O**			
TOTAL QUANTITY OF ITEM:	1 m3			
Type of Material	**Unit**	**Qty ***	**Rate**	**Cost per**
Cement	Qnt.	4.58	280.00	1282.40
Sand	m3	0.41	500.00	205.00
C.Aggregate	m^3	0.62	450.00	278.10
Water	m^3	0.24	5.00	1.19
Crusher dust	kg		0.28	0.00
Total				1766.69

TYPE	**30MPa-O(5%)**			
TOTAL QUANTITY OF ITEM:	1 m3			
Type of Material	**Unit**	**Qty ***	**Rate**	**Cost per Unit**
Cement	Qnt.	4.35	280.00	1218.00
Sand	m3	0.41	500.00	205.00
C.Aggregate	m^3	0.62	450.00	278.10
Water	m^3	0.24	5.00	1.19
Crusher dust	kg	22.91	0.36	8.25
Total				1710.54
Total cost saved due to 5% basaltic crusher dust replacement (%)				**3.2**

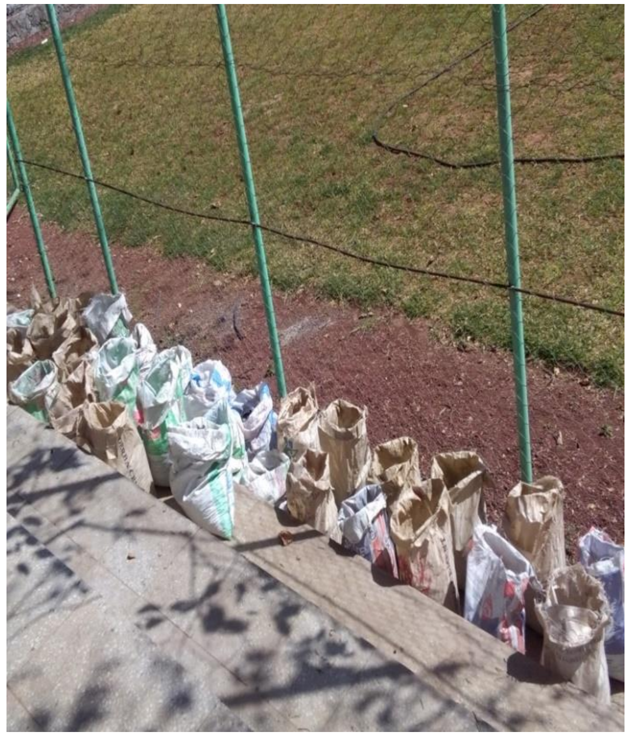
TYPE	**30MPa-O(10%)**			
TOTAL QUANTITY OF ITEM:	1 m3			
Type of Material	**Unit**	**Qty ***	**Rate**	**Cost per Unit**
Cement	Qnt.	4.12	280.00	1153.60
Sand	m3	0.41	500.00	205.00
C.Aggregate	m^3	0.62	450.00	278.10
Water	m^3	0.24	5.00	1.19
Crusher dust	kg	45.82	0.36	16.50
Total				1654.39
Total cost saved due to 10% basaltic crusher dust replacement (%)				**6.4**

APPENDIX I

PHOTOS TAKEN DURING THE RESEARCH

I-1: Crusher site where BCD2 (pure basalt powder) is produced due to proper scalping of parent rock

I-2: Crusher site where BCD1 (crusher dust with 20% clay) is produced due to less scalping



I-3: Materials Preparation

I-4: Blain air permeability test apparatus

I-5: Pycnometer used for determining specific gravity of crusher dust

I-6: Sieving crusher dust through 150µ sieve

I-7: blending it with cement

I-8: Test for setting time of blended cements

I-9: Mixing, molding and vibrating mortar cubes

I-10: Measuring compressive strength of mortar cubes

I-11: Concrete mixing

I-12: slump test

I-13: Concrete under curing and compressive strength test

I-14: Concrete cubes assembled on Permeability apparatus

I-15: Concrete sample after splitting at the end of the water permeability test

APPENDIX J

CHEMICAL COMPOSITION OF CRUSHER DUSTS