UTILIZATION OF BASALTIC QUARRY DUST AS A PARTIAL REPLACEMENT OF CEMENT IN HOLLOW CONCRETE BLOCK PRODUCTION IN THE CITY OF ADDIS ABABA (THE CASE OF KALITY AGGREGATE PRODUCTION SITE)

MSc THESIS

YOHANNIS LEMMA ALEMU

HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

JUNE, 2019

UTILIZATION OF BASALTIC QUARRY DUST AS A PARTIAL REPLACEMENT OF CEMENT IN HOLLOW CONCRETE BLOCK PRODUCTION IN THE CITY OF ADDIS ABABA (THE CASE OF KALITY AGGREGATE PRODUCTION SITE)

YOHANNIS LEMMA ALEMU

A THESIS SUBMITTED TO THE FACULTY OF CIVIL ENGINEERING AND BUILT ENVIRONMENT, HAWASSA INSTITUTE OF TECHNOLOGY SCHOOL OF GRADUATE STUDIES

HAWASSA UNIVERSITY

HAWASSA, ETHIOPIA

IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE IN CIVIL ENGINEERING

(CONSTRUCTION TECHNOLOGY AND MANAGEMENT)

JUNE, 2019

SCHOOL OF GRADUATE STUDIES

HAWASSA UNIVERSITY

ADVISOR'S APPROVAL SHEET

This is to certify that the thesis entitled "Utilization of Basaltic Quarry Dust as a Partial Replacement of Cement in Hollow Concrete Block Production in the City of Addis Ababa (The Case of Kality Aggregate Production Site)" submitted in partial fulfillment of the requirements for the degree of Master's with specialization in construction Technology and Management, the Graduate program of the faculty of Civil Engineering and Built environment, and has been carried out by Yohannis Lemma ID.No. PG CoTM/050/09 under my supervision. Therefore, I recommend that the student has fulfilled the requirement and hence hereby can submit the thesis to the school.

Dr. Bahiru Bewket	____________________	____________________
Name of advisor	Signature	Date

HAWASSA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

EXAMINER'S APPROVAL SHEET

We, the undersigned, members of the board of Examiners of the final open defense by Yohannis Lemma have read and evaluated his thesis entitled "Utilization of Basaltic Quarry Dust as a Partial Replacement of Cement in Hollow Concrete Block Production in the City of Addis Ababa (The Case of Kality Aggregate Production Site)" and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement for the degree.

______________________________	_______________	________________
Name of chairperson	Signature	Date
______________________________	_______________	________________
Name of Major Advisor	Signature	Date
______________________________	_______________	________________
Name of Internal Examiner	Signature	Date
______________________________	_______________	________________
Name of External Examiner	Signature	Date
______________________________	_______________	________________
SGS Approval	Signature	Date

DECLARATION

I hereby declare that this MSc thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

Name: Yohannis Lemma

Signature: _______________

Place of submission: Faculty of Civil Engineering and Built Environment, Hawassa University, Hawassa, Ethiopia.

Date of submission: __________________

ACKNOLEDGEMENT

First of all, I would like to praise the almighty for giving me endurance and patience to cope all the ups and downs throughout the study period.

I sincerely thank my advisor Dr. Bahiru Bewket for his useful suggestions, kind support, guidance, valuable comments and constant encouragement at all stages of the research work.

I also wish to express my sincere gratitude to Hawassa University and Ethiopian Road Authority for creating an opportunity for students like me to bring their effort to light of success.

In addition, I believe that the aggregate production companies found in and around akaki kality sub city, staffs of IFH Engineering Construction Company and Akaki kality construction material production factory (KCMPF) have a big share of acknowledgement. They have helped me in collecting dust samples, and allowed me to produce all the specimens and conduct the laboratory works free of charge.

My special thank due to Ato Kisa Temesgen, Estifanos Teklu and Abebe Ketema, workers in KCMPF for their support during the research. I would like to extend my profound gratitude to Ato Girma Sahlu, Laboratory technician in IFH Engineering, for his assist in conducting PI test of crusher dust.

I am thankful to all my friends who stood by my side throughout my journey by giving me material and moral support.

To end, I would like to extend my deepest gratitude to my family in general and particularly to my mother and father, without their love and support this thesis work would not have been realized.

LIST OF ABBREVIATION

AACRA	Addis Ababa City Road Authority
ACI	American Institute of Concrete
ASTM	American Standard for Testing and Material
BCD	Basaltic crusher dust
Bnt/yr	Billion ton per year
BS	British standard
CES	Compulsory Ethiopian Standard
EPA	Environmental Protection Agency
EN	European norm
ES	Ethiopian Standard
GTZ	Gesellschaft für Technische Zusammenarbeit (German Technical Co-operation)
HCB	Hollow Concrete Block
ICAR	International Center for Aggregate Research
KCMPF	Kality Construction Material Production Factory
LOI	Loss on ignition
OPC	Ordinary Portland cement
PPC	Portland Pozzolana Cement
QDFP	Quarry dust fine powder

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Crusher dust is a byproduct from crushing of coarse aggregate during quarrying activities. The utilization of this materials as a manufactured sand is controversial due to excessive fine particles in it and the disposal of fine materials is causing environmental problem. On other hand, the use of hollow concrete blocks as a walling material has been increased following the boosting of building construction activity in the country. This resulted in shortage of construction materials, especially the cement, creating price escalation. Furthermore, the sustainability problem related with the production of cement is a major issue of the globe. This research was, therefore, conducted to examine the potential of basaltic crusher dust as partial replacement for Portland pozzolana cement in hollow concrete block production. In doing so, Some units of cement pastes and concrete hollow blocks of different classes, i.e. A, B and C, were produced by partially replacing the cement content with 10%, 20%, 30% and 40% by weight of basaltic crusher dust using vibrating block molding machine. The units without basaltic crusher dust serve as a control. The cement pastes were examined for consistency and setting time, and the blocks produced were tested to determine their compressive strength, water absorption rate and density. Furthermore, the possible cost advantages of using basaltic crusher dust as partial replacement of cement in hollow concrete block were analyzed. The result indicates that the experimental HCB of class A and C surpassed the required standard of compressive strength, water absorption and density specified by the Ethiopian standard ES 596:2001; whereas, the compressive strength of class B fails at 40% cement replacement. It was concluded that concrete hollow blocks of class A and C with up to 40% replacement and class B with up to 30% replacement can be used for load bearing walls and save costs of block with comparable properties.

Keywords: Basaltic crusher dust, Blended cement paste, Hollow concrete block, Wall

CHAPTER ONE

INTRODUCTION

1.1. Background

The basic necessity of man after food and water is shelter. One of the major components of any kind of shelter is its walling material [1]. Walling material of different types, the most common in Ethiopia; especially in urban area, is concrete hollow blocks.

Hollow concrete blocks, which are made out of a mixture of cement, sand and stone aggregates, are the major construction materials used in the construction of residential buildings, factories, and multi-storied buildings. Hollow concrete blocks are more useful due to their lightweight and ease of ventilation. The economy of the structure is one of the basic aspects upon which any design is based. The stability plays an important role but the best designer is one who comes out with design which gives the stable and economic structure [2]. Hollow concrete is an important addition to the types of masonry units available to the builders and its use for masonry is constantly increasing in which it saves cement in masonry work, bringing down cost of construction considerably. Additionally, its construction provides facilities for concealing electrical conduit, water, and soil pipes. In Ethiopia different classes of hollow concrete block are produced with a variety of strength. One of the reason for its popularity is its incorporation of locally available materials. [3]

The concrete commonly used to make hollow concrete blocks is a mixture of powdered Portland cement, water, sand, and gravel. These ingredients should be clean and stored separately close to the mixing plant [4]. The proportion of these constituents is controlled by the required strength of the blocks.

Cement, as a binder, is the most expensive input in the production of hollow concrete blocks. In addition, the production of cement, relative to other constituents, is environmentally unfriendly processes due to the release of CO_2 gases to the atmosphere. One of the methods to reduce the cement content in the concrete mixes is the use of wastes as a pozzolanic material [5].

Most common blending materials used in cement production added in plant or sites 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. Environmentally, when industrial wastes are recycled not only the CO_2 emissions are reduced but residual products from other industries are reused and therefore less material is dumped as landfill and more natural resources are saved. Fly ash, blast furnace slag and silica fume are the most widely used industrial wastes in place of cement for concrete production attributed to their reactive nature called pozzolanic behavior [6].

Quarry dust is one of the waste materials abundantly available and unused in a quarry industry. It is a by-product that is produced as a result of crushing operation, containing a large amount of fine materials that passes 150µm sieve. The dust 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 [7]. In recent years; this byproduct of aggregate crushing process has been tested in some parts of the world for its pozzolanic property to replace cement partially and has been found to improve some of the properties of the paste, mortar and concrete. However, specific investigation is needed as the property of crusher dust vary depending on the locality and type of the parent material.

1.2. Statement of the Problem

Among the constituent material of the hollow concrete block, cement is the highly utilized. Its production is environmentally unfriendly processes relative to other constituents due to the release of CO_2 gases to the atmosphere. It is believed that one ton of Portland cement clinker production creates about one ton of CO_2 and other greenhouse gases [8]. This shows that the cement industry contributes to today's worldwide concern, which is global warming. This endangers the sustainability of the cement industry.

In addition to its negative environmental impact, cement is also one of the most expensive materials when compared to the other constituents of concrete. The raw materials for the cement production like lime are also being exploited in large amount which may result in running out of them, as it is predicted to happen in some places of the world [8].

On the other hand, the production of coarse aggregate is increasing as the construction industry developing rapidly. Following this, a byproduct (passing 4.75 mm sieve) of coarse aggregate production is also increasing. About 15-25% of this fine byproducts pass 150μm sieve size, which is basically pulverized rock [7]. At the same time, most of specifications limit the maximum percent of fine aggregate passing 150μm for construction as ten percent. This means, the material cannot be used as manufactured sand. In addition, crusher dust can be discovered in a separated form which is collected naturally by wind around the crusher site. The dust found in this way is generally considered as waste material. Even though it is difficult to determine the amount produced, currently the amount wasted is increasing as more companies joined the industry. So, disposal of this waste material gets concerns since it might cause environmental problems such as; poor permeability of top soil, contamination of surface and ground water, and air pollution.

Despite the difficulty of determining the amount of crusher dust produced in Ethiopia, it is possible to make estimation based on the report organized by the Ministry of Urban Development, Housing and Construction in 2014/15 [9]. The report were organized based on the coarse aggregate demand of Addis Ababa housing development office to conduct government building construction projects. The average annual crusher dust produced and contained in the crusher byproduct were estimated to be more than 110,000 m^3, which can be an indication for a high potential of crusher dust due to coarse aggregate production.

Thus, in order to verify the above cases and to find alternative cementing material, this paper study the suitability of the quarry dust as a partial cement replacement material in hollow concrete block production.

1.3. Research Questions

- Is it practicable to use quarry dust as partial replacement of cement?
- Could crusher dust be used as pozzolanic material?
- What will be the effect of replacing cement partially by crusher dust on consistency and setting time of cement paste?
- What will be the effect of replacing cement partially by crusher dust on compressive strength, water absorption and density of hollow concrete block?
- Does using crusher dust as a partial cement replacement material have cost advantages?

1.4. Objectives

1.4.1. General Objective

The main objective of this research is to investigate the suitability of utilization of quarry dust as a partial replacement of PPC Cement in hollow concrete block production.

1.4.2. Specific Objectives

The specific objectives of this research work can be stated briefly as follows:

- To examine the effect of partial replacement of basaltic crusher dust on consistency and setting time of blended cement paste.
- To investigate the effect of quarry dust on performance of load-bearing hollow concrete block in terms of compressive strength, water absorption and apparent density.
- To conduct cost comparison between Hollow Concrete Blocks produced using cement and crusher dust blended cement as a binding material.

Finally, conclusions and recommendations drawn and forwarded respectively based on the performance and various aspects of the material as a partial replacement of Cement in hollow concrete block production.

1.5. Significance of the Research

Despite the role of cement in the Civil Engineering construction its production releases carbon dioxide (CO_2) in the atmosphere both directly and indirectly which contributes to the global warming. Using crusher dust as a partial cement replacement material in HCB production could be an alternative reasonable approach to create sustainable construction.

The findings from this research has also a significant contribution to the manufacturers of hollow concrete block by inspiring them to use crusher by product which contains high amount of fines as cement replacing material. This will reduce the environmental impact due to the production of crusher byproduct as well as crusher dust. Moreover, the overall cost of hollow concrete block could be minimized because of the reduced quantity of cement.

1.6. Scope and Limitation of the Research

The research addresses studying the chemical composition of quarry dust and physical properties of materials used for making hollow concrete block. Laboratory based investigation of the performance of hollow concrete block (made by blending quarry dust and cement) like water absorption, apparent density and compressive strength were conducted. Throughout the laboratory investigation, the research is limited to quarry dust obtained from coarse aggregate production plant in Akaki Kality sub-city. Moreover, a crusher site in which the crusher plant is located near to the quarry site were selected as can be a representative to crusher site with poor scalping to parent rock which result poor quality crusher dust.

Due to time and resource limitation the research does not consider the effect of partial replacement of cement by more than forty percent basaltic crusher dust on hollow concrete block.

1.7. Organization of the thesis

The research is organized into six chapters that discusses various aspects of Cement and Hollow Concrete Block related with relevance of the thesis. Chapter one explains the background, problem statement, the objectives and scope of the research. Chapter two is literature review which provides a general understanding of previous studies and standards related to the research. Chapter three discusses the Methods and properties of materials used in the investigation. Additionally, it deals with the experimental program that was used in the research. Chapter four is about the analysis and discussion of the results obtained from the study. Chapter five covers the analysis on cost advantages of using crusher dust as cement replacing material in HCB production.

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

In recent years, tremendous efforts have been done in the area of concrete technology to study the utilization of by-products and waste materials as partial cement replacement in concrete production as well as identifying the technical, economic and environmental benefits of incorporating these materials. These Cement replacing materials such as fly ash, blast furnace slag, natural pozzolana and other industrial wastes were reported to improve different properties of mortar and concrete. [2,10]

Quarry dust is one of the waste materials abundantly available and unused in a quarry industry. 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 concrete production [11]. The performance of concrete, specifically the performance of hollow concrete block, is assessed by different tests such as chemical and physical properties of blended cement and cement paste, compressive strength, water absorption capacity and apparent density on the hardened concrete block made of blended cement.

This chapter, therefore, addresses topics such as properties of cement and quarry dust, the production, physical requirements and conforming criteria of hollow concrete block which are helpful to study the block performance, and review of related previous studies.

2.2. Cement

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. This definition embraces a large variety of cementing materials. For constructional purposes, the meaning of the term 'cement' is restricted to the bonding materials used with stones, sand, bricks, building blocks, etc. The credit for its discovery is given to the Romans, who mixed lime ($CaCO_3$) with volcanic ash, producing a cement mortar which was used during construction of such impressive structures as the Colosseum [12, 13].

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. The worldwide annual cement clinker production was approximately 1.6 billion tons on 2000. The resulting concrete, mixed with water and aggregates, is second only to water as the most consumed substance on Earth [13]. The global cement production has reached 2.8Bnt/yr. in 2011 and it is expected to increase to around 4Bnt/yr in 2020. Major growth is forecasted in countries like China and India as well as the Middle East and Africa [15].

There are different types of cement depending on their composition, method of manufacturing (grinding, burning, etc.) and also the relative proportion of different compounds. One of these types and the most commonly used is Portland cement, which in turn divided further into various sub-types.

2.3. Portland cement

The name 'Portland cement', given originally due to the resemblance of the color and quality of the hardened cement to Portland stone – a limestone quarried in Dorset – has remained throughout the world to this day to describe a cement obtained by intimately mixing together calcareous and argillaceous, or other silica, alumina, and iron oxide bearing materials, burning them at a clinkering temperature, and grinding the resulting clinker. Its invention is generally credited to Joseph Aspdin, an English mason, in 1824, he obtained a patent for his product, which he named Portland cement. The method of making cement has been improved upon since that time but the basic process has remained the same and its name has endured and is used throughout the world, with many manufacturers adding their own trade or brand names [13, 16].

The persistent investigation by science and industry has resulted a development in Portland cement through production of a superior quality natural cement. Portland cement is a hydraulic cement composed primarily of hydraulic calcium silicates which helps the cement to combine with water to form a paste. It is this paste combined with aggregate (sand gravel or other granular material) and form a concrete, world's most versatile and most widely used construction material [16].

Modern Portland cement is made from materials which must contain the proper proportion of Lime (CaO), Silica (SiO_2) Alumina (Al_2O_3), and Iron (Fe_2O_3) with minor contents of magnesia (MgO), Sulphur trioxide (SO_3) [17].

2.3.1. Classification of Portland cement

Different types of Portland cement are manufactured to meet various normal physical and chemical requirements for specific purposes. The most common specifications to be met by Portland cement are the ASTM and the EN standards. ASTM C150, Standard Specification for Portland cement, and ASTM C1157, Performance Specification for Hydraulic Cements are the two specification for cement manufacturing, primarily used in U.S; whereas, the classification of cement in European standard is done based on EN 197-1.

ASTM C150 classifies Portland cement in to eight types using Roman numeral designations as follow [16];

- Type I Portland cement is a general-purpose cement suitable for all uses where the special properties of other types are not required.
- Type IA Portland cement is a type I cement containing an integral air-entraining agent.
- Type II Portland cement has moderate sulfate resistant properties which is used where precaution against moderate sulfate attack is important.
- Type IIA Portland cement is a type II cement containing an integral air-entraining agent
- Type III Portland cement is used when there is a requirement for high early strength development of concrete.
- Type IIIA Portland cement is type III cement containing an integral air-entraining agent.
- Type IV Portland cement is used where low rate and amount of heat generated from hydration is required.
- Type V Portland cement is used in concrete exposed to severe sulfate action.

The EN 197-1 classifies common cement, which comprises Portland cement as main constituent, into five groups [18]

- Type I. Portland cement: - Comprises Portland cement and up to 5 percent minor additional constituent.
- Type II. Portland composite cement: - Comprises Portland cement and up to 35 percent of other single constituent.
- Type III. Blast furnace cement: - Portland cement and higher percentage of blast furnace slag.
- Type IV. Pozzolanic cement: - Portland cement and up to 55 percent of pozzolanic constituents.
- Type V. Composite cement: - Portland cement, blast furnace slag and pozzolanas or fly ash.

Constituents that are permitted in Portland composite cements are blast furnace slag, silica fume, natural and industrial pozzolans, siliceous and calcareous fly ash, burnt shale and limestone [18]. The Portland pozzolana cement is the most common and widely available type of Portland composite cement. It is manufactured by inter grinding of OPC clinker with 15 to 35 percent of pozzolanic material. [17]

The classification of common cements in Ethiopia is similar with the European standard since the Ethiopian standard for common cement, CES 28, adopts the EN 197-1: 2011 for implementation with permission of CEN.

2.3.2. Chemical Properties of Portland cement

It is a Portland cement's chemical properties that determine most of its physical properties. This means, a basic understanding of Portland cement chemistry can help to understand how and why it behaves as it does [19].

2.3.2.1. Chemical Composition of Portland cement

The major compounds that constitute the materials in modern cement interacts with one another in the kiln to form serious of more complex products. These compounds are usually regarded as the major constituents of cement and tabulated with their abbreviated symbols in Table 2.1 [13].

Name of compound	Oxide composition	Abbreviation	Mass (%)
Tri-calcium silicate	$3CaO.SiO_2$	C_3S	45-75
Di-calcium silicate	$2CaO.SiO_2$	C_2S	7-32
Tri-calcium aluminate	$3CaO.Al_2O_3$	C_3A	0-13
Tetra-calcium alumino-ferrite	$4CaO.Al_2O_3.Fe_2O_3$	C4AF	0-18
Gypsum	$CaSO_4.2H_2O$	CSH_2	2-10

Table 2.1 Main Compounds of Portland cement [13,20]

Different studies has discussed the effect of major compounds on cement properties. Of these compounds, C3S and C3A are mainly responsible for early strength of concrete. High percentages of C3S (low C2S) results in high early strength but also high heat generation as the concrete sets. The reverse combination, that is, low C3S and high C2S develops strength more slowly and generates less heat. C3A causes undesirable heat and rapid reacting properties, which can be prevented by adding CaSO4 to the final product. [16]

In addition to the main compounds listed in Table 2.1, there exist minor compounds, such as MgO, TiO_2, Mn_2O_3, K_2O and Na_2O; they usually amount to not more than a few per cent of the mass of cement. The term ‘minor compounds’ refers primarily to their quantity and not necessarily to their importance [13].

The actual proportions of the various compounds vary considerably from cement to cement, and indeed different types of cement are obtained by suitable proportioning of the raw materials. The composition of cement is estimated by the methods such as X-ray fluorescence, X-ray spectrometry, atomic absorption, flame photometry, and electron probe micro-analysis [13]. A general idea of the composition limits of Portland cement can be obtained from Table 2.2.

Table 2.2 Composition limits of Portland cement [12]

Oxides	Content, Percent
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

2.3.2.2. Loss on Ignition

The loss on ignition (LOI) shows the extent of carbonation and hydration of free lime and free magnesia due to the exposure of cement to the atmosphere. Loss on ignition of Portland cement is determined by heating of cement sample of known weight to between 900^{o}c to 1000^{o}c until a constant weight is obtained. The weight loss of the sample is then determined. The higher value of loss on ignition is an indication for pre-hydration and carbonation, which may be caused by improper or prolonged, or adulteration during transport. The maximum permissible loss on ignition (at 1000^{o}c) recommended by BS EN 197-1:2000 is 5 percent and ASTM C 150-09 is 3 percent except for type I cement which is 2.5 percent. The 5 percent maximum loss on ignition allowed by BS EN 197-1: 2000 is necessitated for cement containing a calcareous fillers. On other hand, ASTM C 618 specifies a maximum of 10 percent for cement constituting natural pozzolans. The test for loss on ignition is performed in accordance with American standard ASTM C114 (AASHTO T105): chemical analysis of hydraulic cement in American standard; whereas, the test for loss on ignition is contained EN 196-2 No. 7: 1994: standard test methods for determination of LOI in European standard [16, 18].

According to the Ethiopian standard, loss in mass on ignition of Portland cement limited to a maximum of 4 percent [21].

2.3.3. Physical Properties of Portland cement

Portland cements are commonly characterized by their physical properties for quality controlling purposes. These properties can be used to classify and compare Portland cements. Moreover, it is helpful in interpreting results of cement tests which is used to evaluate the properties of the cement rather than the concrete [20].

2.3.3.1. Fineness of Cement

Fineness is the overall particle size distribution of cement. Fineness has effect on properties of cement such as hydration and thus setting time, and rate of strength gain. The rate of hydration depends on the fineness of the cement particles and, for a rapid development of strength, high fineness is necessary; the long term strength is not affected. A higher early rate of hydration means, of course, also a higher rate of early heat evolution [16, 13].

An increase in fineness, on the other hand, increases the amount of gypsum required for proper retardation because, in a finer cement, more tri-calcium aluminate is available for early hydration. Higher fineness of cement results in high cost of production, and also the finer the cement deteriorate rapidly on exposure to the atmosphere. The finer the cement increases the reaction between the cement and alkali – reactive aggregate which result in higher shrinkage and cracking to the cement paste [13].

There are several methods to measure cement fineness [22];

- ASTM C 115: Standard Test Method for Fineness of Portland cement by the Turbid meter
- 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

Today, fineness is usually measured by the Blaine air-permeability test that indirectly measures the surface area of the cement particles per unit mass. Cements with finer particles have more surface area in square meters per kilogram of cement [13].

According to the Ethiopian standard ordinary Portland cement shall have a specific surface area of not less than 2250 cm2/g [21], whereas, the ASTM C 150 standard recommends a minimum of 2800 cm2/g.

2.3.3.2. 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 at which to do these tests. This is defined in terms of the normal consistency of the paste which is measured according to ASTM C 187. Consistency refers to the relative mobility of a freshly mixed cement paste or mortar or to its ability to flow [17, 16].

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% [21]. The test is very sensitive to the conditions under which it is being carried out, particularly the temperature and the way the cement is compacted into the mold. The test does not correlate to the quality of the cement; it only measures the plasticity of cement paste [17].

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 [22].

2.3.3.3. Setting Time

This is the term used to describe the stiffening of the cement paste, which refers to its change from a fluid to a rigid stage [13]. The duration a cement paste requires to undergo setting is its setting time and it is affected by the amount of water used to prepare the cement (water – cement ratio), sulfate (from gypsum), cement fineness and admixture used.

There are two defined stages of setting time: The time that elapses from the moment water is added until the paste ceases to be fluid and plastic (called initial set) and the time required for the paste to acquire a certain degree of hardness (called final set). Initial set of cement paste must not occur too early and final set must not occur too late [16].

Setting time tests for cement are performed using either the Vicat apparatus (ASTM C 191) or the Gillmore needle (ASTM C 266). Vicat test governs if no test method is specified in cement specification. The setting time is an indicator for a cement paste as it is or is not undergoing normal hydration reactions [16].

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 ten hours [21].

2.3.3.4. Hydration of Portland cement

In the presence of water, compounds of Portland cement chemically reacts with water to form new compounds that are the infrastructure of hardened cement in concrete. This chemical reaction of cement and water is called hydration and the new compounds called hydrated cement paste. The two calcium silicates, 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. Hydrated Portland cement contains 15% to 25% of calcium hydroxide and about 50% C-S-H by mass [16, 13].

Both C_2S and C_3S are the main cementitious compounds in cement, and the physical behavior of cement during hydration is similar to these two compounds alone. The rates of hydration of C_3S and C_2S in a pure state differs considerably [13]. This is shown in Equation 2.1 and 2.2 below. [17]

$C_3S + 4.3H \longrightarrow C_{1.7}SH_3 + 1.3H$ ------------------------------------ [Equation 2.1]

$C_2S + 3.3H \longrightarrow C_{1.7}SH_3 + 0.3H$ ------------------------------------ [Equation 2.2]

The hydration of Portland cement as a whole is more complex than the individual compounds, since different constituent compounds have different products, rate of reaction and consumption capacity [17].

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 $C_3A > C_3S > C_4AF > C_2S$. Here, gypsum plays a greater role in lowering the rate of hydration of C_3A, which without calcium sulfate it undergo flash set due to its high rate of reaction with water. But the rate of hydration of these compounds differs from cement to cement depending on the fineness of cement, presence of impurities and other cement compounds [17].

2.4. Pozzolana

ASTM 618 describes pozzolana as a siliceous or siliceous and aluminous material which in itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties. [23]

Pozzolana's main function 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 [24].

Generally, pozzolanic materials can be classified as natural occurring in origin or artificially prepared [13].

Natural pozzolans are naturally occurring volcanic origin materials such as some diatomaceous earths; opaline cherts and shales; tuffs and volcanic ashes or pumices, 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 [24, 13].

The pozzolanic material which are obtained as industrial by-products termed as artificial pozzolans. Fly ashes (fine solid particles of ashes extracted 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 [13].

2.4.1. 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 cementitious 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 pozzolan in a finely divided form react with the calcium hydroxide to form highly stable cementitious 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 is as shown in Equation below [25].

$$\text{Pozzolan} + \text{Calcium Hydroxide} + \text{water} \longrightarrow \text{Calcium Silicate Hydrate (gel)}$$

$$S + CH + H \longrightarrow C\text{-}S\text{-}H \text{-- [Equation 2.3]}$$

This reaction is called pozzolanic reaction. 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, which is the case for most of the pozzolans. The normal C: S ratio is believed to be around 2.0 [13].

The relative degree of pozzolanic activity of natural pozzolana was reported to be intimately related with their reactive silica content [26].

2.4.2. Benefits of Pozzolanic Materials

The reaction of pozzolanic materials with calcium hydroxide results in many advantages. If these pozzolanic materials were not reacted with the calcium hydroxide, free calcium hydroxide would have been present in the concrete resulting in higher permeability of the concrete and susceptibility to other attacks. The pozzolanic reaction reduces the porosity of the concrete by producing cementitious compound. It also reduces the heat of hydration since its reaction is slower than that of Portland cement, which implies that cement that has pozzolanic material has slower rate of strength gain than Ordinary Portland cement, making it suitable for mass concrete construction [17]. Furthermore, advantages such as reduction in shrinkage, improvement in workability and durability, low heat production and economic had been identified by the American Institute of concrete (ACI 2000).

2.5. Fillers

Fillers are micro fine materials passing number 200 sieve (75µm) and has a beneficial effect on some properties of concrete, such as workability, density, permeability, capillarity, bleeding or cracking tendency. Usually fillers are 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, 18].

Fillers can be classified as naturally occurring materials or processed inorganic mineral materials. What is essential is that they have uniform properties, and specially 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 [13].

The study made by international center for aggregates research (ICAR 401) showed that the inclusion of fillers (dolomite and limestones) as a replacing material for cement and sand allows the reduction of cement content while maintaining or improving the performance of baseline mixture and the hardened concrete. Properties of the concrete such as compressive strength, permeability, shrinkage and abrasion are improved in the mixture containing fillers than the baseline.

2.6. Crusher Dust

The utilization of byproducts and waste materials, which can be used as partial cement replacement materials, has been increasing tremendously in construction industry. Blast furnace slag, silica fume, fly ash and rise husk can be sited as an example [10]. Crusher dust as a byproduct from crushing of coarse aggregate during quarrying activities has also received a considerable attention to enhance the properties of concrete and it is found to have such pozzolanic properties.

Crusher dust, as defined by BS EN standard, are the inherent fraction of an aggregate passing 63μm. Many quarries also refer to their fine aggregate finer than 4mm as quarry fines [26]. The term is used here, in this research, to denote a fine byproduct passing 150 micrometer which are produced during aggregate extraction process and it is the most common and widely produced stone byproduct [7]. These materials are left as fine dust and considered to be a waste. According to Agrawal et.al, 2017 [28], 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.

2.6.1. Production of Crusher Dust

Quarrying and the associated processing inevitably leads to the production of quarry fines containing a large amount of material that passes the 150 μm and 75 μm sieve. The amount generated varies depending on geology of the quarry, type of rock crushed, efficiency of the extraction and processing operation, local market for quarried products, and type and size of aggregates produced; it may include up to 15 to 25% of the production [7].

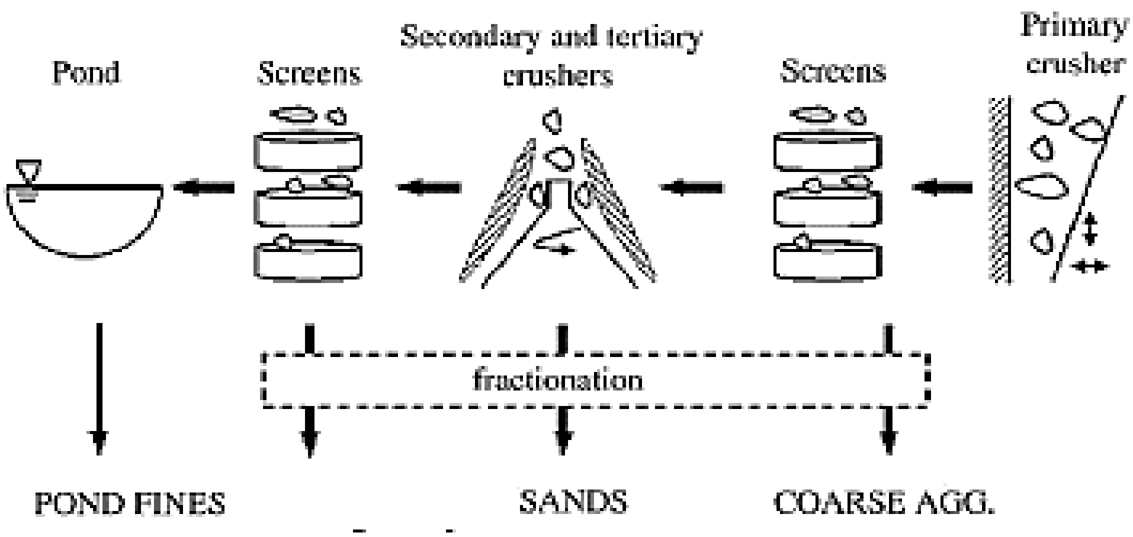


Figure 2.1 Schematic diagram of a typical aggregate production process [29]

Aggregate production typically starts with blasting rock masses and is followed by series of crushing stages. Quarry fines are produced by a process related to blasting, processing, handling and transportation. The amount of fines generated during blasting may be as high as 20 percent. This can be reduced by adopting blasting process to produce larger broken rock fragments since coarse grained rock generate less fines than fine grained rock. Most quarry fines are produced during the crushing, millings and screening of quarried rock to produce single size aggregate. Crushing of quarried rock is carried out in stages, with the primary crushing stage typically carried out using Jaw crushers or gyratory crushers and subsequent (secondary and tertiary) stages by cone or impact crusher. Screening is most commonly done by using inclined vibratory screens. For screening of large sizes of crushed stone, grizzly bar, rod decks and heavy punched steel or plastic plates are used. Fines production increases with an increase in number of crushing stages. The proportion of fines at each stage varies with rock type, type of crusher used and aggregate size. The quarry dust produced at different stages of crushing has been studied by C. Mitchell et.al, for igneous rock as follows [29];

- Primary crusher---------------- 3%-6% (Jaw) to 10%-15% (Gyratory)
- Secondary crusher------------- 10%-23% (Cone)
- Tertiary (and further)---------- 5%-30% (Cone) to 40% (Impact)

The production of a smaller particle size also has had a dramatic effect on the proportion of fines produced. The production of 40mm aggregate results in around 5-10% fines, 20mm aggregate, 15-20% fines and 10mm aggregate, 35-40% fines [29, 30].

2.6.2. Crusher Dust in Ethiopia

The coarse aggregates in Ethiopia are produced naturally from quarries and lacks an advancement as the process shown in Figure 2.1. Jaw and impact crushers are the common types of crusher for primary and secondary crushers. The production process exclude screening activities which are useful to eliminate fines. As a result, the crusher dust (fines) are blended with the potential manufactured sand (usually known as zero zero) in the storage area. Moreover, the portion of the dusts are extracted naturally by the action of wind and they are collected around crusher, screens and spreads over crushing site [22]. The situations are illustrated in Figures 2.2 and 2.3.

Studies on different parts of the world has showed massive potential of fines production from aggregate production plants. Hamid [22], reported that the production of 20mm coarse aggregate in Ethiopia results around 33.3% of byproducts with nominal size less than 4.75mm, which have found to contain about 20% fines with size less than 150μm in it.

Figure 2.2 Crusher dust spread over the quarry area by the action of wind

Figure 2.3 Hauling truck collecting a by-product blended with fines as a manufactured sand

It is an accepted fact that the physical and mechanical properties of aggregates are inherited from parent materials, whereas, the property of the parent rock for the production of coarse aggregate depends on the geological formation. The most commonly found aggregate rocks in Ethiopia is basaltic, while ignimbrite is mostly used for masonry stone [31].

In Ethiopia, The total amount of coarse aggregate production and its corresponding crusher dust is not studied yet. However, the report organized by the Ministry of Urban Development, Housing and Construction of Ethiopia in 2014/15 [9] will help to estimate the amount of fines produced in aggregate production. The report summarizes the potential construction material demand of Addis Ababa housing development office for construction of government buildings. The coarse aggregate demand and the expected by product and fines are depicted here in Table 2.3.

Table 2.3 Coarse aggregate demand of Addis Ababa housing development office for government buildings and expected by products and fines produced [9]

Year EC. (GC.)	Demand of 20mm aggregate (m^3)	Expected byproducts passing 4.75mm sieve size. (m^3)	Expected fines passing 150μm size of sieve, (m^3)
2005(2012/13)	577,370.85	192,437.70	38,487.54
2006(2013/14)	1,450,558.32	483,471.09	96,694.22
2007(2014/15)	2,262,607	754,126.91	150,825.38
2008(2015/16) *	2,262,607	754,126.91	150,825.38
Average annual crusher dust production			≈110,000

* The demand of the aggregate were forecasted to be similar to that of the previous year since the report is organized on 2014/15.

From the Table, it can be concluded that the demand of coarse aggregate by the Addis Ababa housing development is increasing through time. This has resulted an increase in crusher dust amounts. According to the report, the average annual fines (passing 0.15mm sieve) resulted from production of coarse aggregate were around 110,000m^3. These values indicate higher potential of quarry dust production as more production sites are available for various purpose throughout the country.

As the demand for housing in Ethiopia is increasing, the government is being responding to this demand by massive condominium projects at different locations. The Addis Ababa saving house development enterprise is also involved in the construction of condominiums in Addis Ababa and its surrounding. The activity, thus, has generally increased the consumption and demand of crushed coarse aggregates. The annual crushed coarse aggregate demand report by the enterprise can be used to estimate the expected crusher dust produced during aggregate production. The report can be summarized as follow. [32]

Table 2.4 Coarse aggregate (20mm size) production and expected amount of crusher dust for Addis Ababa housing projects [32]

Year in E.C.(G.C.)	Aggregate demand, m^3	Expected by product passing 4.75mm sieve, m^3	Expected crusher dust passing 150µm, m^3
2003 (2010/11)	266, 964	88, 987	17, 799
2004 (2011/ 12)	638, 970	212, 988	42, 600
2005 (2012/ 13)	1, 282,685	427, 557	85, 517
2006 (2013/ 14)	487, 000	162, 332	32, 468
2007 (2014/ 15)	879, 240	293, 077	58, 619
2008 (2015/ 16)	1, 522, 077	507, 354	101, 477
2009 (2016/ 17)	534, 921	178, 305	35, 663
2010 (2017/ 18)	475, 000	158, 332	31, 668
Average annual crusher dust production			50, 726

Furthermore, the aggregate production information from building material provider enterprise, which is now administered under Federal Housing Corporation, indicates that the amount of aggregate produced for the Addis Ababa City Road Authority (AACRA). The report summarizes the five year (2013/ 14 to 2017/18) aggregate supply for road projects of the city. The aggregate supply and expected fines are depicted here in Table 2.5 [33].

Table 2.5 Crushed aggregate produced for Addis Ababa Road Authority and its estimated crusher dust production [33]

Aggregate size, mm	Supply (m^3)	Expected by product passing 4.75mm sieve, m^3	Expected crusher dust passing 150µm size of sieve, m^3
20	124, 776. 79	41,588.10	8,317.62
10	59, 844. 65	19,946.22	3,989.24
< 4.75	53, 732. 12	-	10,746.42
		Average	7,684.43

Based on the data provided, the average amount of aggregate production in eight years for saving house projects of the city were estimated to be 50,726m^3; whereas the aggregates production for the road projects in five year were averaged to be more than 7,684m^3. The average annual production from the two bodies accounts 58,410m^3.

On other hand, the most commonly found aggregate rocks in and around Addis Ababa area are basalt, trachyte, and ignimbrite. Basalt is the most available and dominantly used for aggregate production. The chemical composition of a basaltic aggregate analyzed by Karstaedt, by taking samples from a quarry, which was planned for supply of aggregate for construction of new Addis Ababa International airport, in the vicinity of Addis Ababa Bole International Airport. The chemical composition of the analysis is summarized in Table 2.6 [31].

Table 2.6 Chemical composition of Addis Ababa Basalt, Bole area [31]

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	H_2O	LOI	TiO_2	MnO
49.0	16.1	13.74	8.2	5.4	3.3	0.9	0.8	0.7	2.4	0.2

From these information's we can conclude that the crusher dust which basically composed of basalt with such enormous average annual production and chemical composition can be a best cement replacing material in concrete production.

2.7. Overview of Cement Replacement with Quarry Dust in Construction Industry

The attention on the utilization of quarry dust as cement replacement material in concrete had grows tremendously among researchers due to advantages own by quarry dust. Here, some previous studies of using crusher dust as partial cement replacement is reviewed.

Kartini et al. [10], studied the suitability of quarry dust fine powder (QDFP) as cementitious material in concrete. The research evaluated the performance of concrete in terms of mechanical and durability index by applying various water-cement ratio and replacement level. The replacement level incorporated were 3%, 5%, 10% and 15% with different w/cm ratios (0.3, 0.4, 0.5 and 0.6) for each. Super-plasticizer were included in the mixtures to enhance the workability of concrete. The performance of the hardened concrete was measured at 7, 28, 60, 90 and 120 days of age. The results of the investigation showed that the compressive strength of concrete did not enhanced by the inclusion of quarry dust fine powder. Rebound number for dust concrete made of 0.3 and 0.4 w/cm ratios achieved a good quality, while that of 0.5 and 0.6 w/cm ratios falls under poor and fail respectively. In terms of durability index performance, the QDFP concrete in higher proportion (up to 15%) and with increasing w/b ratio from 0.3 to 0.6 increased the coefficient of permeability. However the concrete produced remain good since the recorded water absorption was below 10% by mass.

In addition Kumar et al. [34], the properties of concrete made with partial replacement of cement using crusher dust has been studied. The study considered properties such as density, splitting tensile strength, dynamic modulus, ultrasonic pulse velocity and acid resistance in addition to the properties studied previously by other researchers. Furthermore, the investigation is conducted on a concrete of 40MPa compressive strength. The result shows that the optimum replacement rate for strength is 20 percent. The resistance toward acidic attack and water absorption remained the same as that of the conventional concrete.

Eldidamony et al. [35] studied the influence of basalt powder as pozzolana and filler in ordinary Portland cement. The investigation was aimed to replace the cement by the powder up to twenty percent. The result showed that the blended cement can be used as filled pozzolanic cement. Moreover, higher compressive strength has attained at twenty percent replacement than lower rate, which means the pozzolanic activity of basalt powder is high at this point of study.

According to Hamid [22], the mechanical behavior of C25 and C30 grade concrete was studied with quarry dust as cement (PPC and OPC) replacement. The study examined the feasibility of dust as cement replacement material at the rate of 5%, 10% 15% and 20% with plain cement concrete. The dust used in the research were a basaltic crusher dusts (designated as BCD1 and BCD2) of different clay content with its chemical and physical properties satisfying the requirements in ASTM standard. The chemical composition of basaltic stone dust used for the research is summarized in Table 2.7.

Table 2.7 Chemical composition of quarry dust powder used by Hamid [22]

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

Based on the finding, cement (both OPC and PPC) are finer than the dusts investigated. The chemical composition of the dusts are found to be within the acceptable limit of ASTM 618; in which the total composition of the three compounds (SiO_2, Al_2O_3 and Fe_2O_3) were 78.88 and 76.36 respectively. The optimum replacement of cement by quarry dust recorded from the findings was 5% and 10% for PPC and OPC respectively. In addition, the study revealed that the clay content in quarry dust will result higher loss in strength. Moreover, it was observed that partial replacement of basaltic crusher dust with OPC as well as PPC favor C-25 than C-30 concrete. Furthermore, the positive impact of dust utilization in environment and economy are shown. The maximum cost reduction in concrete production found to be 6.4 percent per cubic meter of concrete compared with the conventional method of production.

2.8. Concrete Masonry Unit (or Concrete Block)

According to ES 596:2001 [36], masonry unit is described as a block or brick that are normally rectangular shape solid, cellular or hollow, and intended for use in bonded masonry construction Masonry is the assemblage of building units joined with the help of cementitious material or any accepted joining material to perform the required function.

Hollow concrete block is a masonry unit having one or more large holes or cavities having the solid material between 50 to 75% of the total volume of the block calculated from the overall dimensions [36].

2.8.1. Composition of Hollow Concrete Blocks

Hollow concrete blocks are usually made from zero slump concrete (hydraulic binder, mineral aggregates, water and sometimes admixtures). The binders such as Portland cement and Portland pozzolana cement or any other alternative materials of proven quality combined with lightweight or normal weight aggregates produced through controlled grading. This typical combination results a high density block; whereas, lower density blocks may use industrial wastes such as fly ash or autoclaved aerated concrete. Aggregate grading should be done in such a way that all should pass through a sieve of nominal aperture size of 9.5mm and less than two-thirds of the thickness of the thinnest part of the shell or web of the unit [36, 37].

The materials required for the production of hollow concrete block differs from site to site depending on the availability of building materials and the ratios that fulfills the required strength. However, the concrete mixture used for the block has a lower percentages of water, sand and gravel than the concrete mixtures used for general construction purposes. This holds true for all types of HCB production [3].

2.8.2. Applications of Hollow Concrete Block in Building Industry

Most hollow concrete blocks are produced either for construction of floor and roof, or for masonry (or wall) in building construction industry.

Hollow concrete blocks for construction of wall are categorized into two; as load bearing and non-load bearing depending on their structural function. These blocks are further classified as lightweight, medium weight and normal weight concrete block [38]. The classification is summarized in Table 2.8.

Weight classification	Oven dry weight of hollow concrete block (kg/m^3)
Lightweight	Less than 1680
Medium weight	1680 to less than 2000
Normal weight	2000 or more

Table 2.8 Weight classification of hollow concrete blocks [38]

Non-load bearing hollow concrete blocks, on other hand, are manufactured in accordance with the specification of ASTM C 129-03 and they are intended for use in non-load bearing partitions; but, under certain condition they may be suitable for use in non-load bearing exterior walls above grade where effectively protected from weather. As such, the manufactured block should conform to one of the three weight class prescribed in Table 2.8 above.

The classification of hollow concrete block for a wall construction in accordance with Ethiopian standard is discussed in Section 2.8.4 based on different parameters.

2.8.3. Hollow Concrete Blocks Production Process

The typical manufacturing process of hollow concrete block consists the following major steps:

2.8.3.1. Selection and Proportion of Ingredients

Before production can commence, all raw materials such as Portland cement, aggregates and water have to be approved by an official concrete laboratory. The main criteria for the selection and proportion of the ingredients are the desired strength of the block. The greater the proportion of coarse aggregate, the greater will be the strength for the same quantity of cement used [39]. Generally, the concrete used for hollow block has higher proportion aggregate to water than the general purpose concrete.

2.8.3.2. Mixing

The quality of concrete blocks depends largely on the type of mixer used and period of mixing. Mixing can be done either manually or mechanically.

Hand mixing is done with the use of shovels on a level concrete slab or steel plate. First, sand is spread out 50 to 100mm thick, then, cement and aggregates distributed evenly over the sand. Mix the aggregate and the cement until the color is uniform. Sprinkle the mixing water over the surface by spreading the mixture out and mix continue with this process until the right amount of water has been mixed in. For machine mixing, first aggregate and cement are mixed then water is added gradually while mixing until water content is correct [40]. GTZ low cost housing manual [3], recommends a water to cement ratio ranges from 0.49 to 0.55. The proper consistency of a mix possibly be judged by squeezing a handful of concrete mix. In addition, chemical admixtures and coloring pigments can be added to the mix at these stage.

2.8.3.3. Placing and Compaction

After mixing of the concrete materials, the mix will be fed into the mold box. Molding can be operated mechanically or by hand. Too little or poor compaction should be avoided as it results in greatly reduced strengths [40]. Volume I of GTZ low-cost housing manual [3], recommends vibration of mix for about 60 seconds before extruded as hollow concrete blocks. The compacted block then transported and remain on a wooden pallets for 24 hours and the curing process will proceed. Fresh blocks should be protected from rain and drying effects of sun and wind until curing starts [40].

2.8.3.4. Curing

The blocks are either left to set and harden on a place where they were molded, or carried away on pallets to the curing place. In all cases it is important to keep the concrete moist, for example, by regularly spraying with water, until the concrete has obtained sufficient strength. The block is watered after about one day of casting and it is continued for a minimum of 7 days and preferably till 28 days. The longer the curing period, the better will be the block. [40]. On the other hand, volume I of GTZ low-cost housing manual [3], recommends 10 days of curing time, in addition to this, date of production must be written on blocks for the purpose of identification whether it is ready or not for construction.

2.8.4. Requirements of Hollow Concrete Blocks

2.8.4.1. Shape, Appearance, Texture and Color

Hollow unit shall be of nominally rectangular shape and true to the appropriate acceptable pattern. They shall be acceptably free from visible defects that could interfere with the proper laying of the units or impair the strength or the stability (or both) of a construction. When units are used for exposed wall, the surface of the face of the exposed work shall be acceptably uniform in color and texture, and acceptably free from chips, cracks and other imperfections except that if not more than 5% of the units of a sample of consignment contain slight cracks or small chips not larger than 10mm [36]; this shall not be deemed to be ground for rejection. ASTM C90 [38] specify the crack width to 0.5mm (and 25% of the nominal height of the unit).

The units that are intended for use with surface finish (or plaster) should provide adequate adhesion for the finish and their color, if required, shall be as agreed upon between the manufacturer and the purchaser and manufacturer supply to the purchaser for his retention three units of the agreed color to serve as an example of the possible range of such color. The uniformity of color and texture can be assessed, manufacturer's agreement with purchaser, in such a way that the manufacturer submit a sample of 10 units (5 of which to be retained by the purchaser and 5 by the manufacturer) for the purchaser's approval [36]. The ASTM standard on other hand requires that the color and texture of the units to be specified by the purchaser and the finished surfaces that will be exposed in place are cross-checked with the approved samples consisting of not less than four units [38].

2.8.4.2. Dimension and Tolerance of Hollow Concrete Block

Hollow concrete block shall be referred by its nominal dimensions. Nominal dimension of modular size units is expressed as the standard dimension, manufacturer's designated dimensions, plus the thickness of one mortar joint. For modular size units' nominal dimension equal to standard dimension plus 9.53mm but for non-modular size units, it exceeds the standard dimension by 3.2 to 6.4 mm. The tolerance on the deviation of dimensions in the hollow concrete block is specific to a standard. These limits are useful in assisting mason as a guidance for laying units and constructing the masonry work. Furthermore, it helps to offer an aesthetic finish and appearance of the constructed masonry. [38]

The maximum deviation of dimensions for hollow concrete block from the specified standard dimensions is 3.2mm [38].

According to Ethiopian standard, CES 24:2013 [42], for any class of unit the nominal dimensions of concrete masonry blocks are shown in Table 2.9.

Breadth	Height	Length	Face shell	Web
100	200	400	20	20
150	200	400	25	25
200	200	400	30	25
250	200	400	35	30
300	200	400	40	30

Table 2.9 Nominal dimensions of hollow concrete block in mm [42]

The maximum dimensional variation (length, height, breadth) of hollow concrete block should be ±5mm of nominal dimensions mentioned in the table. In addition, the thickness of face shells shall be the average of four distributed measurements at the long side and the web thickness shall be the average of two distributed measurements [42]. On other hand, ES 596:2001 [36] specifies that the thickness of the shell and web of hollow concrete block shall be at least one-sixth of the overall breadth of a unit or 25mm, whichever is the greater.

2.8.4.3. Block Density

According to the ES 596:2001 [36], the density of hollow concrete block is determined in such a way that three blocks taken at random from the samples selected then dried to constant mass in a suitable oven heated to approximately 105°C. After cooling the blocks to room temperature, the dimensions of each block shall be measured in centimeters (to the nearest millimeter) and the overall volume, including holes of cavities and end recesses, computed in cubic centimeters. The block shall then be weighed in kilograms (to the nearest 10 g) and the density of each block calculated as follows:

$$Density = \frac{Mass\ of\ block, in\ Kg}{Volume\ of\ specimen,\ \ in\ cubic\ cm} \text{ X } 10^6 \text{ Kg/m}^3 \text{------------------ [Equation 2.4]}$$

The average for the three blocks shall be taken as the average density. Accordingly, the load bearing hollow concrete blocks (class A,B and C) have a density ranging between 900 to 1200kg/m^3 and non-load bearing (class D) ranging between 600kg/m^3 and 900kg/m^3. [36]

2.8.4.4. Water Absorption

It is a measure of the voids (reachable pore volume) within the net volume of the concrete, including the voids within the aggregate itself.

The test specimens shall be completely immersed in water at room – temperature for 24 hours. The specimens shall then be weighed, while suspended by a metal wire and completely submerged in water. They shall be removed from the water and allowed to drain for one minute by placing them on a 10 mm or coarser wire mesh, visible surface water being removed with a damp cloth and immediately weighed. Subsequent to saturation, all specimens shall be dried in a ventilated oven at 100°C to 115°C for not less than 24 hours and until two successive weighing at intervals of 2 hours show an increment of loss not greater than 0.2 percent of the last previously determined mass of the specimen. The water absorption, being the average of three units, shall not be more than 290 kg/m^3 (25%) for load bearing block and 320 kg/m^3 (30%) for the non-load bearing blocks [36].

According to ASTM C 90 [38], There are two grades of hollow concrete blocks; grade N and S, in which the grade N is suitable for general use such as in exterior walls below and above grade level that may or may not be exposed to moisture penetration, and the grade S is only limited for use above grade level for walls not exposed to weather and for exterior walls with weather protective coating. Both grades are classified further in to moisture controlled units, Type I (N-I and S-I) and non-moisture controlled units, Type II (N - II and S- II). The absorption requirement of the load bearing blocks is shown in Table 2.10.

Grade	Water absorption, Max (kg/m^3)			
	Oven dry weight classification (kg/m^3)			
	Light weight		Medium weight	Normal weight
	< 1362 (kg/m^3)	1362 to less than 1682 (kg/m^3)	1682 to less than 2002 (kg/m^3)	≥ 2002 (kg/m^3)
N-I & II	–	290	240	210
S-I & II	320	–	–	–

Table 2.10 Absorption requirements of the load-bearing Hollow concrete block [38]

2.8.4.5. Compressive Strength

The strength of hollow concrete block is closely related to the specimen size and shape, a method of pore formation, the direction of loading, age, water content, water-cement ratio, the degree of compaction, and cement content, characteristic of its ingredients used, a method of curing, size and number of holes created. Both hollow structure of the air holes and mechanical condition of the pore shells have a great influence on the compressive strength of the hollow concrete block. It has also been found that a reduction in density due to the formation of holes will result in a significant drop in strength. Generally, compressive strength increases linearly with a density of structural concrete. The minimum compressive strength at 28 days is the average of six units, and the minimum compressive strength at 28 days of individual units should be tested. The compressive strength of a concrete masonry unit shall be taken as the maximum load in 'Newton' divided by the net cross-sectional area of the unit in square millimeters finally the results of the nearest 0.1 N/ mm^2, separately for each unit and as the average for the six units will be recorded [2].

The minimum compressive strength requirements for blocks at the age of 28 days achieved by adjusting the mix proportion of the component materials. The following are the minimum compressive strength requirements which are depicted according to the Ethiopian and ASTM standard. The corresponding lowest minimum crushing strength of any unit shall be not less than 80% of the minimum permissible average crushing strength [2].

Type	Class	Average of 6 units	Individual units
		N/mm^3	N/mm^3
Load bearing	A	5.5	5.0
	B	4.5	4.0
	C	3.5	3.0
Non-load bearing	D	2.0	1.8

Table 2.11 Compressive strength of HCB at the age of 28 days [36]

Type	Grade	Minimum compressive strength	
		Average of 3 units	Individual units
Load bearing	N (I and II)	6.9	5.5
	S (I and II)	4.8	4.1
Non-load bearing		Average of 5 units	Individuals
	(I and II)	3.5	3.0

Table 2.12 Compressive strength of hollow concrete blocks [38]

2.8.5 Conformity Criteria for hollow concrete blocks

A lot can be considered as a conforming to the requirements of the specification if; [36]

- The number of units, among those inspected, with dimensional deviation that are outside the tolerance limit and/or with visual defects shall not be more than two.
- The mean value for compressive strength test shall be greater or equal to the specified minimum limit.
- The average value of water absorption shall be equal or less than the specified maximum limit.

ASTM C 90 [38] recommends conforming requirements such as physical (linear shrinkage, moisture content, compressive strength and water absorption), minimum face-shell and web thickness and permissible dimension variation and visual defects.

2.9. Summary of Literatures and Gap Identification

The major problem in stone processing industry is the accumulation of by product. By products such as marble dust and granite powder from marble and granite rock cutting and polishing industries, and crusher dust produced during quarrying process are the common endeavor to the industry.

The crusher by product is a material passing 4.75mm sieve which accounts 25% of the total crushed rock depending on the type of rock and crusher used. The by product contains 20% crusher dust passing 150µm sieve which is difficult to use as a manufactured sand. In Ethiopia, the annual production of crusher dust actually is not known, but, reports indicate that average estimations of 110,000m^3 and 58,410m^3 of crusher dusts are produced due to coarse aggregate production for government building construction projects as a general and the projects administered by Addis Ababa city (saving house office and road authority) respectively.

Hollow concrete block is one of an alternative walling and flooring material in building construction and it is made from zero slump concrete mixture. Among the ingredients of hollow concrete block, cement is the most expensive and environmentally unfriendly in its production.

Research conducted on the use of crusher dust as a partial replacement material for Cement indicated the effect of crusher dust on different properties of cement and concrete. Most of them obtained a positive result and initiate effective replacement ranges. In reviewing researches from different parts of the world, it is observed that different measures, such as grinding and screening the impurities, are taken to further improve the properties of the dust.

In Ethiopia, as discussed in Chapter two, despite the fact that there exist an immense amount of crusher dust in quarry sites, there is a limited study exist to explain the effect of replacing crusher dust partially with cement on the properties of cement paste and concrete. Hamid [22] checked the feasibility of basaltic crusher dust as cement replacing material in production of C-25 and C-30 concrete. The result of his research showed that a basaltic crusher dust can replace PPC and OPC cement up to 5% and 10 % respectively without compromising the properties of both grade of concretes.

There has been an effort in using industrial wastes as cement replacing material for HCB production. Birhanu [2] had studied the effect of Marble powder on performance of HCB by replacing PPC cement up to thirty percent. However, there is no research conducted to investigate the effect of replacing the crusher dust with cement on properties of hollow concrete block. Based on this gap, the study aimed to investigate the effect of basaltic crusher dust blended with PPC cement on the performance of hollow concrete blocks.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Materials Used In the Research

The materials used in the investigation of the effects of replacing cement with a quarry dust on the hollow concrete block production are described in terms of their physical and chemical properties. The laboratory activities on the properties of fine and coarse aggregate, pumice and the HCB made by incorporation of quarry dust are carried out in the Kality construction material production factory (KCMPF). The test for the fineness of the crusher dust and cement was conducted in Addis Ababa University Chemical Engineering laboratory, whereas, the properties of cement and blended cement pastes were studied in Hawassa University construction materials laboratory. On other hand, the chemical composition of quarry dust, and the specific gravity of cement and quarry dust were determined in Ethiopian Geological Survey, center of Ethiopian Geo-science laboratory. Furthermore, the clayey property of the basaltic crusher dust was studied in IFH Engineering soil laboratory.

3.1.1. Basaltic Crusher Dust

Throughout the experiment, crusher dust obtained from the quarry site found in Addis Ababa were used. There are more than three hundred fifty aggregate production plants in the city of Addis Ababa. [43]. The crusher dust from these plants could be different in their chemical composition, clay content and fineness due to the type of parent rock, location of crushing sites and the type of crusher used. The selection was done based on the geological map of Addis Ababa and the population of production plants.

The geological map of Addis Ababa indicates that the common aggregate rock found in Addis Ababa and its surrounding are basalt, trachyte and ignimbrite. On the other hand, according to the report by the Addis Ababa Environmental Protection Authority (EPA) and personal observation most of the aggregate production plants and their quarries are found in Bole- Bulbula and Akaki Kality areas following the Akaki River. [43]. At the same time the parent rock for these quarry sites are mostly basaltic which is widely available and used type of rock for aggregate production in Ethiopia. As a result, the crusher dust from basaltic aggregate production plants were selected.

Figure 3.1 Geological map of Addis Ababa [44]

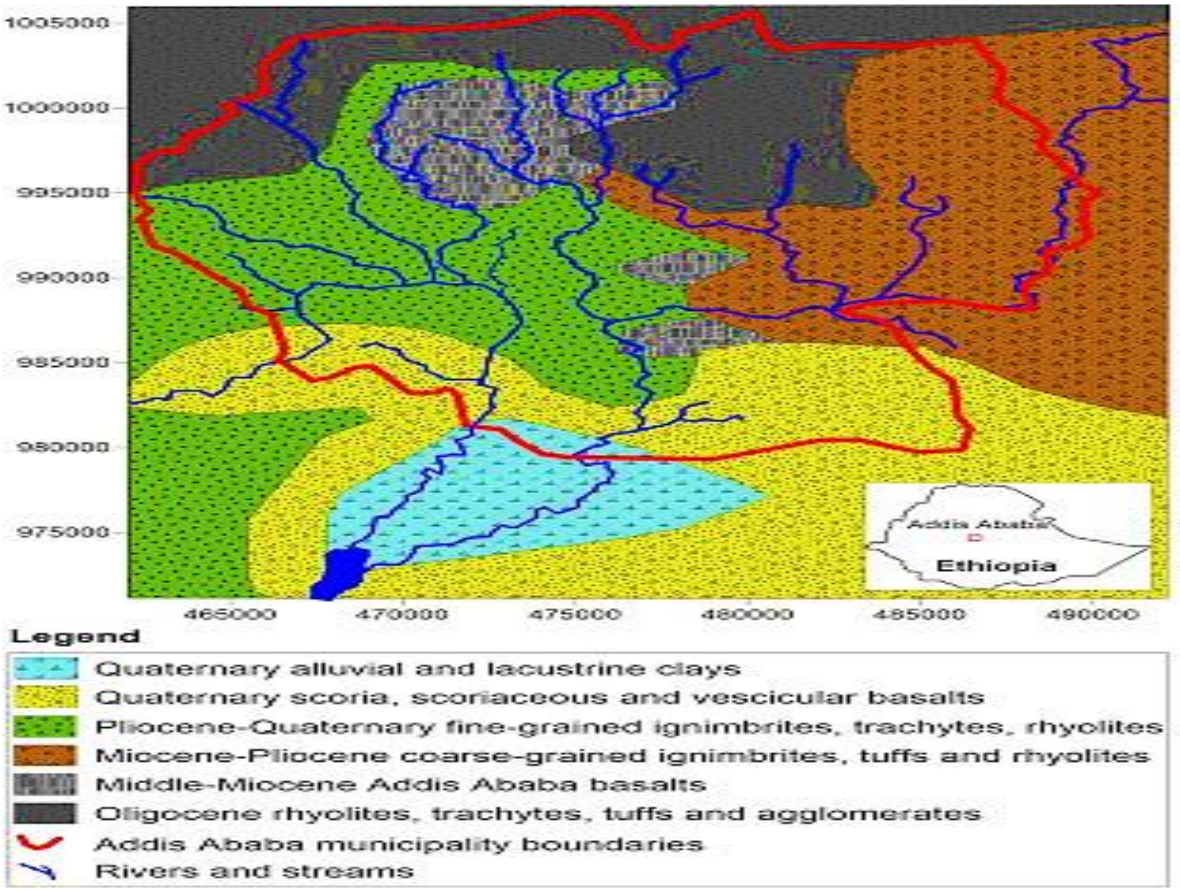


Table 3.1 Total area of quarries in Addis Ababa [43]

No.	Sub-City	Licensed area (m^2)
1	Gullele and Kirkos sub-city	56, 322.00
2	Yeka sub-city	963, 412.50
3	Bole sub-city	4, 087, 078.00
4	Nifas silk laft sub-city	583, 955.35
5	Akaki-Kality sub-city	5, 136, 443.91
	Total area	10, 827, 211.76

According to the crusher site observation, it was attempted to understand that dust produced in different arrangements of crusher plant and crushing process results in different clay contents. Crusher plants can be arranged either closer to or away from the quarry, in which they are defined as worst and best case respectively [22]. Crushing plants installed beside rock quarries; directly feed from the quarry without need of transporting material, are highly susceptible for clay and organic impurities due to poor scalping process, whereas, the crushing plant installed away from the quarry involve scalping prior to transportation which helps to separate rock from organic impurities. This process will lead to production of relatively pure pulverized rock. Based on this fact, a quarry dust produced from later arrangement will replace cement in higher percentage for concrete production. This tells that the dust produced in the worst case (i.e. crusher site located near the quarry area) is a minimum requirement to use quarry dust as cementitious material in concrete production. Accordingly, the dust used in this research was obtained from a crusher plant arranged near the quarry as shown in Figure 3.2.

Figure 3.2 Crusher dust produced from crusher site arranged closer to quarry area (Observation around Akaki-Kality sub city)

The crusher dust used in this research was taken from crusher site located in Akaki Kality sub-city around Akaki River, specifically from 'Worku sefer' area.

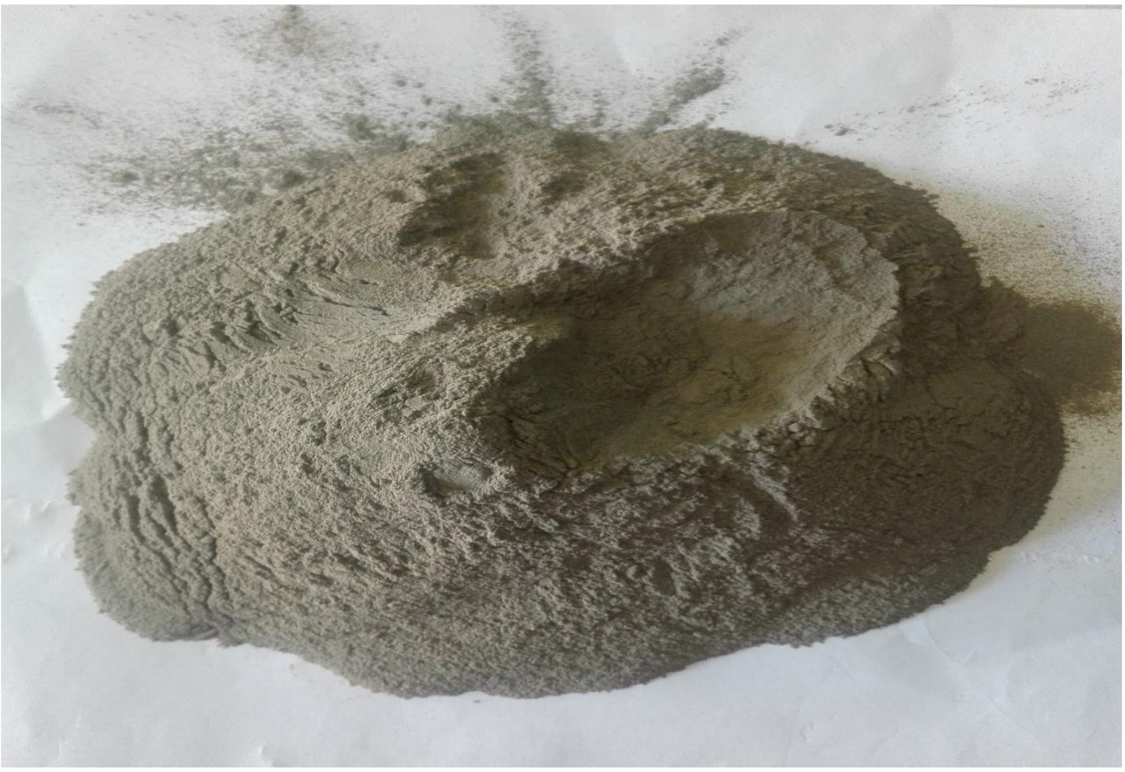
Prior to using quarry dust, three samples from three different crushing plants of such arrangement were collected, sieved and examined for their fineness. The fineness of basaltic crusher dusts, which was conducted in Addis Ababa University Chemical Engineering laboratory, were measured using air permeability meter according to the test procedure recommended by ASTM C 204. The fineness of the samples, then, compared to the cement. The test results are shown in Table 3.2.

Table 3.2 Fineness of the basaltic crusher dust samples and cement

Trials	Time recorded in sec (T)	Average time recorded in sec (T)	Standard specific gravity in cm^2/gm (Ss)	Standard time in sec (Ts)	Calculated specific surface of sample in cm^2/gm ($S = Ss\frac{\sqrt{Ts}}{\sqrt{T}}$)
Sample one					
1	15.4	15.53	3774	29.77	2725.83
2	15.65				
3	15.54				
Sample two					
1	17.51	17.22	3774	29.77	2870.31
2	16.89				
3	17.26				
Sample three					
1	17.19	17.04	3774	29.77	2855.27
2	17.05				
3	16.88				
Cement					
1	28.01	28.24	3774	29.77	3675.74
2	27.76				
3	28.95				

The result on the Table indicates that the second sample (2870.31cm^2/gm) has higher fineness value which is relatively closer to the cement. Thus, the dust from this basaltic crushed aggregate production plant was chosen for the research as all are produced from basaltic parent rock.

Figure 3.3 Basaltic crusher dust sample after sieving with 150µm sieve (Crusher dust used for the research)



Sample of crusher dust from the selected crusher site was submitted to Ethiopian geological; Geoscience laboratory center for complete silicate analysis and specific gravity in which the results are shown in Tables 3.3 and 3.4.

Table 3.3 Chemical composition of Basaltic Crusher Dust (Complete Silicate Analysis)

Chemical oxides	Chemical composition (%)		Chemical oxides	Chemical composition (%)
SiO_2	58.40		K_2O	2.82
Al_2O_3	15.99		MnO	0.22
Fe_2O_3	8.10		P_2O_5	1.35
CaO	3.42		TiO_2	0.66
MgO	1.98		H_2O	1.21
Na_2O	4.14		LOI	2.13

Table 3.4 Specific gravity of basaltic crusher dust used in the research

Trials	I	II
Mass of pycnometer in gm. (m_2)	25.9856	29.2497
Mass of test solution in pycnometer without test sample in gm. (m_3)	75.8655	79.12
Density of test solution in gm/cm^3 (Q_2)	1	1
Mass of pycnometer plus test sample in gm. (m_4)	32.9439	38.7839
Mass of test sample in gm. (m_4-m2)	6.9583	9.5342
Mass of pycnometer, test sample and test solution in gm. (m_5)	80.173	84.9472
Volume of test sample in gm/cm^3 ($m_3+m_4-m_5$)	2.6508	3.707
Specific gravity in gm/cm^3	2.62	2.57
Average	**2.59**	

There was no available mechanism to compute the content of clay in the basaltic crusher dust at the Ethiopian geological survey as well as at Hawassa University. Thus, the plasticity index (PI) of the sample were determined to show the clayey property rather than its amount. The PI test of the crusher dust were conducted in IFH Engineering soil laboratory (at Akaki Kality project office) in accordance with ASTM D 4318. It was found that the crusher dust has a PI of 3.39 (Appendix A), which means that the crusher dust contain clay. ASTM D 242 recommends a mineral filler prepared from rock dust, slag dust and similar materials to be free from organic impurities and should have PI value less than four. This implies that the crusher dust can be used as a cement replacing material. This test is conducted to indicate the clayey property of the crusher dust indirectly.

3.1.2. Cement

Portland cement is one of the most widely used cement in construction activity. In this study Portland Pozolana cement (PPC) from Habesha cement factory with grade of 32.5N, which is manufactured to satisfy Ethiopian standard CES 28-2013, ES 1176 and European standard EN 197-1:2011, were used in production of all HCB specimens for the experimental study. The fineness of the cement, as measured in the chemical laboratory of Addis Ababa University, were conducted by using Blaine air permeability meter according to the test procedure recommended by ASTM C 204. Accordingly, the result shows that Habesha cement (PPC 32.5N- CEM II) used for the research has a fineness of 3675.74 cm^2/gm. In addition, the specific gravity, as determined in Ethiopian geological survey; geoscience laboratory center, were found to be 3.14 (Appendix F).

3.1.3. Aggregates

Throughout the experiment, river sand as fine aggregate, and crushed basaltic rock and pumice as a coarse aggregate from Kality Construction Material Production Factory (KCMPF) aggregate stockpile, with the following physical properties, were used.

3.1.3.1. Properties of Fine Aggregate

Among the available river sand in stockpile, the sand from Meki area was stored for hollow concrete block production since it is believed to have good quality and fulfill the gradation requirement. The properties of the sand were checked for satisfying the fine aggregate requirement stipulated in Ethiopian standard and ASTM standard

(i) Silt Content

The presence of dust, loam and clay materials in sand decreases the bond between the materials to be bound together thereby decreases the strength of concrete besides decreasing the quality of concrete. From the silt content test performed on the sand, 4.5% of silt was identified. This value is less than the maximum amount recommended by the Ethiopian standard, which is 6%. Therefore, the sand used in this research was taken without washing.

(ii) Gradation and Fineness Modulus

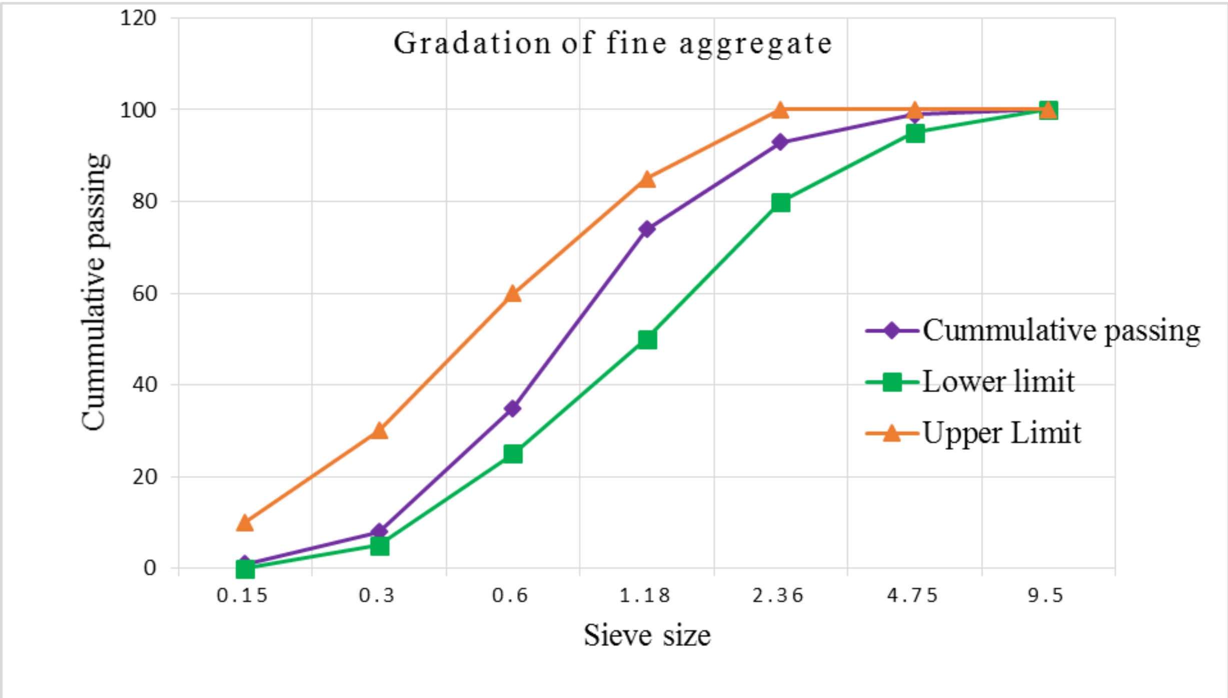
The sieve analysis is a procedure to determine the particle size distribution and fineness modulus, which is an index to fineness, coarseness and uniformity of aggregates. These properties of aggregate greatly affect the quality of concrete. The fineness modules of sand used in this research was calculated as 2.9 which is within the specified range of fineness modules value by the ASTM standard (i.e. ranges between 2.25 to 3.25). The gradation table and curve are shown under Table 3.5 and Figure 3.4.

Table 3.5 Sieve analysis results and standard for fine aggregate

Sieve size (mm)	Weight retained (g)	Percentage retained (%)	Cumulative retained (%)	Cumulative passing (%)	ASTM C33
9.5	0	0	0	100	100
4.75	10	1	1	99	95-100
2.36	60	6	7	93	80-100
1.18	190	19	26	74	50-85
0.6	390	39	65	35	25-60
0.3	270	27	92	8	5-30
0.15	70	7	99	1	0-10
Pan	10	1	100	0	
Total	1000	100	290	-	-

The grading curve for the sieve analysis of sand and the standard (ASTM C33) is shown in the Figure below.

Figure 3.4 Grading curve for fine aggregate distribution



Fineness Modulus (FM)= $\frac{\sum \text{cumulative retained}}{100}$---------------------------------- [Equation 3.1]

N.B: The values in the intermediate sieves are not included in the determination of FM.

$$\text{FM} = \frac{290}{100} = 2.9$$

(iii) Specific Gravity and Absorption Capacity

Specific gravity is an expression of the density of an aggregate. It is the ratio between the weight of the substance and that of the same volume of water. Aggregates contain pores in their structure, therefore the specific gravity depends on whether the pores are included in the measurement or not. Apparent specific gravity of an aggregate refers to the solid materials excluding the pores and bulk specific gravity refers to the total volume, i.e. including pores of the aggregate. Absorption capacity of fine aggregate was also determined simultaneously with specific gravity according to ASTM C 127 test method. The following results were found for Meki sand:

Bulk specific gravity = 1.83

Bulk specific gravity (SSD basis) = 2.09

Apparent specific gravity = 2.48

Absorption capacity = 14.41%

(iv) Moisture Content

The water to cement ratio of a Concrete affects the strength and the workability of a concrete. The increase of water to cement ratio results in a decrease of the strength of the concrete and increase of workability. The aggregates in a Concrete are assumed to be inert materials. However, most of the aggregates do not meet this assumption by either absorbing water or releasing it to the mix. As a result this will affect the design water to cement ratio of mixture. Thus, it is important to determine the moisture content of an aggregate in order to adjust the water to cement ratio. The moisture content of fine aggregate was found to be 4.17%.

(v) Unit Weight

Unit weight can be defined as the weight of a given volume of graded aggregate. It is thus a density measurement and is also known as bulk density. The unit weight effectively measures the volume that the graded aggregate will occupy in concrete and includes both the solid aggregate and the voids between them. The test is conducted according to ASTM C 29 test method. The unit weight of the fine aggregate sample used was found to be 1294 kg/m^3.

Table 3.6 Summary of test results for fine aggregate

<table>
<tr><td>No.</td><td colspan="2">Test description</td><td>Test result</td></tr>
<tr><td>1</td><td colspan="2">Silt content</td><td>4.5</td></tr>
<tr><td>2</td><td colspan="2">Moisture content</td><td>4.17</td></tr>
<tr><td>3</td><td colspan="2">Unit weight, kg/m^3</td><td>1294</td></tr>
<tr><td>4</td><td colspan="2">Absorption capacity, %</td><td>14.41</td></tr>
<tr><td rowspan="3">5</td><td rowspan="3">Specific gravity</td><td>Bulk</td><td>1.83</td></tr>
<tr><td>Bulk (SSD)</td><td>2.09</td></tr>
<tr><td>Apparent</td><td>2.84</td></tr>
<tr><td>6</td><td colspan="2">Fineness modulus</td><td>2.9</td></tr>
</table>

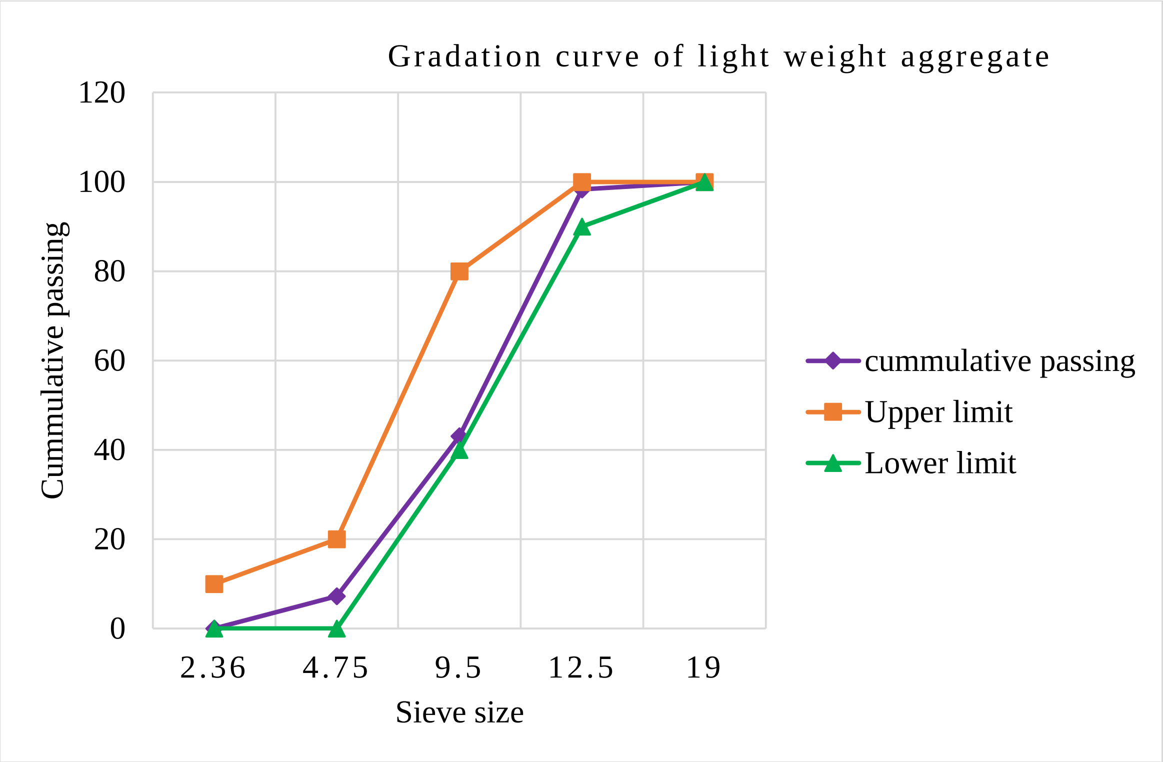
3.1.3.2. Properties of Coarse Aggregate

The coarse aggregate used for this research were crushed basaltic rock and pumice. A crushed basaltic rock with a maximum size of 10mm was utilized for the production of all HCB samples. Furthermore, the pumice size distribution is consistent from size 19mm to 2.36mm on its limit. The sieve analysis test is performed in accordance with the procedure of ASTM C 136 to fulfill the grading requirement of light weight aggregate for concrete masonry units specified on ASTM C 331. Thus, its gradation table is shown in Table 3.7.

Table 3.7 Gradation of light weight aggregate (Pumice)

Sieve size (mm)	Weight retained (gm)	Percentage retained (%)	Cumulative retained (%)	Cumulative passing (%)	ASTM C 331
19	0	0	0	100	100
12.5	48.47	1.68	1.68	98.32	90-100
9.5	1592.81	55.21	56.89	43.11	40-80
4.75	1033.40	35.82	92.71	7.29	0-20
2.36	210.32	7.29	100	0	0-10
Pan	0	0	100	0	
Total	2885	100	-	-	-

Figure 3.5 Gradation curve of light weight aggregate (Pumice)

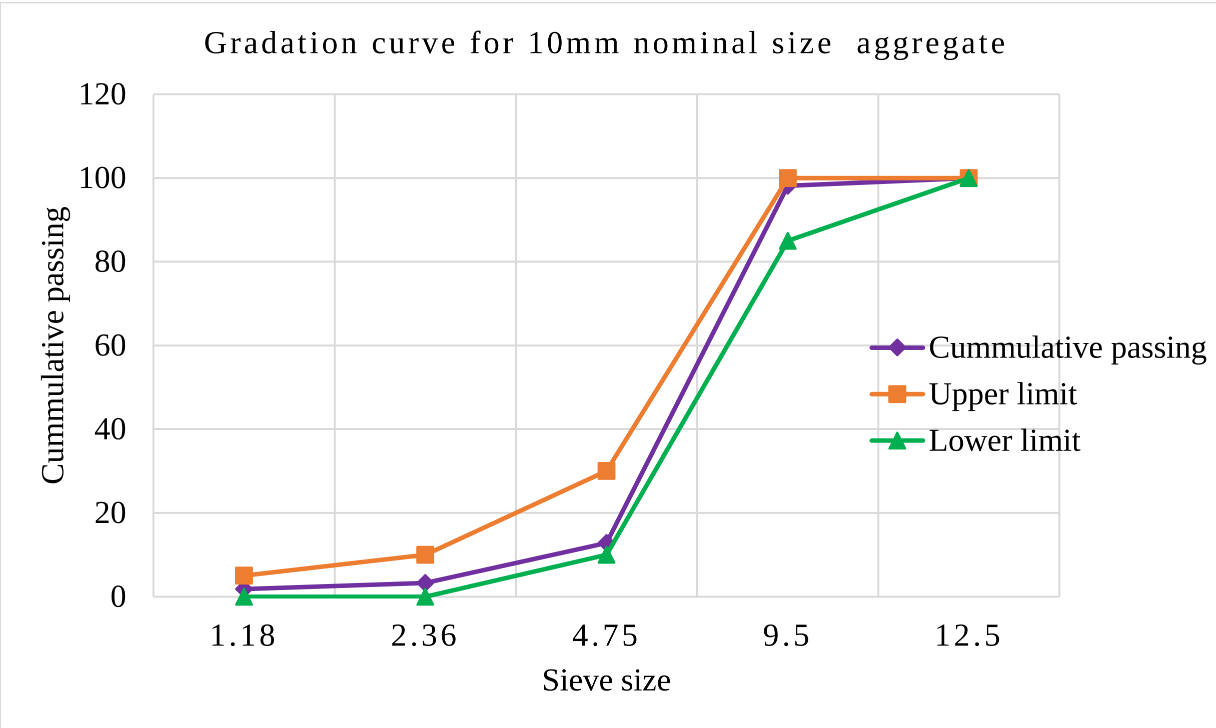


The coarse aggregate distribution for 10mm aggregate size is consistent from size 9.5 to 2.36mm sieve openings. The gradation of coarse aggregate for 01 aggregate is within the range as it fulfill the requirements of ASTM C 33. The gradation table is shown in Table 3.8 and Figure 3.6.

Table 3.8 Gradation of Coarse Aggregate (Nominal size of 10mm aggregate)

Sieve size (mm)	Weight retained (gm)	Percentage retained (%)	Cumulative retained (%)	Cumulative passing (%)	ASTM C 33
12.5	0	0	0	100	100
9.5	91.77	1.9	1.9	98.1	85-100
4.75	4120	85.3	87.2	12.8	10-30
2.36	458.85	9.5	96.7	3.3	0-10
1.18	70.04	1.45	98.15	1.85	0-5
Pan	89.36	1.85	100	0	
Total	4830	100	-	-	

Figure 3.6 Particle distribution curve of 10mm aggregate



In a similar manner as the fine aggregate, the laboratory tests were carried out to determine the physical properties of the coarse aggregates (pumice and 01 aggregate) and the results are summarized in Table 3.9.

Table 3.9 Summary of test results for coarse aggregates

No.	Test description		Test result	
			Pumice	01 aggregate
1	Maximum size (mm)		19	9.5
2	Moisture content (%)		8.65	1.9
3	Unit weight (Kg/m^3)		640	1519
4	Absorption capacity (%)		60.60	2.0
5	Specific gravity	Bulk	0.65	2.65
		Bulk (SSD)	1.05	2.71
		Apparent	1.08	2.80

3.1.4. Water

In this research, a tap water supplied for Kality construction material production factory (KCMPF) was used in producing, curing and soaking of hollow concrete blocks. On other hand, In order to test consistency of blended cement a drinking water supplied to Hawassa University from Hawassa water and sewerage authority were utilized.

3.2. Experimental Program

The main objectives of the experimental program were to study the extent of suitability of basaltic crusher dust as cement replacing material in production of concrete hollow block. These includes studying of properties of dust separately, and properties of paste and hollow concrete block by replacing parts of cement with crusher dust in different percentages.

In the experimental activity, two sets of tests were conducted to achieve the objectives of the research. The first set of experiment was conducted to determine the effect of replacing part of cement with basaltic crusher dust on the properties of cement such as normal consistency and setting time. Prior to these, crusher dust were prepared, the fineness of cement and crusher dust, and chemical composition of the crusher dust were also determined. The second set of experiment, then, were done to determine the performance in terms of compressive strength, water absorption and density of three classes of hollow concrete blocks, i.e. class A, B and C, which were produced using Portland pozzolana cement blended with crusher dust.

3.2.1. Experiment I

Experiment one includes preparation of basaltic crusher dust, determination of chemical composition of crusher dust, specific gravity of quarry dust and cement, fineness of cement and dust, preparation of pastes of cement blended with crusher dust by different percentages and determination of normal consistency and setting time of the paste.

3.2.1.1. Preparation of Basaltic Crusher Dust Sample

The crusher dust was originally found at crushed aggregate production plant area blended with other grades of aggregate as a byproduct and are located near the secondary and tertiary crusher by the action of natural wind. These by products was collected, packed in sack and transported to the construction material laboratory of KCMPF for further processing. The intention of the research was to use basaltic quarry dust passing sieve with aperture opening of 150μm. Therefore, the original collected crusher dust was sieved and its fineness and chemical composition were determined before blending it with cement.

3.2.1.2. Fineness

The fineness of the three basaltic crusher dust samples and cement was tested by Blaine air permeability apparatus and the results are depicted in Table 3.2. The Blaine air method is based on the ASTM C 204 standard and it is expressed as total surface area in square centimeter per gram, or square meter per kilogram, of cement.

3.2.1.3. Chemical Composition and Specific Gravity

The sample collected from the selected crushed aggregate production plant (i.e. from sample 2) was tested for the chemical composition, and the specific gravity of cement used in the research and the dust were determined in Ethiopian geological survey geoscience laboratory.

3.2.1.4. Normal Consistency of Cement

The normal consistency test of both hydraulic and blended cement are conducted in accordance with ASTM C 187 test method. This test was done to determine the extent of effect of quarry dust on the water requirement of blended cement paste. Pastes of both control mix (cement with no quarry dust) and experimental mixes (cement replaced by 10%, 20%, 30% and 40% of quarry dust) were prepared. The water content was varied for each of the pastes produced until normal consistency of pastes obtained. The designation of test samples for the different pastes are depicted in Table 3.10.

Table 3.10 Naming and proportioning of cement pastes

S. No.	Code	Percentage by weight*	
		Crusher dust (%)	Portland pozzolana Cement (%)
1	P-0	0	100
2	P-10	10	90
3	P-20	20	80
4	P-30	30	70
5	P-40	40	60

* The replacement is done in such a way that 1kg of crusher dust replaces 1kg of cement.

3.2.1.5. Setting Time

The initial and final setting time of both controlled and blended pastes were measured according to the test procedure on ASTM C 191. The naming of the samples were the same as designated for normal consistency.

3.2.2. Experiment II

The second set of experiment consists of determination of the mix design, preparation of hollow concrete block specimens and conduction of tests on the hardened specimens; in which conducted to investigate the effect of replacing part of cement by crusher dust on concrete block.

3.2.2.1. Mix Design and Trial Mix Preparation

Mix design is defined as a process of determining required or specifiable characteristics of concrete mixture. Determining characteristics such as properties of fresh concrete, required mechanical properties of hardened concrete (strength and durability), limits on specific ingredients leads to proportioning of concrete mixtures; in which the quantities of concrete ingredients are determined to achieve specified characteristics of concrete. Before concrete mixture can be proportioned, mixture characteristics are selected based on the intended use of the concrete, the exposure condition, the size and shape of building elements, and the physical properties of the concrete required for the structure [16]. Proper selection of material and mixture characteristics enables to obtain an economic concrete with an acceptable qualities of fresh and hardened concrete.

Proportioning of materials for hollow concrete block requires careful adjustment of water to cement ratio, unless the mix could be friable when the water content in it is too little or it may cause difficulty of immediate withdrawal from mold as the water content became too high. Because of this controlling water-cement ratio of a mix in between 0.3 to 0.4 is recommended; in which the quantity of water required for one cubic meter of mix can be calculated. [2]

In this research, a mix designing and proportioning prepared by the KCMPF are utilized for production of load bearing hollow concrete blocks, i.e. class A, B and C. The proportion of the materials per bag (50kg) of cement for the control trial mix proportion is shown in Table 3.11.

Table 3.11 Mix proportion for trial mix of the Research

HCB class	Block size			Number of box (20cmx40cmx50cm) of material			Quantity of water (Liter)	No. of blocks produced per bag of cement
	H	W	L	Sand	01aggregate	Pumice		
A	20	20	40	2	4	2	15	21
B				2	4	3	17	26
C				2	5	4	20	32

Following this proportioning mechanism, the other experimental mixes were prepared according to the control mix by replacing part of cement with crusher dust. For studying the effect of partial replacement of cement with crusher dust, three groups of concrete block specimen were prepared. These are; the class A, B and C block groups of specimens prepared with replacement percentages 0 to 40% in 10% increment. The final mix proportion for trial mix of different control and experimental concretes of the groups are shown in Table 3.12.

Table 3.12 Mix proportion for concrete hollow block work

Mix code	Cement type	Cement (kg)	Crusher dust (kg)	W/Cm	Water (l)	Amount (No. of box)		
						Sand	01 aggregate	Pumice
Class A								
A 0	Habesha PPC	50	0	0.3	15	2	4	2
A 10	Habesha PPC	45	5	0.3	15	2	4	2
A 20	Habesha PPC	40	10	0.3	15	2	4	2
A 30	Habesha PPC	35	15	0.3	15	2	4	2
A 40	Habesha PPC	30	20	0.3	15	2	4	2
Class B								
B 0	Habesha PPC	50	0	0.34	17	2	4	3
B 10	Habesha PPC	45	5	0.34	17	2	4	3
B 20	Habesha PPC	40	10	0.34	17	2	4	3
B 30	Habesha PPC	35	15	0.34	17	2	4	3
B 40	Habesha PPC	30	20	0.34	17	2	4	3
Class C								
C 0	Habesha PPC	50	0	0.4	20	2	5	4
C 10	Habesha PPC	45	5	0.4	20	2	5	4
C 20	Habesha PPC	40	10	0.4	20	2	5	4
C 30	Habesha PPC	35	15	0.4	20	2	5	4
C 40	Habesha PPC	30	20	0.4	20	2	5	4

3.2.2.2. Preparation of Hollow Concrete Block Specimens and Mixing Procedure

For the preparation of constituents, both volume batching and weight measurement were used. After determining the relative amounts of materials to be used for the specimens' production, the aggregates and the cements (hydraulic and blended) were dry mixed for approximately one minute. The mixing process continued for another one minutes after the addition of water. As the mixing process completed, the mixture is transported in to the mold by the help of conveyer belt and compacted for about one minute using mechanical vibrator. Finally, the specimen, after compacted thoroughly, was demolded and transported to curing area. The specimen were cured on wooden pallet being covered by plastic sheet for 24 hours after which they were released from pallet and stored on flat surface in honeycomb fashion with horizontal voids until test period.

3.2.2.3. Compressive Strength

Compressive strength test of concrete is the most common test type for hardened concrete since it is a basis for many codes and design manuals, and other properties of concrete [13].

It is known that different factors, such as specimen size and shape, method of pore formation, direction of loading, amount and rate of loading, degree of compaction, characteristics of ingredients, cement content, size and number of holes, and method of curing can affect the compressive strength of hollow concrete block. [45]

In this study, more than two hundred seventy 20cm thick full units of HCB samples, in which each class consists ninety samples of block, with three holes were prepared by blending PPC of 32.5N and crusher dust in different percentages and tested for compressive strength test at the ages of 3, 7 and 28 curing days.

The compressive strength of each of the block samples was determined by using compression machine of KCMPF. The samples were positioned in a testing machine such that the sample were centralized between pressure surfaces and the load was applied in the same direction as in service; for which it was increased at the rate of 0.25 MPa per second until the sample breaks.

For each of the mixes average of six samples were taken as the 3, 7 and 28 days compressive strength value. The mix codes for the test program are shown in Table 3.13.

Table 3.13 Mix code and their description for HCB samples

Mix code	PPC (%)	Crusher dust (%)	Test days			Number of sample	Remark
Class A							
A 0	100	0	3	7	28	18	Control mix
A10	90	10	3	7	28		Experimental mixes
A 20	80	20	3	7	28	18	
A 30	70	30	3	7	28	18	
A 40	60	40	3	7	28	18	
Class B							
B 0	100	0	3	7	28	18	Control mix
B 10	90	10	3	7	28	18	Experimental mixes
B 20	80	20	3	7	28	18	
B 30	70	30	3	7	28	18	
B 40	60	40	3	7	28	18	
Class C							
C 0	100	0	3	7	28	18	Control mix
C 10	90	10	3	7	28	18	Experimental mixes
C 20	80	20	3	7	28	18	
C 30	70	30	3	7	28	18	
C 40	60	40	3	7	28	18	
Total Samples						270	

The values of the compressive strength of each block unit were computed as follow;

$$\text{Compressive strength, MPa} = \frac{\text{Failure load}}{\text{Effective area}} \text{ -------------------- [Equation 3.2]}$$

Where; Effective area = Gross area (A_{gross}) – Area of holes (A_{holes}).

The blocks contain three holes; in which two of them are equal and arranged at the end, and the third hole which has a smaller dimension is located at the middle. The detailing for dimensions are described in Figure 3.7.

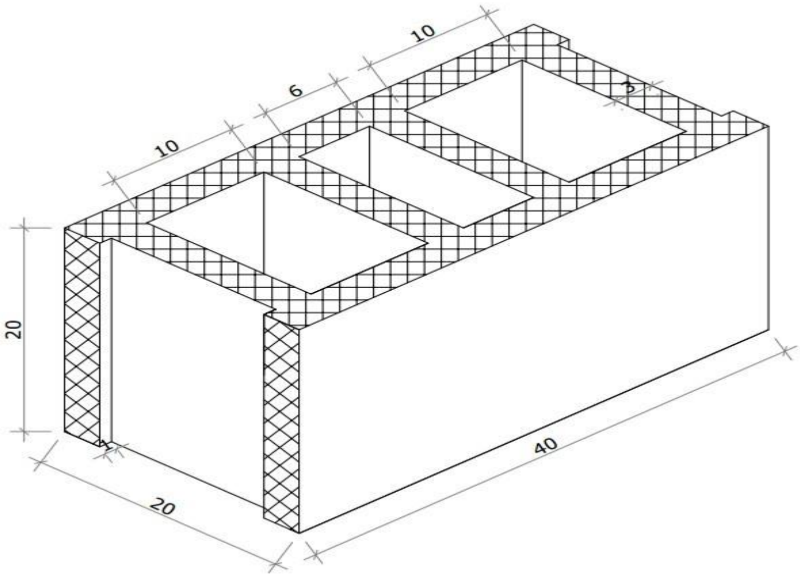


Figure 3.7 Dimension details for hollow Concrete blocks produced in the research [in cm]

Thus, A_{gross} = 20cm x 40cm = 800cm^2

A_{holes} = ((14cm x 6cm) + (2 x ((14cm x 1cm) + (14cm x 10cm))) = 392cm^2

$A_{effective}$ = (800 – 392) cm^2 = 408cm^2 (the area which is used to compute the compressive strength of blocks).

3.2.2.4. Water Absorption of Concrete Block

After completely immersing the blocks for 24 hours, water was wiped-off the surface of the blocks and air dried for one minute. Each of the block was then weighed. Subsequently, each specimen were dried in a ventilated oven at 110^{o}c for 24 hours. Then, after the dried samples removed from oven and cooled at room temperature by placing on dry surface, each of them were weighed. The mass of each of the block after drying was subtracted from its mass after 24 hours of immersion in water in order to determine the mass of water absorbed. The water absorption in percent was determined by the ratio of the mass of water absorbed to the dry mass of concrete block.

In this study, more than forty-five full units of blocks, fifteen for each class, were prepared by blending PPC and crusher dust in different percentages. The samples were then tested for water absorption at the age of 28 curing days. The average value of three samples were taken as water absorption of block of each of different classes with different percentages of cement replacement.

3.2.2.5. Density of Concrete Block

In this study, the concrete block samples of water absorption were used for testing the density. Three units from each of the oven dried samples were measured for their dimensions and weights such that the dimensions were measured in centimeter (to the nearest 0.1 centimeter); whereas, the weights in kilograms to the nearest 10g. Considering the dimensions of the hollow concrete block, the overall volume were computed in cubic centimeter and the density of each units were calculated.

CHAPTER FOUR

EXPERIMENTAL RESULTS AND DISCUSSIONS

4.1.Introduction

This section presents the results and discussions of the two set of tests on crusher dust suitability as cement replacing material in hollow concrete block production. The experimental results are described with the help of graphs and tables, and discussed by comparing with the controlled specimens and reference standards (or specification) and other previous related researches.

4.2. Results and Discussions on Experiment One

In this part, the test results of physical and chemical properties of the crusher dust and its effect on the blended cement paste are presented, analyzed and discussed.

4.2.1. Fineness and Specific Gravity of Crusher Dust and Cement

The selected basaltic crusher dust sample (BCD) as cement replacement material sieved through 150µm sieve opening. Then, samples of dust were sieved by sieve opening of 75µm to check the percentage of particles passing this opening prior to fineness test. The percentages of the dust passing sieve opening of 75µm were recorded around 25 % (as average value); which means, more than 75% of samples of crusher dust was coarser than 75µm sieve opening.

The Blaine fineness of the selected basaltic crusher dust (BCD) was 2870.31 cm^2/gm, which is less than the fineness of cement which was measured to have a specific surface area of 3675.74 cm^2/gm. This finding shows that the Crusher dust passing 150µm sieve openings, from which its 20% are less than 75µm, cannot be used as a filler material in concrete unless further processing or grinding is considered to enhance the fineness of the dust.

The specific gravity of the crusher dust measured in Ethiopian geological laboratory found to be 2.59. This indicates that the crusher dust is less dense than cement used in this research which has a specific gravity value of 3.14.

The experimental result for fineness of cement and crusher dust, and the specific gravity of the dust and cement are shown in Tables 3.2 and 3.4 of Chapter Three and Appendix F.

4.2.2. Chemical Composition of Crusher Dust

The complete silicate analysis of the BCD were conducted to detect the chemical properties of the dust, such as oxide composition, moisture and alkali content, and loss on ignition. The chemical compositions are shown in Table 3.3 and Appendix G.

The major oxides; SiO_2, Al_2O_3 and Fe_2O_3, in the crusher dust are composed such that the higher and lower proportions are made by SiO_2 and Fe_2O_3 respectively. According to the complete silicate analysis result of the crusher dust, the amount of SiO_2 is obtained to be 58.4%; indicates the pozzolanic character of the raw material. The relative degree of pozzolanic activity of natural pozzolana was reported to be directly related with their reactive silica content [46].

The combined chemical composition of major oxides were found in percentage to be $SiO_2 + Al_2O_3 + Fe_2O_3 = 58.40 + 15.99 + 8.10 = 82.49$ %. According to ASTM C 618, the chemical composition of class N pozzolana should contain at least 70 percent by mass of major oxides. Based on this prescription the crusher dust can be classified as raw natural pozzolana (or class N pozzolana). The test result for complete silicate analysis is shown in Table 3.3 and Appendix G.

The experimental value of moisture content for the crusher dust were obtained to be 1.21% by mass. This result is less than the maximum limits of water content, i.e. 3%, for class N pozzolana as stated on ASTM C 618.

The basaltic crusher dust was found to have an alkalis content, as equivalent Na_2O, more than the requirement specified on ASTM C 618; which specify as less or equal to 1.5 percent by mass.

Equivalent Na_2O, % = Na_2O, % + 0.658 x k_2O, % [46] ------------------ [Equation 4.1]

Where: Na_2O, % = 4.14 % and k_2O, % = 2.82 %

Based on the above values the equivalent Na_2O becomes (4.14 +0.658 x 2.82) %; which equals to approximately 6%. This is an implication for high alkali – silica reaction in concrete in case when used with alkali reach aggregates. Accordingly, Neville A.M. [13] Testified that the increase in value of equivalent alkalis result high early strength development while reducing the long term strength. Furthermore, Cavdar and Yetgin [11] reported that an increase in Al_2O_3, Fe_2O_3, MgO and K_2O content of natural pozzolans adversely affects pozzolanic activity.

The loss in mass on ignition of the crusher dust; which represent the total amount of carbon in the sample, hydration of free lime and free magnesia due to atmospheric exposure, measured as 2.13. The measured LOI of the basaltic crusher dust was much lower than the limit specified for class N natural pozzolana on ASTM C 618. The standard specifies a maximum of 10 percent loss of mass on ignition for class N pozzolans, hence, the dust satisfies this chemical requirement. Furthermore, it is below 4 percent, which is the maximum allowable total loss on ignition for Portland cement specified by Ethiopian standard. Although, the requirements of both standard are satisfied the clay content in crusher dust can affect the amount of mass loosed due to ignition. According to Hamid [22] The loss on ignition of basaltic crusher dust increases as the clay content increases and reported that a basaltic crusher dust with 20 percent of clay losses about 1.5 times of its mass on ignition relative to pure pulverized rock.

4.2.3. Consistency of Cement and Blended Cement Pastes

The normal consistency of cement blended with crusher dust at different percentage were performed according to the procedure on ASTM C 187. It has been conducted by the use of vicat apparatus to observe the changes in water requirement of pastes due to crusher dust powder. The results of the test on the pastes are shown in Table 4.1 and the changes due to replacement of crusher dust are illustrated graphically in Figure 4.1. The control paste, i.e. P-0 had a normal consistency of 27.5%. All the pastes containing crusher dust showed consistency of higher than the control paste. The consistency of pastes increased by 0.9% initially as the replacement of the crusher dust is 10 percent, then after the water requirement showed an increment of 0.4% and 0.7% for 20% and 30% replacement; which are relatively slow increment in water requirement. As the replacement percent increased to 40 percent, the consistency attained 30%.

Table 4.1 Normal consistency of cement and blended cement pastes

S. No.	Code	Consistency (%)
1	P-0	27.5
2	P-10	28.4
3	P-20	28.8
4	P-30	29.5
5	P-40	30

As given in the table above, despite the coarseness of the crusher dust, the water requirements of the blended cement pastes increased as the percent of replacement increased. This might be due to the clay content of the dust. Clay by its nature consumes more water, therefore, it needs more water for gauging and then the water of consistency increased with the basalt content. This finding on the consistency of blended cement pastes conformed to previous research [22]; in which crusher dust with 20% clay resulted an increase in water consistency of blended cement paste.

The blended cement pastes, i.e. P-10, P-20, P-30 and P-40 had a water requirement that are 103.3%, 104.7%, 107.3% and 109.1% of the control paste, P-0. Moreover, ASTM C 618 limits the maximum water consistency for class N pozzolana blended cement relative to the controls to be 115% [23]. Based on this prescription, the results of all the blended pastes satisfy the requirement.

4.2.4. Setting Time of Cement and Blended Cement Pastes

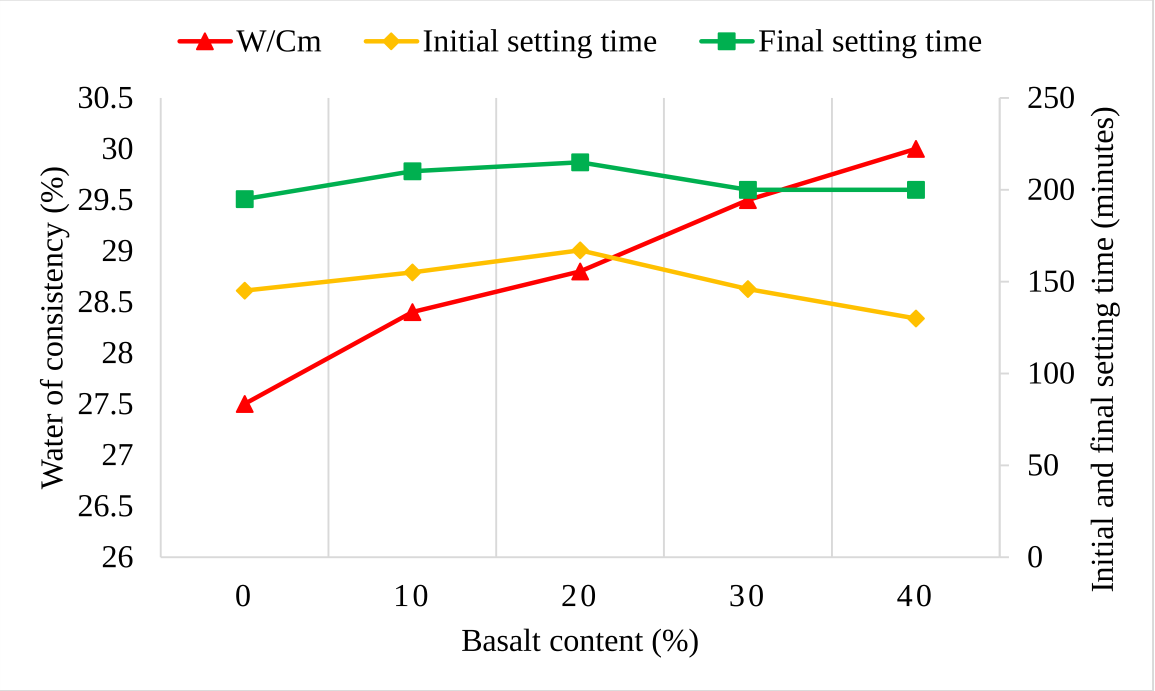
The Ethiopian standard specifies the minimum limit of initial setting time and maximum limits of final setting time for Portland pozzolana cement as 45 minutes and 600 minutes respectively. ASTM C 150, on other hand, specify the corresponding limits to be 45minutes and 375 minutes. Furthermore, ASTM C 595 states time of initial setting not to be less than 45 minutes and restricts the final setting time not to exceed 7 hours in case of blended cement pastes.

The setting time tests for this research are done based on the procedure of ASTM C 191 using Vicat apparatus and the results are tabulated in Table 4.2 and the changes in the initial and final setting time for different percentages of replacement are illustrated in Figure 4.1.

Table 4.2 Initial and Final Setting time of Pastes

S.NO.	Code	Initial setting time (minutes)	Final setting time (minutes)
1	P-0	145	195
2	P-10	155	210
3	P-20	167	215
4	P-30	146	200
5	P-40	130	200

Figure 4.1 Water of consistency, initial and final setting time of PPC and basaltic crusher Dust blended cement pastes



The general consensus is that the less pozzolanity property of the pozzolans in PPC cement at the early age compared with the basaltic crusher dust [22].

For these particular basaltic crusher dust, the result showed that the addition of crusher dust has increasing effect on initial setting time up to 30 percent crusher dust replacement than the control paste (P-0). The addition of the crusher dust powder has also increases the final setting time compared to the control paste. The increasing rate of both the initial and final setting time with the addition of crusher dust increased up to 20% replacement; whereas the rate is slow as the cement is replaced with 30 percent crusher dust. The trend of increment of the initial as well as the final setting time with the percentage increment of crusher dust is not uniform.

These increment in initial and final setting time is observed due to the less involvement of the pozzolanas in the PPC during the initial hydration compared with the basaltic crusher dust [22] which result retarded hydration than the control paste.

The initial and final setting time of blended cement paste of this research are within the limit specified by both the Ethiopian standard and ASTM.

4.3. Results and Discussions on Experiment Two

The different results of tests conducted on hardened concrete hollow blocks made from crusher dust blended cement are presented, analyzed and discussed here. The test results of compressive strength, water absorption and the density of hardened concrete blocks of both control and experimental mixtures of all classes are included in this sub-section.

4.3.1. Compressive Strength of PPC – Crusher Dust Concrete Blocks

For observing of changes in performance of concrete block due to the substitution of part of cement by basaltic crusher dust in hollow concrete block, three classes of HCB, class A, B and C, were prepared and tested for compressive strength at the ages of 3, 7 and 28 days.

The test results of all samples are presented at the appendices; but the summarized test results of each classes are presented here from Tables 4.3 to 4.5 for the purpose of discussion, and the graphical demonstration of the relation between the compressive strength and the replacement percentage are shown in Figure 4.2.

In this study, ES 596:2001; specification for concrete masonry units is used as a compliance criteria for checking the suitability of crusher dust blended cement in production of concrete hollow blocks.

Table 4.3 The average block compressive strength of class A HCB

Mix code	3 – days		7 – days		28 – days	
	Average compressive strength (MPa)	Change in strength (± %)	Average compressive strength (MPa)	Change in strength (± %)	Average compressive strength (MPa)	Change in strength (± %)
A 0	4.24	0.00	4.72	0.00	7.73	0.00
A 10	5.21	(+) 22.88	5.77	(+) 22.25	7.99	(+) 3.36
A 20	4.49	(+) 5.90	4.77	(+) 1.06	7.15	(-) 7.50
A 30	3.45	(-) 18.63	4.65	(-) 1.48	6.41	(-) 17.08
A 40	3.37	(-) 20.52	3.75	(-) 20.55	6.00	(-) 22.38

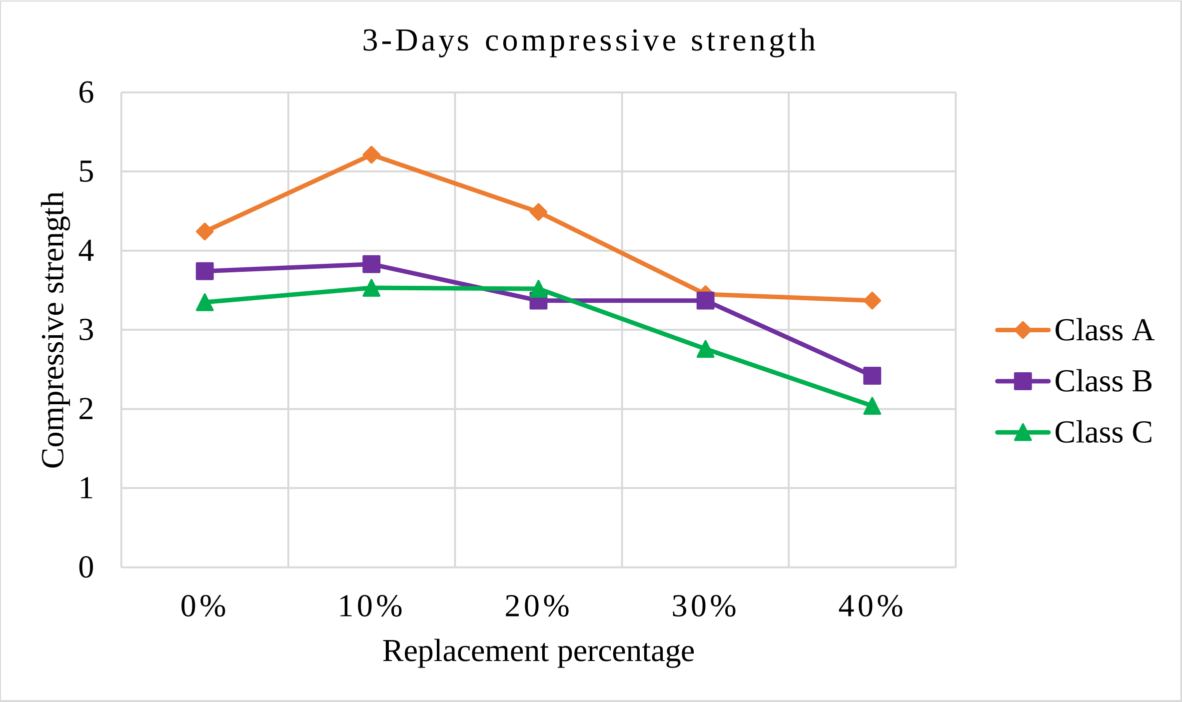
Table 4.4 The average block compressive strength of class B HCB

Mix code	3 – days		7 – days		28 – days	
	Average compressive strength (MPa)	Change in strength (± %)	Average compressive strength (MPa)	Change in strength (%)	Average compressive strength (MPa)	Change in strength. (± %)
B 0	3.74	0.00	4.65	0.00	6.92	0.00
B 10	3.83	(+) 2.41	4.8	(+) 3.23	7.04	(+) 1.73
B 20	3.37	(-) 9.89	3.98	(-) 14.41	5.77	(-) 16.62
B 30	3.37	(-) 9.89	3.47	(-) 25.38	5.46	(-) 21.10
B 40	2.42	(-) 35.29	2.99	(-) 35.70	4.21	(-) 39.16

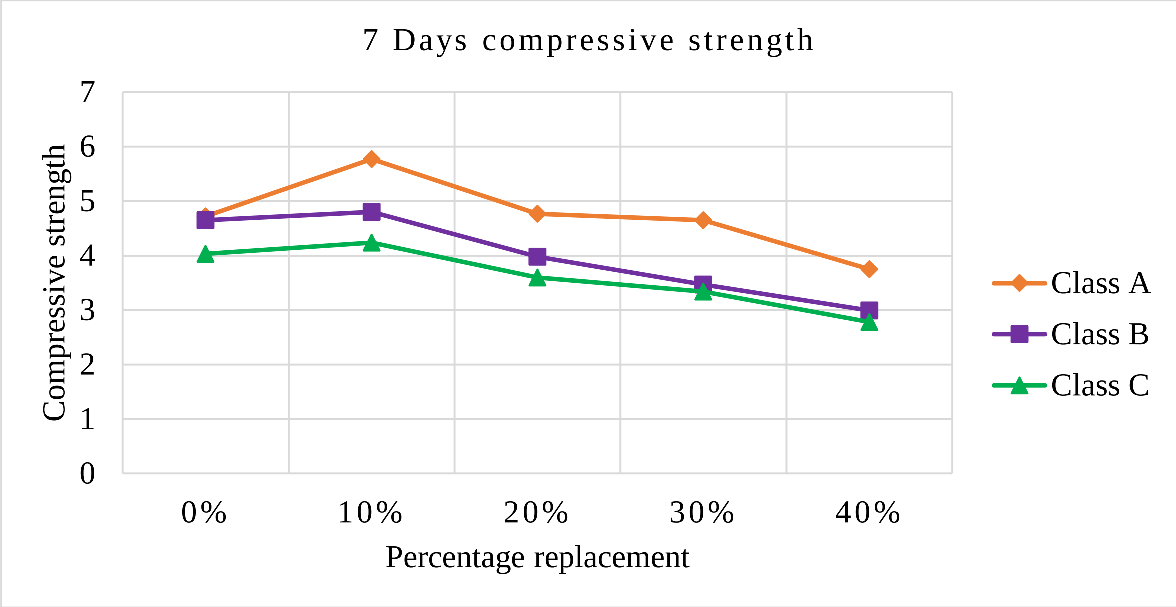
Table 4.5 The average block compressive strength of class C HCB

Mix code	3 – days		7 – days		28 – days	
	Average compressive strength (MPa)	Change in strength (%)	Average compressive strength (MPa)	Change in strength (%)	Average compressive strength (MPa)	Change in strength (± %)
C 0	3.35	0.00	4.03	0.00	6.41	0
C 10	3.53	(+) 5.37	4.24	(+) 5.21	5.85	(-) 8.74
C 20	3.52	(+) 5.07	3.60	(-) 10.67	5.64	(-) 12.01
C 30	2.76	(-) 17.61	3.34	(-) 17.12	5.16	(-) 19.50
C 40	2.04	(-) 39.10	2.78	(-) 31.02	4.83	(-) 24.65

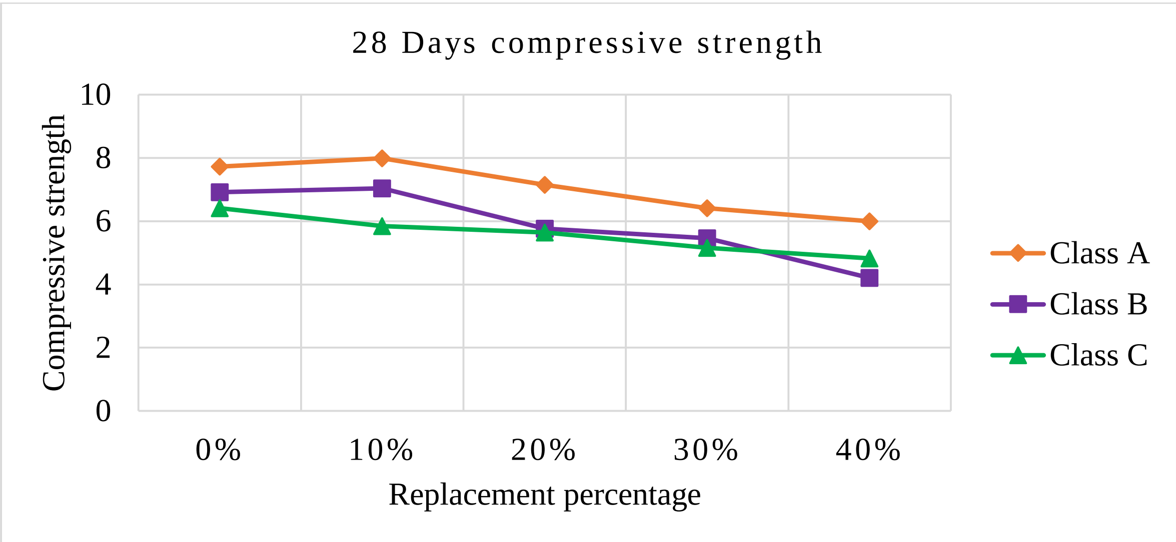
NB: The (+) sign indicates the relative increment in compressive strength; whereas the (-) sign indicates a reduction in compressive strength.



(a)



(b)



(c)

Figure 4.2 Effect of cement replacement by basaltic crusher dust on compressive strength of 3 days (Figure a), 7 days (Figure b) and 28 days (Figure c) hollow concrete blocks

Tables 4.3 to 4.5 and Figure 4.2 shows the variation of compressive strength of controlled, i.e. zero percent replacement, and experimental concrete blocks of all classes at 3, 7 and 28 days of curing ages.

At 3 days, controlled concrete block of class A, i.e. A 0, achieved 4.24 MPa, whereas, concrete mix with 10%, 20%, 30% and 40% of crusher dust, i.e. A 10, A 20, A 30 and A 40, achieved 5.21, 4.49, 3.45, and 3.37 MPa respectively. An increase of 22.88% and 5.9% in compression with the strength of A 0 is achieved for A 10 and A 20 concrete mixes. For A 30 and A 40 compressive strength at 3 days are 81.37% and 79.5% of A 0. At 7 days, A 0 achieved a compressive strength of 4.72 MPa. Compressive strengths of A 10 and A 20 concretes are increased by 22.25% and 1.06% respectively when compared with A 0. For A 30 and A 40 compressive strengths at 7 days achieved 98.5% and 79.45% of A 0. Similarly, the compressive strength of A 0 achieved at 28 days is 7.73 MPa. The compressive strength of A 10 were increased by 3.36% when compared with A 0. At 20%, 30% and 40% of crusher dust in concrete block at 28 days a reduction in compressive strength of 7.5%, 17.08% and 22.38% was observed when compared with A 0.

The compressive strength of class B concrete hollow block with 10% crusher dust, i.e. B10 increased by 2.41% when compared with controlled mix, i.e. B 0, which achieved 3.74 MPa in compression. Whereas, B 20, B 30 and B 40 concrete mixes achieved 3.37, 3.37 and 2.42 MPa respectively, which are 90.1% and 64.7% of B0. At 7 days, B 0 achieved a compressive strength of 4.65 MPa. Compressive strength of B 10 is increased by 3.23% when compared with B 0. Whereas, the compressive strength of B 20, B 30 and B 40 achieved 84.59%, 74.6% and 64.3% of B 0. At 28 days, B 0 achieved compressive strength of 6.92MPa. The compressive strength of B 10 relatively increased by 1.73%. As the percent of replacement increased by 20%, 30% and 40%, the average compressive strengths becomes 5.77, 5.46 and 4.21 MPa respectively.

As given in the Tables and Graphs above, class C concrete hollow block increased by 5.37% and 5.07% in compressive strength at 10% and 20% cement replacement by crusher dust (C 10 and C 20) after 3 days of curing, respectively. Whereas, reduction by 17.61% and 39.10% of controlled concrete mix (C 0) were observed for 30% and 40% replacement ranges. After 7 days of curing, C 0 achieved 4.03 MPa which is exceeded by 5.21% as the crusher dust replacement increased with 10%. The compressive strength of this class shows a reduction by 10.67%, 17.12% and 31.02% of C 0 for C 20, C 30 and C 40 concrete hollow block. At 28 days, the C 0 achieved a compressive strength of 6.41 MPa, whereas, C10, C 20, C 30 and C 40 concrete mixes achieved 5.85, 5.64, 5.16 and 4.83 MPa, respectively. A reduction of 8.74, 12.01, 19.5 and 24.65% in comparison with the strength of C 0 is achieved for C 10, C 20, C 30 and C 40 concrete mixes, respectively.

When it is tried to compare crusher dust replacement in class A, B and C, it was able to understand that the early strength developments (3 and 7 days) up to 10 percent replacement were fast relative to the control mix. This continues up to 20 percent replacement for class A at these curing ages; whereas, the strength development limited to 3 days of curing for Class C blocks. At 28 days, the compressive strength of class A and B increased for 10 percent replacement of crusher dust, whereas, the compressive strength of class C concrete block declines as the replacement percentages increased from 10 percent to 40 percent. In all classes of concrete hollow blocks, the compressive strength at all ages decreases for 30 and 40 percent of crusher dust in concrete. This might be the amount of reduction in cement content in concrete mix, thus reduces the anhydrous products to form C-S-H gel. Despite the reductions in compressive strengths, the concrete blocks of class A and C with different percentage replacement of cement by basaltic crusher dust achieves the minimum requirement of compressive strength specified in ES 596:2001. The class B hollow concrete block achieve this requirement for replacement of 10 to 30 percent crusher dust, after which it fails to achieve.

4.3.2. Water Absorption of PPC – Basaltic Crusher Dust Concrete Blocks

In order to observe the changes in the resistance of concrete blocks to moisture three samples of full units of crusher dust blended cement concrete hollow blocks were prepared for each percentage of replacements and classes.

The water absorption test results of concrete hollow blocks at the age of 28 days of curing are given in Table 4.6 in terms of percentage and the changes in absorption through percentage replacements are demonstrated graphically in Figure 4.3.

According to ASTM C 140, rate of absorption (%) is calculated as;

Absorption (%) = [(Ws – Wd)/Wd] x 100 [44] --------------------------- [Equation 4.2]

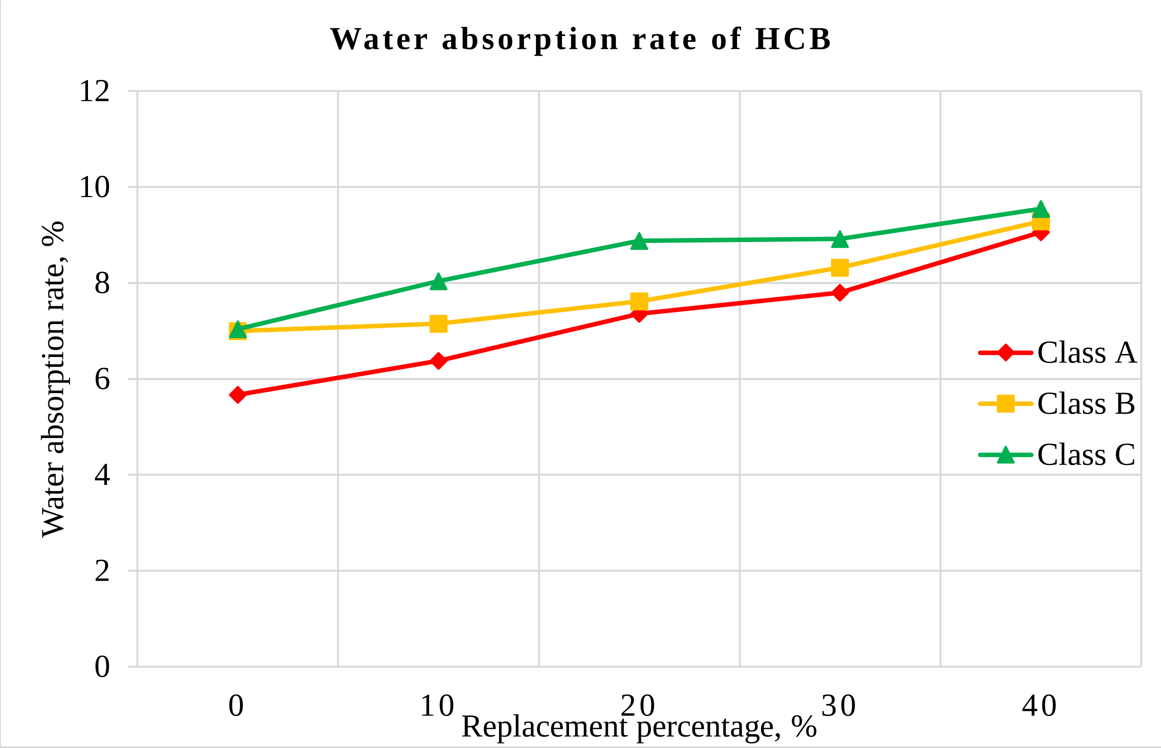
Where; Ws = Saturated weight of specimen, kg

Wd = Oven dry weight of specimen, kg

Table 4.6 Average Water Absorption rate for all classes of HCB

Mix code	Average of 28th day		
	Saturated weight of block [Kg] (A)	Oven dried weight of block [Kg] (B)	Absorption (%) $[\frac{A-B}{B}]$ x 100
A 0	21.93	20.76	5.67
A 10	21.78	20.47	6.38
A 20	21.93	20.43	7.36
A 30	21.53	20.02	7.80
A 40	21.37	19.6	9.06
B 0	20.82	19.46	7.0
B 10	20.66	19.28	7.15
B 20	19.96	18.55	7.62
B 30	19.65	18.47	8.32
B 40	19.29	17.65	9.29
C 0	19.57	18.28	7.04
C 10	19.70	18.23	8.04
C 20	19.20	17.64	8.88
C 30	18.90	17.35	8.92
C 40	18.82	17.18	9.55

Figure 4.3 Graphical representation of crusher dust effect on water absorption of HCB



Different results as described in Table 4.6 and Figure 4.3, where the absorption satisfied the standard at all replacement percentage for all the classes of concrete hollow block. The class C block at the replacement percentage of 40% only reached the absorption rate of 9.55 percent. This is far below the maximum absorption rate, 25 percent, recommended by the Ethiopian standard. The achievement in water absorption requirement benefits the concrete hollow block in durability aspects.

Further analysis can be explained for the increasing effect of crusher dust replacement on water absorption of hollow concrete block. Increase in crusher dust resulted in increase in water absorption percent for all classes of concrete blocks. This is might be due to the high void spaces or pores created because of the replacement of finer material (cement), with coarser material (crusher dust). In other word, Pores would be increased as the number of cement was being limited to bind higher portion of aggregates so that the void of the air will be available. As the air space between particles increased more water is absorbed to fill the gap during wet condition. It was also observed that the absorption percentage is higher in class C for all replacement percentages and class B concrete block is the second most absorbent. Furthermore, class A has higher variation in absorption as the cement content replaced by the ranges 20% to 40% of crusher dust in which it varies from 29.81% to 59.79%

for the corresponding percent of replacement. The water absorption test on class B shows that the relative variation in absorption for 10%, 20%, 30% and 40% cement replacement to be 2.14%, 8.86%, 18.86% and 32.71% respectively; whereas a variation of 14.2%, 26.14%, 26.7% and 35.65% were found in class C for the corresponding replacement percentages.

The results show that, the coarser particles of crusher dust decreased the packing density of fresh concrete leading to increase in pore volume in hardened concrete blocks. This causes higher rate of absorption.

4.3.3. Density of PPC – Basaltic Crusher Dust Concrete Block

The oven dried weights and dimensions of three blocks for each of the replacement rate and classes were measured at the age of 28 curing days in order for calculating the density of hollow concrete blocks. The block density were computed by dividing the mass of block by the overall volume, including holes or cavities and end recesses [35, 47].

The density of hollow concrete block depends primarily on the aggregate density and the proportion of aggregate since the particle density of individual grading fraction can differ considerably and thus will affect the density of the final product. Furthermore, the content of cement, air and water also influence this property. In this research, three blocks were dried in oven heated to 105^{o}c. After cooling the units at room temperature, the dimension of the units was measured to calculate the overall volume in cubic centimeter.

The average block density recorded at the age of 28 days of curing are given in Table 4.7 and the changes in density through percentage replacements are demonstrated using graph as shown in Figure 4.4.

Table 4.7 Average density of control and blended concrete blocks

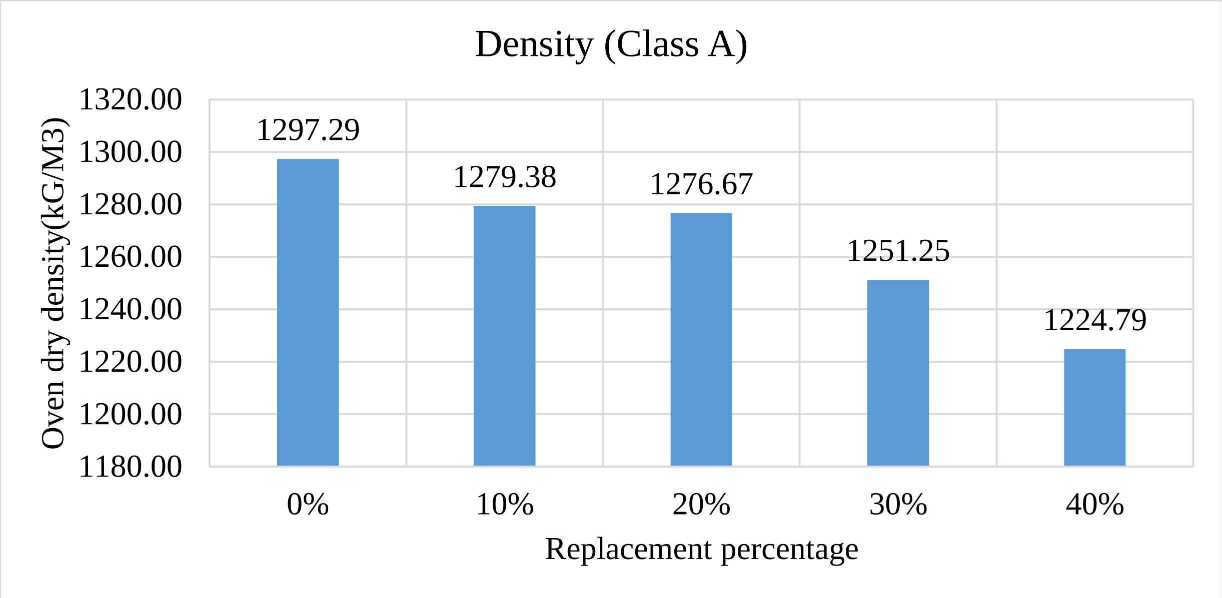
Mix code	Replaced PPC (%)	Oven dried weight (kg)	Average Block density (kg/m^3)	Change (%)	Remark
A 0	0	20.76	1297.29	0.00	Control
A 10	10	20.47	1279.38	0.73	Reduced
A 20	20	20.43	1276.67	0.92	Reduced
A 30	30	20.02	1251.25	1.06	Reduced
A 40	40	19.6	1224.79	1.20	Reduced
B 0	0	19.46	1216.46	0.00	Controlled
B 10	10	19.28	1205.21	0.38	Reduced
B 20	20	18.55	1159.17	2.72	Reduced
B 30	30	18.47	1154.58	4.19	Reduced
B 40	40	17.65	1103.33	4.40	Reduced
C 0	0	18.28	1142.50	0.00	Controlled
C 10	10	18.23	1139.58	1.11	Reduced
C 20	20	17.64	1102.29	1.25	Reduced
C 30	30	17.35	1084.38	1.50	Reduced
C 40	40	17.18	1073.54	4.53	Reduced

From the experimental results, it was observed that the density of specimens reduced for all classes of HCB. A slight reduction of density up to 1.2% was recorded in class A when 40% of cement replaced by crusher dust. Whereas a reduction of 0.73%, 0.92% and 1.06% were found at 10%, 20% and 30% replacement range.

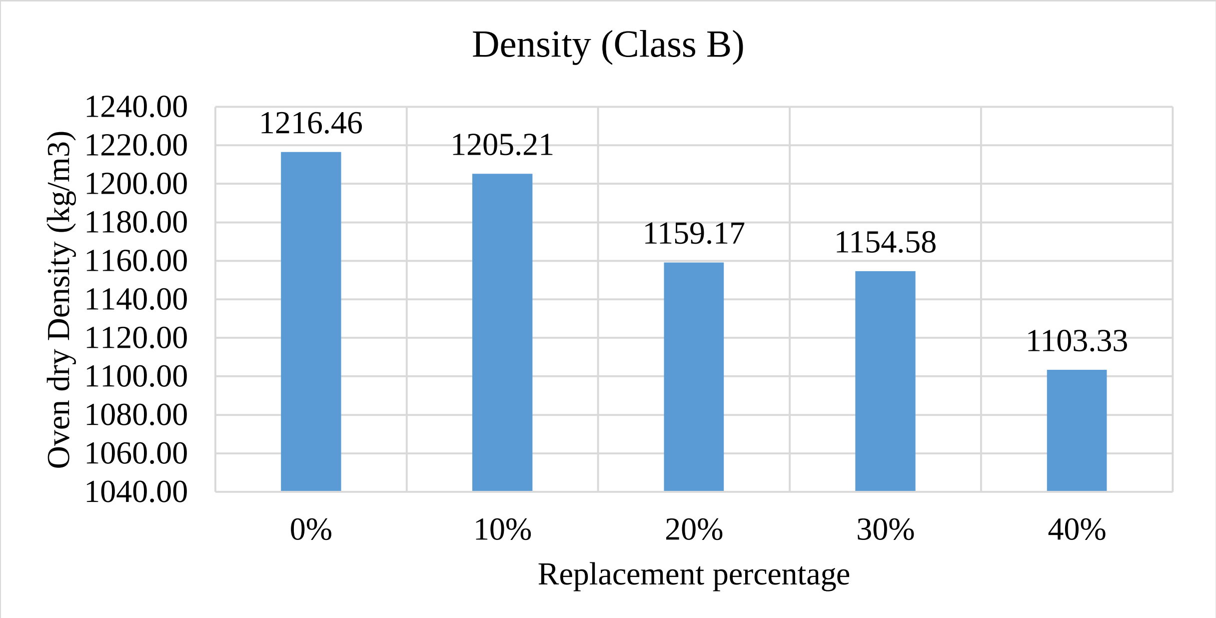
The experimental class B concrete blocks, i.e. B 10, B 20, B 30 and B 40, shows reduction in density of 0.38%, 2.72%, 4.19% and 4.40% from the controlled specimen, B 0. Similarly, it was found that the class C concrete blocks exhibit 1.11%, 1.25%, 1.5% and 4.53% density reduction for the corresponding replacement percentage.

The low specific gravity of basaltic crusher dust, 2.59 as compared to cement, i.e. 3.14, resulted in reduction of density of blended hollow concrete block. Figure 4.4 below also shows the reduction in density as the percentages of crusher dust increased in different classes.

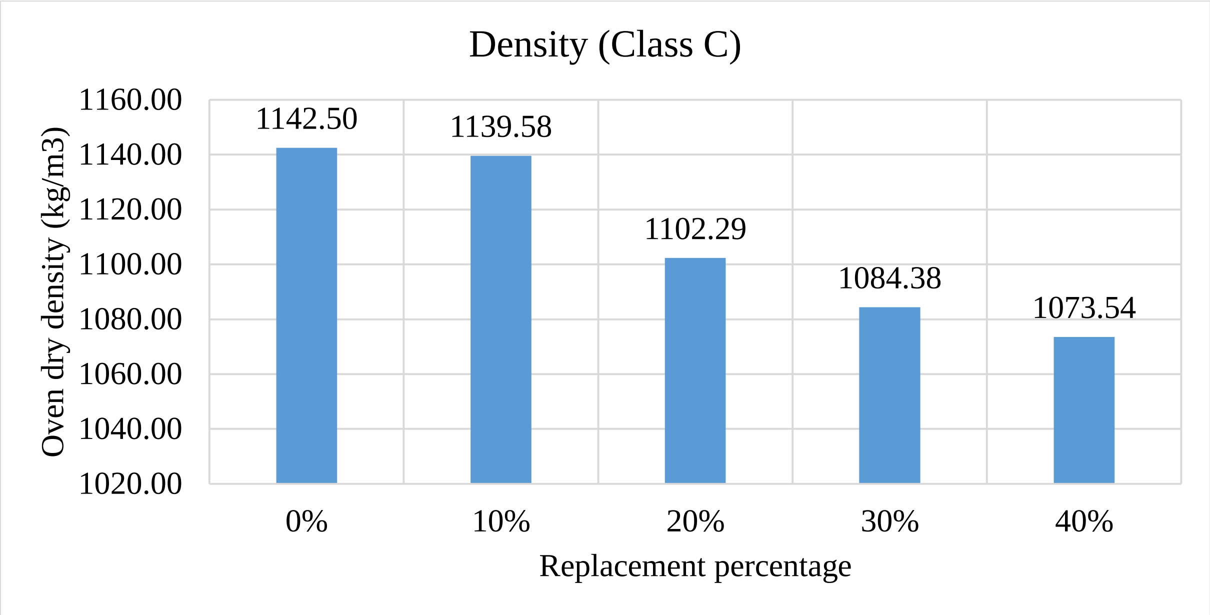
Figure 4.4 Graphical comparison of density for different classes of HCB and replacement percentages



(a)



(b)


Density (Class C)
Oven dry density (kg/m3)
1160.00
1140.00
1120.00
1100.00
1080.00
1060.00
1040.00
1020.00
1142.50
1139.58
1102.29
1084.38
1073.54
0%
10%
20%
30%
40%
Replacement percentage

(c)

CHAPTER FIVE

COST ANALYSIS

5.1. Introduction

Our today's world is greatly concerned with sustainability of human activities. Sustainability is mainly concerned about the world we will be leaving behind for future generations. Social, environmental, and economic issues of our activities are its focus.

As reviewed in the literature, cement is one of the basic materials used in the production of concrete, however, its production has sustainability problems. In order to alleviate these problems different measures were being implemented, especially in developed countries. Re-using of industrial wastes or byproducts which has less cost and energy effective will contribute economic and environmentally friendly materials. Furthermore, the economic benefits are expected to be boosted as the demand for the waste increased.

Quarry dusts was found to have greater potential to be used as cement replacing material at some parts of the world. Its use as partial cement replacing material reduces the cost of the final product.

In this research work, it is tried to prepare cost break down and cost comparison of concrete hollow block made with and without partial replacement of cement by crusher dust such that the average cost of the constituent materials for the production of HCB up to effective replacement rate were considered. However, this is not a detailed cost breakdown rather it gives an insight for the cost advantage.

Assumptions and information for crusher dust price in the cost analysis;

- ❖ The purchasing price of crusher byproduct (locally known as 'fino') were surveyed from different crusher site and found to be 200birr/m^3; which is 0.14birr/kg.
- ❖ The dust were assumed to have similar transportation cost as that of the coarse aggregate, which is calculated by Ministry of Urban development, Housing and Construction [8] as 3.28 birr/m^3 per kilometer for distance ranges of 20.1 to 40 km. This means, the total cost of crusher dust for the longest distance become (0.14 + 0.09450 = 0.235) birr per 1kg of dust.

- Furthermore, consideration has been made on a continuous utilization of crusher dust which will create a condition for extraction of dusts that are blended with crusher byproducts which are traditionally known as fino (zero-zero). As discussed in the Chapter two of this research, the crusher by product contains 15% to 25% fine materials smaller than 150μm sieve.

Table 5.1 Average price of raw materials for production of HCB in Addis Ababa

S.NO.	Type of material	Units	Average price (birr)
1	Cement (PPC)	Quintals	230
2	Crusher dust	Quintals	23.50
2	Sand	m^3	500
3	Coarse aggregate	m^3	281
4	Pumice	m^3	100
5	Water	m^3	5

The cost breakdowns are shown in Appendix E -1 to E- 3, however, for the purpose of discussion it is summarized here in Table 5.2.

Table 5.1 Summarized cost comparison for different classes of HCB

Class of HCB	Code	Total numbers of block produced	Calculated cost per number of blocks produced (Birr)	Cost saved per total no. of HCB produced (%)	Cost saved per single block (%)
A	A 0	21	198.76	.....	.....
	A 10	21	188.44	5.19	0.25
	A 20	21	178.11	10.39	0.49
	A 30	21	167.79	15.58	0.74
	A 40	21	157.46	20.78	0.99
B	B 0	26	205.96	…..	…..
	B 10	26	195.64	5.01	0.19
	B 20	26	178.11	13.52	0.52
	B 30	26	167.79	18.53	0.71

Class of HCB	Code	Total numbers of block produced	Calculated cost per number of blocks produced (Birr)	Cost saved per total no. of HCB produced (%)	Cost saved per single block (%)
C	C 0	32	216.08	…..	…..
	C 10	32	205.76	4.78	0.15
	C 20	32	188.23	12.89	0.40
	C 30	32	177.91	17.67	0.55
	C 40	32	167.58	22.45	0.70

As given in Table 5.2 above, the cement replacement by crusher dust in class A concrete hollow block could save 0.25%, 0.49%, 0.74% and 0.99% production cost of single concrete hollow block for 10%, 20%, 30% and 40% replacement respectively. These replacement saves relatively small in class B concrete blocks as 0.19%, 0.52% and 0.71% of production cost saved for the replacements of crusher dust up to 30%, whereas, replacement in class C block saves 0.15%, 0.40%, 0.55% and 0.70% for 10% up to 40% replacement. These results indicates that the replacement of cement by crusher dust up to 40% saves cost in production of classes A and C blocks, and up to 30% in case of class B blocks with comparable characteristics for strength, water absorption and density to the control mix.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

The conclusion and recommendations that could be drawn from the results of this research's experimental studies and cost analysis are summarized as follows;

6.1.Conclusion

1. The basaltic crusher dust is coarser than the Portland pozzolana cement. This means, the basaltic crusher dust cannot be used as a filler in cement because a mineral admixture is required to have a specific surface area that is equal or greater than cement.
2. The basaltic crusher dust sample used for the study satisfies the chemical requirements of standard for class N raw natural pozzolana. The chemical composition of major oxides is greater than the minimum requirement specified by ASTM C618. Furthermore, the amount of SiO_2, 58.4%, is an indication for high pozzolanic character of the dust.
3. Replacement of Portland pozzolana cement with the basaltic crusher dust at higher percentage increased the water requirement of the blended cement paste than the 100% PPC cement paste. The initial and final setting time of blended cement pastes are elongated as the replacement percent of basaltic crusher dust increased except at 40 percent replacement which result in reduction of the initial setting time.
4. The result of concrete block work revealed that the compressive strength of class A and B concrete hollow blocks with 10 percent cement replacement by basaltic crusher dust exhibited an improvement at the ages of 28 days over the concrete block with 100% Portland pozzolana cement. Whereas, a general reduction of compressive strength is observed in class C concrete hollow block as the replacement percentage increased. However, the compressive strength achieved at all replacement percentage, i.e. 10%, 20%, 30% and 40% for class A and C blocks are well above the minimum requirement specified by the Ethiopian standard for the corresponding classes. On other hand, the crusher dust replace cement effectively for only up to 30% in production of class B concrete hollow block.
5. The water absorption of the hollow concrete blocks increased as the replacement percentage increased and all classes of blocks with basaltic crusher dust have an absorption greater than the control blocks. It was also observed that class C concrete

block absorbs more water than other classes. Nevertheless, blocks of all class have an absorption far below the maximum limit specified by the Ethiopian standard.

6. The result of concrete block work has revealed that the density of class A concrete block containing basaltic crusher dust have shown a slight reduction. It has been observed that class B and C concrete block have higher density reduction as the replacement percentage of cement by crusher dust increased. It was found that a reduction of density up to 4.40% and 4.53% was observed when 40 percent of cement was replaced by basaltic crusher dust in class B and C concrete blocks respectively.
7. The result of the research has found that cement can be advantageously replaced up to 40% in class A and C hollow concrete blocks; whereas it goes up to only 30% in class B. Replacing cement by 40 percent crusher dust results saving of 0.99% and 0.7% cost of production per single block of class A and C concretes respectively, with a comparable characteristics in compressive strength, water absorption and density. Similarly, concrete block of class B saves a maximum of 0.71% per block at 30% replacement percentage.

6.2. Recommendations

In fact the construction industry in Ethiopia is booming, however, there is a limitation in using industrial wastes and byproducts as an alternative cement replacing material in a cost effective manner and conserve the natural resources. Thus, based on the study the following recommendations are forwarded;

- The basaltic crusher dust as investigated in the study can be used as cement replacing material with economic and technical advantages. However, there is no way for either separating blended dusts or constructing storage pond for the dust at the crusher sites. Therefore, the concerned bodies, i.e. government entities and the aggregate crusher companies, need to be aware of this potential so as to dispose carefully and ease of access.
- The result of the study showed that the basaltic crusher dust sample can replace cement partially up to 40% in production of load bearing hollow concrete blocks; conversely, it is observed that there are a limited numbers of hollow concrete block producing companies with no experience in using crusher dust as cement replacing materials. Therefore, it is necessary to increase the number of hollow concrete production factories close to aggregate production plants as well as to give training in order to make the use of this waste feasible.

Regarding many limitations made in this research, there will be many possibilities in the near future to increase the validity of replacement percentage as the useful guidance for public to be easier to get a required properties. Thus, the following suggestion are forwarded for further research

- Considerations should be made for more variation in the crusher dust amount. Maximizing the clay content may also be an advantage in order to cover more crusher sites with arrangement closer to the quarry site and lacks scalping of parent rock and screening process.
- The effects of basaltic crusher dust at different fineness should be studied as well.
- The crusher dust from different crusher sites of other parent rock type such as ignimbrite, trachyte or limestone should be studied and compared with the result of this study.

- Detail study of durability of hollow concrete block made by basaltic crusher dust blended cement should be done.

REFERENCES

[1] A. A. Raheem and O. K. Sulaiman, 2013. Saw Dust Ash as Partial Replacement for Cement in the Production of Sandcrete Hollow Blocks. International Journal of Engineering Research and Applications, Vol. 3, Issue 4, pp.713-721.

[2] Birhanu Negesse, 2018. Utilization of Marble waste powder as partial replacement of cement in HCB Production, MSc. Thesis: Addis Ababa University Printing press.

[3] GTZ (German Technical Co-operation), 2003. Low- Cost Housing Technical Manual. Addis Ababa: Ethiopian Ministry of Federal Affairs.

[4] www.madehow.com/Volume-3/Concrete-Block.html, How concrete block is made - material, manufacture, used, componenets. (Accessed on 17 January 2019)

[5] Adebakin I.H., Adeyemi A.A., Adu J.T., Ajayi F.A., Lawal A.A and Ogunrinola O.B., 2012. "Uses of Sawdust as admixture in production of low cost and light weight hollow concrete blocks," American Journal of Scientific and industrial research, pp. 458-463.

[6] Sonja A.A., Fennis M., Joost C., Joop A. Walraven and den Uijil, 2009. The use of Particle Packing Models to Design Ecological Concrete, vol. 54, Delf University of Technology: Heron.

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

[8] Naik T.R. and Marconi G., 2006. Environmental-friendly durable concrete made with recycled materials for sustainable concrete construction. University of Wisconsin Milwaukee.

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

[10] Kartini K., Hamidah M. S., Norhana A. R. and Nur Hanani A. R., 2014. Quarry dust fine powder as substitute for ordinary portland cement in concrete mix. Journal of Engineering Science and Technology, vol. 9, no. 2, pp. 191-205.

[11] A. Cavdar and S. Yetgin, 2007. Availability of tuffs from northeast of Turkey as natural pozzolan on cement, some chemical and mechanical relationships. Journal of Construction and Building Materials, vol. 21, pp. 2066 - 2071.

[12] Peter Hewlett, 2004. Chemistry of Cement and Concrete, Elsevier Science & Technology Books, pp. 1-5.

[13] Neville A M., 2011. Properties of Concrete, 5th ed., London: Pearson Educational limited.

[14] https://www.ifc.org/Publications/biodiversity_guide, 2000. A Guide to Biodiversity for the Private Sector – Cement. (Accessed on 05 Deceember 2018)

[15] Martin S. and Verein D., 2011. New cement technologies, Retrieved from http://www.globalcement.com. (Accessed on 10 December 2018)

[16] Steven H. Kosmatka, Beatrix Kerkhoff and William C. Panaresse, 2003. Design and Control of Concrete Mixtures, 14th ed., Illinois (Skokie): Portland Cement Association.

[17] Biruk Hailu, 2011. Bagasse ash as a cement replacing material, MSc. Thesis: Addis Ababa University School of graduates.

[18] Abrar Awol, 2011. Using marble waste powder in cement and concrete production, MSc. Thesis: Addis Ababa University School of graduates.

[19] https://www.scribd.com/doc/39643059, (Accessed on 14 December 2018)

[20] "Portland cement: Retrived from http://en.m.wikipedia.org/wiki/Portland_cement, (Accessed on 21 November 2018)

[21] Abebe Dinku, 2002. Construction materials laboratory manual, Addis Ababa: Addis Ababa University printing press.

[22] Hamid Ebrahim, 2018. Feasibility of using selected Addis Ababa basaltic crusher dust as partial replacement material in concrete production, MSc. Thesis: Addis Ababa University School of graduates.

[23] American Society for Testing and Materials, 2003. Standard Specification for Coal, Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete (ASTM C 618), West Conhohocken: ASTM International.

[24] 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.

[25] M. Sidney, J. F. Young and D. David, 2002. Concrete, 2nd ed., Pearson Education, Inc.

[26] I.Alp, H. Deveci, Y.H. Sungun, A.O. Yilmaz, A. Kesimal and E. Yilmaz, 2009. Pozzolanic characteristics of a natural raw material for use in blendd cement. Iranian Journal of Science and Technology, vol. 33, pp. 291-300.

[27] Michell C., 2009. Quarry fines and waste. Retrived from https://www.mineralsuk.com, (Accessed on 04 November 2018)

[28] V. Agrawal, P. Shah, A. Gupta. and R. Shah, 2017. Utilization of quarry dust as fine aggregates in concrete, Kalpa publication in Civil Engineering, pp. 170-175.

[29] M.S. Guimaraes, J.R. Valdes, A.M. Palomino and J.C. Santamarina, 2007. Aggregate production: Fines generation during rock crushing, International Journal of mineral process, vol. 81, pp. 237-247.

[30] C.J. Mitchell, P. Mitchell and R.D. Pascoe, 2008. Quarry fines minimization: Can we really have aggregate 10mm aggregate with no fines?, London, Walton G. proceedings of 14th Extractive Industry Geology Conference, pp. 37-44.

[31] Abebe Dinku, 2005. The need for standardization of aggregate for concrete production in Ethiopian construction industry, Michigan, International conference on Africa Development Archives, Paper 90.

[32] በአዲስ አበባ ቤቶች ልማት እና ኮንስትራክሽን ጽ/ቤት የቤቶች ግንባታ ፕሮጀክት ቢሮ፣ 2011። የዋና ዋና ግብዓቶች የስርጭት መጠን （ከ 2003 ዓ.ም-2010 ዓ.ም）፤ አአ/ቤ/ል/ጽ/ቤት፣ አዲስ አበባ።

[33] Federal Building Material Supply Enterprise, 2011. Aggregate demand for Addis Ababa city road projects, Addis Ababa.

[34] N.Venkata, S. Kumar and K.S.Sai Ram, 2018. Experimental study on properties of concrete containing crushed rock dust as partial replacement of cement, Science direct (Materials today), Proceeding 5: pp. 7240-7246.

[35] El-Didamony H., Helmy I.M., Randa M. O. and Habboud A.M., 2015. Basalt as pozzolana and Filler in ordinary Portland cement, Zagazig: American Journal of Engineering and Appplied Sciences, pp. 263-274.

[36] Ethiopian Standard Agency, 2012. Specification for Concrete Masonry Units (ES 596), Addis Ababa.

[37] Concrete Masonry Unit, Available at https://en.m.wikipedia.org. (Accessed on 01 August 2018)

[38] American Society for Testing and Materials,2005. Standard Specification for Load Bearing Concrete Masonry Units (ASTM C90), West Conshohocken: ASTM International.

[39] Michael G., 2008. Hollow Concrete Block Production & Quality Management Guidelines.

[40] Chaure A.P, Shinde P.A., Raut H.M, Dudhal P.D and Khotkar R.G, 2018. Hollow concrete blocks, IJARIIE, vol. 4, no. 1.

[41] Concrete-blocks, May 2015. Available at http://www.civileblog.com. (Accessed on 24 July 2018).

[42] Ethiopian Standard Agency, 2013. Compulsor Ethiopian standard for hollow concrete blocks and beam tiles (CES 24), Addis Ababa.

[43] Semere Mulatu, 2013. Environmental Impacts of coarse aggregate production in and around Addis Ababa., MSc. Thesis, Addis Ababa University School of Graduate studies.

[44] Nicolò C, Giuseppe D, Kebede S and Micòl Mastrocicco, 2018. Assessment of the anthropogenic fluoride export in Addis Ababa urban environment, Journal of Geochemical Exploration.

[45] American Society for Testing and Materials, 2011. Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related units (ASTM C 140), West Conshohocken: ASTM international.

[46] Ercikdi B, Cihangir F, Kesimal A, Deveci H and Alp I, 2008. The effect of natural pozzolan properties on the strength and stability of paste backfill, Journal of the Earth sciences, vol. 29, no. 1, pp. 25-35.

[47] American Society for Testing and Materials, 2003. Standard Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use as a Mineral Admixture in Portland-Cement Concrete(ASTM C 311), West Conshohocken: ASTM Intenational.

[48] Bureau of Indian Standards, 2005. Concrete Masonry Units, Part 1: Hollow and Solid Concrete blocks (IS 2185-1), New Delhi.

APPENDIX A

PLASTICITY INDEX

A-1: Plastic limit and plasticity index of crusher dust

	LIQUID LIMIT (LL)				PLASTIC LIMIT (PL)	
	LL-1	LL-2	LL-3		PL-1	PL-2
Container no.	C-1	C-2	C-3		C-4	C-5
Number of blows	29	24	16		29	29
Wt. of container (g)	16.18	17.19	16.16		19.19	18.12
Wt. of container + wet soil (g)	33.44	32.16	34.19		20.1	20.16
Wt. of container + dry soil (g)	30.29	29.25	30.78		19.95	19.82
Wt. of water (g)	3.15	2.91	3.41		0.15	0.34
Wt. of dry soil (g)	14.11	12.06	14.62		0.76	1.7
Moisture content (%)	22.32	24.13	23.32	**23.26**	19.74	20
				Average	**19.87**	

- Liquid limit = 23.26
- Plastic limit = 19.87
- Plasticity index (PI)= LL – PL = 3.39

APPENDIX B

COMPRESSIVE STRENGTH OF CLASS A, B AND C CONCRETE HOLLOW BLOCKS

B-1A. Three days compressive strength of Class A hollow concrete blocks

No.	Test ages (days)	Dimensions (cm)			Effective area (cm^2)	Weigh t (Kg)	Failure load (KN)	Compressiv e strength (MPa)
		L	W	H				
A 0								
1	3	40	20	20	408	24.42	175	4.29
2		40	20	20	408	22.65	156.25	3.83
3		40	20	20	408	22.78	200	4.90
4		40	20	20	408	23.19	137.5	3.37
5		40	20	20	408	22.91	206.25	5.06
6		40	20	20	408	23.16	162.5	3.98
						Mean	172.92	4.24
A 10								
1	3	40	20	20	408	23.65	206.25	5.06
2		40	20	20	408	23.04	225	5.51
3		40	20	20	408	22.23	212.5	5.21
4		40	20	20	408	22.02	200	4.90
5		40	20	20	408	22.8	193.75	4.75
6		40	20	20	408	22.56	237.5	5.82
						Mean	212.5	5.21
A 20								
1	3	40	20	20	408	23.44	225	5.51
2		40	20	20	408	22.75	175	4.29
3		40	20	20	408	23.92	150	3.68
4		40	20	20	408	23.33	143.75	3.52
5		`40	20	20	408	22.96	206.25	5.06
6		40	20	20	408	23.02	200	4.90
						Mean	183.33	4.49

No.	Test ages (days)	Dimensions (cm)			Effective area (cm^2)	Weight (Kg)	Failure load (KN)	Compressive strength (MPa)
		L	W	H				
A 30								
1	3	40	20	20	408	21.35	156.25	3.83
2		40	20	20	408	22.21	151.25	3.71
3		40	20	20	408	21.92	112.5	2.76
4		40	20	20	408	21.78	162.5	3.98
5		40	20	20	408	21.99	125	3.06
6		40	20	20	408	21.74	137.5	3.37
						Mean	140.83	3.45
A 40								
1	3	40	20	20	408	23.04	156.25	3.83
2		40	20	20	408	22.65	125	3.06
3		40	20	20	408	23.22	131.25	3.22
4		40	20	20	408	23.02	150	3.68
5		40	20	20	408	22.97	150	3.68
6		40	20	20	408	22.56	112.5	2.76
						Mean	137.5	3.37

B-1B. Three days compressive strength of class B hollow concrete blocks

No.	Test ages (days)	Dimensions (cm) L	W	H	Effective area (cm^2)	Weight (Kg)	Failure load (KN)	Compressive strength (MPa)
B 0								
1	3	40	20	20	408	22.26	175	4.29
2		40	20	20	408	21.22	119.75	2.94
3		40	20	20	408	21.05	169.75	4.16
4		40	20	20	408	21.65	187.5	4.60
5		40	20	20	408	21.75	137.5	3.37
6		40	20	20	408	21.97	125	3.06
						Mean	152.42	3.74
B 10								
1	3	40	20	20	408	21.52	187.5	4.60
2		40	20	20	408	20.85	156.25	3.83
3		40	20	20	408	21.29	125	3.06
4		40	20	20	408	21.59	193.25	4.74
5		40	20	20	408	21.65	150	3.68
6		40	20	20	408	21.98	125	3.06
						Mean	156.17	3.83
B 20								
1	3	40	20	20	408	20.93	125	3.06
2		40	20	20	408	21.65	137.5	3.37
3		40	20	20	408	21.55	150	3.68
4		40	20	20	408	21.41	162.5	3.98
5		40	20	20	408	21.52	137.5	3.37
6		40	20	20	408	21.26	112.5	2.76
						Mean	137.5	3.37

No.	Test ages (days)	Dimensions (cm) L	W	H	Effective area (cm^2)	Weight (Kg)	Failure load (KN)	Compressive strength (MPa)
B 30								
1	3	40	20	20	408	20.37	150	3.68
2		40	20	20	408	20.96	150	3.68
3		40	20	20	408	21.83	112.5	2.76
4		40	20	20	408	20.96	156.25	3.83
5		40	20	20	408	21.68	137.5	3.37
6		40	20	20	408	20.54	119.75	2.94
						Mean	137.67	3.37
B 40								
1	3	40	20	20	408	19.21	87.5	2.14
2		40	20	20	408	20.88	119.75	2.94
3		40	20	20	408	21.08	87.5	2.14
4		40	20	20	408	20.42	112.5	2.76
5		40	20	20	408	20.56	91.38	2.24
6		40	20	20	408	20.19	93.75	2.30
						Mean	98.73	2.42

B-1C. Three days compressive strength of Class C hollow concrete blocks

No.	Test ages (days)	Dimensions (cm) L	W	H	Effective area (cm^2)	Weight (Kg)	Failure load (KN)	Compressive strength (MPa)
C0								
1	3	40	20	20	408	20.99	119.75	2.94
2		40	20	20	408	22.2	150	3.68
3		40	20	20	408	22.09	137.5	3.37
4		40	20	20	408	21.17	119.75	2.94
5		40	20	20	408	21.73	156.25	3.83
6		40	20	20	408	21.71	137.5	3.37
						Mean	136.79	3.35
C 10								
1	3	40	20	20	408	20.9	169.75	4.16
2		40	20	20	408	22.48	137.5	3.37
3		40	20	20	408	21.59	125	3.06
4		40	20	20	408	21.67	156.25	3.83
5		40	20	20	408	21.79	162.5	3.98
6		40	20	20	408	21.54	112.5	2.76
						Mean	143.92	3.53
C 20								
1	3	40	20	20	408	22.35	125	3.06
2		40	20	20	408	22.3	156.25	3.83
3		40	20	20	408	22.55	150	3.68
4		40	20	20	408	22.5	175	4.29
5		40	20	20	408	22.42	131.25	3.22
6		40	20	20	408	22.02	125	3.06
						Mean	143.75	3.52

No.	Test ages (days)	Dimensions (cm)			Effective area (cm^2)	Weight (Kg)	Failure load (KN)	Compressive strength (MPa)
		L	W	H				
C 30								
1	3	40	20	20	408	21.69	112.5	2.76
2		40	20	20	408	20.64	87.5	2.14
3		40	20	20	408	21.96	137.5	3.37
4		40	20	20	408	21.68	112.5	2.76
5		40	20	20	408	21.98	125	3.06
6		40	20	20	408	21.89	99.75	2.44
						Mean	112.46	2.76
C 40								
1	3	40	20	20	408	22.39	93.75	2.30
2		40	20	20	408	21.63	87.5	2.14
3		40	20	20	408	20.84	68.75	1.69
4		40	20	20	408	20.96	87.5	2.14
5		40	20	20	408	21.61	87.5	2.14
6		40	20	20	408	21.78	75	1.84
						Mean	83.33	2.04

B-2A. Seven Days compressive strength of class A hollow concrete blocks

No.	Test ages (days)	Dimensions (cm)			Effective area (cm^2)	Weight (Kg)	Failure load (KN)	Compressive strength (MPa)
		L	W	H				
A 0								
1	7	40	20	20	408	23.25	175	4.29
2		40	20	20	408	21.85	225	5.51
3		40	20	20	408	23.53	200	4.90
4		40	20	20	408	21.97	162.5	3.98
5		40	20	20	408	21.97	200	4.90
6		40	20	20	408	23.22	193.75	4.75
						Mean	192.71	4.72
A 10								
1	7	40	20	20	408	22.7	225	5.51
2		40	20	20	408	21.65	237.5	5.82
3		40	20	20	408	21.98	250	6.13
4		40	20	20	408	23.2	231.25	5.67
5		40	20	20	408	21.4	193.75	4.75
6		40	20	20	408	21.7	275	6.74
						Mean	235.42	5.77
A 20								
1	7	40	20	20	408	23.72	206.25	5.06
2		40	20	20	408	22.75	212.5	5.21
3		40	20	20	408	22.97	175	4.29
4		40	20	20	408	22.71	187.5	4.60
5		40	20	20	408	22.89	175	4.29
6		40	20	20	408	23.1	212.5	5.21
						Mean	194.79	4.77

No.	Test ages (days)	Dimensions (cm) L	W	H	Effective area (cm^2)	Weight (Kg)	Failure load (KN)	Compressive strength (MPa)
A 30								
1	7	40	20	20	408	23.38	175	4.29
2		40	20	20	408	21.35	175	4.29
3		40	20	20	408	22.43	200	4.90
4		40	20	20	408	23.21	212.5	5.21
5		40	20	20	408	22.6	200	4.90
6		40	20	20	408	22.54	175	4.29
						Mean	189.58	4.65
A 40								
1	7	40	20	20	408	21.44	125	3.06
2		40	20	20	408	22.37	150	3.68
3		40	20	20	408	22.73	143.75	3.52
4		40	20	20	408	22.1	187.5	4.60
5		40	20	20	408	22.3	162.5	3.98
6		40	20	20	408	21.9	150	3.68
						Mean	153.13	3.75

B-2B. Seven days compressive strength of class B hollow concrete blocks

No.	Test ages (days)	Dimensions (cm)			Effective area (cm^2)	Weight (Kg)	Failure load (KN)	Compressive strength (MPa)
		L	W	H				
B 0								
1	7	40	20	20	408	21.52	156.25	3.83
2		40	20	20	408	21.9	231.25	5.67
3		40	20	20	408	20.92	181.25	4.44
4		40	20	20	408	19.98	181.25	4.44
5		40	20	20	408	21.34	181.25	4.44
6		40	20	20	408	20.58	206.25	5.06
						Mean	189.58	4.65
B 10								
1	7	40	20	20	408	21.81	169.25	4.15
2		40	20	20	408	20.64	225	5.51
3		40	20	20	408	21.76	225	5.51
4		40	20	20	408	21.49	200	4.90
5		40	20	20	408	21.87	175	4.29
6		40	20	20	408	21.39	181.25	4.44
						Mean	195.92	4.80
B 20								
1	7	40	20	20	408	22.16	187.5	4.60
2		40	20	20	408	22.2	125	3.06
3		40	20	20	408	20.31	156.25	3.83
4		40	20	20	408	21.1	181.75	4.45
5		40	20	20	408	21.18	175	4.29
6		40	20	20	408	20.04	150	3.68
						Mean	162.58	3.98

No.	Test ages (days)	Dimensions (cm) L	W	H	Effective area (cm^2)	Weight (Kg)	Failure load (KN)	Compressive strength (MPa)
B 30								
1	7	40	20	20	408	21.8	112.5	2.76
2		40	20	20	408	21.5	125	3.06
3		40	20	20	408	21.27	125	3.06
4		40	20	20	408	19.79	162.5	3.98
5		40	20	20	408	19.85	175	4.29
6		40	20	20	408	20.9	150	3.68
						Mean	141.67	3.47
B 40								
1	7	40	20	20	408	20.38	137.5	3.37
2		40	20	20	408	20.54	125	3.06
3		40	20	20	408	21	112.5	2.76
4		40	20	20	408	21.17	125	3.06
5		40	20	20	408	21.54	93.75	2.30
6		40	20	20	408	19.85	137.5	3.37
						Mean	121.88	2.99

B-2C. Seven days compressive strength of class C hollow concrete blocks

No.	Test ages (days)	Dimensions (cm)			Effective area (cm^2)	Weight (Kg)	Failure load (KN)	Compressive strength (MPa)
		L	W	H				
C 0								
1	7	40	20	20	408	21.15	187.5	4.60
2		40	20	20	408	20.88	125	3.06
3		40	20	20	408	21.62	156.25	3.83
4		40	20	20	408	21.66	200	4.90
5		40	20	20	408	22.13	137.5	3.37
6		40	20	20	408	22.02	181.25	4.44
						Mean	164.58	4.03
C 10								
1	7	40	20	20	408	21.29	225	5.51
2		40	20	20	408	22.57	131.25	3.22
3		40	20	20	408	22.1	137.5	3.37
4		40	20	20	408	21.5	187.5	4.60
5		40	20	20	408	22.5	181.25	4.44
6		40	20	20	408	21.73	175	4.29
						Mean	172.92	4.24
C 20								
1	7	40	20	20	408	22.13	150	3.68
2		40	20	20	408	22.72	137.5	3.37
3		40	20	20	408	22.51	125	3.06
4		40	20	20	408	22.45	150	3.68
5		40	20	20	408	22.5	137.5	3.37
6		40	20	20	408	22.52	181.75	4.45
						Mean	146.96	3.60

No.	Test ages (days)	Dimensions (cm)			Effective area (cm^2)	Weight (Kg)	Failure load (KN)	Compressive strength (MPa)
		L	W	H				
C 30								
1	7	40	20	20	408	20.95	100	2.45
2		40	20	20	408	22.43	125	3.06
3		40	20	20	408	21.38	137.5	3.37
4		40	20	20	408	21.5	150	3.68
5		40	20	20	408	22.68	150	3.68
6		40	20	20	408	21.78	156.25	3.83
						Mean	136.46	3.34
C 40								
1	7	40	20	20	408	21.77	112.5	2.76
2		40	20	20	408	21.22	112.5	2.76
3		40	20	20	408	22.22	125	3.06
4		40	20	20	408	21.49	125	3.06
5		40	20	20	408	21.76	93.75	2.30
6		40	20	20	408	21.69	112.5	2.76
						Mean	113.54	2.78

B-3A. Twenty eight days compressive strength of class A hollow concrete blocks

No.	Test ages (days)	Dimensions (cm)			Effective area (cm^2)	weight (Kg)	Failure load (KN)	Compressive strength (MPa)
		L	W	H				
A 0								
1	28	40	20	20	408	20.66	300	7.35
2		40	20	20	408	20.28	337	8.26
3		40	20	20	408	21.83	318.25	7.80
4		40	20	20	408	20.86	281.5	6.90
5		40	20	20	408	21.87	306.25	7.51
6		40	20	20	408	21.2	350	8.58
						Mean	315.5	7.73
A 10								
1	28	40	20	20	408	21.63	300	7.35
2		40	20	20	408	21.61	312.5	7.66
3		40	20	20	408	20.87	306.25	7.51
4		40	20	20	408	20.07	337.5	8.27
5		40	20	20	408	21.26	306.25	7.51
6		40	20	20	408	21.2	393.75	9.65
						Mean	326.04	7.99
A 20								
1	28	40	20	20	408	21.93	287.5	7.05
2		40	20	20	408	21.36	325	7.97
3		40	20	20	408	21.28	312.5	7.66
4		40	20	20	408	21.54	343.75	8.43
5		40	20	20	408	20.6	250	6.13
6		40	20	20	408	21.16	231.25	5.67
						Mean	291.67	7.15

No.	Test ages (days)	Dimensions (cm)			Effective area (cm^2)	weight (Kg)	Failure load (KN)	Compressive strength (MPa)
		L	W	H				
A 30								
1	28	40	20	20	408	20.28	275	6.74
2		40	20	20	408	20.49	325	7.97
3		40	20	20	408	20.56	225	5.51
4		40	20	20	408	21.01	281.25	6.89
5		40	20	20	408	21.02	237.5	5.82
6		40	20	20	408	20.22	225	5.51
						Mean	261.46	6.41
A 40								
1	28	40	20	20	408	20.09	237.5	5.82
2		40	20	20	408	20.14	300	7.35
3		40	20	20	408	20.87	262.5	6.43
4		40	20	20	408	21.39	193.75	4.75
5		40	20	20	408	21.3	250	6.13
6		40	20	20	408	21.15	225	5.51
						Mean	244.79	6.00

B-3B. Twenty eight days compressive strength of class B hollow concrete blocks

No.	Test ages (days)	Dimensions (cm)			Effective area (cm^2)	Weight (Kg)	Failure load (KN)	Compressive strength (MPa)
		L	W	H				
B 0								
1	28	40	20	20	408	20.42	262.5	6.43
2		40	20	20	408	20.74	300	7.35
3		40	20	20	408	19.88	218.25	5.35
4		40	20	20	408	20.59	312.5	7.66
5		40	20	20	408	20.31	293.75	7.20
6		40	20	20	408	19.51	306.25	7.51
						Mean	282.21	6.92
B 10								
1	28	40	20	20	408	20.21	262.5	6.43
2		40	20	20	408	21.36	293.25	7.19
3		40	20	20	408	21.04	275	6.74
4		40	20	20	408	21.59	262.5	6.43
5		40	20	20	408	21.35	293.75	7.20
6		40	20	20	408	20.62	337.5	8.27
						Mean	287.42	7.04
B 20								
1	28	40	20	20	408	20.86	225	5.51
2		40	20	20	408	20.76	237.5	5.82
3		40	20	20	408	21.27	256.25	6.28
4		40	20	20	408	19.86	256.25	6.28
5		40	20	20	408	20.14	200	4.90
6		40	20	20	408	20.75	237.5	5.82
						Mean	235.42	5.77

No.	Test ages (days)	Dimensions (cm)			Effective area (cm^2)	Weight (Kg)	Failure load (KN)	Compressive strength (MPa)
		L	W	H				
B 30								
1	28	40	20	20	408	19.98	275	6.74
2		40	20	20	408	20.23	225	5.51
3		40	20	20	408	21.97	193.75	4.75
4		40	20	20	408	19.71	237.5	5.82
5		40	20	20	408	21.29	181.25	4.44
6		40	20	20	408	20.46	225	5.51
						Mean	222.92	5.46
B 40								
1	28	40	20	20	408	19.24	156.25	3.83
2		40	20	20	408	19.74	150	3.68
3		40	20	20	408	18.41	250	6.13
4		40	20	20	408	19.57	137.5	3.37
5		40	20	20	408	20.87	206.25	5.06
6		40	20	20	408	20.13	131.25	3.22
						Mean	171.88	4.21

B-3C. Twenty eight days compressive strength of class C hollow concrete blocks

No.	Test ages (days)	Dimensions (cm)			Effective area (cm^2)	Weight (Kg)	Failure load (KN)	Compressive strength (MPa)
		L	W	H				
C 0								
1	28	40	20	20	408	20.16	287.5	7.05
2		40	20	20	408	18.56	281.25	6.89
3		40	20	20	408	19.12	250	6.13
4		40	20	20	408	18.7	262.5	6.43
5		40	20	20	408	20.04	250	6.13
6		40	20	20	408	18.93	237.5	5.82
						Mean	261.46	6.41
C 10								
1	28	40	20	20	408	18.83	225	5.51
2		40	20	20	408	19.34	206.25	5.06
3		40	20	20	408	19.75	206.25	5.06
4		40	20	20	408	19.93	262.5	6.43
5		40	20	20	408	19.25	281.25	6.89
6		40	20	20	408	20.28	250	6.13
						Mean	238.54	5.85
C 20								
1	28	40	20	20	408	20.9	275	6.74
2		40	20	20	408	19.96	212	5.20
3		40	20	20	408	19.83	206.25	5.06
4		40	20	20	408	19.84	187.5	4.60
5		40	20	20	408	19.35	275	6.74
6		40	20	20	408	19.31	225	5.51
						Mean	230.13	5.64

No.	Test ages (days)	Dimensions (cm)			Effective area (cm^2)	Weight (Kg)	Failure load (KN)	Compressive strength (MPa)
		L	W	H				
C 30								
1	28	40	20	20	408	19.2	225	5.51
2		40	20	20	408	19.84	231.25	5.67
3		40	20	20	408	19.4	200	4.90
4		40	20	20	408	19.39	225	5.51
5		40	20	20	408	18.96	175	4.29
6		40	20	20	408	19.82	206.25	5.06
						Mean	210.42	5.16
C 40								
1	28	40	20	20	408	19.81	237.5	5.82
2		40	20	20	408	19.02	193.5	4.74
3		40	20	20	408	19.48	169.75	4.16
4		40	20	20	408	18.16	200	4.90
5		40	20	20	408	19.44	150	3.68
6		40	20	20	408	19.77	231.25	5.67
						Mean	197	4.83

APPENDIX C

SUMMARY OF MEAN COMPRESSIVE STRENGTH RESULTS OF 40X20X20 HOLLOW CONCRETE BLOCKS

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)
A 0	172.92	4.24	192.71	4.72	315.5	7.73
A 10	212.5	5.21	235.42	5.77	326.04	7.99
A 20	183.33	4.49	194.79	4.77	291.67	7.15
A 30	140.83	3.45	189.58	4.65	261.46	6.41
A 40	137.5	3.37	153.13	3.75	244.79	6.00
B 0	152.42	3.74	189.58	4.65	282.21	6.92
B 10	156.17	3.83	195.92	4.80	287.42	7.04
B 20	137.5	3.37	162.58	3.98	235.42	5.77
B 30	137.67	3.37	141.67	3.47	222.92	5.46
B 40	98.73	2.42	121.88	2.99	171.88	4.21
C 0	136.79	3.35	164.58	4.03	261.46	6.41
C 10	143.92	3.53	172.92	4.24	238.54	5.85
C 20	143.75	3.52	146.96	3.60	230.13	5.64
C 30	112.46	2.76	136.46	3.34	210.42	5.16
C 40	83.33	2.04	113.54	2.78	197	4.83

APPENDIX D

TYPE OF TESTS AND NUMBER BLOCK SAMPLES FOR DIFFERENT REPLACEMENT PERCENT OF CEMENT BY CRUSHER DUST IN CLASS A, B AND C CONCRETE HOLLOW BLOCKS

Replacement percent	Class of hollow concrete blocks and tests at different ages					Total no. of blocks
	A					
	Compressive strength			Water absorption	Density	
	@ 3days	@ 7days	@ 28days	@ 28days	@ 28 days	
Zero percent	6	6	6	3		21
Ten percent	6	6	6	3		21
Twenty percent	6	6	6	3		21
Thirty percent	6	6	6	3		21
Forty percent	6	6	6	3		21
	B					
Zero percent	6	6	6	3		21
Ten percent	6	6	6	3		21
Twenty percent	6	6	6	3		21
Thirty percent	6	6	6	3		21
Forty percent	6	6	6	3		21
	C					
Zero percent	6	6	6	3		21
Ten percent	6	6	6	3		21
Twenty percent	6	6	6	3		21
Thirty percent	6	6	6	3		21
Forty percent	6	6	6	3		21
Total	90	90	90	45		**315**

APPENDIX E

COST BREAK DOWN FOR DIFFERENT CLASSES OF HOLLOW CONCRETE BLOCK

E-1. Cost breakdown for class A concrete hollow block

item:	Hollow Concrete Block
Code :	A 0 (No replacement)
Total quantity of Item :	20 full units

Types of Material	Unit	Quantity	Unit rate (birr)	Unit cost (birr)
Cement	Quintal	0.5	230	115
Crusher dust	Quintal	0	23.5	0
Sand	m^3	0.072	500	36
01 coarse aggregate	m^3	0.144	281	40.464
Pumice	m^3	0.072	100	7.2
Water	m^3	0.02	5	0.1
			Total	198.764

Code:	A 10 (Ten percent replacement)
Total quantity of item	20 full units

Types of Material	Unit	Quantity	Unit rate (birr)	Unit cost (birr)
Cement	Quintal	0.45	230	103.5
Crusher dust	Quintal	0.05	23.5	1.175
Sand	m^3	0.072	500	36
01 coarse aggregate	m^3	0.144	281	40.464
Pumice	m^3	0.072	100	7.2
Water	m^3	0.02	5	0.1
			Total	188.439

Code	A 20 (Twenty percent replacement)			
Total quantity of item	20 full units			
Types of Material	Unit	Quantity	Unit rate (birr)	Unit cost (birr)
Cement	Quintal	0.4	230	92
Crusher dust	Quintal	0.1	23.5	2.35
Sand	m^3	0.072	500	36
01 coarse aggregate	m^3	0.144	281	40.464
Pumice	m^3	0.072	100	7.2
Water	m^3	0.02	5	0.1
			Total	178.114

Code	A 30 (Thirty percent replacement)			
Total quantity of item	20 full units			
Types of Material	Unit	Quantity	Unit rate (birr)	Unit cost (birr)
Cement	Quintal	0.35	230	80.5
Crusher dust	Quintal	0.15	23.5	3.525
Sand	m^3	0.072	500	36
01 coarse aggregate	m^3	0.144	281	40.464
Pumice	m^3	0.072	100	7.2
Water	m^3	0.02	5	0.1
			Total	167.789

Code	A 40 (Forty percent replacement)			
Total quantity of item	20 full units			
Types of Material	Unit	Quantity	Unit rate (birr)	Unit cost (birr)
Cement	Quintal	0.3	230	69
Crusher dust	Quintal	0.2	23.5	4.7
Sand	m^3	0.072	500	36
01 coarse aggregate	m^3	0.144	281	40.464
Pumice	m^3	0.072	100	7.2
Water	m^3	0.02	5	0.1
			Total	157.464

E-2. Cost breakdown for class B hollow concrete blocks

item:	Hollow Concrete Block
Code :	B 0 (No replacement)
Total quantity of Item :	26 full units

Types of Material	Unit	Quantity	Unit rate (birr)	Unit cost (birr)
Cement	Quintal	0.5	230	115
Crusher dust	Quintal	0	23.5	0
Sand	m^3	0.072	500	36
01 coarse aggregate	m^3	0.144	281	40.464
Pumice	m^3	0.144	100	14.4
Water	m^3	0.02	5	0.1
			Total	205.964

Code	B 10 (Ten percent replacement)
Total quantity of item	26 full units

Types of Material	Unit	Quantity	Unit rate (birr)	Unit cost (birr)
Cement	Quintal	0.45	230	103.5
Crusher dust	Quintal	0.05	23.5	1.175
Sand	m^3	0.072	500	36
01 coarse aggregate	m^3	0.144	281	40.464
Pumice	m^3	0.144	100	14.4
Water	m^3	0.02	5	0.1
			Total	195.639

Code	B 20 (Twenty percent replacement)
Total quantity of item	26 full units

Types of Material	Unit	Quantity	Unit rate (birr)	Unit cost (birr)
Cement	Quintal	0.4	230	92
Crusher dust	Quintal	0.1	23.5	2.35
Sand	m^3	0.072	500	36
01 coarse aggregate	m^3	0.144	281	40.464
Pumice	m^3	0.072	100	7.2
Water	m^3	0.02	5	0.1
			Total	178.114

Code	B 30 (Thirty percent replacement)
Total quantity of item	26 full units

Types of Material	Unit	Quantity	Unit rate (birr)	Unit cost (birr)
Cement	Quintal	0.35	230	80.5
Crusher dust	Quintal	0.15	23.5	3.525
Sand	m^3	0.072	500	36
01 coarse aggregate	m^3	0.144	281	40.464
Pumice	m^3	0.072	100	7.2
Water	m^3	0.02	5	0.1
			Total	167.789

E-3. Cost breakdown for class C hollow concrete blocks

item:	Hollow Concrete Block
Code :	C 0 (No replacement)
Total quantity of Item :	32 full units

Types of Material	Unit	Quantity	Unit rate (birr)	Unit cost (birr)
Cement	Quintal	0.5	230	115
Crusher dust	Quintal	0	23.5	0
Sand	m^3	0.072	500	36
01 coarse aggregate	m^3	0.18	281	50.58
Pumice	m^3	0.144	100	14.4
Water	m^3	0.02	5	0.1
			Total	216.08

Code	C 10 (Ten percent replacement)
Total quantity of item	32 full units

Types of Material	Unit	Quantity	Unit rate (birr)	Unit cost (birr)
Cement	Quintal	0.45	230	103.5
Crusher dust	Quintal	0.05	23.5	1.175
Sand	m^3	0.072	500	36
01 coarse aggregate	m^3	0.18	281	50.58
Pumice	m^3	0.144	100	14.4
Water	m^3	0.02	5	0.1
			Total	205.755

Code	C 20 (Twenty percent replacement)
Total quantity of item	32 full units

Types of Material	Unit	Quantity	Unit rate (birr)	Unit cost (birr)
Cement	Quintal	0.4	230	92
Crusher dust	Quintal	0.1	23.5	2.35
Sand	m^3	0.072	500	36
01 coarse aggregate	m^3	0.18	281	50.58
Pumice	m^3	0.072	100	7.2
Water	m^3	0.02	5	0.1
			Total	188.23

Code	C 30 (Thirty percent replacement)
Total quantity of item	32 full units

Types of Material	Unit	Quantity	Unit rate (birr)	Unit cost (birr)
Cement	Quintal	0.35	230	80.5
Crusher dust	Quintal	0.15	23.5	3.525
Sand	m^3	0.072	500	36
01 coarse aggregate	m^3	0.18	281	50.58
Pumice	m^3	0.072	100	7.2
Water	m^3	0.02	5	0.1
			Total	177.905

Code	C 40 (Forty percent replacement)
Total quantity of item	32 full units

Types of Material	Unit	Quantity	Unit rate (birr)	Unit cost (birr)
Cement	Quintal	0.3	230	69
Crusher dust	Quintal	0.2	23.5	4.7
Sand	m^3	0.072	500	36
01 coarse aggregate	m^3	0.18	281	50.58
Pumice	m^3	0.072	100	7.2
Water	m^3	0.02	5	0.1
			Total	167.58

APPENDIX F

SPECIFIC GRAVITY OF CEMENT AND CRUSHER DUST SAMPLE

F-1. Specific gravity of cement used in the research

Geological Survey of Ethiopia

Mineralogy & Geotechnical Laboratory Directorate

Result Form

Directorate: - Mineralogy and Geotechnical Laboratory: - Mineralogy [ ] Physical [x]

Client /Originator Name:- Yohannis Lemma

Client Category: - Survey [ ] Gov. [ ] Pvt. [x]

File name:- 4941/19 PVT Area Ref:- No of Samples:- 1 Sample No. YL-01

Sample Type:- Cement Lab No: -

Type of Analysis: - Specific gravity Preparation required: - Date Submitted: - 19/02/19

Coll.No.	Lab. No.	Pycnometer No.	m_2 Mass of picnometer in g	m_3 Mass of test solution in the picnometer without test sample in g	Q_2 Density of test solution in g/cm^3	m_4 Mass of picnom.plus test sample in g	m_4-m_2 mass of test sample in g	m_5 mass of picnom. test sample and test solution in g	m_3+m_4-m_5 volume of test sample in g/cm^3	Specific Gravity in g/cm^3	Average
YL-01	4941/19	20/20	27.7091	77.6683	1 g/cm^3	35.8085	8.0994	83.1861	2.5816	3.13	3.14
		24/24	28.0691	78.0108	1 g/cm^3	36.3386	8.2695	83.6603	2.62	3.15	

Described By / Analysts: - Abdu Ebrahim

Checked by: - Girma Asemu

Date Completed: - 21/02/19

F-2. Specific gravity of crusher dust sample

Geological Survey of Ethiopia
Mineralogy & Geotechnical Laboratory Directorate
Result Form

Case Team: - Chemical: Lab Section: - Silicate ☐ Gold & Base metal ☐ Water ☐
Hydrocarbon ☐

Case Team: - Mineralogical: Lab section: - Mineralogy ☐ Physical x
Client /Originator Name:- Yohannis Lemma

Client Category: - Survey ☐ Gov. ☐ Pvt. x
File name:- 4569/18 PVT Area Ref:- Kality No of Samples:- 1 Sample No. YL-01
Sample Type:- Dust Powder Lab No: -
Type of Analysis: - Specific gravity Preparation required: - Date Submitted:- 28/03/11

Coll.No.	Lab. No.	Pycnometer No.	m_2 Mass of picnometer in g	m_3 Mass of test solution in the picnometer without test sample in g	Q_2 Density of test solution in g/cm³	m_4 Mass of picnom.plus test sample in g	m_4-m_2 mass of test sample in g	m_5 mass of picnom. test sample and test solution in g	m_3+m_4-m_5 volume of test sample in g/cm³	Specific Gravity in g/cm³	Average
YL-01	4569/18	48/48	25.9856	75.8655	1 g/cm³	32.9439	6.9583	80.173	2.6508	2.62	2.59
		42/42	29.2497	79.12	1 g/cm³	38.7839	9.5342	84.9472	3.707	2.57	

Described By / Analysts: - Aregahagn Kefelegn
Checked by: - Girma Asemu
Date Completed: - 01/01/19

APPENDIX G

CHEMICAL COMPOSITION OF CRUSHER DUST

	GEOLOGICAL SURVEY OF ETHIOPIA	Doc.Number: GLD/F5.10.2	Version No: 1
	GEOCHEMICAL LABORATORY DIRECTORATE		Page 1 of 1
Document Title:	Complete Silicate Analysis Report	Effective date:	May, 2017

Issue Date: - 18/12/2018

Customer Name:- **Yohannis Lemma**

Request No: GLD/TR/0878/18

Report No:- GLD/TR/0818/18

Sample type:- Rock

Sample Preparation: - 200 Mesh

Date Submitted: -10/12/2018

Number of Sample:- One (1)

Analytical Result: In percent (%) Element to be determined Major Oxides & Minor Oxides

Analytical Method: $LiBO_2$ FUSION, HF attack, GRAVIMETERIC, COLORIMETRIC and AAS

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
YL-01	58.40	15.99	8.10	3.42	1.98	4.14	2.82	0.22	1.35	0.66	1.21	2.13

Note: - This result represent only for the sample submitted to the laboratory.

Analysts	Checked By	Approved By	Quality Control
Dessie Abebe	Tamiru Siraye	Gosa Haile	Negash Worku
Tihitna Beletkachew			
Nigist Fikadu			
Elsa Fesseha			
Wondim Maru			
Yohanis Getachew			
Yirgalem Abriham			

APPENDIX H

SAMPLE PHOTOS TAKEN DURING THE RESEARCH

Photo 1. Crusher dust collection (left) and preparation using 150µm sieve size (right)

Photo 2. Fineness test under progress by Blaine air permeability apparatus

Photo 3. Blending the crusher dust with cement

Photo 4. The sieve analysis of coarse aggregate (01) under progress (left) and Specific gravity determination of pumice under progress (right)

Photo 5. The specific gravity test for fine aggregate under progress (left) and plasticity index determination of BSD by Casagrande method (right)

Photo 6. Consistency and setting time determination under progress using vicat apparatus

Photo 7. Conveyor belt transporting a mix to the mold (Left); HCB produced using the crusher dust and cement (Right)

Photo 8. Transportation of extruded green blocks


Photo 9. Fresh blocks left on wooden pallet for 1 day (Left) and Curing of blocks by covering plastic (Right)

Photo 10. Recording the weight of blocks

Photo 11. Arranging HCBs according to their mix code (left) and compressive strength under progress (right)

Photo 12. Immersion of blocks for Water absorption test (left), and drying HCB in oven under progress for density and water absorption test (right)