Jimma University

School of Graduate Studies

Jimma Institute of Technology

Faculty of Civil and Environmental Engineering

Construction Engineering and Management Stream

EFFECTS OF USING SAWDUST AS A PARTIAL REPLACMENT OF FINE AGGREGATE FOR THE PRODUCTION OF HOLLOW CONCRETE BLOCK AROUND JIMMA.

A Thesis submitted to the School of Graduate Studies of Jimma University in Partial fulfillment of the requirements for the Degree of Master of Science in Civil Engineering (Construction Engineering and Management)

By: Mikiyas Alemeshet

October 2017

Jimma, Ethiopia

Jimma University

School of Graduate Studies

Jimma Institute of Technology

Faculty of Civil and Environmental Engineering

Construction Engineering and Management Stream

EFFECTS OF USING SAWDUST AS A PARTIAL REPLACMENT OF FINE AGGREGATE FOR THE PRODUCTION OF HOLLOW CONCRETE BLOCK AROUND JIMMA.

A Thesis submitted to the School of Graduate Studies of Jimma University in Partial fulfillment of the requirements for the Degree of Master of Science in Civil Engineering (Construction Engineering and Management)

By: Mikiyas Alemeshet

Advisor: Prof. Emer T. Quezon

Co-Advisor: Engr. Getachew Kebede

October 2017

Jimma, Ethiopia

JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

CONSTRUCTION ENGINEERING AND MANAGEMENT CHAIR

EFFECTS OF USING SAWDUST AS A PARTIAL REPLACEMENT OF FINE AGGREGATE FOR THE PRODUCTION OF HOLLOW CONCRETE BLOCK AROUND JIMMA

By: MIKIYAS ALEMESHET

APPROVED BY BOARD OF EXAMINERS:

Main Advisor	Signature	Date
Co-Advisor	Signature	Date
External Examiner	Signature	Date
Internal Examiner	Signature	Date
Chairman	Signature	Date

Declaration

I, the undersigned, declare that this thesis entitled “Effects of using sawdust as a partial replacement of fine aggregate for the production of hollow concrete block around jimma”.is my original work, and has not been presented by any other person for an award of a degree in this or any other University, and all sources of material used for these have been dually acknowledged.

Candidate:

Mr. Mikiyas Alemeshet

Signature:________________________.

As Master research Advisors, we here by certify that we have read and evaluate this Msc research prepared under our guidance, by Mr. Mikiyas Alemeshet entitled: “Effects of using sawdust as a partial replacement of fine aggregate for the production of hollow concrete block around Jimma”

We recommend that it can be submitted as fulfilling the MSc Thesis requirements.

______________________	____________	____________
Advisor	Signature	Date
______________________	____________	____________
Co-Advisor	Signature	Date

ACKNOWLEDGEMENT

First of all I would like to thank GOD giving me the patience and strength to finish this work. Then I would like to express my gratitude and deep appreciation to my advisor Prof. Emer T. Quezon and my co-advisor: Engr. Getachew Kebede for all their limitless and valuable comments, suggestions and advice through my work. My second gratitude goes to DHL Hollow concrete production firm manager and owner Ato Degene and for all workers for their willingness and help during Hollow concrete block production process. Finally, my deepest appreciation goes to Jimma University, School of Graduate Studies, Jimma Institute of Technology, Civil Engineering Department, Construction Engineering and Management Stream.

ABESTRACT

Hollow concrete blocks are a construction material produced from a mixture of Portland cement (OPC or PPC), Fine aggregates and Water. But the concrete mixture used for blocks has a higher percentage of fine aggregate and a lower percentage of water than the concrete mixtures used for general construction purposes. The construction industry is rapidly growing industry in the world and hollow concrete blocks are being widely used in construction of residential buildings, factories and multi-storied buildings. Due to these there is a scarcity of good quality fine aggregate due to depletion of resources and restriction due to environmental consideration, to make a hollow concrete block manufacturing to look for suitable alternative fine aggregate.

The objective of this experimental study was to investigate the effect of using sawdust as an alternative fine aggregate for hollow concrete block production and to determine an optimum content of sawdust for the replacement of fine aggregate that can be acceptable for the production of hollow concrete blocks, in order to help contribute to the industry in saving the environment, to provide new knowledge to the contractors and developers on how to improve the construction industry methods and services by using sawdust concrete mixture, and sustain good product performance.

The study was a laboratory experimental study conducted by preparing two types of HCB test samples. The first test sample of HCB was produced by using mix proportion 1:2:1:2 of cement, sand, gravel 00 and crushed aggregate respectively as a control group. The second sample HCBs were produced by replacing sand with sawdust in 4% increment in volume 4%. 8%, 12%, 16%, 20%, and 24%. but the result between 8% and 12% replacement shows high difference therefore 10% replacement is needed to get the intermediate result.

According to this study, the HCB without sawdust achieved 5.09Mpa mean compressive strength and the HCB with 10% sawdust achieved 4.01Mpa mean compressive strength and the HCB with 20% sawdust achieved 2.13Mpa. The acceptable replacement was obtained at 10% for the desired class B HCB and at 20% for class C HCB. The result from density and absorption show replacing sand with sawdust 4% in volume can decrease the density by 3.86% and increase the absorption by 2%. Material cost of all HCBs with sawdust was found lower than the HCB without sawdust. Replacing sand with sawdust 4% in volume can decrease the material cost by 3.68birr or 2%.

According to the result hollow concrete block with sawdust replacement in this study has achieved a better reduction in material cost and density and a smaller increment in absorption also achieved the desired compressive strength by limiting the sawdust replacement percentage. Therefore as a recommendation for contractors, HCB manufacturer, Wood product manufacturing firm, construction industry and other researcher that the benefit of using sawdust as a replacement of fine aggregate has to be considered and deeply investigated.

Keywords: Compressive Strengths, fine aggregate, hollow concrete block, sawdust

Table of Contents

List of table

Contents

List of figure

Contents

ABREVIATIONS

ASTM	American Society for Testing and Materials
BS	British standard
CM	Centimeter
CMU	Concrete masonry units
EBCS	Ethiopian Building Code Standard
ES	Ethiopian standard
GTZ	Deutsche Gesellschaft fuer Technische Zusammenarbei
HCB	Hallow concrete blocks
IS	Indian standard
KG	Kilo gram
KG/M^3	Kilo gram per meter cube
L, W and H	Length, Width and Height
MPa	Mega Pascal
MHUPA	Ministry of House and Urban Poverty Alleviation
N/CM^2	Newton per centimeter square
N/M^3	Newton per meter cube
OPC	Ordinary Portland cement
PDDG	Planing and Development Department Government
PPC	Portland Pozolana cement
RHPS	Rapidly hardening Portland cement
W/C	Water cement ratio

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUNDS

The use of concrete in building construction dates back to the time of the Romans. Though their only cement was a mixture of volcanic scoria with slaked lime, they showed a degree of skill and boldness in the moldings of walls arches and domes which are scarcely equaled at the present day, and many of them structures still stand as striking examples of the everlasting qualities of artificial stone (Elliott and Walker 2008).

The molding of concrete into separate blocks, to be used for building in the same manner as brick or blocks of stone, appears first to have been introduced in the early part of the 19th century. Solid blocks were first made, but they are over heavy to handle and found, but scanty use, Hollow blocks to be used as such or filled up with concrete after placing in the walls, were patented by Sellers, in England, in 1875. Concrete facing slabs, with projections to secure them to the concrete filling, soon followed, and in 1878 Listh, of Newcastle, patented a very ingenious Z-shaped block. All accounts indicate that these blocks were made by pouring wet concrete, and allowed to harden many hours before removing the molds, a somewhat costly and tedious process. The modern rapid method of molding hollow concrete blocks, from semi-wet mixtures of such consistency as to permit immediate removal from the machine, is an American invention (Elliott and Walker 2008.).

Concrete blocks are walling materials that are made of natural sand or crushed rocks mixed in proportion with cement and water then compacted to mold into different shapes and sizes (Tesfaalem 2014). Hollow blocks are the most common type of concrete blocks and generally in the construction are defined as structural walling units manufactured in different shape and size and have one or more large holes or cavities passing through it. The solid materials are 50% to 75% of the total volume of the block calculated from the overall dimension (Tewoderos . 2016).

It broadly has porous rough surface and silver gray color. This makes it attain adequate strength to be used as walling materials. Hollow concrete blocks are in use form a very long time in building construction works in the world(Osuji and Egbon, 2015).

The units are formed in a block machine, which uses vibration and pressure to form the blocks from a relatively dry mix with a low water/cement ratio. The basic ingredients are Portland cement, graded aggregates and water; although lightweight aggregates, plasticizers, pozzolans, coloring pigments and water repellants may also be used [Manufacturing and specification section 2.2.1].

Hollow concrete blocks used for wall construction classified as load bearing and non-load bearing depends on their structural function According to ASTM C90-70 hollow load bearing concrete blocks have three weight classifications, those are normal weight, medium weight and light weight blocks On the other hand non load bearing hollow concrete blocks are manufactured in accordance with specification ASTM C129-70. Those blocks intended for use in non-load bearing partitions.

According to Ethiopian standards ES 596:2001 hollow concrete block shall conform four classes depends on their strength, as Class A, B, C and D. The concrete mixture used for blocks has a higher percentage of fine aggregate and lower percentage of water than the concrete mixtures used for general construction purposes[Ethiopian standard (ES 596:2001)].

This experimental study has assess the hollow concrete block production trend and processes in the study area and evaluate the potential of sawdust to use as a partial substitute of fine aggregate for the production of hollow concrete block in order to get cost efficient, light weight and have the required strength product Finally, comparison of the results with different standard specification had undertaken and then formulate a conclusion and recommendation to whom it may concerns.

1.2 STATEMENT OF THE PROBLEM

The construction industry consumes more natural resources than any other industry. With increasing public awareness of the needs and demands of sustainable development and environmental conservation, no other industry is called on as much as the country's construction and building industry to evolve their practices to satisfy the needs of our current generation, without curtailing the resources of future generations to meet theirs (MEMON , 2016).

The construction industry is rapidly growing industry in the world and hollow concrete blocks are being widely used in construction of residential buildings, factories and multi-storied buildings. Due to this the demand of HCB in the construction industry is increasing. The blocks are made out of mixture of cement, sand and stone chips [Ministry of Housing and Urban Poverty Alleviation 2010].

The culture of using locally available ingredients for the construction materials is very week in Ethiopia and also the culture of using alternative construction materials other than the conventional one. This culture should be improved by conducting experimental researches on locally available materials (Tewoderos .2016).

The fine aggregate is one of the predominant contents of concrete mix for hollow block production. Scarcity of good quality fine aggregate due to depletion of resources and restriction due to environmental consideration, to make concrete manufacturing look for suitable alternative fine aggregate.

In Jimma there is no source of quality fine aggregate, therefore the contractor and the supplier are forced to look to another places. Sawdust is a by-product of wood which comes through the activities of wood based industries. As wood is converted and used for different purposes, it produces heaps of sawdust at milling sites. In Jimma there is a high number of wood product manufacturing firms as a result, a high amount of sawdust is available. This paper seeks for ways of utilizing sawdust as a partial replacement of fine aggregate for the hollow block production to minimize disposal problems, environmental pollution and also enhance the economy.

1.3 RESEARCH QUESTION

In light of the above statement of the problem, the study try to answer the following basic research question

1. What are the effects of sawdust in concrete mix properties for HCB production?
2. How much compressive strength will be achieved by using sawdust as a fine aggregate?
3. What are the benefits of using saw dust for hollow concrete block?

1.4 OBJECTIVE

1.4.1 General objective

The general objective of this study is to determine the acceptable quantity of fine aggregate to be replaced with sawdust to obtain strong, light weight, and economical result for HCB production.

1.4.2 Specific objective

- To investigate the effect of sawdust on the properties of concrete mix and physical properties of HCB.
- To compare the compressive strength of HCB produced by partial replacement of sawdust with standard specification.
- To analyze the economical benefit of using sawdust as fine aggregate for HCB production.

1.5 SIGNIFICANCE OF THE STUDY

Implementation of waste sawdust can decrease environmental damage also save the concrete materials. Its own stakes many advantages over traditional hollow concrete block, low density, light weight better economy and lower pollution for our environment.

This study has tried to determine the ways of utilizing sawdust as a replacement of fine aggregate for HCB production then compare the result with different standards and formulate a conclusion and recommendation depends on the result found therefore this provide helpful information to various stakeholders as follows;

- To the HCB manufacturing firms and to the contractors, that, the possibility of using sawdust as a partial replacement of fine aggregate for HCB production.
- For the construction industry that, the idea of investigating the possibility of using locally available materials for construction purposes.
- Wood product manufacturing firm that, the possibility of using their production waste (sawdust) for generating income by selling instead of other disposal method like burning or damping.
- Other researchers will use the findings as a reference for further research on the utilization of sawdust as a fine aggregate.

- And the implementation of waste sawdust could also be generalized to the use of straw in countryside, which could lead to more environmental saving profit.

1.6 JUSTIFICATION OF THE STUDY

The rationale for conducting this study will be providing the benchmarks under which the utilization of sawdust as a fine aggregate is improved. Facts are showing that; in Jimm there is a surplus amount of sawdust and scarcity of fine aggregate especially natural aggregates. To mitigate this shortage contractor and owners are facing different challenges and additional cost However, it may be a chance to solve this problem, but it needs different investigation and experimental analysis around Jimma.

1.7 SCOPE AND LIMITATION OF THE STUDY

1.7.1 SCOPE OF THE STUDY

The research addresses the objectives and tries to investigate the effect of using saw dust replacement in different percentage on the physical property of the hollow concrete block such as compressive strength, density, moisture content and absorption capacity. Also the physical properties of the ingredient (sand, crushed aggregate and saw dust) are studied in the laboratory.

In the study the standard size of hollow concrete block (20cm*20cm*40cm) are produced also cement used and the mix proportion has remained constant, but the sawdust content is increasing in 4% from 0 % (control mix) to 24% and comparison are made on the physical properties and cost of the hollow concrete blocks between control mix and other mixes.

1.7.2 LIMITATION OF THE STUDY

In this study, only the physical properties of the saw dust used were determined. But the chemical composition of the saw dust used was not determined due to the lack of laboratory for such tests in Jimma University.

The research also limited only on the physical properties of hollow concrete blocks such as compressive strength, density, moisture content and absorption capacity there for the durability, fire resistance and sound insulation of hallow concrete block ware not studied due to time constraint.

CHAPTER TWO

REVIEW OF RELATED LITERATURES

2.1 BACKGROUND

History of sawdust technology goes back to at least the 1930's, and it has been researched and applied in parts of the United State of America, United Kingdom, Germany and also Singapore and Malaysia region. In some instances, the materials (with various adaptations) have been used for flooring as well as walls. The possibilities for this material are probably endless (Thomas , 2015).

Wood wastes in the form of wood shavings can be incorporated into wood sand concretes without any preliminary treatment. The results have demonstrated that the inclusion of shavings in sand, concrete not only reduces the density of the material, but also improves its thermal conductivity, while the structure of the material remains homogeneous and with strong adherence of the wood to the concrete matrix (Ganiron 2014).

Implement waste sawdust that has been widely regarded as a partial sand replacement material to produce sawdust concrete, make sure that the overall structure is strong and secure without reliance on the sawdust cement infill (Cheng, Yong and et al, 2013).

Sawdust has been used in concrete, but not widely. Although seriously limited by its low compressive strength. It has serious limitations that must be understood before it is subject to use. Within these limitations, the advantages that sawdust concrete are offers considerable reduction in weight of the structure, thereby reducing the dead loads transmitted to the foundation, high economy when compared to and normal weight concrete, reduce damage and prolonged life of formwork due to lower pressure being exerted, ,Easier handling, mixing and placing as compared with other types of concrete, improved sound absorbent properties due to its high void ratio (Thomas , 2015).

Improved thermal insulation because the incorporation of wood aggregates in concrete decreases its thermal properties. For a mass percentage of wood aggregates ranging from 0 to 10%, the reduction in the thermal conductivity increases to 35% for the concrete-sawdust (Ganiron 2014)

The use of sawdust for making lightweight concrete has received some attention over the past years. Although studies on structural properties of sawdust concrete have shown encouraging results (Thomas , 2015).

.Globally, there is a resurgence of interest in this era of information revolution and environmental awareness. However, modern applications are being discovered and several are based on wood's unique physical and mechanical properties like strength (Ganiron, 2014).

The use of concrete for building construction dates back to the time of the Romans. Though they only cement was a mixture of volcanic scoria with slaked lime, they showed a degree of skill and boldness in the moldings of walls arches and domes which are scarcely equaled at the present day, and many of them structures still stand as striking examples of the everlasting qualities of artificial stone (The Elliott and Walker 2008).

The molding of concrete into separate blocks to be used for building in the same manner as brick or blocks of stone appears first to have been introduced in the early part of the 19th century. Solid blocks were first made but they are over heavy to handle, but scanty use Hollow blocks to be used as such or filled up with concrete after placing in the walls were patented by Sellers in England, in 1875. Concrete facing slabs, with projections to secure them to the concrete filling, soon followed, and in 1878 Listh, of Newcastle, patented a very ingenious Z-shaped block. All accounts indicate that these blocks were made by pouring wet concrete, and allowed to harden many hours before removing the molds, a somewhat costly and tedious process.

The modern rapid method of molding hollow concrete blocks, from semi-wet mixtures of such consistency as to permit immediate removal from the machine, is an American invention (The Elliott and Walker 2008).

The first hollow concrete block was designed in 1890 by Harmon S. Palmer in the United States. After 10 years of experimenting, Palmer patented the design in1900. Palmer's blocks were 8 in (20.3 cm) by 10 in (25.4 cm) by 30 in (76.2 cm), and they were so heavy they had to be lifted into place with a small crane. By 1905, an estimated 1,500 companies were manufacturing concrete blocks in the United States. These early blocks were usually cast by hand, and the average output was about 10 blocks per person per hour. Today, concrete block manufacturing is a highly automated process that can produce up to 2,000 blocks per hour (MHUPA. 2010).

A concrete block is primarily used as a building material in the construction of walls. It is sometimes called a concrete masonry unit (CMU). A concrete block is one of several precast concrete products used in construction. The term precast refers to the fact that the blocks are formed and hardened before they are brought to the job site. Most concrete blocks have one or more hollow cavitiy, and their sides may be cast smooth or with a design. In use, concrete blocks are stacked one at a time and held together with fresh concrete mortar to form the desired length and height of the wall (MHUPA. 2010).

2.2 HOLLOW CONCRETE BLOCK (HCB)

Hollow concrete block is an alternative wall and floor, making material in the building construction having one or more large holes with the solid material between 50 and 75 percent of the total volume of the block calculated from the overall dimensions [ES 596:2001]. Most hollow concrete blocks have one or more hollow cavity manufactured from a zero-slump mixture of Portland cement (and possibly other cementitious materials), aggregates, water and sometimes admixtures[Ethiopian standard (ES 596:2001)].

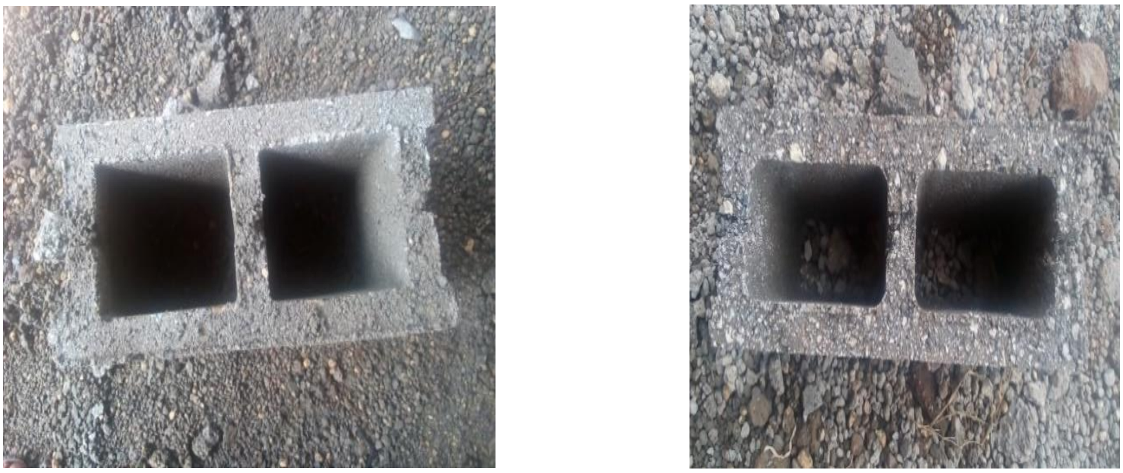


Figure 2.21 Sample HCB photo taken from HCB production site in jimma

Cement concrete hollow blocks have an important place in modern building industry. They are cost effective and better alternative to burnt clay bricks by virtue of their good durability, fire resistance, partial resistance to sound, thermal insulation, small dead load and high speed of construction. Concrete hollow blocks being usually larger in size than the normal clay building bricks and less mortar is required, faster of construction is achieved. Also building construction with cement concrete hollow blocks provides facility for concealing electrical conduit, water and sewer pipes wherever so desired and requires less plastering (Glass & Ceramics Division MSME Development Institute Govt of India, 2011).

Hollow concrete blocks are substitutes for conventional bricks and stones in building construction. They are lighter than bricks, easier to place and also confer economics in foundation cost and consumption of cement. In comparison to conventional bricks, they offer the advantages of uniform quality, faster speed of construction, lower labour involvement and longer durability. In view of these advantages, hollow concrete blocks are being increasingly used in construction activities (PDDG AJandK, 2014).

The hollow blocks shall be manufactured as per pattern shown on the drawing. These block units shall be provided by the Contractor for use where required in building structures from approved type of materials. Units shall have uniformly fine smooth surfaces of uniform colour. These shall be free of any honey combing or other imperfections or deformations, all edges true and straight, and at right angles with each other and without any chipped or otherwise broken edges (PDDG AJandK, 2014).

2.3 HOLLOW CONCRETE BLOCKS FOR WALL CONSTRUCTION

Hollow concrete blocks used for wall construction classified as load bearing and non-load bearing depends on their structural function (Abebe Dinku,. 2002). According to ASTM C90-70 hollow load bearing concrete blocks have three weight classifications those are normal weight, medium weight and light weight blocks as listed in Table 1 and shall conform two grades those are grade N and grade S.

Grade N blocks are suitable for general use such as in exterior walls below and above grade level that may or may not be exposed to moisture penetration. But grade S blocks limited to use above grade level for walls not exposed to weather and for exterior walls with weather protective coating.

Both grades have two types such as moisture controlled units designed as Type I (N-I and S-I)and shall conform all requirement listed in the Table 2 and non-moisture controlled units designed as type II (N-II and S-II) and shall conform all requirements except moisture content requirements listed in Table 1(Abebe Dinku,. 2002).

Table 2.3.1 Weight classification of hollow concrete block [ASTM C90-70]

Classification of HCB	Kg/m3
Light weight	Less than 1682
Medium weight	1682 – 2002
Normal weight	2002 or more

On the other hand non load bearing hollow concrete blocks are manufactured in accordance with specification ASTM C129-70. Those blocks intended for use in non-load bearing partitions, but under certain conditions may be suitable for use in non-load bearing walls above grade, where effectively protected from weather (Abebe Dinku, 2002).

Table 2.3.2 Moisture content requirement for type I units [ASTM C 90- 70] & [ASTM C 129 - 70]

Linear shrinkage percen	Moisture content requirement max percent of total absorption average of 3 units		
	Humidity condition at job site or point of use		
	Humid (Average annual relative humidity above 75%)	Intermediate (Average annual relative humidity 50 to 75%)	Arid(Average annual relative humidity less than 50%)
0.03 or less	45	40	35
From 0.03 to 0.045	40	35	30
0.045 to 0.065, max	35	30	25

According to Ethiopian standards ES 596:2001 hollow concrete block shall conform four classes depends on their strength, as Class A, B, C and D. The concrete mixture used for blocks has a higher percentage of fine aggregate and lower percentage of water than the concrete mixtures used for general construction purposes [Ethiopian standard (ES 596:2001)].

- **Class A** used for load bearing wall construction above or below ground level in damp proof course, in exterior walls that may or may not be treated with weather-protective coating and for interior walls and density of Class A blocks must conform between the range of 900 – 1200 kg/m3on the other hand Indian standard IS: 2185 (Part I) – 1979 recommended minimum density 1500 kg/m3

- **Class B and C** are used for load bearing wall construction above ground level in damp proof course in exterior walls that are treated with suitable weather-protective coating and their density should be between 900 – 1200 kg/m3on the other hand Indian standard IS: 2185 (Part I) – 1979 recommended minimum density within the range of 1000-1500 kg/m3 but class C is recommended for non-load bearing wall.

- **Class D** is used for non-load bearing interior walls and exterior panel walls in steel or reinforced concrete framed construction when protected from weather by rendering or by some other efficient treatment and their density should be between 600 - 900 kg/m3

2.4 RAW MATERIALS FOR HCB

Materials for Concrete Blocks Since the ingredients of concrete can be of very different types and qualities, not only depending on their local availability, but also on the desired properties of block, equipment and production method, it is not possible to give detailed recommendations on materials and mix proportions, other than very general guidelines. It is up to the manufacturer to select the most suitable materials and design of mixes by trial and error, and making tests with the available equipment under the conditions of full-scale production (Materials, Building Council, Technology Promotion Alleviation, Urban Poverty).

Portland cement (OPC or PPC), fine aggregates and water are commonly raw materials used to make concrete mixture for production of hollow concrete blocks. But concrete mixture used for blocks has a higher percentage of fine aggregate and a lower percentage of water than the concrete mixtures used for general construction purposes. This produces a very dry, stiff mixture that holds its shape when it is removed from the block mold. In addition to these, basic components various chemicals, called admixtures, can be used to alter curing time, increase compressive strength, or improve workability sometimes pigments may be added to give the blocks a uniform color throughout. Aggregates should be pass through a sieve of nominal aperture of 9.5 mm in addition to this the size of aggregate should not exceed two–third of the thickness of the thinnest part of the shell or web unit (Tesfaalem . 2014).

2.4.1 Cement

Most widely used cement for hollow concrete production are ordinary Portland cement (OPC), Portland pozzolana cement (PPC) and special cements (SRCCD, 2008). Type I, or ordinary cement, is used where extended curing periods are no handicap, or where blocks can be yarded for 7 to 28 days, allowing time for the blocks to attain specification strength. Different brands may vary somewhat in color, ranging from yellowish to slate gray, and may affect slightly the color of the finished products when various brands are used. The color of two dry cements can be compared by placing small quantities of each close together and pressing a piece of glass down over them so they run together. Small differences in color will be quite noticeable at the line of contact of equal importance to the color conscious producer are changes in the amount of extremely fine material in the aggregates and changes in the processing. Type II cement is generally darker than Type I. It is therefore preferred in some localities where darker units are more popular. It may set and harden somewhat slower than Type I. Type III (high early strength) cement is being used more and more for concrete products. This cement is ground to greater fineness and produces a paste of greater coating capacity. The mix is reported to be able to carry more water, and responds more under vibration or compaction, forming denser units. This cement hardens rapidly so normal curing and storage periods are reduced and units are ready for marketing sooner. Some plants use this type of cement exclusively, finding that the small extra cost is offset by the advantages it offers (Lyons ., 2008).

The following cements are commonly used in concrete block making:

Ordinary Portland cement (OPC). Most common type used.

Rapid hardening Portland cement (RHPC): more finely ground cement, which hardens much faster than OPC. It is especially useful:

- Where storage space is limited,
- When rapid production is important, and
- To produce good strength blocks despite poor gradation of aggregate.

Block mix cement: marketed especially for block making, but can vary from one manufacturer to another. It has the high early strength qualities of RHPC, but is lower in price. Special cements: such as Portland blast furnace cement, sulphate-resisting Portland cement and others, used where special properties are of importance. The partial replacement of cement by a pozzolana, eg rice husk ash, fly ash, may be acceptable in certain cases, but should not be implemented without prior laboratory testing (Materials, Building Council, Technology Promotion Alleviation, Urban Poverty).

The three constituents of hydraulic cements are lime, silica and alumina. In addition, most cements contain small proportions of iron oxide, magnesia, sulphur trioxide and alkalis. There has been a change in the composition of Portland cement over the years, mainly reflected in the increase in lime content and in a slight decrease in silica content. An increase in lime content beyond a certain value makes it difficult to combine completely with other compounds. Consequently, free lime will exist in the clinker and will result in an unsound cement. An increase in silica content at the expense of alumina and ferric oxide makes the cement difficult to fuse and form clinker. The approximate limits of chemical composition in cement are given in Table (Duggal, 2008).

Table 2.4.1 chemical composition of cement (Duggal, 2008)

Oxide	Function	Composition (%)
CaO	Control strength and soundness. Its deficiency reduces strength and setting time	60-65
SiO_2	Gives strength. Excess of it causes slow setting.	17-25
Al_2O_3	Responsible for quick setting, if in excess, it lower the strength	3-8
Fe_2O_3	Gives color and help in fusion of different ingredients	0.5-6
MgO	Important color and hardness. If in excess, it causes cracks in mortar and concrete and unsoundness	0.5-4
$Na_2O + K_2O$	These are residues and if in excess efflorescence and cracking	0.5-6
TiO_2		0.1-0.4
P_2O_5		0.1-0.2
SO_3	Makes cement sound	1-2

2.4.2 Aggregates

Aggregates are the materials basically used as filler with binding material in the production of mortar and concrete. They are derived from igneous, sedimentary and metamorphic rocks or manufactured from blast furnace slag, etc. Aggregates form the body of the concrete, reduce the shrinkage and effect economy. They occupy 70-80 per cent of the volume and have considerable influence on the properties of the concrete. It is therefore significantly important to obtain right type and quality of aggregates at site.

They should be clean, hard, strong, durable and graded in size to achieve utmost economy from the paste. Earlier aggregates were considered to be chemically inert but the latest research has revealed that some of them are chemically active and also that certain types exhibit chemical bond at the interface of aggregate sand cement paste. To increase the bulk density of concrete aggregates are used in two markedly different sizes—the bigger ones known to be coarse aggregate (grit) and the smaller ones fine aggregate (sand). The coarse aggregate form the main matrix of concrete and the fine aggregate from the filler matrix between the coarse aggregate (Duggal, 2008).

a) On the bases of size

According to size aggregates are classified as coarse aggregate, fine aggregate and all-in aggregate.

i) **Coarse aggregate: -** Aggregate retained on 4.75 mm sieve are identified as coarse. They are obtained by natural disintegration or by artificial crushing of rocks. The maximum size of aggregate can be 80 mm. The size is governed by the thickness of section, spacing of reinforcement, clear cover, mixing, handling and placing methods. For economy the maximum size should be as large as possible but not more than one-fourth of the minimum thickness of the member. For reinforced sections the maximum size should be at least 5 mm less than the clear spacing between the reinforcement and also at least 5 mm less than the clear cover. Aggregate more than 20 mm size are seldom used for reinforced cement concrete structural members.

ii) **All in aggregate: -** naturally available aggregates of different fractions of fine and coarse sizes are known as all-in-aggregate. The deficiency of any particular fraction can be corrected for use in the mix but they are not recommended for quality concrete.

iii) **Graded aggregate: -** Most of which passes through a particular size of sieve are known as graded aggregate. For example, a graded aggregate of nominal size 20 mm means an aggregate most of which passes IS sieve 20 mm.

iv) **Fine aggregate: -** Aggregate passing through 4.75 mm sieve are defined as fine. They may be natural sand—deposited by rivers, crushed stone sand—obtained by crushing stones and crushed gravel sand. The smallest size of fine aggregate (sand) is 0.06 mm. Depending upon the particle size, fine aggregates are described as fine, medium and coarse sands. On the basis of particle size distribution, the fine aggregates are classed into four zones; the grading zones being progressively finer from grading zone I to grading zone IV (IS: 383).

b) Based on unit weight

Aggregates are classified as normal-weight, heavy-weight and light-weight aggregate depending on weight and specific gravity as given in Table below(Duggal, 2008)

Table 2.4.2 classification of aggregate in weight (Duggal, 2008)

Aggregate	Sp.gr.	Unit weight [KN/m^3]	Bulk density [kg/m^3]	Example
Normal weight	2.5-2.7	23-26	1520-1680	Sand, gravel, granite, Sandston, limestone
Heavy-weight	2.8-2.9	25-29	>2080	Magnetite, Baryte, scrapiron
Light-weight		12	<1120	Dolomite,pumice,cinder,clay

The aggregates used will consist of sand, gravel, crushed stone, slag, cinders or other inert materials or combinations of them. They must be free from excessive amounts of dust, soft flaky particles or shale, or other deleterious materials (Lyons, 2008).

All the aggregates also should be free from frost or lumps of frozen materials. Where stationary aggregate bins are provided, a coil of steam pipes should be arranged around the outlet of the bin to thaw out frozen lumps. This heating' will' also aid in the early hardening of the concrete in cold weather. Aggregates are usually classified by an arbitrary division of fine and coarse (Michael and John. 2006).

In general practice the No.4 screen is taken as the line of demarcation between the course and the fine material. The maximum and minimum sizes of aggregate used will be governed by the process of manufacture, the desired surface effects and the type and dimensions of the manufactured units (Lyons. 2008). As described by (Lyons , 2008), the importance of fineness and gradation makes it obvious that the use of pit-run or crusher-run materials undesirable, since in the handling of such aggregates segregation of sizes always occurs and the proper proportioning of fine to coarse will be impossible to control.

i) Fine aggregates

Fine aggregates are aggregates passing the 9.5mm sieve and almost entirely passing 4.75-mm (No. 4) sieve and predominantly retained on the 75- µm (No.200) (ASTM C 125-93).

The amount of moisture contained in the sand is important since it bulks when damp and then weighs less per cubic foot than dry sand. In proportioning mixes this has an important effect on the resulting concrete and the sand should be dry if volume measurements are used, or the amount of moisture should be determined and corrections made for it. If this is not considered, a mixture richer than necessary may result (Michael and John, 2006).

Small amounts of silt, clay or loam may not be objectionable. Where the cement supplies sufficient fine material, silt introduced with sand will result in a loss of strength (James, , 2004).

ii) Course aggregates

Aggregate predominantly retained on the 4.75-mm (N0.4) sieve or portion of an aggregate retained on the 4.75-mm (No.4) sieve (ASTM C 125-93).

The maximum size will be limited by the dimensions of the unit to be produced. The largest pieces should not exceed one-third the thickness of the thinnest web of the units. The maximum size of aggregate should be 10 mm. Gravel, since it occurs widely, is largely used. It must, of course, be clean and durable and free from soft, flat or elongated pieces and should be evenly graded from the minimum to the maximum sizes (James., 2004).

Aggregates used for hollow concrete blocks are divided in to two according to the weight of hollow concrete blocks they produce. Well-graded sand, gravel and crushed stone are used to manufacture normal–weight units and they are called normal weight aggregates. Whereas lightweight aggregates such as pumice, scoria, cinder, expanded clay and expanded shale are used to manufacture light weight units (Michael S. and John P., 2006)

Crushed stone is an excellent coarse aggregate, although slate and shales are not recommended and some forms of sedimentary rocks may be lacking in durability. Density is an important requirement; soft and easily-abraded stone is to be avoided. It is also very important that the stone be free from dust, and washed material should be obtained if possible. Tolerances the same as those in the case of gravel are allowable (James, 2004).

2.4.3 Water for hollow concrete blocks

The purpose of using water with cement is to cause hydration of the cement. Water in excess of that required for hydration acts as a lubricant between coarse and fine aggregates and produces a workable and economical concrete. Water is also used for washing aggregates and curing (Duggal, 2008).

Quality of mixing water

Almost any natural potable water that has no pronounced taste or odor is acceptable for the concrete mix. Many sources of water unsuitable for drinking may also be used. In case of a doubt, water samples should be tested for suitability. Excessive impurities may affect setting time, strength, durability and may cause efflorescence, surface discoloration, and corrosion of steel. The effects of impurities in water are mainly expressed in terms of setting time of Portland cement. The initial setting time of the mixes with impure water and that with the pure water are obtained. Their difference in the initial setting time of ± 30 minutes with initial setting time not less than 30 minutes is supposed to be acceptable. The 7 day and 28 day compressive strengths of the cube/cylinder specimens prepared with impure water should not differ by 10 per cent from that of cubes/cylinders prepared with pure water. The tolerable concentrations of some of the impurities in water are given in Table 7.1 (Duggal, 2008).

Table 2.4.3 tolerable concentration of some impurities in water

s.no	Impurity	Tolerable Concentration
1	Silt and suspended particles	2000ppm
2	carbonate and bicarbonate Na or K	1000ppm
3	Bicarbonates of Mg	1000ppm
4	Chlorides	400ppm
5	Sulphates	20000ppm
6	Sulphur anhydride	3000ppm
7	Calcium chloride	2% by weight of cement
8	Sodium sulphide	<100ppm
10	sodium hydroxide	0.5 %by weight of cement provided quick set is not included
11	Dissolved salts	15000ppm
12	Organic matter	3000ppm
12	pH	3-8
13	Iron salt	10000ppm
14	Acids (HCL, H2SO4	500ppm

The mixing water should be free from injurious amounts of oils, acids, strong alkalies, organic matter or factory wastes. Water that is fit to drink is usually satisfactory. The water is used not only to make the mixture plastic and easy to mold, but is essential in the hydration of the cement. Any impurities present may seriously lower the strength of the concrete units and may cause undesirable acceleration or retardation of the setting time of the cement. It should not be colder than 600 F. Since temperatures much lower than this tend to retard the setting time and early hardening of the block and, unless it is clean, stains on the finished units may result (Michael S. and John P., 2006). Water cements ratio: .According to (Ethiopian Ministry of Federal Affairs, 2006), GTZ Low-Cost Housing Manual volume I recommended water- cement ratio is 0.49-0.55(Tewodros, 2016).

2.5 PRODUCTION PROSESS OF HCB

2.5.1 Aggregate-Cement Ratio

After determining the correct blend of aggregates, the proportion of aggregate to cement must be found by trials with different ratios, eg 1:6, 1:8, 1:10, up to 1:16 by weight, end testing the qualities of block produced.

The proportion of fine aggregate to cement is of special importance: if the ratio is too high, the mortar will lack the cohesiveness needed for green strength and will be too weak to impart enough strength to the matured blocks; if the proportion is too low, the mortar will be very cohesive and the mix may not flow easily in handling and filling the mold (Materials, Building Council, Technology Promotion Alleviation, Urban Poverty).

Suitable proportion of aggregate to cement must be found by testing, Common ratios are 1:6, 1:8 Test the quality of block produced.

2.5.2Water-CementRatio

Only water that is fit for drinking should be used to mix the concrete. The correct amount of water to be added to the mix depends on the types and mix proportions of aggregates and cement, the required strength of the block, and the production method and equipment used. The concrete must contain just enough water to facilitate production without any slumping of blocks occurring after demolding. If the aggregates are dry, they may absorb some of the water (lightweight aggregates may absorb up to 20 % by weight), but if the aggregates are wet, the blocks will take longer to dry out.

As a simple test for cohesiveness, no excess water should be visible when a lump of concrete is squeezed in the hand, but if the sample is rubbed quickly on a smooth round metal bar or tube (2 to 4 cm in diameter) a slight film or paste should be brought to the surface (GIZ, 2008).

2.5.3Batching

Aggregates can be batches by volume or by weight, but the latter is more accurate. For this reason, cement should only be batches by weight, or preferably by using only whole bags of 50 kg. In backyard block production, with less stringent quality standards, batching by volume using buckets, tins, wooden boxes or wheelbarrows is quite acceptable, if done with care to ensure uniform proportions of mix. (Ministry of Housing and Urban Poverty Alleviation 2010].

2.5.4 Mixing

Before starting production the different materials used to produce the HCB will be dry-mixed thoroughly on a clean and dry ground by hand or the mixture will be put in the mixing machine with the appropriate amount of water required (water to cement ratio of 0.49 – 0.55) [GTZ, (2011)].

The quality of concrete blocks depends largely on the type of mixer and period of mixing. The free fall, revolving drum type mixers are not suitable, because of the semi-dry nature of the mix. Pan mixers have a quick moving action and are thus recommended. [Ministry of Federal Affairs 2003].

2.5.5 Molding

According to Indian standard IS: 2185 (Part I) – 1979, manual compaction, the mixture shall be placed into the mold in layers of about 50 to 75 mm and each layer thoroughly tamped with suitable tampers until the whole mold is filled up and struck off level with a trowel. In the case of mechanical compaction, the mold shall be filled up to overflow, vibrated or mechanically tamped and struck off level. After remolding the blocks shall be protected against sun and wind by placing on the shade until they are sufficiently hardened to permit handling without damage. On the other hand, GTZ low cost housing manual Volume I specify to vibrate the mixture for 60 second before extruded as hollow concrete block and transported and remains for 24 hours on wooden pallet then it is be cured covered by plastic sheet to enhance the curing process and preventing the water from evaporation [GTZ, (2011)].

Figure 2.5.1 Casting procedure and casting machine

2.5.6 Curing:

Shelter the blocks from sun and draying winds. After 24 hours they should be watered and kept damp. Once molded blocks have sufficiently hardened to permit removal of the supporting wooden pallet they may be carefully turned on side or edge and the pallet removed, the pallet oiled and reused. Keep blocks damp for several days to permit the cement to hydrate completely. The longer the curing time the better is the strength. The blocks should thereafter be completely dried prior to placing in the wall [Ministry of Housing & Urban Poverty Alleviation 2010].

2.6 PHYSICAL PROPERTIS OF HCB

2.6.1 General

All units shall be sound and free of cracks or other defects which interfere with the proper placing of the unit or damage the strength or performance of the construction. Minor chipping resulting from the customary methods of handling during delivery, shall not be deemed grounds for rejection. Where units are to be used in exposed wall construction, the face or faces that are to be exposed shall be free of chips, cracks, or other imperfections, except that if not more than 5 percent of a batch contains slight cracks or small chippings not larger than 25 mm [ASTM C90- 70] or 10mm [ES596:2001] or [IS: 2185-1979], this shall not be deemed grounds for rejection

2.6.2 Dimension and Tolerance of Hollow concrete block

Hollow Concrete block, shall be referred to by its nominal dimensions. The term ‘nominal’ means the standard dimension which designed by manufacturer plus thickness of the mortar joint. For modular size units nominal dimension equal to standard dimension plus 9.53 mm but for non-modular size units it exceeds the standard dimension by 3.18 to 6.35 mm [ASTM C90-70]. Other standards such as Indian standards [IS: 2187-1979] recommended mortar joint 10 mm for modular size and 6 mm for non-modular ones.

Different standards specify their own limits on the permissible variations in the dimensions of standard hollow concrete block masonry units. These limits make easy laying of the units, assist the mason to construct the masonry within the suitable tolerances and help to offer an aesthetic finish and appearance of the constructed masonry.

According to ASTM C90-70 and ASTM C129-70 overall dimensions tolerance (length, width and height) of hollow concrete block shall not differ by more than 3.18 mm from specified standard dimension. In addition to this, face shells and webs thickness shall not less than ½ in or 12.7 mm for non-load bearing hollow concrete block but load bearing shall conform the Table 2.24. In case of Indian standard IS: 2185:1979 over all dimensions shall not differ by +5 mm for length and +3 mm for height and breadth in addition to this face shells and webs thickness shall conform the Table 2.25.

British standard BS: 6073-part I 1981 specify the maximum dimensional deviation for masonry units by measuring at four corners of end faces for length and for height at six position using caliper it should be +3 mm or -5 mm and +2 mm for thickness by measuring at seven position. On the other hand Ethiopian standard [ES 596:2001] specify maximum dimensional variation (length, height, breadth), it should be + 5mm for nominal dimensions of concrete masonry blocks these are listed below in Table. In addition to this, face shells and webs thickness of hollow units shall be at least one-sixth of overall breadth of a unit or 25mm whichever is the greater.

Table2.6.1 Minimum face-shell and web thickness [ASTM C90-70]

Nominal width(mm)	Face shall thickness (mm)	Web min (mm)
102	19	19
152	25	25
203	32	25

Table2.6.2 Minimum face-shell and web thickness [IS: 2185-1979]

Nominal block width (mm)	Face shall thickness (mm)	Web min (mm)
Less than 100 mm	25	25
100 to 150	25	25
150 to 200	30	25

Table 2.6.3 Nominal dimension of hollow concrete block [ES 596 2001]

Length(L) mm	Breadth (B) mm	Height (H) mm
400	100	200
	150	
	200	
500	100	100
	120	150
	150	200
600	200	250
	100	100
	120	150
	150	200
	200	250

2.6.3 Block Density

For hollow concrete, low density is probably the most characteristic feature. This is due to the holes. In addition, it depend primary on the aggregate density and the proportions of aggregate because the particle density of individual grading fraction can differ considerably and thus will affect the density of concrete. This property also influenced by the cement, water and air contents (ACI Committee 213, 2003).

The density of a block can only be obtained after the casting process by taking three blocks taken randomly from the selected samples and 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 computed in cubic centimeters. According to Ethiopian standard ES 596:2001 and Indian standard IS: 2185- (part 1)-1979 three blocks shall be taken for average density and it should conform to the requirements specified in Table 2.27 below. The blocks shall then be weighed in kilograms (to the nearest 10 g) and the density of each block calculated as follows:

$$\text{Density} = \frac{\text{mass of block in kg}}{\text{volume of specimen in cm}^3} \times 10^6 \text{kg/m}^3$$

Table2.6.4 Density classification of masonry unit [ES 596 2001 & IS: 2185-1979]

Class of Hollow concrete block	Ethiopian standard ES 596 2001 (kg/m^3)	Indian standard IS 2185-1979 (kg/m^3)
A	900-1200	1500
B	900-1200	1000-1500
C	900-1200	1000-1500
D	600-900	1800

2.6.4 Compressive Strength

The strength of hollow concrete is closely related to the specimen size and shape, method of pore formation, direction of loading, age, water content, water-cement ratio, degree of compaction, and cement content characteristic of its ingredients used, 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 hollow concrete block. It is also been found that a reduction in density due to formation of holes will results in a significant drops in strength. Generally, compressive strength increases linearly with density of structural concrete (Emmanuel and et al 2016).

The minimum compressive strength at 28 days being the average of six units, and the minimum compressive strength at 28 days of individual units should be tested. Compressive strength of a concrete masonry unit shall be taken as the maximum load in Newton divided by the gross cross-sectional area of the unit in square millimeters finally the results of the nearest 0.1 N/mm2, separately for each unit and as the average for the six units will be recorded [ES 596 2001. On the other hand British standard BS: 6073 (part I) 1981 recommended for blocks having a thickness of 75mm or more to test for compressive strength and their average compressive strength of 10 blocks shall not less than 2.8 MPa or individual block shall not less than 80 % of the minimum permissible average compressive strength.

The following are the minimum compressive strength requirements for blocks at the age of 28 days. The mix proportions of the material components are to be adjusted as required to obtain the required compressive strength according to Ethiopian standard, Indian standard and ASTM standards listed in the Table 2.28, 2.29 and 2.30 respectively.

Table 2.6.5 Compressive strength of hollow concrete block at 28 days [ES 596 2001]

Types of hollow concrete block	Class	Minimum compressive strength (N/mm2)	
		Average of 6 unit	Individual unit
Load bearing	A	5.5	5
	B	4	3.2
Non load bearing	C	2	1.8

Table 2.6.6 Compressive strength of hollow concrete block at 28 days [ES 2185-1979]

Types of hollow concrete block	Class	Density of block kg/m3	Minimum compressive strength (N/mm2)	
			Average of 8 unit	Individual unit
Load bearing	A	Not less than 1500	3.5	2.8
			3.5	3.6
			5.5	4.4
			7.5	5.6
	B	1000-1500	2	1.6
			3	2.4
			5	4
Non load bearing		1000-1500	1.5	1.2

Note: - the density of block is specified for the guidance of manufacturer; wile ordering the block purchaser shall specify the grade only.

Table 2.6.7 Compressive strength of HCB at 28 days [ASTM C 90-70 & C 129-70]

Type of hollow concrete block	Grade	Minimum compressive strength (N/mm^2)	
		Average of 3 unit	Individual unit
Load bearing	Type N (type I & II)	6.9	5.5
	Type S (type I & II)	4.8	4.1
Non load bearing	(type I & II)	Average of 5 units	Individual units
		3.5	3

Table 2.6.8 Absorption requirement for load bearing hollow concrete block [ASTM C 90-70]

Grade	Water absorption max (kg/m^3)				
	Oven dry weight classification (kg/m^3)				
	Light weight			Medium weight	Normal weight
	>1362(kg/m^3)		1362-1682 (kg/m^3)	1682-2002 (kg/m^3)	<2002 (kg/m^3)
N-I & II	-		290	240	210
S-I & II	320		-	-	-

2.6.6 Drying Shrinkage

The drying shrinkage is defined as the change in linear dimension of test specimen due to drying from saturated condition to an equilibrium weight and length under specified accelerated drying condition. dimensional changes of units has a significant effect on cracking that may be takes place during the early curing and drying which leads to a reduction in volume due to loss of moisture. The amount of drying shrinkage that occurs depends on the properties of the materials used for production, for instance units produced with normal weight aggregates tend to shrink less than units produced with lightweight aggregates and high strength units, with the corresponding high cement content, will shrink more. In addition to this the weather conditions at the job site also contribute to the dimensional changes in concrete masonry. Clearly, there will be more shrinkage in hot, arid climates as the amount of moisture lost to the atmosphere is greater than in cooler, humid climates.

Units when unrestrained being the average of three units shall not exceed 0.1 percent [IS: 2185:1979]. The ‘drying shrinkage’ shall be calculated for each specimen as the difference between the ‘original wet measurement’ and the ‘dry measurement’ expressed as a percentage of the ‘dry length’ [IS:2185:1979].

2.6.7 Moisture content

Moisture content requirement of concrete block masonry units is related to their linear shrinkage characteristics. Concrete loses or absorbs moisture with changes in the moisture content or relative humidity of the surrounding air. The cement paste may gain moisture and hence “swell”, or lose moisture and “shrink” before it attains an air dry equilibrium condition. It will undergo no dimensional change when the moisture content of the concrete is in equilibrium with the relative humidity of the surrounding so that masonry units are never delivered to a construction site in a saturated condition, and moreover, could not be laid in this condition. If unacceptably moist units are laid in a wall at the time of construction, and this inherent shrinkage is restrained in-service, stresses are developed within the masonry that may cause cracking. ASTM C90-70 specifies three moisture content requirements corresponding to linear shrinkage as listed in the table 2.23 below.

Table 2.6.9 Moisture content requirements for type I unit [ASTM C90-70] &[ASTM C129 70]

Linear shrinkage percent	Moisture content requirement max percent of total absorption average of 3 unit		
	Humidity condition at Job site or point of use		
	Humid	Intermediate	Arid
	Average annual relative humidity above 75%	Average annual relative humidity 50%-75%	Average annual relative humidity less than 50%
0.03 or less	45	40	35
0.03-0.045	40	35	30
0.045-0.065max	35	30	25

2.7 ADVANTAGES OF HOLLOW CONCRETE BLOCKS

There are many advantage of HCB with respect to structural, architectural and construction point of view (ecological building system, 2014).

- Highly Durable: The good concrete compacted by high pressure and vibration gives substantial strength to the block. Proper curing increase compressive strength of the blocks.
- Low Maintenance, Color and brilliance of masonry withstands outdoor elements.
- Load Bearing, strength can be specified as per the requirement.
- Fire Resistant
- Provide thermal and sound insulation: The air in hollow of the block, does not allow outside heat or cold in the house. So it keeps house cool in summer and warm in winter.
- Economical
- Environment Friendly, fly ash used as one of the raw materials.
- Low insurance rates

2.7.1 Structural Advantages

- In this construction system, structurally, each wall and slab behaves as a shear wall and a diaphragm respectively, reducing the vulnerability of disastrous damage to the structure/building, during the natural hazards.

- Due to the uniform distribution of reinforcement in both vertical and horizontal directions, through each masonry element, increased tensile resistance and ductile behavior of elements could be achieved. Hence, this construction system can safely resist lateral or cyclic loading, when compared to other conventional masonry construction systems. This construction system has also been proved to offer better resistance under dynamic loading, when compared to other conventional systems of construction.

2.7.2 Constructional Advantages

- No additional formwork or any special construction machinery is required for reinforcing the hollow block masonry.
- Only semi-skilled labour is required for this type of construction.
- It is a faster and easier construction system, when compared to the other conventional construction systems.
- It is also found to be a cost-effective disaster resistant construction system, as explained in the next section.

2.7.3 Architectural and Other Advantage

- ✓ This construction system provides better acoustic and thermal insulation for the building.
- This system is durable and maintenance free.
- Reduction in Dead Load
- Reduced Air Conducting Load: - Approx.50% saving.
- No salt peter or leaching: - Reduction in maintenance.
- Increased carpet area: - Due to smaller in size.
- Faster construction: - Easy to work with bigger in size.
- Assured Quality: - Fully automatic block plant.
- Better sound absorption: - Being hollow in nature.
- Reduced thickness of plaster: - Due to size accuracy & less cement consumption due to fewer joints.
- Load bearing walls: - Due to higher strength of blocks.
- Recommended for earth quake resistance.
- Less water absorption:- Approx. 3 to 4%
- Environmental Eco-Friendly

- Reduce in total cost of project: - Being less dead load of walls.
- They can be made larger than solid blocks, and if lightweight aggregate is used, can be very light, without forfeiting much of their load-bearing capacity;
- They require far less mortar than solid blocks (because of the cavities and less proportion of joints, due to large size), and construction of walls is easier and quicker;
- The voids can be filled with steel bars and concrete, achieving high seismic resistance.
- The air-space provides good thermal insulation, which is of advantage in most climatic regions, except warm-humid zones; if desirable, the cavities can also be filled with thermal insulation material;
- The cavities can be used as ducts for electrical installation and plumbing

2.8 SAWDUST

Sawdust or wood dust is an industrial waste obtained as by-products from cutting, sawing or grinding of timber in the form of fine particle. The physical and chemical properties of sawdust vary significantly depending on several factors; especially the species of wood By nature, sawdust particles are porous and absorb most of the water leaving insufficient water for the setting of cement. It is also presumed that if sawdust particles take up enough water during hydration, they could aid the hydration process particularly in the inner parts of concrete that is not possible to cure with water thus eliminating the need for curing since water deposited in sawdust particles are being harvested by cement particles. [Adebakin . Ogunrinola . et al 2012].

At sawmills, unless reprocessed into particleboard, burned in a sawdust burner or used to make heat for other milling operations, sawdust may collect in piles and add harmful leachates into local water systems, creating an environmental hazard. This has placed small sawyers and environmental agencies in a deadlock (Ganiron Jr 2014).

Questions about the science behind the determination of sawdust being an environmental hazard remain for sawmill operators (though this is mainly with finer particles), who compare wood residuals to dead trees in a forest. Technical advisors have reviewed some of the environmental studies, but say most lack standardized methodology or evidence of a direct impact on wildlife. They don’t take into account large drainage areas so the amount of material that is getting into the water from the site in relation to the total drainage area is minuscule (Ganiron, 2014).

In the construction industry, sawdust has been used to develop sawdust concrete which consists of Portland cement, sand, sawdust and water to give a slump of between 25-50mm.This kinds of concrete has been found to bond well with ordinary concrete. The sawdust used often requires treatment. Chemical treatment is necessary to prevent rotting since it‘s organic. Secondly it serves to make the sawdust neutral to prevent reactions that would adversely affect the concrete during hydration and setting. This has often been achieved by making sure the sawdust is clean without a large amount of bark. Finally it would lower moisture movement in the sawdust as it has a tendency to absorb water.

Best results are obtained when sawdust of between 1.18-6.3mm in size. However due to the variable nature of different kind of sawdust, use of a trial mix is recommended. This kind of concrete can achieve density ranging from 650 to 1600 kg/m3 .Sawdust concrete resulting from use of sawdust from tropical hardwoods have recorded compressive strengths of 30N/mm2, splitting strength of 2.5N/mm2 with a density of 1490kg/m3.Recent studies have shown successful use of sawdust as a brick material However due to the limited research on it, there has been no standard and codes developed to guide use.(Thomas Joseph Odero, 2015)

Sawdust can be used as alternative substitute for fine aggregate in concrete production. Sawdust should be washed and cleaned before use as concrete constituent because of large amount of bark which can affect setting and hydration of cement. Concrete obtained from sawdust is a mixture of sawdust, gravel with certain percentage of water to entrance the workability and full hydration of the cement which help in bonding of the concrete. Sawdust concrete is light in weight and has satisfactory heat insulation and fire resisting values. Nails can be driven and firmly hold in sawdust concrete compare to other lightweight concrete which nail can also easily drive in but fail to hold (Thomas Joseph Odero, 2015)

According to (Thomas Joseph Odero, 2015) the flexural strength increased from 1.43 N/ mm2 at 7 days to 2.24 N/mm2 at 28 days for control slab (i.e. about 57% increment). However, the strength of the 25% replacement by sawdust showed increased in flexural strength from 1.15N/mm2 at 7 days to 1.67 N/mm2 at 28days (45% increments). Similarly, the 50% replacement of sawdust showed an increase from 0.89 to 1.12N/mm2 between 7 and 28 days. According to BS 1881, part 4 (1970), a grade 15 concrete should have acquired a flexural strength of 1.2N/mm2 at 28days.In term of compressive strength, the 25% replacement slab gave a value of 15.9N/ mm2 which is equivalent to grade 15 concrete which a specified value of 15N/mm2 for lightweight concrete (BS 8110, 1997) . As the construction community might well be aware of, incorporating organic materials into solid concrete is not such a good idea to begin with. First of all, its loose molecular structure would cause the structure to fail at a certain stage and second, it would compete and retard the hydration process of cement.

Certain predictions state that if sawdust is mixed with cement and gravel, it might simulate a synthetic wood fiber bond found in trees. Since trees exhibit great strength and feats that manmade concrete structures cannot do without steel reinforcements, wood fiber bonding that could be more flexible and intricate in its own way might be adapted by most concrete structures allowing them to be shaped in more complicated forms. Also, presumptions indicate that if each sawdust particle took up enough water during hydration, they could aid the hydration process especially in the center parts of concrete that is impossible to cure with water thus eliminating the need of curing because water deposited in sawdust particles are being harvested by cement particles. The most important aspect and main target of the experiment are proving that sawdust-cement-gravel mixtures can prove to be more lightweight and cost efficient]. Since sawdust already wastes then the cost would go down as well as weight cause of its extremely light unit weight (Ganiron, 2014).

The properties of saw dust are shown in Table 4.1.It shows the density of light weight aggregate and will reduce the overall density of concrete. When the concrete density is decreased the self-weight and dead loads may be reduced in structures, resulting which the design details will be economic and ultimately the construction cost will decrease The moisture content of the saw dust is to be considered while finding the water cement ratio as the moisture content is 9.8%. Also sun drying was carried out for a further time period before concreting. As this is not a cementitious material and used only as an inert material the fineness modulus is verified and found as satisfactory. The Saw dust affects the setting and hardening of concrete. (Mynuddin, 2015)

Table 2.8.1 Properties of sawdust

Si. No	Parameters	Value
1	Fineness Modulus	1.9
2	Moisture Content	9.80%
3	Bulk Density	615kg/m3

2.8.2 Chemical Composition

The chemical composition of sawdust is complex often similar to the wood from which they are derived. Wood tissue is made of chemical components which are distributed none uniformly as a result of the anatomical structure. As a result, the chemical behavior of wood cannot be determined in detail from the properties of the component substances. The principal components of wood include Carbon, Hydrogen, Oxygen (O) and small amounts of Nitrogen. The chemical analysis of a number of species of softwoods and hardwoods shows that proportion of these elements in percentage of oven dry weight of wood are approximately: Carbon 49 50%,Hydrogen 6%,Oxygen 44-45% and Nitrogen 0.1-1%. Carbon, hydrogen and oxygen combine to form the principal organic components of wood substances namely cellulose, hemicellulose, lignin and small amounts of pectin substances. The terms cellulose and hemicellulose are generic, and each include a number of chemically related compounds. Separation and quantitative analysis of each in the laboratory has shown that the proportions in percentage of the oven dry weight of wood are approximately:

- Cellulose :40-45%, about the same for both hardwoods and softwoods
- Hemicellulose: 20% in softwoods,15-35% in hardwoods
- Lignin :25-35% in softwoods,17-25% in hardwoods

2.8.3 Physical properties

1. Flammable

   Sawdust is flammable, especially when dry hence has been used as a ready source of fuel by manufacturing charcoal briquettes which are then burnt to produce energy.

2. Hygroscopic

   Sawdust is hygroscopic; it has a tendency to absorb moisture when in contact with liquid water or water vapor. Due to this property, it has been used to absorb spills. (Thomas Joseph Odero, 2015)

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 STUDY AREA

The study will be conducted in Jimma zone, Southwestern Ethiopia, which is located 335km by road southwest of Addis Ababa. Its geographical coordinates are between 7° 13'- 8° 56N latitude and 35°49'-38°38'E longitude with an estimated area of 19,506.24. The town is found in an area of average altitude, of about 5400 ft. (1780 m) above sea level. It lies in the climatic zone locally known as Woynā Dagā which is considered ideal for agriculture as well as human settlement.

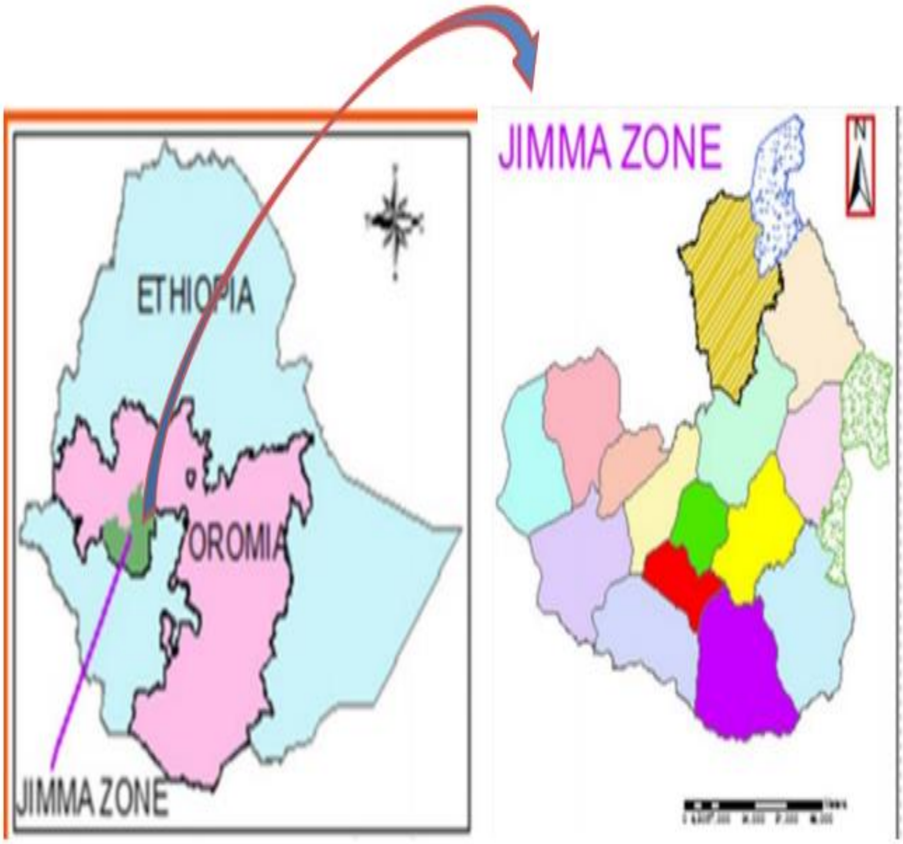


Figure 3.1.1 Location of the study

3.2 STUDY PERIOD

This research was carryout within a total duration of 8 months starting from March 2017 up to October 2017 G.C.

3.3 STUDY DESIGN

The study was an experimental study on hollow concrete blocks in a partial replacement of fine aggregate with sawdust in different proportion. The amount and kind of cement was constant, but the quantity of sawdust, aggregate and water was varied. The study was conducted in different steps. These include material preparation, determining engineering property of materials and production of hollow blocks then compressive strength, density, moisture content, absorption test and production cost calculation were conducted.

3.3.1 Material preparation

a) Cement

The type of Cement used for the study was DANGOTE grade 43.5 ordinary Portland cement and purchased from the local market.

b) Sand

The sand used for the study was purchased from local supplier and their sources are from GAMBELA.

Figure3.3.1 natural sand

c) Crushed aggregate (01) and crushed fine aggregate (00)

The Crushed aggregate (01) and crushed fine aggregate (00) used for the study was purchased from local quarry site fund in jimma.

Figure 3.3.2 crushed aggregate 01 & 00

d) **Sawdust**

For this research the sawdust was collected from wood manufacturing firm found in JIMMA and used without any pre-treatment. The wood manufacturing firm used wanza for manufacturing therefore the sawdust used was the byproduct of wanza and it is a hard wood . there are different size of sawdust, courser and finer but in the study sawdust used was finner sawdust.

Figure 3.3.3 sawdust at the sawmill

3.3.2 Determining engineering property of materials

The engineering property of all materials necessary for describing the type of materials used and also properties that can affect the production of HCB were determined prior to production. The test methods used for the aggregates are listed below in Table 3.3.1.

Table 3.3.1 material property test

sand	
property tests	test method
silt content	ASTM C 117
moisture content	ASTM C 566
gradation	ASTM C 136
unit weight	ASTM C 29
specific gravity and absorption	BS 812-105.1:1989

sawdust	
property tests	test method
moisture content	ASTM C 29
gradation	ASTM C 136
unit weight	ASTM C 29
specific gravity and absorption	BS 812-105.1:1989

crushed aggregate 00	
property tests	test method
moisture content	ASTM C 566
gradation	ASTM C 136
unit weight	ASTM C 29
specific gravity and absorption	BS 812-105.1:1989

crushed aggregate 01	
property tests	test method
moisture content	ASTM C 566
gradation	ASTM C 136
unit weight	ASTM C 29
specific gravity and absorption	ASTM C127

The samples for the property test were taken by using quartering method and sample splitter. The results for the tests are presented in the data sheets in **Appendix one.**

Figure 3.3.4 quartering and sample splitter for crushed aggregate

3.3.3 Production of HCB

The HCB produced for the research was class B and has the conventional dimension 40cm*20cm*20cm (L, W and H).

Proportioning

a) **Cement aggregate ratio**

After the materials was prepared, by adopting the proportioning for class B HCB in accordance to ESC D3.301: prepare the materials with cement aggregate ratio of 1:5 by volume.

Table 3.3.2 mix proportion

Class	Proportions by volume of				
	Sand	Gravel 00	Gravel 01	Red ash or pumice	Cement
A	2	1	1		1
	2	1		1	1
B	2	1	2		1
	2	1		2	1
C	3	1	2		1
	3	1		2	1

Volume beaching was used for the proportioning of materials. Two box were prepared for measuring materials, the first on was the conventional box used to proportioning material that have the volume of $0.04M^3$ or 50cm*40cm*20cm (L, W and H) in dimension and the other one is that used to measure quantity of sawdust 4% of the total quantity of sand in one mix. The total quantity of sand in the mix was 2*0.04M^3 = 0.08M^3. Therefore 4% of sawdust from the total quantity of sand in one mix is (4*0.08)/100 = 0.0032M^3 or 20cm*16cm*10cm (L, W and H) in dimension

Figure 3.3.5 measuring box

The first sample was prepared by replacing 0% of fine aggregate with sawdust that was used as a control mix and the other sample mixes was prepared by increasing the percentage of sawdust replacement in 4%. The replacement was continued up 28%.

Figure 3.3.6 batch mix

b) Water cement ratio

According to GTZ Low Cost Housing Manual Volume I water cement ratio for hollow concrete block is between (0.49 - 0.55) was recommended. Therefore for this research 0.5

water cement ratio was selected but when the amount of sawdust increase, the amount of water to get the desired workable mix was also increased.

Table 3.3.3 water cement ratio

%of sawdust	Amount of cement in Kg	Amount of water in Liter	Water cement ratio
0	50	25	0.5
4	50	25.3	0.506
8	50	25.7	0.514
10	50	26.1	0.522
12	50	26.5	0.53
16	50	27	0.54
20	50	27.5	0.55
24	50	28.2	0.564

The table shows the relation sheep between water cement ratio and sawdust replacement percentage. When the amount sawdust increase, the water cement ratio also increases, the reason for this relation sheep is due to the moisture absorption property of sawdust.

3.3.5 Mixing process

The mixing process was conducted in two steps. The first step was dry mix of aggregates and cement on the floor by hand and the second step was wet mixing of aggregates and cement inside electrically operated mixer.

Figure 3.3.7 dry mixing of material

3.3.6 Molding process

The next step was casting of sample HCB by using a block machine which use vibration and pressure to form the block within the conventional dimension of 40cm x 20cmx 20cm (L, W, and H) and there was a proper curing for 14 days.

Figure 3.3.8 casting of HCB

3.3.7 Curing

After the HCB was molded they were kept for 24 hours under the shade to prevent moisture loss due to sunlight before start curing. Then the curing was done for 14 days as recommended on GTZ Low Cost Housing Manual Volume I also the method of curing used was spraying water.

3.3.8 Laboratory test

Then after there were laboratory tests within 7^{th}, 14^{th} and 28^{th} days for the compressive strength of HCB and at 28^{th} day such as, density, moisture content and absorption test for the HCB has been carryout then comparison are made between the mixes and with different standards specification.

Figure3.3.9 testing of HCB

3.4 SAMPLING PROCEDURE AND SAMPLE SIZE

The sampling procedure was purposive sampling, therefore the sample size was determined accordingly to the test specimen number required to conduct compressive strength, density, moisture content and absorption test for HCB. Therefore there were 6 samples for compressive strength and 3 samples for moisture content, absorption and density tests in each % replacement and age.

Table 3.5.1total number of sample required

% of sawdust	Number of sample				Total
	For compressive strength test			Density, moisture content and absorption test	
	7th	14th	28th	28th	
0%	6	6	6	3	21
4%	6	6	6	3	21
8%	6	6	6	3	21
10%	6	6	6	3	21
12%	6	6	6	3	21
16%	6	6	6	3	21
20%	6	6	6	3	21
24%	6	6	6	3	21
total number of sample					168

3.5 STUDY VARIABLES

- Dependent Variable:

  Compressive strength of HCB

  Moisture content of HCB

  Absorption of HCB

  Density of HCB

  Weight of HCB

  Cost of production for HCB

- Independent Variable:

  Percentage of sawdust replaced

  Mix proportion

  Water cement ratio

3.6 DATA COLLECTION PROCESS

The data for this research was collected from laboratory results. In the study analytical data will be collected.

3.7.1 Experimental or laboratory tests

The data were obtained from the results of experimental procedures in the laboratory recorded with proper format and the data are becoming input for the analytical analysis and the result are tell as some outputs of the findings.

3.7 DATA PROCESSING AND ANALYSIS

The data were analyzed based on the experimental results found from the compressive strength, density, moisture content and absorption test results. The Result and findings were presented in table, chart or other methods.

3.8 ETHICAL CONSIDERATION

The data's are only collected after ethical permission given from different contractor and HCB manufacturing firm and Jimma university civil engineering department.

3.9 DISSEMINATION PLAN

These researches are going to carry out for the partial fulfillment of master's degree of civil engineering in construction engineering and management, therefor the research finding should be presented for the construction engineering and management department and will be submitted both in hard and soft copy to the department and for all interested body.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 INTRODUCTION

In this chapter the results found from laboratory investigation on the physical properties of hollow concrete blocks ingredient and the physical properties of HCB are discussed.

4.2 Physical properties of materials

4.2.1 Sand

a) Size Gradation

According to the test method of ASTM C136 sieve analysis was carryout and the test result and are shown below in the table

Table 4.2.1 sieve analysis of sand

Sieve size	%pass	ATEM standard	remark
9.5	100	100	ok
4.75	98.25	95-100	ok
2.36	89.5	80-100	ok
1.18	74	50-85	ok
0.6	37	25-60	ok
0.3	15.5	10-30	ok
0.15	2	2-10	ok
pan	0	**FM=2.83**	

According to **ASTM C33** fine aggregates should have fineness modules between 2.3 and 3.1; the sand used has fineness modules of 2.83, therefore it is within the ASTM limits. Also the gradation curve lays between ASTM upper limit and lower limit as shown in the figure below

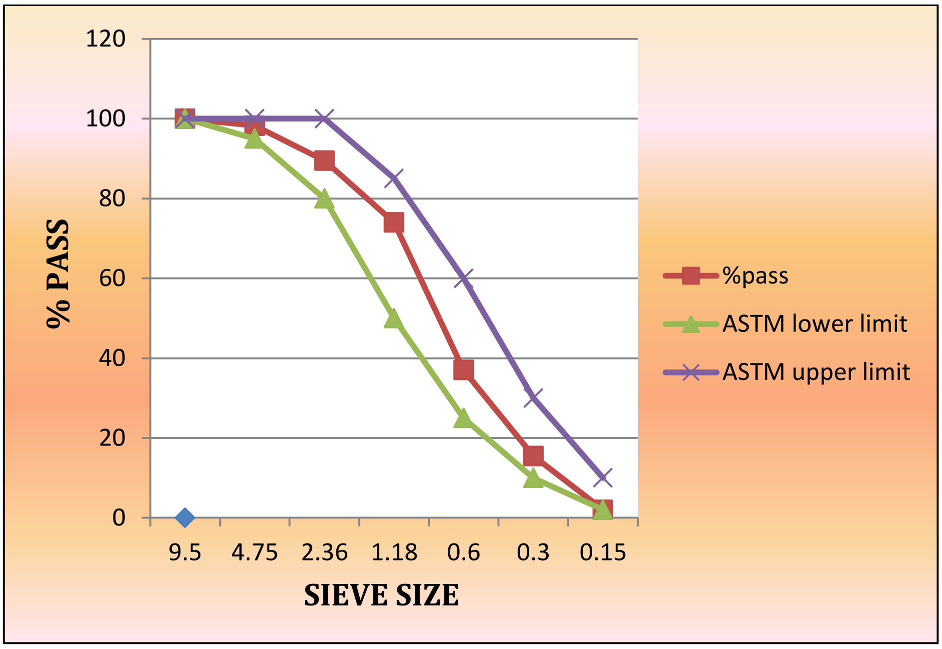


Figure 4.2.1 sieve analysis result graph

Both from the **Table** and **Figure**, the result shown that the sand is fulfilling ASTM C33 requirement as a result it can be used to produce HCB.

b) Specific gravity and absorption

According to the test method of BS 812: part 2:1995, specific gravity and absorption of sand was investigated and the results are shown below in table

Table4. 2.2 Specific gravity and absorption test result

description	var	weight in kg		
sample		sample 1	sample 2	sample 3
mass of saturated surface dry sample	A	0.5	0.5	0.5
mass of pycnometer + water + sample	B	1.81	1.814	1.799
mass of pycnometer + water	C	1.5	1.5	1.5
mass of oven dry sample	D	0.49	0.492	0.494
bulk Sp.gr.(SSD)=A/(A-(B-C))	Sg	2.631	2.688	2.487
mean bulk Sg				2.602

Absorption (A-D/D)*100	Abs	2.040	1.626	1.214
min Absorption				1.627

Figure 4.2.2 Pycnometer

According to ASTM C33, the limitation for bulk specific gravity (SSD) is from 2.4 to 3.0 also the absorption should be within the range of from 0.2 to 2% for fine aggregates.

From the result found either specific gravity or absorption is satisfying ASTM limitation.

c) Silt content

According to the test method of ASTM C117 silt content of sand was carryout and the test result and are shown below in table

Table 4.2.3 Silt content result

description	measurement		
sample	sample 1	sample 2	sample3
weight of sample A	1	1	1
weight of oven dry sample after washing B	0.97	0.972	0.975
silt content % (A-B/A)*100	3	2.8	2.5

mean silt content	2.76

According to ASTM C33, silt content should not be greater than 3%. The sand has less silt content than ASTM limitations as a result it can be applicable to use the sand for HCB production.

d) Moisture content

According to the test method of ASTM C566 moisture content of sand was carryout and the test result and are shown below in table

Table 4.2.4 Moisture content test result

description	measurement		
sample	sample 1	sample 2	sample3
weight of sample A	0.5	0.5	0.5
weight of oven dry sample B	0.493	0.492	0.494
moisture % (A-B/B)*100	1.419	1.626	1.214
mean moisture content			1.420

The moisture contents should be within 0.5% to 2%. The sand used to produce the HCB are within the limits.

e) Bulk unit weight

According to the test method of ASTM C29 bulk unit weight of fine aggregate was carryout and the test result are shown below.

Table4.2.5 Bulk unit weight test result

description	measurement		
	sample1	sample2	sample3
weight of container (A)	1.06	1.06	1.06

weight of container + sample (B)	8.6	8.63	8.655
weight of sample (B-A)=(D)	7.54	7.57	7.595
volume of container C	0.005	0.005	0.005
unit weight= (D/C)	1508	1514	1519
mean unit weight			**1513.67**

ASTM C33 limits the bulk unit weight of sand is from 1320 – 1680kg/m3, as it is shown from **Table 4.2.5**, the unit weights are within the limits. Therefore, the sand is acceptable for HCB production.

4.2.2 Crushed fine aggregate (5mm-0.15 or 00)

a) Size Gradation

According to the test method of ASTM C136 sieve analysis of was carryout and the test result and are shown below in table

Table4.2.6 sieve analysis test result for crushed aggregate 00

Sieve size	%pass	ATEM standard	remark
9.5	100	100	ok
4.75	90.5	95-100	ok
2.36	52.5	80-100	ok
1.18	35.75	50-85	ok
0.6	21.5	25-60	ok
0.3	15.25	10_30	ok
0.15	9.25	2_10	ok
pan	0	**FM=3.75**	

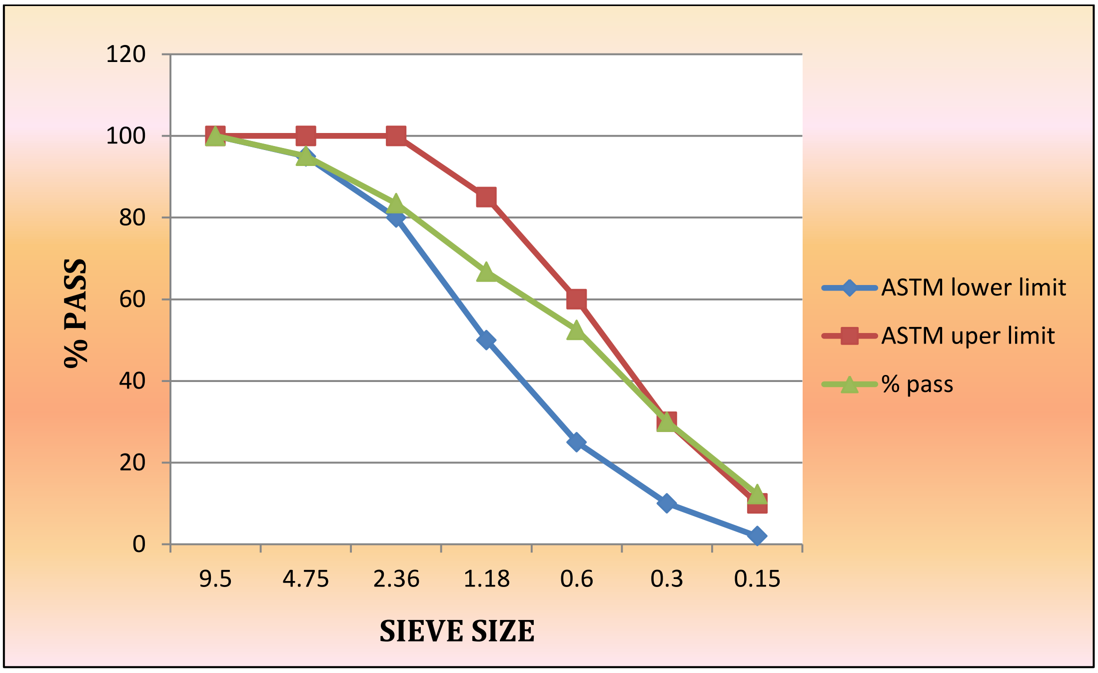


Figure 14 sieve analysis result graph

From the table we can see the % pass of the aggregates are within the range of ASTM upper limit and lower limit also the figure support the table but as we see in the figure the first three consecutive sieve the %pass is near to the lower limit and it shows that high amount of materials are retain or they are courser materials on the other hand in the last three consecutive sieve the %pass was near to the upper limit and it shows that high amount of material was pass or there are finer materials.

b) Specific gravity and absorption

According to the test method of BS 812: part 2:1995, specific gravity and absorption of crushed aggregate 00 was investigated and the results are shown below in table

Table 4.2.7 Specific gravity and absorption test result for crushed aggregate 00

description	var	weight in kg		
sample		sample 1	sample 2	sample 3
mass of saturated surface dry sample	A	0.5	0.5	0.5
mass of pycnometer + water + sample	B	1.82	1.81	1.8
mass of pycnometer + water	C	1.5	1.5	1.5

mass of oven dry sample	D	0.49	0.492	0.494
bulk Sp.gr.(SSD)=A/(A-(B-C))	Sg	2.777	2.631	2.5
mean bulk Sg				2.636
Absorption (A-D/D)*100	Abs	2.04	1.626	1.214
min Absorption				1.627

According to ASTM C33, the limitation for bulk specific gravity (SSD) is from 2.4 to 3.0. Accordingly the aggregates are within ASTM limitations. And absorption from 0.2% to 2% for fine aggregates.

c) Silt content

According to the test method of ASTM C117 silt content of crushed aggregate 00 was carryout and the test result and are shown below in table

Table 4.2.8 Silt content test result for crushed aggregate 00

description	measurement		
sample	sample 1	sample 2	sample3
weight of sample A	1	1	1
weight of oven dry sample after washing B	0.967	0.972	0.975
silt content % (A-B/A)*100	3.3	2.8	2.5
mean silt content			2.86

According to ASTM C33, silt content should not be greater than 3%. Therefor the materials are satisfy ASTM standard

d) Moisture content

According to the test method of ASTM C566 moisture content of crushed fine aggregate (5mm-0.15mm) was carryout and the test result are shown below in the table below

Table 4.2.9 moisture content test result for crushed fine aggregate(5mm-0.15mm) (00)

description	measurement		
sample	sample 1	sample 2	sample3
weight of sample A	0.5	0.5	0.5
weight of oven dry sample B	0.495	0.492	0.494
moisture % (A-B/B)*100	1.01	1.62	1.21
mean moisture content			1.28

And the moisture contents should be within 0.5% to 2%. The result shown from the table is within the limits therefore it is applicable for use.

e) Bulk unit weight

According to the test method of ASTM C29 bulk unit weight of fine aggregate was carryout and the test result are shown below.

Table 4.2.10 bulk unit weight test result for crushed fine aggregate (5mm-0.15mm) (00)

description	measurement		
	sample1	sample2	sample3
weight of container (A)	1.06	1.06	1.06
weight of container + sample (B)	8.819	8.63	8.655
weight of sample (B-A)=(D)	7.759	7.57	7.595
volume of container C	0.005	0.005	0.005
unit weight= (D/C)	1551.8	1514	1519
mean unit weight			**1528.27**

ASTM C33 limits the bulk unit weight from 1250 - 1460kg/m3, as it is shown from **Table 4.1.2.2**, the unit weights are within the limits. Therefore, the aggregates fulfill specification.

4.2.3 Crushed fine aggregate (10mm - 2.36mm or 01)

a) Size Gradation

According to the test method of ASTM C136 sieve analysis of was carryout and the test result and are shown below in table

Table 4.2.11 sieve analysis test result for Crushed fine aggregate (10mm - 2.36mm or 01)

Sieve size	%pass	ATEM standard	remark
19	100	100	ok
12.5	100	90-100	ok
9.5	52.5	40-70	ok
4.75	12.5	0-15	ok
2.36	2.5	0-5	ok
pan	0		

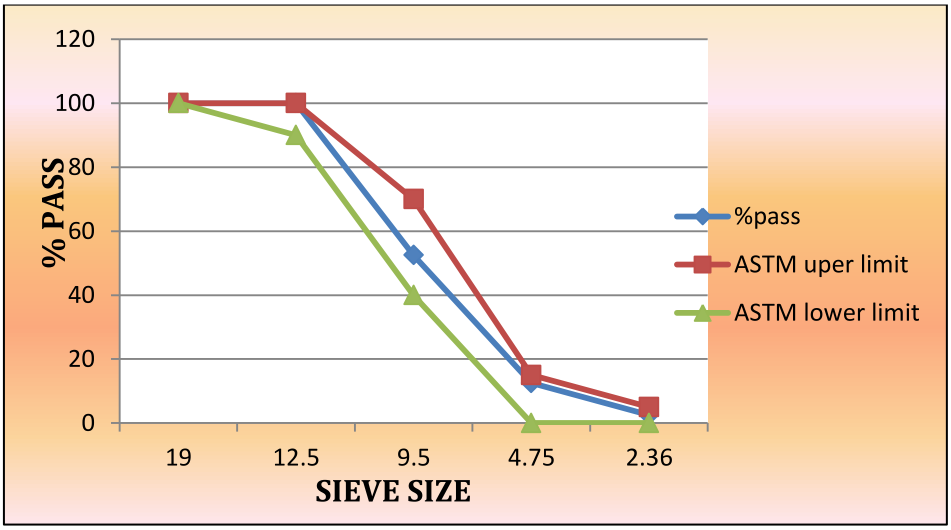


Figure 15 sieve analysis test result graph

From both the table and the figure the result shows that the aggregate are within the upper and lower limit of ASTM standard.

b) Specific gravity and absorption

According to the test method of ASTM C127 specific gravity and absorption of crushed aggregate (10mm - 2.36mm or 01) was investigated and the results are shown below in table

Table 4.2.12 Specific gravity and absorption test result for crushed aggregate 01

description	var	weight in kg		
sample		sample 1	sample 2	sample 3
weight of oven dry sample in air	A	1.985	1.982	1.981
weight of saturated surface dry sample	B	2.02	2.01	2.03
weight of wire basket in water	C	0.26	0.26	0.26
weight in water o(SSD) sample + wire basket	D	1.53	1.51	1.54
weight in water of SSD = D-C	E	1.27	1.25	1.28
bulk Sp.gr.(SSD)=B/B-E	Sg	2.69	2.64	2.7
mean bulk Sg				2.68
Absorption (B-A)/A*100	Abs	1.76	1.41	2.47
min Absorption				1.88

According to ASTM C33, the limitation for bulk specific gravity (SSD) is from 2.4 to 3.0. Accordingly the aggregates are within ASTM limitations. And absorption from 0.2% to 4%, for coarse aggregates and 0.2 to 2% for fine aggregates.

c) Moisture content

According to the test method of ASTM C117 silt content of sand was carryout and the test result and are shown below in table

Table 4.2.13 moisture content test result for crushed fine aggregate(10mm-2.36mm) (01)

description	measurement		
sample	sample	sample	sample3

	1	2	
weight of sample A	2	2	2
weight of oven dry sample B	1.978	1.983	1.9692
moisture % (A-B/B)*100	1.11	0.85	1.56
mean moisture content			1.17

And the moisture contents should be within 0.5% to 2%. All aggregates are within the limits.

d) Bulk unit weight

According to the test method of ASTM C29 bulk unit weight of crushed aggregate was carryout and the test results are shown below.

Table 4.2.14 bulk unit weight test result for crushed fine aggregate(10mm-2.36mm) (01)

description	measurement		
	sample1	sample2	sample3
weight of container (A)	1.06	1.06	1.06
weight of container + sample (B)	8.613	8.6537	8.655
weight of sample (B-A)=(D)	7.553	7.5937	7.595
volume of container C	0.005	0.005	0.005
unit weight= (D/C)	1510.6	1518.74	1519
mean unit weight			**1516.11**

ASTM C33 limits the bulk unit weight from 1250 - 1460kg/m3, as it is shown from **Table 4.1.2.2**, the unit weights are within the limits. Therefore, the aggregates fulfill specification.

4.2.4 Sawdust

a) Size Gradation

According to the test method of ASTM C136 sieve analysis of sawdust was carryout and the test result and are shown below in table

Table 4.2.15 sieve analysis test result for sawdust

Sieve size	%pass	ASTM standard	remark
9.5	100	100	ok
4.75	97	95-100	ok
2.36	91	80-100	ok
1.18	84	50-85	ok
0.6	58	25-60	ok
0.3	32	10_30	not ok
0.15	10	2_10	ok
pan		**FM=2.28**	

On the sieve size 0.3 the result of %pass is above the upper limit of ASTM standard, this imply that on that particular sieve the amount of sawdust retain is smaller and the sawdust has very fine particles.

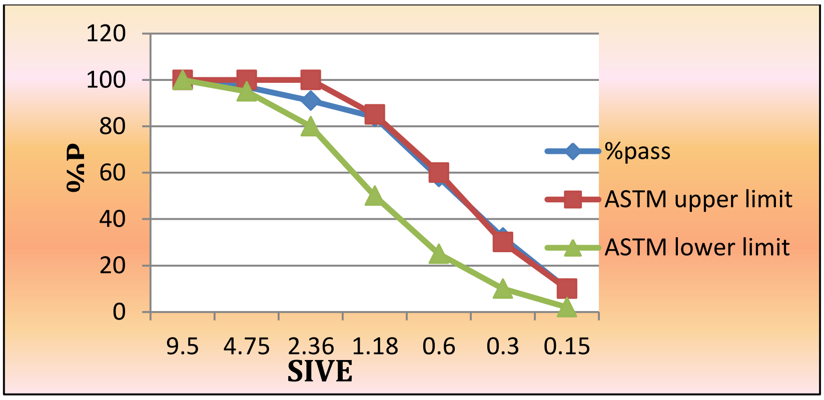


Figure 16 sieve analysis test result graph

According to **ASTM C33** fine aggregates should have fineness modules between 2.3 and 3.1; the sawdust used has fines modules of 2.28 and this result doesn't fit with ASTM standard and it implies that the sawdust are very fine

Also the figure show that the % pass is very near to the upper limit and it describes the sawdust was very fine particles.

b) Specific gravity and absorption

According to the test method of BS 812: part 2:1995, specific gravity and absorption of sand was investigated and test results are shown below in table

Table 4.2.16 Specific gravity and absorption test result for sawdust

description	var	weight in kg		
sample		sample 1	sample 2	sample 3
mass of saturated surface dry sample	A	0.1	0.1	0.1
mass of pycnometer + water + sample	B	1.52	1.519	1.521
mass of pycnometer + water	C	1.47	1.47	1.47
mass of oven dry sample	D	0.096	0.097	0.095
bulk Sp.gr.(SSD)=A/(A-(B-C))	Sg	2	1.960784	2.040816327
mean bulk Sg				2.000533547
Absorption (A-D/D)*100	Abs	4.166667	3.092784	5.263157895
min Absorption				4.174202689

According to ASTM C33, the limitation for bulk specific gravity (SSD) is from 2.4 to 3.0. Accordingly the aggregates are within ASTM limitations. And absorption from 0.2% to 4%, for coarse aggregates and 0.2 to 2% for fine aggregates. The sawdust has grater absorption capacity and lesser specific gravity then the standard.

c) Moisture content

According to the test method of ASTM C566 moisture content of sawdust was carryout and the test result and are shown below in table

Table4.2.17 moisture content test result for sawdust

description	measurement		
sample	sample 1	sample 2	sample3
weight of sample A	0.1	0.1	0.1
weight of oven dry sample B	0.099	0.098	0.0979
moisture % (A-B/B)*100	1.01010101	2.040816327	2.145045965
mean moisture content			1.731987767

And the moisture contents should be within 0.5% to 2%. The sawdust is within the limits.

d) Bulk unit weight

According to the test method of ASTM C29 bulk unit weight of sawdust was carryout and the test results are shown below.

Table 4.2.18 bulk unit weight test result for sawdust

description	measurement		
	sample1	sample2	sample3
weight of container (A)	1.06	1.06	1.06
weight of container + sample (B)	2.02	2	2.04
weight of sample (B-A)=(D)	0.96	0.94	0.98
volume of container C	0.005	0.005	0.005
unit weight= (D/C)	192	188	196
mean unit weight			**192**

4.3 Hollow concrete block test result

After the hollow concrete blocks are casted and cured to determine the physical requirement of HCB deferent laboratory tests like, compressive strength, density, absorption and moisture content are carryout that help us to compere the result between different percentage of sawdust and with standard specification.

4.3.1 Compressive strength

Compressive strength of the 7^{th}, 14th and 28^{th} days of HCB was tested in the laboratory in different age of the HCB. A total of six (6) samples for each age and percentage of sawdust are taken and the results are shown below.

Figure 4.3.1 laboratory test of HCB

The HCBs are produced according to Ethiopian standard ESC D3. 301 from a mix ratio of **1:5** (cement to aggregate ratio) or **1:2:1:2** of (cement, sand, crushed fine aggregate (5mm – 0.15mm) and crushed aggregate (10mm – 2.36mm))to produce **class B** HCB with a mean compressive strength of **4.0MPa.**

Table 4.3.1 compressive strength result of HCB

% Of sawdust	Mean compressive strength in MPa (average of six(6) HCB)		
	7th day	14th day	28th day
0	2.6	3.71	5.09
4	2.44	3.5	4.76

8	2.27	3.4	4.5
10	2.2	3.33	4.01
12	1.92	2.99	3.58
16	1.74	2.17	2.73
20	1.67	1.98	2.13
24	1.21	1.42	1.69

The above table shows us the relationships between compressive strength with percentage of sawdust replacements and compressive strength with age. In the first relation sheep when the percentage of sawdust replacement increases, the compressive strength decreases. These results tell us that, using sawdust as a replacement of fine aggregate has a negative effect on the compressive strength of concrete.

The next thing we have to see from the result is that, the relationships between the 7th day and 28th day compressive strength within different % of sawdust replacement. In any concrete structure, the 7th day compressive strength should be 50 – 75% of the desired compressive strength at 28th day.

Table 4.3.2 7th day compressive strength test result

% Of sawdust content	7th day	Desired strength for class B HCB in MPa at the 28th day	% Of strength achieved at the 7th day
0	2.6	4	65
4	2.44	4	61
8	2.27	4	56.75
10	2.2	4	55
12	1.92	4	48
16	1.74	4	43.5
20	1.67	4	41.75
24	1.21	4	30.25

From the above table we can see that in the first four consecutive replacements from (0% - 10%) the result gained at the 7th day was greater than 50% and from the rest replacement, lower percentage of strength was gained.

The second relation sheep was between compressive strength and age. When age of HCB increases, the compressive strength also increase and this relation sheep occur due to curing and hydration process of the Hollow Concrete Block.

The next thing we have to see from the compressive strength result is that, the optimum amount of sawdust replacement without affecting the desired strength of class B HCB at the 28th day according to Ethiopian Standard ESC .D3. 301.

Table 4.3.3 desired strength of class B HCB at the 28th day

Types of HCB	Class	Minimum compressive strength (N/mm2)	
		Average of 6 units	Individual unit
Load bearing	A	5.5	5
	B	4	3.2
Non load bearing	C	2	1.8

The above table shows us the required 28th day compressive strength in different classes of HCB according to Ethiopian Standard ESC. D3. 301.

Figure 4.3.3 28th day compressive strength test result

% Of sawdust	Mean compressive strength in MPa (average of six(6) HCB)		
	7th day	14th day	28th day
0	2.6	3.71	5.09
4	2.44	3.5	4.76
8	2.27	3.4	4.5
10	2.2	3.33	4.01
12	1.92	2.99	3.58
16	1.74	2.17	2.73

20	1.67	1.98	2.13
24	1.21	1.42	1.69

From the above table we can see that, the maximum compressive strength was gained at 0% replacement and we can achieve the desired class B HCB (4MPa) strength by replacing sand with sawdust up to 10% in volume also we can achieve class C HCB (2MPa) strength by replacing sand with sawdust up to 20% in volume.

The result shows that HCB with sawdust has low strength than the HCB with the conventional materials and in case of replacement, when the percentage of sawdust replacement increases it can lower the compressive strength of HCB. The reason behind this effect of sawdust that found during the study was discussed below.

1) Naturally sawdust has low strength
2) Due to high amount of water in the mix.

In the process of mixing, when the percentage of sawdust increase, the amount of water to get the desired workable mix was also increased and it leads to the presence of high amount of water in the mix. The relation sheep between strength and water cement ratio is inversely proportional therefore, when the amount of sawdust replacement increase the compressive strength of the HCB had decreased.

3) Due to low bonding characteristics of sawdust with other materials.

4.3.2 Moisture content, Absorption and Density

According to Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units ASTM C140 laboratory test was conducted to determine the moisture content, absorption and density of HCB. There were three (3) samples in each percentage replacement and the results are described below.

Figure 4.3.4 density, moisture content & absorption test

a) Moisture content

According to ASTM C140 to calculate the moisture content of the unit at the time it was sampled (when *Wr* is measured) as follows:

Moisture Content, % of total absorption = $[(Wr - Wd) / (Ws - Wd)] \times 100$

where:

Wr= received weight of unit, kg,

Wd = oven-dry weight of unit, kg, and

Ws= saturated weight of unit, kg

Table 4.3.4 density, moisture content & absorption test result

% Of sawdust	Sample weight(Mr) in Kg	Weights in water (Wi) in Kg	SSD weight (Ws) in Kg	Oven dray weight (Wd) in Kg	Moisture content, %of total absorption
0	15.6	8.7	16.1	14.8	61.94
4	15.38	8.5	16	14.4	60.12
8	15.14	8.2	15.9	14.05	58.6
10	14.89	8	15.8	13.6	57.33
12	14.62	7.7	15.7	13.2	56.34
16	14.33	7.4	15.6	12.7	55.55
20	14.02	7.1	15.5	12.2	54.87
24	13.69	6.8	15.4	11.7	54.3

As we see from the above table the moisture content, % of total absorption slightly decrease when the amount of sawdust increase .

b) Absorption

According to ASTM C140 calculate absorption as follows:

Absorption, kg/m^3 $[(Ws - Wd) / (Ws - Wi)] \times 1000$

Absorption, % $[(Ws - Wd) / (Wd)] \times 100$

Where:

Ws= saturated weight of specimen, kg,

Wi = immersed weight of specimen, kg, and

Wd = oven-dry weight of specimen, kg.

Table 4.3.5 Laboratory result for absorption

% Of sawdust	Sample wight (Mr) in Kg	Weights in water (Wi) in Kg	SSD weight (Ws) in Kg	Oven dray weight (Wd) in Kg	Absorption	
					in %	in kg/m3
0	15.6	8.7	16.1	14.8	8.8	175.6
4	15.38	8.5	16	14.4	11.1	213.3
8	15.14	8.2	15.9	14.05	13.1	240.25
10	14.89	8	15.8	13.6	16.2	282.05
12	14.62	7.7	15.7	13.2	19	312.5
16	14.33	7.4	15.6	12.7	22.9	353.65
20	14.02	7.1	15.5	12.2	27.3	392.85
24	13.69	6.8	15.4	11.7	36	455.55

Table 4.3.6 Absorption requirements of load bearing HCB[ASTM C90-70

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 - 1682 (kg/m^3)	1682 - 2002 (kg/m^3)	<2002 (kg/m^3)
N-I & II	-	290	240	210
S-I & II	320	-	-	-

On the other hand Ethiopian standard [ES 596:2001] specify water absorption 290 kg/m3 (25%) for load bearing hollow concrete block and 320 kg/m3 (30%) for non-load bearing hollow concrete block but Indian standard recommended 10 percent.

As we see from the above table all the results are fulfill the standards requirement of ASTM C 90-70. Therefore with respect to absorption, the sawdust has no major effect until the sawdust content is greater than 20 present. When the percentage of sawdust increase, the absorption capacity of HCB also increases. Replacing sand with sawdust 10% in volume can increase the absorption by7% and 20% sawdust can increase the absorption by 16%. These properties can limit us to replace limited amount of sawdust to produce HCB.

c) Density

According to ASTM C140 calculate oven-dry density as follows:

Density, (D), kg/m^3 = $[Wd/(Ws - Wi)]$ x 1000

Where:

Wd = oven-dry weight of specimen, kg,

Ws= saturated weight of specimen, kg, and

Wi = immersed weight of specimen, kg

Table 4.3.7 Laboratory result for density of HCB.

% Of sawdust	Average Sample mass(Mr) in Kg	Average Weights in water (Wi) in Kg	Average SSD weight (Ws) in Kg	Average Oven dray weight (Wd) in Kg	Average Density in Kg/m^3
0	**15.6**	**8.7**	**16.1**	**14.8**	**2000.05**
4	**15.38**	**8.5**	**16**	**14.4**	**1921.54**
8	**15.14**	**8.2**	**15.9**	**14.05**	**1829.13**
10	**14.89**	**8**	**15.8**	**13.6**	**1743.41**
12	**14.62**	**7.7**	**15.7**	**13.2**	**1657.76**
16	**14.33**	**7.4**	**15.6**	**12.7**	**1549.09**
20	**14.02**	**7.1**	**15.5**	**12.2**	**1452.65**
24	**13.69**	**6.8**	**15.4**	**11.7**	**1309.04**

Table 4.3.8 Density classification of hollow concrete block [ASTM C90-70]

Grade	**oven dry density classification (kg/m3)**		
	Light weight	**Medium weight**	**Normal weight**
N-I & II	**1362 - 1682 (kg/m3)**	**1682 - 2002 (kg/m3)**	**<2002 (kg/m3)**
S-I & II	**>1362 (kg/m3)**	**-**	**-**

From the above result we can see the relation sheep between amount of sawdust and density of the HCB. When the amount of sawdust increase, the density of HCB decreases. Replacing sand with sawdust 10% in volume can decrease the density by 12% and 20% sawdust can decrease the density by 26%. This relationship occurs due to the nature of low unit weight of sawdust.

This relation sheep can help us to reduce the weight of individual HCB without compromising the desired strength and minimize the dead load of the structures by producing HCB with partial replacement of sand in sawdust.

4.3.3 Production cost comparison

The production cost for both type of HCB contain direct and indirect cost and in the direct cost there are material cost, labor cost and equipment cost. In indirect cost there is an overhead cost. The major cost that makes deference in my study was the material cost but both labor and equipment costs are remain constant because the replacing of sand with sawdust didn't affect both labor cost and equipment cost only affect material cost.

Material cost

The HCBs are produced by using a mix ratio of 1:2:1:2 of cement, sand, crushed sand, crushed aggregate therefor for one bag of cement the material needed is shown below in the table

Table 4.3.10 Material needed for one mix without sawdust replacement

Type of material	Unit	Qty
Cement	m^3	0.035
Sand	m^3	0.08

Crushed sand	m^3	0.04
Crushed aggregate	m^3	0.08

Table 4.3.11 Material needed for one mix with 4% sawdust replacement

Type of material	Unit	Qty
Cement	m^3	0.035
Sand	m^3	0.0768
Crushed sand	m^3	0.04
Crushed aggregate	m^3	0.08
Sawdust	m^3	0.0032

The replacement of sand with sawdust was continued by increasing the amount of sawdust in 4% or by 0.0032m^3 and decreasing the amount of sand in 4% by 0.0032m^3 up to the amount of sawdust reach 24% of the total amount of sand. The costs for the materials are shown below in the table below.

Table 4.3.12 Material cost

Type of material	Unit	Qty	Rate/m^3
Cement	m^3	0.035	175
Sand	m^3	0.0768	1200
Crushed sand	m^3	0.04	1000
Crushed aggregate	m^3	0.08	600
Sawdust	m^3	0.0032	50

Table 4.3.13 Cost of materials without sawdust for one mix

Type of material	Unit	Qty	Rate/m3	Amount in birr

Cement	m^3	0.035	175	6.125
Sand	m^3	0.08	1200	96
Crushed sand	m^3	0.04	1000	40
Crushed aggregate	m^3	0.08	600	48
				190.125

Table 4.3.14 Cost of materials with 4% sawdust mix

Type of material	Unit	Qty	Rate/m3	Amount
Cement	m^3	0.035	175	6.125
Sand	m^3	0.0768	1200	92.16
Crushed sand	m^3	0.04	1000	40
Crushed aggregate	m^3	0.08	600	48
Sawdust	m^3	0.0032	50	0.16
				186.445

Table 4.3.15 Total material cost for different % of sawdust.

% of sawdust	Total material cost	Individual material cost
0	190.12	12.67
4	186.44	12.42
8	182.76	12.18
10	179.08	11.93
12	175.4	11.69
16	171.72	11.44

20	168.04	11.2
24	164.36	10.95

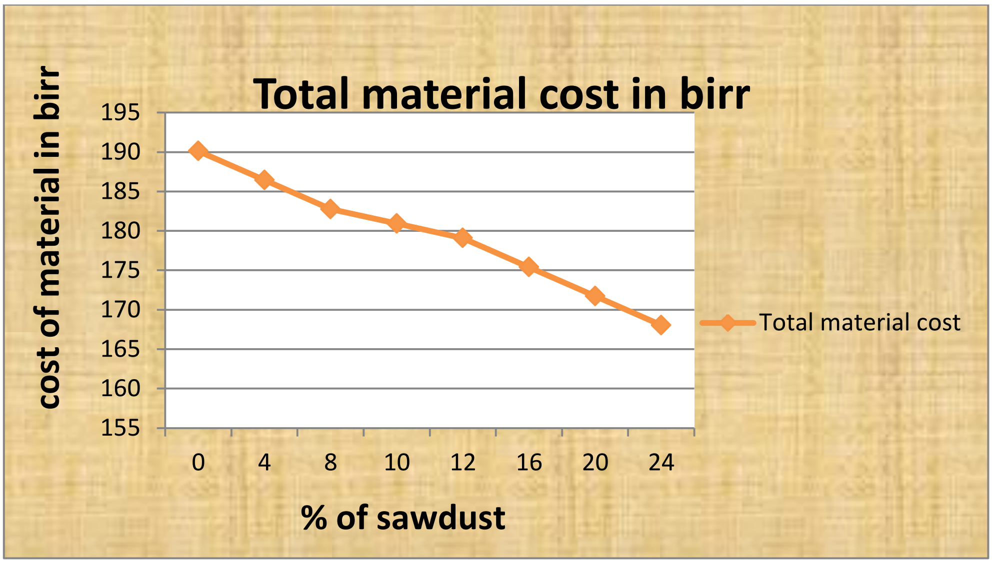


Figure 4.3.5 total material cost graph

As we see from the above tables and figure when the percentage of sawdust increase by 4% , the total cost of material decreases by 3.68 birr or by 2% from the total cost of materials. For the desired class B HCB by replacing 10% sawdust we can achive 5% cost saving and by replacing upto 20% of sawdust for class C HCB we can save 10% of material cost. As a result shows that we can produce economical products by replacing sand with sawdust in different percentage.

CHAPER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The main objective of the study was to determine the optimum quantity of fine aggregate to be replaced with sawdust to obtain maximum strength and economical result for HCB production. And from the result gain, the optimum quantity of sawdust can be replaced without affecting the desired class B standard HCB strength by replacing sand with sawdust up to 10% in volume for one mix. And we can achieve class C standard HCB strength by replacing sand with sawdust up to 20% in volume for one mix. The standared strength is according to Ethiopan Standard ES C D3 301.

From the study the effects of using sawdust as a partial replacement of natural sand for the production of HCB are clearly identified and these effects are discussed. Replacing of sand with sawdust to produce HCB can increase the water cement ratio due too high moisture absorption properties of sawdust, can increses the absorption capacity of classB and class C HCB 7%-16% respectively, can decrease the required strength of HCB due to low compressive strength properties of sawdust, dueto high water cement ratio and low bonding caracterstics of sawdust, can decreases the density of class B and class C HCB 12%-26% respectively due to the low unit weight property of sawdust, also can decreases the material cost of the class B and class C HCB 5%-10% respectively due to the availability of sawdust.

The compressive strength results were compared with ETHIOPIAN STANDARD ESC D3 301 and the result fulfill class B HCB upto 10% sawdust and class C HCB up to 20% sawdust replacement and when the replacement percentage was greater than 20% the strength result doesn’t fulfill the standard. The the moisture content, absorption and density of the 28th day HCB result also fulfill the standard specification ASTM C 90-70 and ASTM C 129 for both class B and class C HCB

The economic benefit of using sawdust as fine aggregate for HCB production was analyzed and the results shows that by replacing sand with sawdust by 10% in volume we can save 11.04 birr or 5% of total material cost in one mix for class B HCB and by replacing sawdust up to 20% in volume we can save 18.4 birr or 10% of total material cost in one mix for class C HCB.

In general replacing of sand with sawdust for the production of Hollow Concrete Block can be applicable and the replacement can give us low cost and light weight product without compromising the desired strength but the replacement percentage should not be greater than 10% in volume for class B HCB and should not be greater than 20% in volume for class C HCB.

5.2 RECOMENDATION

After the study was carryout depending on the result found the recommendation was formulated for concerned body therefore the recommendation provides helpful information to various stakeholders as follow.

For the construction industry

The construction industry are highly dependent on natural resources and this can leads us to the depletion of natural resources therefore the culture of using locally available materials for the construction industry as an input should be improved thought deep investigation and researches.

To the HCB manufacturing firms

Using of sawdust for partial replacement of sand for the production of HCB can give us lightweight, low cost and strong product therefore they should consider that, using of sawdust for HCB production to make their products more economical and light weight.

To the contractors

Using HCB that produced by replacing sand with sawdust can give many benefits to the contractors like reducing cost and minimizing the structural dead load due to the light weight of the HCB that produced from sawdust replacement. There for I highly recommend the contractors that they should be use sawdust concrete block to gain the benefit from it but they should investigate the chemical properties of sawdust.

Wood product manufacturing firm

The wood product manufacturing firm should see other possibilities rather than burning the sawdust as a disposal method and using their production waste (sawdust) for generating income by selling to HCB manufacturing firms.

And the implementation of waste sawdust could also be generalized to the use of straw in countryside, which could lead to more environmental saving profit.

For other researchers

Other researchers can use the findings as a reference for further research on the utilization of sawdust as a fine aggregate and also they should deeply investigate sawdust chemical properties and also sawdust concrete block other properties like durability, thermal insulation and fire resistance properties.

REFERENCE

1. Abebe Dinku, (June 2002); Construction Materials Laboratory Manual, Addis Ababa University press.
2. Abebe , Dinku,{2005}The Need for Standardization of Aggregates for Concrete Production in Ethiopian Construction Industry
3. ACI Committee 213, 2003
4. Adebakin I. Adeyemi A., Adu J. T,.Ajayi F., Lawal A. and Ogunrinola O. "Uses of sawdust as admixture in production of lowcost and light-weight hollow sandcrete blocks"(2012)
5. Application, Innovative and Sawdust, of and Used, Wastage, {2016}
6. ASTM C90, Standard Specification for Load-Bearing Concrete Masonry Units {Control, Quality},{2004}
7. ASTM C129, Standard Specification for Non Load-Bearing Concrete Masonry Units {Control, Quality},{2004}
8. ASTM C140 Standard Test Methods for Masonry Units and Related Units {Astm, International},{2012}
9. Building materials book {Duggal, S.K.}, {2008 }
10. Building Materials & Technology Promotion Council Ministry of Housing & Urban Poverty Alleviation Government of India New Delhi "Techno economic feasibility report on concrete hollow & solid block" 2010
11. British standard BS: 6073-part I 1981
12. Compressive strength,sawdust,water absorption,wood-concrete block {Ekhuemelo, David Oriabure and Tembe, Emmanuel Terzungwue},{2016}
13. Cheng, Yong and You, Wen and Zhang, Chaoyong and Li, Huanhuan and Hu, Jian},{2013},Concrete, mechanical property, optimal sawdust replacement ratio, waste sawdust {
14. Development of sawdust {Ravindrarajah, R Sri and Carroll, Chistopher},{2012}
15. Ecological building system, Pvt Ltd 2014. Advantage of hollow concrete block.
16. Effect on strength properties of concrete by using waste wood powder as partial replacement of cement {Saini, Kamlesh and Chaudhary, Vijay and Bisnohi, Ankush and Agarwal, Harshit and Ram, Meghalal and Saraswat, Sandeep},{2016}

17. Elliott & Walker 2008, History of Hollow Concrete Block
18. Ethiopian standard (ES 596:2001); specification for concrete masonry units
19. Ethiopian standard (ES C D3.301) specification for concrete masonry units
20. Experimental Study on Strength of Concrete by Partial Replacement of Fine Aggregate with Sawdust and Robosand {Mynuddin, Shaik Ahamed},{2015}
21. GTZ, (2011). Concrete blocks producing equipment
22. Hossain, M Z,{2016}Some aspects of physical and mechanical properties of sawdust
23. Indian standard 2158{Kisan, Mazdoor and Sangathan, Shakti and Nehru, Jawaharlal},{2005}
24. Indian standard 2158{Kisan, Mazdoor and Sangathan, Shakti and Nehru, Jawaharlal and Pitroda, Satyanarayan Gangaram},{1983}
25. Innovation in Construction : Ideas are the currency of the future {Dale, Jamie},{2007}
26. Investigation of Properties of Concrete Using Sawdust as Partial Replacement for Sand {Joseph, Olugbenga and Seun, Oyedepo and Oluwajana, Daniel and Peter, Sunmbo},{2014}
27. Investigation of Some Mechanical Properties of Sawdust and Chopped Reeds {Al-omairi, Ahmed Jadah Farhan},{2011}
28. Load Carrying Capacity of Hollow Concrete Block Masonry Column {Maroliya, M K},{2012}
29. Low Cost Construction Material for Concrete {Kumar, Dilip and Singh, Smita and Kumar, Neetesh and Gupta, Ashish},{2014}
30. Mechanical and thermal properties of sawdust concrete {Memon, Ruhal Pervez and A},{2016}
31. Ministry of Federal Affairs “Low cost housing technical manual” 2003
32. Mortar industry association learning text part 5 “brick and block production “2010
33. Performance of Saw-Dust in Low Cost Sandcrete Blocks {Boob, T N},{2014}
34. Project Delivery {Anyanwu, C I},{2013}
35. Project profile on cement concrete hollow blocks {{Glass {\&} Ceramics Division MSME Development Institute Govt of India}, Ministry of MSME},{2011}
36. Recycling Sawdust Waste for Construction Pl Problems {Tiough, Daniel Momngu},{2010}

37. Study Of Compressive Strength Characteristics Of Hollow Sandcrete Blocks Partially Replaced By Saw Dust Ash {Popoola, O C and Ayegbokiki, S T and Gambo, M D},{2015}
38. Study on the feasibility of using sawdust as partial replacement for sand in concrete {{Thomas Joseph Odero}},{2015}
39. Scrutiny on physical properties of sawdust from tropical commercial wood species : effects of different mills and sawdust ' s particle size {Maharani, Rizki and Yutaka, Tamai and Yajima, Takashi and Minoru, Terazawa},[2011]
40. Suitability of saw dust ash-lime mixture for production of sandcrete hollow blocks {Tyagher, S T and Utsev, J T and Adagba, T},{2011}
41. Techno economic feasibility report on concrete hollow & solid block ” ″Manufacturing and spesifcation section 2.2.1
42. Tesfaalem Kahsay, ,{2014}Study on the Effectiveness of Quality Control for the Production of Reinforced Concrete and Hollow Concrete Blocks (In projects administered by Addis Ababa housing Projects)
43. Tewodros Getachew,{2016}Quality Control Concepts in the Manufacture of Masonry Blocks for Building Comparative study on the compressive strength and production cost of hollow concrete block (hcb) with and without red ash in tepi town, Ethiopia.
44. Tomas U. Ganiron Jr 2014). Effect of Sawdust as Fine Aggregate in Concrete Mixture for Building Construction
45. Utilization of Saw Dust in Cement Mortar {\&} Cement Concrete {Gopinath, K and Anuratha, K and Harisundar, R and Saravanan, M},{2015}
46. Use of Recycled Plastic Water Bottles in Concrete Blocks {Safinia, Sina and Alkalbani, Amani},{2016}
47. Wood ash as an effective raw material for concrete blocks {Subramaniam, Prabagar and Subasinghe, Kalya and Fonseka, W R Keerthi},{2015}

APPENDIX ONE

Laboratory data sheet for material property test

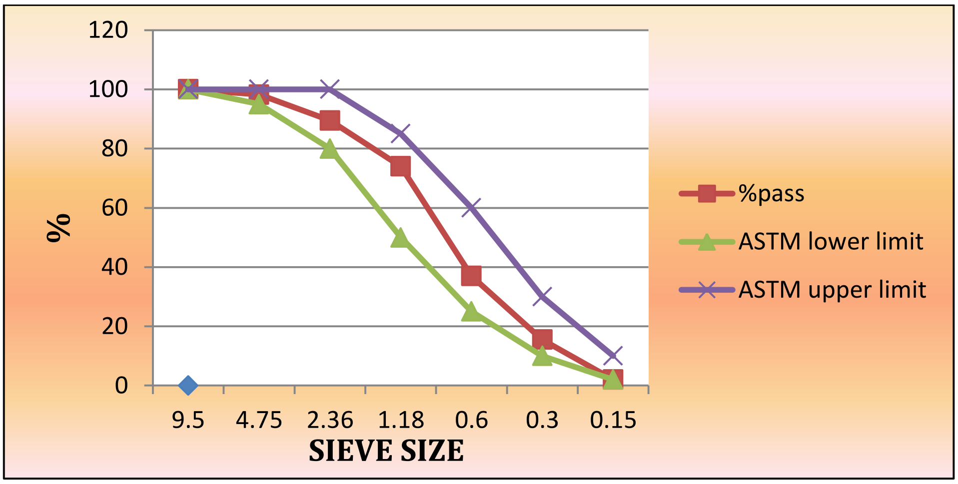
Place	**Jimma inistitut of technology**
Department	**Civil enginnering department**
Laboratory	**Constraction material laboratory**

Sample description **Sand**

1. **Sieve analysis**

Test methodology ASTM C136

Sive size	Mass retain	%retain	Commulative %retain	%pass	ATEM standard	remark
9.5	0	0	0	100	100	ok
4.75	0.035	1.75	1.75	98.25	95-100	ok
2.36	0.175	8.75	10.5	89.5	80-100	ok
1.18	0.31	15.5	26	74	50-85	ok
0.6	0.74	37	63	37	25-60	ok
0.3	0.43	21.5	84.5	15.5	10_30	ok
0.15	0.27	13.5	98	2	2_10	ok
pan	0.04	2	100	0		



2. spacific gravity and absorption

Test method: (BS 812: part 2:1995)

Test method: (BS 812: part 2:1995)

description	var	weight in kg		
sample		sample 1	sample 2	sample 3
mass of saturated surface dry sample	A	0.5	0.5	0.5
mass of pyknometer + water + sample	B	1.81	1.814	1.799
mass of pyknometer + water	C	1.5	1.5	1.5
mass of oven dry sample	D	0.49	0.492	0.494
bulk Sp.gr.(SSD)=A/(A-(B-C))	Sg	2.63157895	2.688172	2.487562189
mean bulk Sg				2.602437726
Absorbtion (A-D/D)*100	Abs	2.04081633	1.626016	1.214574899
min Absorbtion				1.627135828

3. Unit weight

Text method ASTM C29

Description	Measurement		
Sample	Sample 1	Sample	Sample3

		2	
Weight of sample A	1	1	1
Weight of oven dry sample after washing B	0.97	0.972	0.975
Silt content % (A-B/A)*100	3	2.8	2.5
mean silt content			2.76

4. **Moisture content**

Test method ASTM C566

Description	Measurement		
Sample	Sample 1	Sample 2	Sample3
Weight of sample A	0.5	0.5	0.5
Weight of oven dry sample B	0.493	0.492	0.494
Moisture % (A-B/B)*100	1.419	1.626	1.214
Mean moisture content			1.420

5. **Silt content**

Test method ASTM C117

description	measurement		
sample	sample 1	sample 2	sample3
weight of sample A	1	1	1

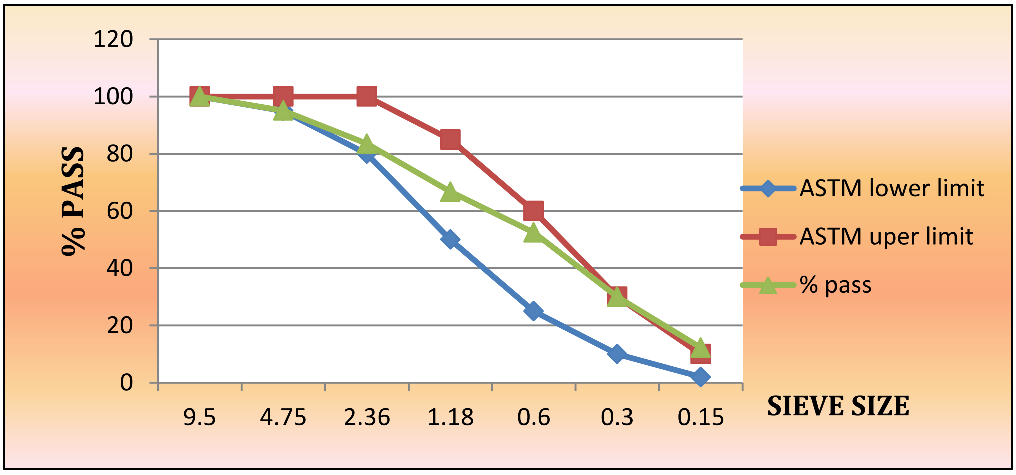
weight of oven dry sample after washing B	0.97	0.972	0.975
silt content % (A-B/A)*100	3	2.8	2.5
mean silt content			2.76

Sample description **<u>Crushed fine aggregate (5mm-0.15 or 00)</u>**

1. **Sieve analysis**

Test method ASTM C136

Sive size	Mass retain	%Retain	Commulative %Retain	%Pass	ATEM standard	Remark
9.5	0	0	0	100	100	ok
4.75	0.098	4.9	4.9	95.1	95-100	ok
2.36	0.232	11.6	16.5	83.5	80-100	ok
1.18	0.335	16.75	33.25	66.75	50-85	ok
0.6	0.285	14.25	47.5	52.5	25-60	ok
0.3	0.45	22.5	70	30	10_30	ok
0.15	0.355	17.75	87.75	12.25	2_10	ok
pan	0.185	9.25	97	3		



2. **Spacific gravity and absorption**

Test method BS 812: part 2:1995

Description	Var	Weight in kg		
Sample		Sample 1	Sample 2	Sample 3
Mass of saturated surface dry sample	A	0.5	0.5	0.5
Mass of pycnometer + water + sample	B	1.82	1.81	1.8
Mass of pycnometer + water	C	1.5	1.5	1.5
Mass of oven dry sample	D	0.49	0.492	0.494
Bulk Sp.gr.(SSD)=A/(A-(B-C))	Sg	2.777	2.631	2.5
mean bulk Sg				2.636
Absorption (A-D/D)*100	Abs	2.04	1.626	1.214
min Absorption				1.627

3. **Bulk unit weight**

Test method of ASTM C29

Description	Measurement		
	Sample1	Sample2	Sample3

Weight of container (A)	1.06	1.06	1.06
Weight of container + sample (B)	8.819	8.63	8.655
Weight of sample (B-A)=(D)	7.759	7.57	7.595
Volume of container C	0.005	0.005	0.005
Unit weight= (D/C)	1551.8	1514	1519
Mean unit weight			**1528.27**

4. **Moisture content**

Test method of ASTM C566

Description	Measurement		
Sample	Sample 1	Sample 2	Sample3
Weight of sample A	0.5	0.5	0.5
Weight of oven dry sample B	0.495	0.492	0.494
Moisture % (A-B/B)*100	1.01	1.62	1.21
Mean moisture content			1.28

5. **Silt content**

test method of ASTM C117

Description	Measurement		
Sample	Sample 1	Sample 2	Sample3
Weight of sample A	1	1	1

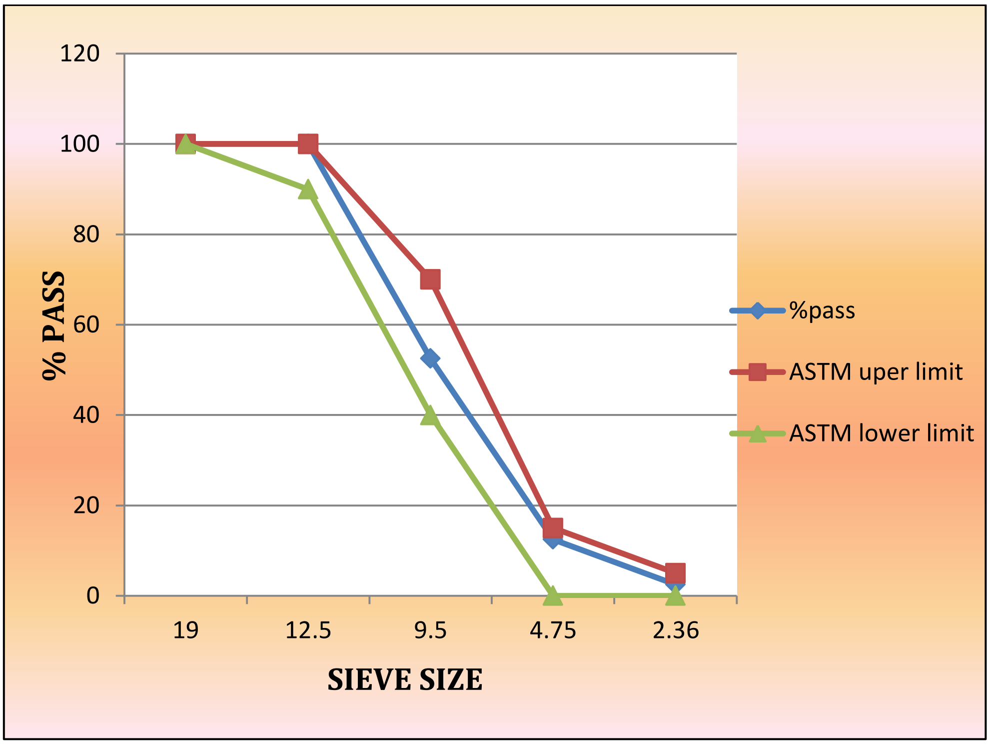
Weight of oven dry sample after washing B	0.967	0.972	0.975
Silt content % (A-B/A)*100	3.3	2.8	2.5
mean silt content			2.86

Sample description **Crushed fine aggregate (10mm - 2.36mm or 01)**

1. **Sieve alalysis**

Test method: ASTM C136

Sive size	Mass retain	%retain	Commulative %retain	%pass	ATEM standard	remark
19	0	0	0	100	100	ok
12.5	0	0	0	100	90-100	ok
9.5	0.95	47.5	47.5	52.5	40-70	ok
4.75	0.8	40	87.5	12.5	0-15	ok
2.36	0.2	10	97.5	2.5	0-5	ok
pan	0.05	2.5	100	0	2.325	



2. Spacific gravity and absorption

Test method of astm C127

description	var	weight in kg		
sample		sample 1	sample 2	sample 3
weight of oven dry sample in air	A	1.985	1.982	1.981
weight of saturated surface dry sample	B	2.02	2.01	2.03
weight of wire basket in water	C	0.26	0.26	0.26
weight in water o(SSD) sample + wire basket	D	1.53	1.51	1.54
weight in water of SSD = D-C	E	1.27	1.25	1.28
bulk Sp.gr.(SSD)=B/B-E	Sg	2.69	2.64	2.7
mean bulk Sg				2.68

Absorption (B-A)/A*100	Abs	1.76	1.41	2.47
min Absorption				1.88

3. **Bulk unit weight**

Test method of ASTM C29

description	measurement		
	sample1	sample2	sample3
weight of container (A)	1.06	1.06	1.06
weight of container + sample (B)	8.613	8.6537	8.655
weight of sample (B-A)=(D)	7.553	7.5937	7.595
volume of container C	0.005	0.005	0.005
unit weight= (D/C)	1510.6	1518.74	1519
mean unit weight			**1516.11**

4. **Moisture content**

Test method of ASTM C566

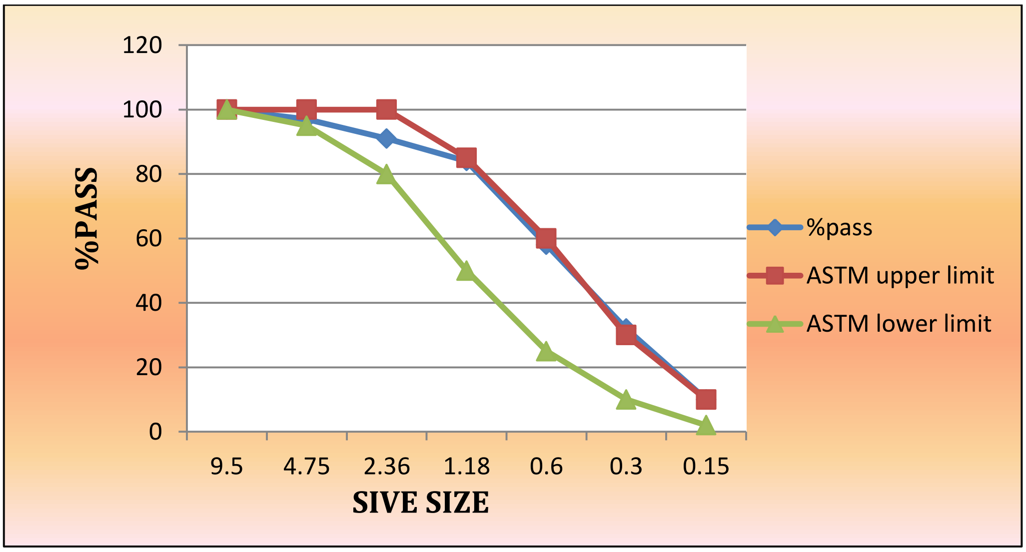
description	measurement		
sample	sample 1	sample 2	sample3
weight of sample A	2	2	2
weight of oven dry sample B	1.978	1.983	1.9692
moisture % (A-B/B)*100	1.11	0.85	1.56
mean moisture content			1.17

Sample description __**Sawdust**__

1. Sieve analysis

Test methodology ASTM C136

Sive size	Mass retain	%retain	Commulative %retain	%pass	ATEM standard	remark
9.5	0	0	0	100	100	ok
4.75	0.06	3	3	97	95-100	ok
2.36	0.12	6	9	91	80-100	ok
1.18	0.14	7	16	84	50-85	ok
0.6	0.52	26	42	58	25-60	ok
0.3	0.52	26	68	32	10_30	not ok
0.15	0.44	22	90	10	2_10	ok
pan	0.2	10	100	0		



2. **Spacific gravity and absorption**

Test method BS 812: part 2:1995

description	var	weight in kg		
sample		sample 1	sample 2	sample 3

mass of saturated surface dry sample	A	0.1	0.1	0.1
mass of pycnometer + water + sample	B	1.52	1.519	1.521
mass of pycnometer + water	C	1.47	1.47	1.47
mass of oven dry sample	D	0.096	0.097	0.095
bulk Sp.gr.(SSD)=A/(A-(B-C))	Sg	2	1.960784	2.040816327
mean bulk Sg				2.000533547
Absorption (A-D/D)*100	Abs	4.166667	3.092784	5.263157895
min Absorption				4.174202689

3. **Bulk unit weight**

Test method of ASTM C29

description	measurement		
	sample1	sample2	sample3
weight of container (A)	1.06	1.06	1.06
weight of container + sample (B)	2.02	2	2.04
weight of sample (B-A)=(D)	0.96	0.94	0.98
volume of container C	0.005	0.005	0.005
unit weight= (D/C)	192	188	196
mean unit weight			**192**

4. **Moisture content**

Test method of ASTM C566

description	measurement

sample	sample 1	sample 2	sample3
weight of sample A	0.1	0.1	0.1
weight of oven dry sample B	0.099	0.098	0.0979
moisture % (A-B/B)*100	1.01010101	2.040816327	2.145045965
mean moisture content			1.731987767

APPENDIX TWO

Compressive strength Laboratory test result

Place	**Jimma inistitut of technology**
Department	**Civil enginnering department**
Laboratory	**Constraction material laboratory**

1. **0% SAWDUST REPLACMENT**

The 7th day compressive strength test result

Sample no	Casting date						
	Testing date						
	Dimention(cm)			Area (m2)	Weight (kg)	Failer load (kn)	Compressive Strength (kn/m2)
	L	W	H				
1	40	20	20	0.08	16	212.3	2.65375
2	40	20	20	0.08	15	204.2	2.5525
3	40	20	20	0.08	15.3	209.4	2.6175
4	40	20	20	0.08	15.5	210.4	2.63
5	40	20	20	0.08	15	207.6	2.595
6	40	20	20	0.08	15.9	204.1	2.55125
					Mean		**2.6**

The 14th day compressive strength

Sample no	Casting date						
	Testing date						
	Dimention(cm)			Area (m2)	Weight (kg)	Failer load (kn)	Compressive Strength (kn/m2)
	L	W	H				
1	40	20	20	0.08	15.8	300.1	3.75125
2	40	20	20	0.08	14.9	292.3	3.65375
3	40	20	20	0.08	15.3	294.7	3.68375
4	40	20	20	0.08	15.5	302.2	3.7775
5	40	20	20	0.08	14.9	290.4	3.63
6	40	20	20	0.08	15.7	301.1	3.76375
					Mean		**3.71**

The 28th day compressive strength

Sample no	Casting date						
	Testing date						
	Dimention(cm)			Area (m2)	Weight (kg)	Failer load (kn)	Compressive Strength (kn/m2)
	L	W	H				
1	40	20	20	0.08	15.6	388.6	4.8575
2	40	20	20	0.08	14.8	413.4	5.1675
3	40	20	20	0.08	15.1	420.6	5.2575
4	40	20	20	0.08	15.2	395.3	4.94125
5	40	20	20	0.08	14.9	408.1	5.10125
6	40	20	20	0.08	15.5	417.2	5.215

Mean	**5.09**

2. 4% SAWDUST REPLACMENT

The 7th day compressive strength test result

Sample no	Casting date						
	Testing date						
	Dimention(cm)			Area (m2)	Weight (kg)	Failer load (kn)	Compressive Strength (kn/m2)
	L	W	H				
1	40	20	20	0.08	14.9	196.4	2.455
2	40	20	20	0.08	15.2	201.1	2.51375
3	40	20	20	0.08	15	189.9	2.37375
4	40	20	20	0.08	14.9	182.3	2.27875
5	40	20	20	0.08	15	198.4	2.48
6	40	20	20	0.08	15.3	203.1	2.53875
					Mean		**2.44**

The 14th day compressive strength

Sample no	Casting date						
	Testing date						
	Dimention(cm)			Area (m2)	Weight (kg)	Failer load (kn)	Compressive Strength (kn/m2)
	L	W	H				
1	40	20	20	0.08	14.7	274.3	3.42875
2	40	20	20	0.08	15.1	271	3.3875

3	40	20	20	0.08	14.9	278.4	3.48
4	40	20	20	0.08	14.7	283.8	3.5475
5	40	20	20	0.08	14.9	292.9	3.66125
6	40	20	20	0.08	15	279.6	3.495
					Mean		**3.5**

The 28th day compressive strength

Sample no	Casting date						
	Testing date						
	Dimention(cm)			Area (m2)	Weight (kg)	Failer load (kn)	Compressive Strength (kn/m2)
	L	W	H				
1	40	20	20	0.08	14.6	369.8	4.6225
2	40	20	20	0.08	14.9	396.7	4.95875
3	40	20	20	0.08	14.8	379.2	4.74
4	40	20	20	0.08	14.6	382.5	4.78125
5	40	20	20	0.08	14.7	376.3	4.70375
6	40	20	20	0.08	14.9	380.3	4.75375
					Mean		**4.76**

3. **8% SAWDUST REPLACMENT**

The 7th day compressive strength test result

Sample no	Casting date	
	Testing date	

	Dimention(cm)			Area (m2)	Weight (kg)	Failer load (kn)	Compressive Strength (kn/m2)
	L	W	H				
1	40	20	20	0.08	14.5	182.2	2.2775
2	40	20	20	0.08	14.8	177.5	2.21875
3	40	20	20	0.08	15	185.1	2.31375
4	40	20	20	0.08	15.2	180.1	2.25125
5	40	20	20	0.08	14.9	179.4	2.2425
6	40	20	20	0.08	15	185.3	2.31625
					Mean		**2.27**

The 14th day compressive strength

Sample no	Casting date						
	Testing date						
	Dimention(cm)			Area (m2)	Weight (kg)	Failer load (kn)	Compressive Strength (kn/m2)
	L	W	H				
1	40	20	20	0.08	14.3	274.3	3.42875
2	40	20	20	0.08	14.7	270.6	3.3825
3	40	20	20	0.08	14.9	269.3	3.36625
4	40	20	20	0.08	15	273.2	3.415
5	40	20	20	0.08	14.7	277.4	3.4675
6	40	20	20	0.08	14.8	267.2	3.34
					Mean		**3.4**

The 28th day compressive strength

Sample no	Casting date						
	Testing date						
	Dimention(cm)			Area (m2)	Weight (kg)	Failer load (kn)	Compressive Strength (kn/m2)
	L	W	H				
1	40	20	20	0.08	14.2	357.3	4.46625
2	40	20	20	0.08	14.5	349.2	4.365
3	40	20	20	0.08	14.5	364.1	4.55125
4	40	20	20	0.08	14.9	360.1	4.50125
5	40	20	20	0.08	14.6	367.2	4.59
6	40	20	20	0.08	14.6	362.1	4.52625
					Mean		**4.5**

4. **10% SAWDUST REPLACMENT**

The 7th day compressive strength test result

Sample no	Casting date						
	Testing date						
	Dimention(cm)			Area (m2)	Weight (kg)	Failer load (kn)	Compressive Strength (kn/m2)
	L	W	H				
1	40	20	20	0.08	14.9	170.2	2.1275
2	40	20	20	0.08	15	177.3	2.21625
3	40	20	20	0.08	14.7	180.1	2.25125
4	40	20	20	0.08	14.8	176	2.2
5	40	20	20	0.08	14.3	179.1	2.23875

6	40	20	20	0.08	14.7	173.3	2.16625
					Mean		**2.2**

The 14th day compressive strength

Sample no	Casting date						
	Testing date						
	Dimention(cm)			Area (m2)	Weight (kg)	Failer load (kn)	Compressive Strength (kn/m2)
	L	W	H				
1	40	20	20	0.08	14.7	265.1	3.31375
2	40	20	20	0.08	14.9	263	3.2875
3	40	20	20	0.08	14.5	273.4	3.4175
4	40	20	20	0.08	14.7	259.3	3.24125
5	40	20	20	0.08	14.2	267.4	3.3425
6	40	20	20	0.08	14.6	270.2	3.3775
					Mean		**3.33**

The 28th day compressive strength

Sample no	Casting date						
	Testing date						
	Dimention(cm)			Area (m2)	Weight (kg)	Failer load (kn)	Compressive Strength (kn/m2)
	L	W	H				

1	40	20	20	0.08	14.6	323.7	4.04625
2	40	20	20	0.08	14.8	319.5	3.99375
3	40	20	20	0.08	14.4	325.5	4.06875
4	40	20	20	0.08	14.6	320.7	4.00875
5	40	20	20	0.08	14.1	316.5	3.95625
6	40	20	20	0.08	14.5	318.9	3.98625
					Mean		**4.01**

5. **12% SAWDUST REPLACMENT**

The 7th day compressive strength test result

Sample no	Casting date						
	Testing date						
	Dimention(cm)			Area (m2)	Weight (kg)	Failer load (kn)	Compressive Strength (kn/m2)
	L	W	H				
1	40	20	20	0.08	14	160.6	2.0075
2	40	20	20	0.08	13.9	155.3	1.94125
3	40	20	20	0.08	14.2	148.5	1.85625
4	40	20	20	0.08	14.8	151.5	1.89375
5	40	20	20	0.08	14.3	158.3	1.97875
6	40	20	20	0.08	14.7	147.4	1.8425
					Mean		**1.92**

The 14th day compressive strength

Sample no	Casting date	
	Testing date	

	Dimention(cm)			Area (m2)	Weight (kg)	Failer load (kn)	Compressive Strength (kn/m2)
	L	W	H				
1	40	20	20	0.08	13.9	240.2	3.0025
2	40	20	20	0.08	13.7	238.4	2.98
3	40	20	20	0.08	14	244.4	3.055
4	40	20	20	0.08	14.7	230.5	2.88125
5	40	20	20	0.08	14.2	247.3	3.09125
6	40	20	20	0.08	14.6	234.4	2.93
					Mean		**2.99**

The 28th day compressive strength

Sample no	Casting date						
	Testing date						
	Dimention(cm)			Area (m2)	Weight (kg)	Failer load (kn)	Compressive Strength (kn/m2)
	L	W	H				
1	40	20	20	0.08	13.8	283.1	3.53875
2	40	20	20	0.08	13.6	293.3	3.66625
3	40	20	20	0.08	13.8	289.2	3.615
4	40	20	20	0.08	14.6	286.6	3.5825
5	40	20	20	0.08	14.1	285	3.5625
6	40	20	20	0.08	14.5	281.2	3.515
					Mean		**3.58**

6. **16% SAWDUST REPLACMENT**

The 7th day compressive strength test result

Sample no	Casting date						
	Testing date						
	Dimention(cm)			Area (m2)	Weight (kg)	Failer load (kn)	Compressive Strength (kn/m2)
	L	W	H				
1	40	20	20	0.08	13.9	138.1	1.72625
2	40	20	20	0.08	13.8	135.6	1.695
3	40	20	20	0.08	14	145.4	1.8175
4	40	20	20	0.08	14.5	149.5	1.86875
5	40	20	20	0.08	14	134.3	1.67875
6	40	20	20	0.08	14.2	132.3	1.65375
					Mean		**1.74**

The 14th day compressive strength

Sample no	Casting date						
	Testing date						
	Dimention(cm)			Area (m2)	Weight (kg)	Failer load (kn)	Compressive Strength (kn/m2)
	L	W	H				
1	40	20	20	0.08	13.8	173.2	2.165
2	40	20	20	0.08	13.7	178.2	2.2275
3	40	20	20	0.08	13.8	165.9	2.07375
4	40	20	20	0.08	14.3	177.3	2.21625
5	40	20	20	0.08	13.8	169.6	2.12
6	40	20	20	0.08	14	177.4	2.2175

Mean	**2.17**

The 28th day compressive strength

Sample no	Casting date						
	Testing date						
	Dimention(cm)			Area (m2)	Weight (kg)	Failer load (kn)	Compressive Strength (kn/m2)
	L	W	H				
1	40	20	20	0.08	13.6	219.6	2.745
2	40	20	20	0.08	13.6	213.4	2.6675
3	40	20	20	0.08	13.6	223.5	2.79375
4	40	20	20	0.08	14.1	215.2	2.69
5	40	20	20	0.08	14.1	216.9	2.71125
6	40	20	20	0.08	13.8	221.8	2.7725
					Mean		**2.73**

7. **20% SAWDUST REPLACMENT**

The 7th day compressive strength test result

Sample no	Casting date						
	Testing date						
	Dimention(cm)			Area (m2)	Weight (kg)	Failer load (kn)	Compressive Strength (kn/m2)
	L	W	H				
1	40	20	20	0.08	13.9	135.1	1.68875
2	40	20	20	0.08	13.8	137.2	1.715

3	40	20	20	0.08	14	136.1	1.70125
4	40	20	20	0.08	14.5	129.4	1.6175
5	40	20	20	0.08	14	133.3	1.66625
6	40	20	20	0.08	14.2	130.5	1.63125
					Mean		**1.67**

The 14th day compressive strength

Sample no	Casting date						
	Testing date						
	Dimention(cm)			Area (m2)	Weight (kg)	Failer load (kn)	Compressive Strength (kn/m2)
	L	W	H				
1	40	20	20	0.08	13.8	160.2	2.0025
2	40	20	20	0.08	13.7	156.5	1.95625
3	40	20	20	0.08	13.8	162.1	2.02625
4	40	20	20	0.08	14.3	161.3	2.01625
5	40	20	20	0.08	13.8	158.2	1.9775
6	40	20	20	0.08	14	152.1	1.90125
					Mean		**1.98**

The 28th day compressive strength

Sample no	Casting date						
	Testing date						
	Dimention(cm)			Area (m2)	Weight (kg)	Failer load (kn)	Compressive Strength (kn/m2)
	L	W	H				

1	40	20	20	0.08	13.6	177.3	2.21625
2	40	20	20	0.08	13.6	172.4	2.155
3	40	20	20	0.08	13.6	175.6	2.195
4	40	20	20	0.08	14.1	161.7	2.02125
5	40	20	20	0.08	14.1	165.5	2.06875
6	40	20	20	0.08	13.8	169.9	2.12375
					Mean		**2.13**

8. **24% SAWDUST REPLACMENT**

The 7th day compressive strength test result

Sample no	Casting date						
	Testing date						
	Dimention(cm)			Area (m2)	Weight (kg)	Failer load (kn)	Compressive Strength (kn/m2)
	L	W	H				
1	40	20	20	0.08	13.5	94.1	1.17625
2	40	20	20	0.08	13.4	98.3	1.22875
3	40	20	20	0.08	13.4	90	1.125
4	40	20	20	0.08	14	102.4	1.28
5	40	20	20	0.08	13.9	96	1.2
6	40	20	20	0.08	13.6	100	1.25
					Mean		**1.21**

The 14th day compressive strength

Sample no	Casting date	
	Testing date	

	Dimention(cm)			Area (m2)	Weight (kg)	Failer load (kn)	Compressive Strength (kn/m2)
	L	W	H				
1	40	20	20	0.08	13.4	114.5	1.43125
2	40	20	20	0.08	13.4	118.8	1.485
3	40	20	20	0.08	13.3	108.7	1.35875
4	40	20	20	0.08	13.8	116.4	1.455
5	40	20	20	0.08	13.8	112.3	1.40375
6	40	20	20	0.08	13.5	110.9	1.38625
					Mean		**1.42**

The 28th day compressive strength

Sample no	Casting date						
	Testing date						
	Dimention(cm)			Area (m2)	Weight (kg)	Failer load (kn)	Compressive Strength (kn/m2)
	L	W	H				
1	40	20	20	0.08	13.3	134.4	1.68
2	40	20	20	0.08	13.3	136.2	1.7025
3	40	20	20	0.08	13.3	138.3	1.72875
4	40	20	20	0.08	13.7	129.8	1.6225
5	40	20	20	0.08	13.7	132.3	1.65375
6	40	20	20	0.08	13.4	140.2	1.7525
					Mean		**1.69**

APPENDIX THREE

Density, Moisture content and Absorption test result

Place	**Jimma institute of technology**
Department	**Civil engineering department**
Laboratory	**Construction material laboratory**

1. **0% SAWDUST REPLACMENT**

Sample no	Sample mass(Mr) in Kg	Weights in water (Wi) in Kg	SSD weight (Ws) in Kg	Oven dray weight (Wd) in Kg	Density in Kg/m^3	Moisture content	Absorbtion	
							in %	in kg/m^3
1	15.78	8.68	15.97	14.77	2026.06	84.16	8.12	164.60
2	15.56	8.66	16.2	15.12	2005.3	40.74	7.14	143.23
3	15.46	8.76	16.13	14.51	1968.79	58.64	11.16	219.81

Mean	**15.6**	**8.7**	**16.1**	**14.8**	**2000.05**	**61.94**	**8.8**	**175.6**

2. **4% SAWDUST REPLACMENT**

Sample no	Sample mass(Mr) in Kg	Weights in water (Wi) in Kg	SSD weight (Ws) in Kg	Oven dray weight (Wd) in Kg	Density in Kg/m³	Moisture content	Absorbtion	
							in %	in kg/m³
1	15.48	8.55	15.8	14.65	2020.69	72.17	7.84	158.62
2	15.37	8.51	16.2	14.55	1892.06	49.69	11.34	214.56
3	15.29	8.44	16	14	1851.85	64.5	14.28	264.55
Mean	**15.38**	**8.5**	**16**	**14.4**	**1921.54**	**60.12**	**11.1**	**213.3**

3. **8% SAWDUST REPLACMENT**

Sampl e no	Sample mass(Mr) in Kg	Weights in water (Wi) in Kg	SSD weight (Ws) in Kg	Oven dray weight (Wd) in Kg	Density in Kg/m³	Moisture content	Absorbtion	
							in %	in kg/m³
1	15.38	8.38	15.59	14.2	1969.48	84.89	9.78	192.78
2	15.16	8.15	16.11	14.04	1763.81	54.1	14.74	260.05
3	14.88	8.07	16	13.91	1754.09	46.41	15.02	263.55
Mean	**15.14**	**8.2**	**15.9**	**14.05**	**1829.13**	**58.6**	**13.1**	**240.26**

4. **10% SAWDUST REPLACMENT**

Sample no	Sample mass(Mr)	Weights	SSD weight	Oven dray	Density in	moisture content	absorbtion

	in Kg	in water (Wi) in Kg	(Ws) in Kg	weight (Wd) in Kg	Kg/m^3		in %	in kg/m3
1	15.1	8	15.86	14.05	1787.53	58.01	12.88	230.27
2	14.36	7.56	15.28	13.27	1718.91	54.22	15.14	260.36
3	15.21	8.44	16.26	13.48	1723.78	62.23	20.62	355.49
Mean	**14.89**	**8**	**15.8**	**13.6**	**1743.41**	**57.33**	**16.2**	**282.05**

5. 12% SAWDUST REPLACMENT

Sample no	Sample mass(Mr) in Kg	Weights in water (Wi) in Kg	SSD weight (Ws) in Kg	Oven dray weight (Wd) in Kg	Density in Kg/m^3	Moisture content	Absorbtion	
							in %	in kg/m^3
1	15	8	15.97	13.85	1737.76	54.24	15.30	265.99
2	14.52	7.62	15	13	1761.51	76	15.38	271.00
3	14.34	7.48	16.13	12.75	1473.98	47.04	26.51	390.75
Mean	**14.62**	**7.7**	**15.7**	**13.2**	**1657.76**	**56.34**	**19**	**312.5**

6. 16% SAWDUST REPLACMENT

Sample no	Sample mass(Mr) in Kg	Weights in water (Wi) in Kg	SSD weight (Ws) in Kg	Oven dray weight (Wd) in Kg	Density in Kg/m^3	Moisture content	Absorbtion	
							in %	in kg/m^3
1	14.8	7.8	15.96	13.4	1642.15	54.68	19.10	313.72

2	14.19	7.3	15.48	12.5	1528.11	56.71	23.84	364.30
3	14	7.1	15.36	12.2	1476.99	56.96	25.90	382.56
Mean	**14.33**	**7.4**	**15.6**	**12.7**	**1549.09**	**55.55**	**22.9**	**353.65**

7. 20% SAWDUST REPLACMENT

Sample no	Sample mass(Mr) in Kg	Weights in water (Wi) in Kg	SSD weight (Ws) in Kg	Oven dray weight (Wd) in Kg	Density in Kg/m^3	Moisture content	Absorbtion	
							in %	in kg/m^3
1	14.54	7.43	15.83	13.1	1559.52	52.74	20.84	325
2	14	7.06	15.38	12	1442.30	59.17	28.16	406.25
3	13.52	6.81	15.29	11.5	1356.13	53.29	32.95	446.93
Mean	**14.02**	**7.1**	**15.5**	**12.2**	**1452.65**	**54.87**	**27.3**	**392.85**

8. 24% SAWDUST REPLACMENT

Sample no	Sample mass(Mr) in Kg	Weights in water (Wi) in Kg	SSD weight (Ws) in Kg	Oven dray weight (Wd) in Kg	Density in Kg/m^3	Moisture content	Absorbtion	
							in %	in kg/m3
1	14.1	7.1	15.86	13.01	1485.16	38.24	21.90	325.34
2	13.81	6.83	15.28	11.45	1355.03	61.61	33.45	453.25
3	13.16	6.47	16.26	10.64	1086.82	44.83	52.82	574.05
Mean	**13.69**	**6.8**	**15.8**	**11.7**	**1309**	**54.3**	**36**	**455.55**