Addis Ababa University

Addis Ababa Institute of Technology

School of Civil and Environmental Engineering

Study of Partial Replacement of Sand with Wanza Sawdust to Produce Concrete

A thesis submitted to Addis Ababa Institute of Technology School of Civil and Enviromental Engineering in partial fulfillment of the requirments for the degree of Master of Science in Civil Engineering
(Construction Technology and Management)

By:- Getish Lemma

Advisor: Dr. Ephraim Senbetta

June, 2019

Addis Ababa

DECLARATION

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

Name: -	Getish Lemma
Signature	______________
Place: -	Addis Ababa Institute of Technology, School of Civil and Environmental Engineering.
Date of submission: -	June , 2019

ACKNOWLEDGEMENTS

First of all I want to thank GOD for helping me to complete my study. Then I want to give great thanks, first and foremost to my advisor Ephraim Senbetta, PhD. Dr. Ephraim Senbetta deserves the highest acknowledgement because he advised me with critical and constructive comments and guided me throughout this thesis work. He has also spent his precious time in reviewing and improving the quality of this thesis work. I learned precious things from you which can make me different from the crowd. I will not forget about things you shared with me during your advising; especially “when you explain you lose”, “don’t say try, just do it”, and about “time”. It will be my motto throughout my life. I really thank you.

At last but not the least, I would also to thank my friends Zenebe, Bereket, Eyerusalem and Meseret you helped me a lot by reviewing and give me supportive ideas for my research. I spent very good time with you my friends Thanks a lot.

ABSTRACT

Concrete is a composite material of which 60-75% by volume is aggregates. Out of this volume, 30-40% is composed of fine aggregates. Fine aggregate is one of the predominant contents of concrete usually natural river sand is used as the fine aggregate. Wanza Sawdust which is the byproduct Wanza wood is abundantly available in Tepi, Ethiopia. However, there is no sand source in Tepi, Ethiopia. Therefore, this research tried to study the possibility of sawdust to replace sand in the production of concrete.

The objective of this experimental study was to investigate the effect of using sawdust as an alternative for fine aggregate in concrete production and by determining the optimum replacement of sand with sawdust that can be acceptable for the production of concrete. The research studied workability, setting time, density, compressive strength and water Penetration of C-20 class of concrete produced by replacing 5%, 10%, 15%, 20% and 25% by volume of sand with sawdust.

In studying the properties of concretes, a total of twelve concrete mixes made with OPC and PPC were prepared by replacing sand with sawdust. The investigation of this thesis has revealed that compressive strengths of OPC concrete mixes with 5%, 10% and 15% sand with sawdust replacement satisfy the 20MPa cube Compressive strength compliance criteria of ACI 301, Specifications for Structural Concrete, at 28 days. The strengths achieved, 21.4, 20.8 and 20.2MPa respectively, are greater than the specified .At 56 days the compressive strengths of PPC concrete mixes with 5%, 10% and 15% sawdust replacement satisfy the compliance criteria of ACI 301. The strengths achieved, 21.8MPa, 20.8MPa and 20.4MPa respectively, are greater than the specified.

Sawdust retarded the hydration reaction of cement because the setting time of concrete increased when percentage replacement of sand with sawdust increased. The slump of the concrete decreased through percentage replacement of sand with sawdust and also the density of concrete decreased with the percentage replacement of sand with sawdust. The water permeability of concrete increased through percentage replacement of sand with sawdust. Finally, based on 15% optimum replacement of sand with sawdust, the material cost of concrete with sawdust was found lower than concrete without sawdust. In one meter cube, the cost of concrete made with sawdust decreased by 49.8 birr or 3.78% than concrete without sawdust.

Keywords*: sand, sawdust, partial replacement*

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

1.1 Background

Concrete has been predominantly used as the preferred material for construction due to its various qualities especially strength that have made it suitable for numerous construction purposes. Selection of aggregates used in concrete is important as aggregate makes up approximately 60 to 75% of the total volume of concrete. Not only do they contribute to the strength exhibited by concrete but also to its bulkiness, a property that enables the concrete to be placed (1).

The development in the construction industry all over the world is progressing. Attempts have also been made by various researchers to reduce the cost of concrete constituent and hence total construction cost by investigating and determining the usefulness of materials which could be classified as local materials (2).

Some of these local materials are agricultural or industrial waste, which include fly ash, sawdust, marble powder, concrete debris and so on. As a result of the increase in the cost of construction materials, especially cement, coarse aggregate, fine aggregate; there is the need to investigate the use of alternate building materials which are locally available. In this changing time, sawdust might just be one of solutions for the increase in cost of concrete production by replacing sand (3).

Sawdust, which is a wood waste, refers to the tiny sized and powdery waste produced by the sawing of wood. It is a wood waste in wood workshop and its nuisance to both the health and environment when not properly managed. It is a highly variable material with differing particle size, chemical composition, density and color (4).

This experimental study focused on using sawdust as partial replacement of sand in the production of concrete, which can be used in G+0 building construction by ensuring the desired compressive strength of concrete.

1.2 Statement of problem

The construction industry is rapidly growing industry in Ethiopia and concrete is being widely used in construction of residential buildings, factories and multi-storied buildings. Due to this the demand of concrete in the construction industry is increasing.

The fine aggregate is one of the predominant contents of concrete production. Scarcity of fine aggregate due to lack of source nearby, depletion of resources and restriction due to environmental consideration, make concrete manufacturing look for suitable alternative to fine aggregate (2).

The culture of using locally available waste materials for construction is very weak in Ethiopia. This culture should be improved by conducting experimental researches on locally available materials (5).

In Tepi, there is no source of fine aggregate therefore, the contractor and the supplier are forced to look to another places. The cost of sand in Tepi per meter cube is 1100 birr which is very expensive.

Sawdust is a by-product of wood which comes through the activities of wood based industries. At the time of using timber for furniture, it produces heaps of sawdust at milling sites. In Tepi there are a high number of Wanza wood manufacturing firms as a result; availability of a Wanza sawdust is high.

1.3 Objectives

The aim of this research is to study the possibility of using sawdust as a partial replacement of sand in the production of concrete. Specifically this research aims to:

- Find the optimum replacement of fine aggregate by sawdust to produce C- 20 concrete.
- Evaluate slump, setting time, density, compressive strength and water permeability of concrete produced with sawdust.
- Compare cost of concrete produced with and without sawdust.

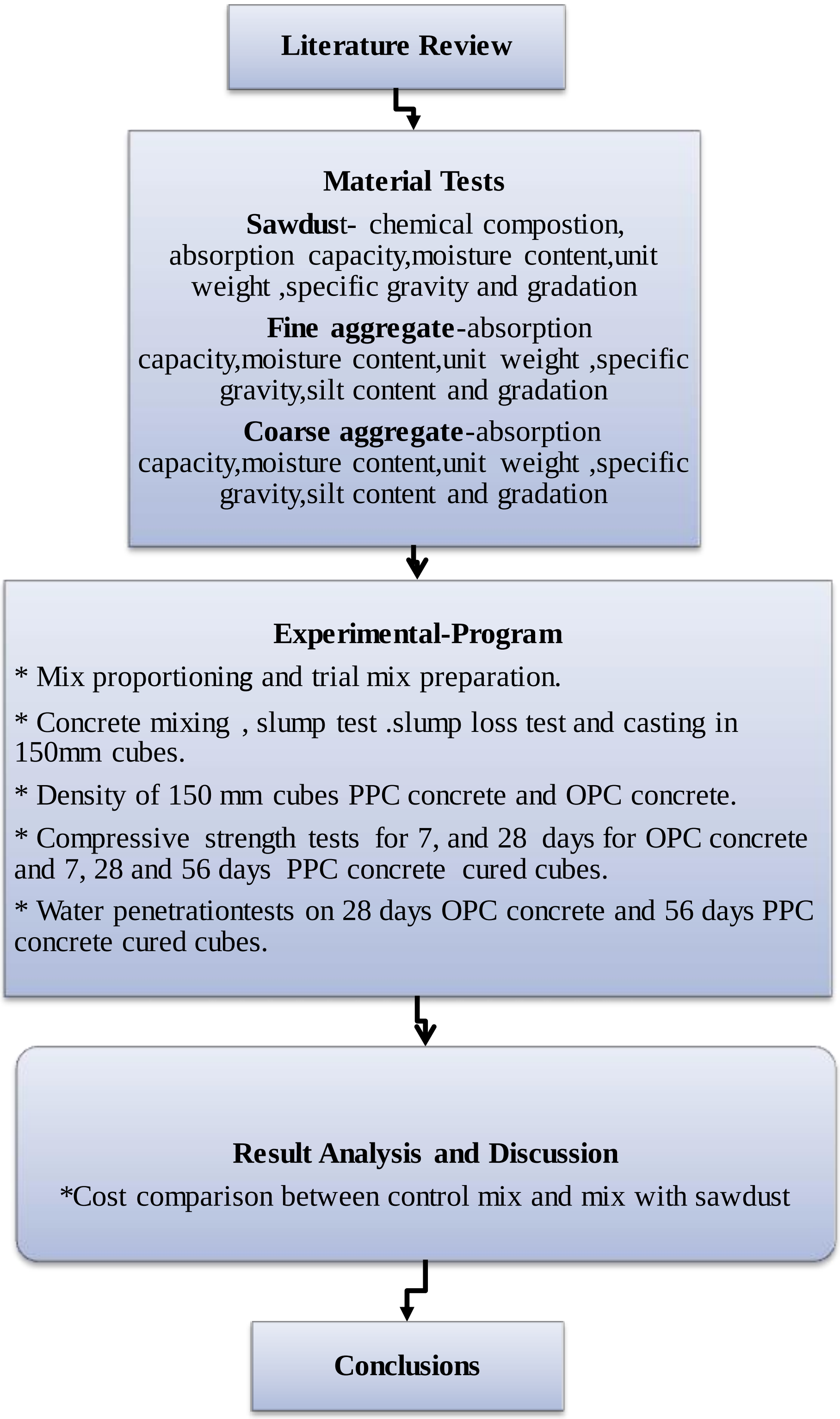
1.4 Scope of the study

The scope of this research is limited to produce concrete with strength class of C-20 with slump of 75mm, using sawdust of Cordia Africana (Wanza) to be used for G+0 buildings in Tepi, Ethiopia.

1.5 Methodology

This research involved laboratory test by preparing samples of concrete mixes containing varying amounts of sawdust and then carried out slump, slump loss, density, water permeability and compressive strength test of concrete. Prior to this, physical properties of sawdust, fine aggregate and coarse aggregate were determined in the laboratory. In addition to this, chemical composition of sawdust was also tested. The methodology for this research is illustrated in Fig 1.1

Figure1.1 Summary of research methodology



CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

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. In some instances, the materials have been used for flooring as well as walls (6).

Wood wastes in the form of wood waste can be incorporated into concretes by replacing sand without any preliminary treatment. The results have demonstrated that the inclusion of shavings in 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 (7).

Sawdust has been used in concrete, but not widely. Although it is seriously limited by its low compressive strength, it has also serious limitations that must be understood before it is subject to use. Sawdust is organic material as a result of this it will affect the setting and hydration reaction of cement. Within these limitations, the advantages that sawdust concrete offers considerable reduction in weight of the structure, thereby reducing the dead loads transmitted to the foundation, low cost when compared to normal weight concrete, reduce damage and prolong life of formwork due to lower pressure being exerted, easier handling, mixing and placing as compared with normal weight concrete, improved sound absorbent properties due to its high void ratio (8). Sawdust also improved thermal insulation of concrete because its incorporation decreases the thermal conductivity of concrete (9). The use of sawdust for making lightweight concrete has received some attention over the past years. Studies on structural properties of sawdust concrete have shown encouraging results (10).

2.2 Concrete

Concrete plays a vital role in the development of infrastructure, buildings, industrial structures, bridges and highways etc. leading to utilization of large quantity of concrete. It is difficult to point out another material of construction which is as vital as concrete. Where strength, durability, impermeability and fire resistance are required, concrete is the best material (11).

2.2.1 Workability of Concrete

ASTM C 125 defines workability as the property determining the effort required to manipulate freshly mixed quantity of concrete with minimum loss of homogeneity. The term "manipulate" includes the early age operations of placing, compacting and finishing (12).

A workable concrete allows full compaction using a reasonable amount of work. This helps in achieving maximum possible density (i.e. minimum possible voids) of concrete, which results in more strength and durability of concrete (13).

Water content is the most important factor affecting the workability of concrete. Increasing the amount of water will increase the workability of concrete. However the increase in water content of the mix will decrease the strength and also result in segregation and bleeding (14).

The amount of aggregate, the proportion and fine aggregate and shape and texture of the aggregate particles affect the workability of concrete. Keeping the water content and cement content constant increasing the amount of aggregate reduces the workability of concrete (14).

Freshly mixed concrete stiffens with time. The change in workability with time depends on the moisture condition of aggregate, evaporation and hydration reaction. The loss of workability is greater with dry aggregate due to the absorption of water by aggregate. The workability of a concrete is also affected by the temperature of the concrete itself (13).

2.2.2 Setting time of concrete

ASTM C125 defines time of setting as the elapsed time from addition of mixing water to a cementitious mixture until reaches a specified degree of rigidity as measured by a specific procedure. The development of rigidity in cementitious mixture is a gradual and continuous process. For cementitious mixture development of rigidity is measured as the elapsed time to attain a specified level of resistance penetration by a probe.

The setting time of concrete is measured by ASTM C403.A mortar portion is extracted by wet sieving using a 5 mm (No.4 ASTM) sieve from the concrete sample. A spring reaction-type probe known as Proctor probe, is used to determine the times when the resistance to penetration is 3.5MPa (500 psi) (15).

The initial setting time and indicates that the concrete has become too stiff to be made mobile by vibration. These setting times are distinct from the setting times of cement (13).

The stiffening of concrete can be recognized by a loss of workability that usually occurs during placing, but is dependent upon the composition and fineness of the cement, any admixtures used, mixture proportions, and temperature conditions. Subsequently, the concrete sets and becomes hard. In addition to this, Organic impurities may also delay setting of concrete (16).

2.2.3 Strength of concrete

Concrete is required to provide a specified strength. The most common measure of concrete strength is the compressive strength, determined either using a cube or a cylinder. Although in many practical cases other characteristics, such as durability and permeability may in fact be important (17).

The compressive strength of concrete attracts greatest interest as compared to other types of concrete strengths since compressive strength of concrete is mostly used for designing of building structures. In addition, it has a great practical and economic significance because the sections and sizes of the concrete structures are determined by it (16).

Since most concrete structures are designed to resist compressive stress, it is this property which is usually prescribed by codes or standards. The strength of concrete depends on the cohesion of the cement paste, on its adhesion to the aggregate particles, and to a certain extent on the strength of the aggregate itself (13).

2.2.4 Durability

The durability of concrete may be defined as the ability of concrete to resist weathering action, chemical attack and abrasion while maintaining its desired engineering properties. Different concretes require different degrees of durability depending on the exposure environment condition. The concrete ingredients, proportioning of those ingredients, interactions between the ingredients, and placing and curing practices determine the durability and life of the concrete (18).

The durability of concrete depends mostly upon conditions of exposure, grade of concrete used, quality of its materials and the extent of voids and pores present in the concrete cover over the reinforcement also influences the durability of concrete (19).

The durability of concrete is a function of permeability. Hence concrete can be made durable by reducing the extent of voids by suitable grading and proportioning the materials, using adequate quantity of cement and low water cement ratio thereby ensuring impermeability (13).

2.2.5.1 Permeability

Permeability refers to flow through a porous medium. Three fluids principally relevant to durability which can enter concrete: water, aggressive ions and carbon dioxide. They can move through the concrete in different ways, but all transport depends primarily on the structure of the hydrated cement paste. Durability of concrete largely depends on the ease with which fluids, both liquids and gases, can enter into, and move through concrete; this is commonly referred to as permeability of concrete (20).

The permeability of concretes with the same water/cement ratio is affected by the type of aggregate. If the aggregate has a very low permeability, its presence reduces the effective area over which flow can take place (13).

- **Water permeability**

The impermeability of concrete can be determined in the laboratory by applying water under controlled pressure to the surface of concrete and measuring the penetration of water in to the specimen (21).

As water represents the most important liquid among those penetrating through concrete, improvement in impermeability of concrete to water implies improvement in durability of concrete. Water permeability of concrete can be evaluated under both steady state and non-steady state condition (14).

a) Steady state water permeability

In this case, water is allowed to move across the specimen until steady state flow is attained. This is done by subjecting the specimen to specific pressure and recording penetrated water until constant flow of water is obtained. Water penetrates into the concrete to a certain depth, and an expression has been developed by Valenta to convert the depth of penetration into the coefficient of permeability, K (in meter per second) equivalent to that used in Darcy's law:(13).

$$K=\frac{e^{2v}}{2ht}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \text{[Eq. 2.1]}$$

Where e = depth of penetration of concrete in meters

h = hydraulic head in meters,

t = time under pressure in seconds, and

v = the fraction of the volume of concrete occupied by pores.

It is also possible to use the depth of penetration of water as a qualitative assessment of concrete: a depth of less than 50 mm classifies the concrete as 'impermeable'; a depth of less than 30 mm, as 'impermeable under aggressive conditions'. (13)

b) Non steady state water permeability

In this case, the depth of water penetration is measured without the water flow necessarily reaching steady state. A succession of water pressure is applied across the specimen as follows (ISO/DIS/7031):

- 0.3MPa (3 bar) for the first 24 hour
- 0.5MPa (5 bar) for the next 24 hour and
- 0.7MPa (7 bar) for the last 24 hours

At the last 24 hours the specimens will be removed from water penetration apparatus and will be split using tensile splitting machine. After Splitting, the maximum and average depths of water penetration will be measured (21).

2.2.6 Constituent of concrete

2.2.6.1 Cement

Cement is a hydraulic binder and is defined as a finely ground inorganic material, when mixed with water, forms a paste which sets and hardens by means of hydration reactions and processes which, after hardening, retains its strength and stability even under water(23).

Portland cement is the one which is used in Ethiopia for concrete production. It is one of the hydraulic cements which are capable of setting and hardening under water (21).

- **Types of cement**

Types of cement can be varied by changing the relative proportions of its four prominent chemical compounds, by the degree of fineness of the clinker grinding and/or by adding some pozzolanic materials. As a result, there are several types of cements for different purposes. Some of them are: - Ordinary Portland Cement (OPC), Rapid Hardening Portland cement, Sulphate Resisting Portland Cement, Low heat Portland Cement, Portland Pozzolana Cement (PPC) (16).

Among those types of cements, two of them i.e. Portland pozzolana cement and ordinary Portland cements produced in Ethiopia by the different cement factories are discussed below.

a) Ordinary Portland cement

Ordinary Portland (Type-I) cement is a general-purpose cement suitable for all uses where the special properties of other types are not required. Its uses in concrete include pavements, floors, reinforced concrete buildings, bridges, tanks, reservoirs, pipe, masonry units, and precast concrete products. The standard requires that it is made from 95 to 100 percent of Portland cement clinker and 0 to 5 percent of gypsum. Filler is defined as any natural or inorganic mineral material other than a cementitious material (16).

b) **Portland pozzolana cement**

In the Ethiopian Standard ES C.D5.210 definition Portland Pozzolana cement is defined as cement resulting from a homogeneous mixture of finely ground Portland clinker and less than 25 percent by mass of pozzolana.

ASTM 618-08a describes pozzolana as siliceous and aluminous materials which in itself possess little or no cementitious value but will in finely divided form and in the presence of moisture, chemically reacts with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties.

Pozzolanic properties mean the ability of a material to combine with lime at ambient temperature and in the presence of water in order to produce compounds that set and hardened with the formation of hydrated phases (24).

The activity of Pozzolanas when mixed with cement is that the silica of the pozzolana combines with the free lime released during the hydration of the cement. Silica of amorphous form reacts with lime more readily than those of crystalline form and this constitutes the difference in many cases between active pozzolanas and materials of similar chemical composition which exhibit little pozzolanic activity and further quantities of calcium silicate hydrate are produced;

$2S + 3CH \rightarrow C_3S_2H$

The reaction is clearly secondary to the hydration of the Portland cement, which lead to 'latent hydraulic material' (13).

2.2.6.2 Water

ASTM (C1602, 2012) defines sources of mixing water as batch water. Batch water is discharged into the mixer from municipal water supply, reclaimed water, or water resulting from concrete production operation.

Almost Any natural water that is drinkable and has no pronounced taste or odor can be used as mixing water for making concrete, However , some water that are not fit for drinking may be suitable for use in concrete(16).

Excessive impurities in mixing water not only may affect setting time and concrete strength, but also may cause efflorescence, corrosion of reinforcement and reduced durability. Therefore, certain optional limits may be set on chlorides, sulfates, alkalis and solids in the mixing water or appropriate tests can be performed to determine the effects the impurities has on various properties(16).

2.2.6.3 Aggregate

Aggregates are known to be particles of rock or equivalent to particles of rock which, when brought together in a bound or unbound condition, form part or whole of an engineering or building structure (22). Aggregate properties significantly affect the workability of plastic concrete and also the durability, strength, thermal properties, and density of hardened concrete(25).

The quality of aggregate is considerably important because at least three-quarters of the volume of concrete is occupied by it. This indicates that it is impossible to get good quality concrete without good quality aggregates. Aggregate has both economical and technical advantages in making concrete (26).

In choosing aggregate for use in a particular concrete, attention should be given among other things to three important requirements (14)

1. Workability, when fresh for which the size and gradation of the aggregate should be such that undue labour in mixing and placing will not be required.
2. Strength and durability when hardened for which the aggregate should:
   - Be stronger than the required concrete strength
   - Contain no impurities which adversely affect strength and durability
   - Not go in to undesirable reaction with the cement
   - Be resistant to weathering action
3. Economy of the mixture –meaning to say that the aggregate should be:
   - Available from local and easily accessible deposit or quarry
   - Well graded in order to minimize paste hence cement requirement.

- **Classification of aggregate**

Aggregates can be divided into several categories according to different criteria (20).

i. In accordance with size:
   - Coarse aggregate: Aggregates predominately retained on the No. 4 (4.75 mm) sieve.
   - Fine aggregate (sand): Aggregates passing No.4 (4.75 mm) sieve and predominately retained on the No. 200 (75μm) sieve.

ii. In accordance with unit weight
   - Light weight aggregate: The unit weight of aggregate is less than 1120 kg/m3.The corresponding concrete has a bulk density less than 1800 kg/m3

- Normal weight aggregate: The aggregate has unit weight of 1520-1680 kg/m3.The concrete made with this type of aggregate has a bulk density of 2300-2400 kg/m3
- Heavy weight aggregate: The unit weight is greater than 2100 kg/m3. The bulk density of the corresponding concrete is greater than 3200 kg/m3.

iii. In accordance with sources

- Natural aggregates: This kind of aggregate is taken from natural deposits without changing their nature during the process of production such as crushing and grinding.
- Manufactured aggregates: This is a kind of man-made materials produced as a main product or an industrial by-product.

- **Physical Property of aggregate**

Most properties of aggregate depends on the properties of parent rock e.g. chemical and mineral composition, , specific gravity, hardness, strength, physical and chemical stability, pore structure etc. All properties may have a considerable influence on the quality of fresh or hardened concrete (13).

The physical properties of aggregates such as size shape, texture, porosity, absorption, moisture content, bulking of fine materials and presence of deleterious substances affects significantly the resulting concrete quality produced (13).

a) Grading of Aggregates

The particle size distribution is important because it determines the paste requirement for workable concrete. Since cement is most expensive component, It is desirable to minimize the cost of concrete by using the smallest amount of paste consistent with the production of concrete that can be handled, compacted and finished and provide the necessary strength and durability. Well graded aggregate produces dense concrete and needs less quantity of fine aggregate and cement paste. Hence it is essential that the coarse and fine aggregate be well graded to produce quality concrete (20).

b) Porosity and Absorption of Aggregate

Due to the presence of air bubbles, which are entrapped in a rock during its formation or on account of the decomposition of certain constituent minerals by atmospheric action, holes or cavities are formed in it that are commonly known as pores. The porosity and absorption affect the bond between aggregate and the cement paste, the resistance of concrete to freezing and thawing, chemical stability, resistance to abrasion, and the specific gravity of the aggregate (27) .

c) Moisture content of Aggregates

The determination of moisture content of an aggregate is necessary in order to determine the net water-cement ratio for a batch of concrete. Otherwise; if the moisture content and absorption of aggregates is not properly determined, the water added during preparing the mix becomes variable. This results in either high or low water to cement ratio. Higher water to cement ratio may affect the properties of concrete like workability in which concretes with lower water content becomes less workable as a result it makes difficult to attain full compaction and leave excessive void in the concrete mass (28).

d) Strength of aggregate

Aggregates contribute the significant proportion of strength possessed by concrete due to their higher modulus of elasticity as compared to the cement paste. Since, Aggregates exist in granular form. Consequently, measures of aggregate granular strength are more useful for assessing aggregate performance in concrete (20).

To have a strong concrete, the aggregate should have high load bearing capacity and resistant to wearing and abrasion effects. The hardness of the minerals that make up the aggregate particles and the firmness with which the individual grains are cemented or interlocked control the resistance of the aggregate to abrasion and degradation (13).

e) Potential harmful materials

Various substances in aggregates can interact with the cement in concrete or have otherwise undesirable effects. For example, sulphates may influence cement hydration, while excessive chlorides can incur corrosion of reinforcing steel.

"*Materials finer than the 75- µm (No. 200) sieve, especially silt and clay, shale, coal, lignite, and certain lightweight and soft particles may form a coating on the aggregate particle and may weaken the bond between cement paste and aggregate. If certain types of silt or clay are present in excessive amounts, water requirements may increase significantly*" (16)

Table 2.1 Deleterious substances in aggregates (16)

Deleterious Substances	**Effect on Concrete**
Organic impurities	Affects setting and hardening, may cause deterioration
Materials finer than 75µm (No. 200)	Affects bond, increase water requirement
Coal, lignite, or other lightweight materials	Affects durability, may cause stains and pop outs
Soft particles	Affects durability
Clay lumps and friable particles	Affects workability and durability, may cause pop outs
Cherty of less than 2.04 relative density	Affects durability, may cause pop outs
Alkali-reactive aggregates	Causes abnormal expansion, map cracking, and

Reactions between active aggregates and alkalis that affect concrete quality, one of these reactions is the deleterious chemical reaction which takes place between the active silica of aggregate and the alkalis in cement that is called the alkali-aggregate reaction (AAR). The reactive forms of silica occur in opaline, chalcedonic,cherts, siliceous limestone, rhyolites and rhyolitic tuffs, andesite and andesite tuffs, phyllites, etc. The reaction between the siliceous mineral of the aggregate and the alkaline hydroxide of the cement results in an alkali silicate gel. The gel is confined by the surrounding cement paste and an internal pressure is developed leading to expansion resulting in cracks and disruption of cement paste (16).

f) Bulk Density

The bulk density or unit weight of an aggregate is the mass or weight of the aggregate required to fill a container of a specified unit volume. The volume referred to here is that occupied by both aggregates and the voids between aggregate particles. The bulk density is used to convert quantities by weight to quantities by volume for batching concrete. Bulk specific gravity determined on the saturated surface-dry basis is used if the aggregate is wet, that is, if its absorption has been satisfied. Conversely, the bulk specific gravity determined on the oven-dry basis is used for computations when the aggregate is dry or assumed to be dry (20).

g) Specific Gravity

The density of the aggregate is required in mix proportioning to establish weight-volume relationships. The density is expressed as the specific gravity, which is a dimensionless ratio relating the density of the aggregate to that of water (13).

The bulk specific gravity is defined as the ratio of the weight in air of a given volume of a material at the standard temperature to the weight in air of equal volume of distilled water at the standard temperature. For use in the computation of concrete mixes the bulk specific gravity is always determined for saturated surface dry aggregates (16).

- **Coarse Aggregate**

The most commonly available local coarse aggregates are obtained from normal weight crushed basaltic rocks. The maximum size of coarse aggregate is typically 19 mm 25 mm.

An Intermediate size aggregate, around 9.5mm, is sometimes added to improve overall aggregate gradation (1).

- **Fine Aggregate**

Sand is a material that mainly passes through a 5.00mm BS test sieve. Sand can be classified as natural, crushed stone sand, crushed gravel sand or a combination of any of these. They should be hard, durable, clean and free from adherent coatings like and in clay pallet form. It should not contain harmful substances like iron pyrites, salts, coal, other organic impurities, mica, and shale, flaky or elongated particles (16).

It consists of a uniformly distributed particle of different sizes. The grading of sands shall be determined by the method of sieve analysis. Grading of fine aggregates has a great influence on the workability of a concrete mix (1).

To ensure that the proper amount of sand is present, the separate delivery, storage and batching of coarse and fine aggregate is essential. Production of concrete with uniform quality requires a consistent source, grading and moisture content of fine aggregate. Sands coming from beaches are generally unsuitable for good quality concrete, since they are likely to have high concentration of chloride because of the accumulation of salt crystals above the high-tide mark. They are also single-sized, which can make the mix design difficult (14).

Since sand is naturally occurring granular material composed of finely divided rock and mineral particle. it is defined by the size, being finer than gravel and coarser than silt. The composition of sand varies, depending on the local rock sources and conditions. But the most common constituent of sand is silica (silica dioxide or sio_2**)** (29)**.**

Table 2.2 Chemical composition river sand of Jimma(1)

Component	Jimma Sand
SiO_2	94.6
Al_2O_3	1.81
Fe_2O_3	1.58
TiO_2	0.18
CaO	0.42
MgO	0.22
K_2O	0.38
Na_2O	1.08
H_2O	0.05
LOI	0.85

- **Silica**

Silica is the name given to a group of minerals composed of silicon and oxygen, the two most abundant elements in the earth's crust. Silica is found commonly in the crystalline state and rarely in an amorphous state. It is composed of one atom of silicon and two atoms of oxygen resulting in the chemical formula SiO_2 (30).

Sand consists of small grains or particles of mineral and rock fragments. Although these grains may be of any mineral composition, the dominant component of sand is the mineral quartz, which is composed of silica (silicon dioxide). The silica in the sand will normally be in the crystalline form of quartz, which is because of its chemical inertness and considerable hardness, is the most common mineral resistant to weathering The composition of mineral sand is highly variable depend on the local rock sources and conditions (30).

- **Requirement of Sand for concrete**

Aggregate provides technical advantage on concrete which has higher volume stability better than the cement paste alone. So, before using aggregate as concrete making material, it is important to examine whether those aggregates fit for the purpose to which they are intended to be used and tests on site and laboratory should have to be made. Some of the requirement will be discussed below:

a) Grading of fine aggregate

Fine aggregate grading has a greater effect on workability of concrete than coarse aggregates. The grading determine the paste requirement for a workable concrete since the amount of void requires needs to be filled by the same amount of cement paste in a concrete mixture (20).

b) Fineness Modulus

Using the sieve analysis results, a numerical index called the fineness modulus (FM) is often computed. The fineness modulus (FM) of either fine or coarse aggregate according to ASTM C 125 is calculated by adding the cumulative percentages by mass retained on each of a specified series of sieves and dividing the sum by 100 (16).

The specified sieves are 9.5 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600μm, 300μm, and 150μm. Note that the lower limit of the specified series of sieves is the 150 μm (No. 100) sieve and that the actual size of the openings in each larger sieve is twice that of the sieve below. The coarser the aggregate size, the higher the FM. For fine aggregate used in concrete, the FM generally ranges from 2.3 to 3.1 according to ASTM C 33(16).

It is used as an index to the fineness or coarseness and uniformity of aggregate supplied, but it is not an indication of grading since there could be an infinite number of grading which will produce a given fineness modulus. The following limits may be taken as guidance: (31)

- Fine sand: F.M. 2.2 - 2.6
- Medium Sand: F.M. 2.6 - 2.9
- Coarse Sand: F.M. 2.9 - 3.2

Sand having a fineness modulus more than 3.2 will be unsuitable for making satisfactory concrete. However, it is clear that one parameter, the average, cannot be representative of a distribution: thus the same fineness modulus can represent an infinite number of totally different size distributions or grading curves (31).

The fineness modulus cannot, therefore, be used as a description of a grading of an aggregate but it is valuable for measuring slight variations in the aggregate from the same source (22).

c) Silt Content

Sand is a product of natural or artificial disintegration of rocks and minerals. Sand is obtained from glacial, river, lake, marine, residual and wind-blown (very fine sand) deposits. These deposits, however, do not provide pure sand. They often contain other materials such as dust, loam and clay that are finer than sand. Therefore it is necessary to conduct a test on the silt content and checks against permissible limits (26).

A simple test which can be made on site to give a guide to the amount of silt in natural sand is the 'field settling' test. This test should not be used for crushed rock sands. According to the Ethiopian Standard it is recommended to wash the sand or reject if the silt content exceeds a value of 6% (32).

d) Deleterious substance of fine aggregate

Certain substances in aggregates are undesirable for use in Portland cement concrete. Therefore, the Specifications limit the amount of deleterious constituents to a level consistent with the quality sought in the final product.

Table 2.3 Permissible limits for deleterious substances in fine aggregates (33)

Deleterious Substances	**Maximum Percent by Mass**
Friable particles Clay	1.0
Fine silt (passing 63 µm sieve)	3.0
ll other concrete coal and lignite	1.0

2.3 Sawdust

2.3.1 Origin

Sawdust is a by-product of cutting, grinding, drilling, sanding, or otherwise pulverizing wood with a saw or other tool; it is composed of fine particles of wood. It is also the byproduct of certain animals, birds and insects which live in wood, such as the woodpecker and carpenter ant are also responsible for producing the sawdust. Sawdust's are produced as a small discontinuous chips or small fragments of wood during sawing of logs of timber into different sizes (11).

(a) (b)

(c) (d)

Figure 2.1 Size and shape of sawdust (2)

2.3.2 Physical Properties of Sawdust

Sawdust is composed of fine particles of wood. The physical and chemical properties of sawdust vary significantly depending on several factors, especially the species of wood. The physical and chemical properties of the sawdust will not be the same and it will vary from one tree to another tree (34).

a) Flammable

Sawdust is flammable, especially when dry hence it has been used as a source of fuel.

b) Hygroscopic

Sawdust is hygroscopic; it has a tendency to absorb moisture when in contact with liquid water or water vapor.

Table 2.4 Physical Properties of Sawdust of pine (softwood) (6)

S. No.	Parameters	Values
1	Fineness Modulus	1.9
2	Moisture content	9.8%
3	Bulk density	615 kg/m^3

`

2.3.2 Chemical composition of sawdust

The chemical composition of sawdust is complex often similar to the wood from which it is derived. Wood tissue is made of chemical components which are distributed none uniformly. The chemical analysis of a number of species of softwoods and hardwoods shows that it is made of cellulose and lignin each includes a number of compounds. The laboratory analysis has shown that the percentage of lignin in the oven dry weight of wood is approximately: 25-35% in softwoods, 17-25% in hardwoods. Studies show that lignin has a retarding effect on concrete (29).

Table 2.5 Chemical Composition of Sawdust of pine (softwood) (35)

S.No	Constituents	Percentage
1.	SiO_2	87
2.	Al_2O_3	2.5
3.	Fe_2O_3	2.0
4.	MgO	0.24
5.	CaO	3.5
6.	Loss on ignition (LOI)	4.76

2.3.3 Density of sawdust

Density of the sawdust can be determined by the method employed by Araki and Terazawa (36). The sawdust density determine by:-

$$\text{Density of sawdust (g/cm}^{-3}) = \left[\frac{W_b - W_a}{V_o} \right]$$

Where, W_b=weight of sawdust with volumetric cylinder

W_a= weight of empty volumetric cylinder

$V_o = 100$ cm^3

2.3.4 Use of sawdust

A major use of sawdust is serving as a fuel.

2.3.5 Use of sawdust in concrete

The physical and chemical properties of sawdust vary significantly depending on several factors; especially the species of wood. Sawdust particles are porous and absorb most of the water, leaving insufficient water for cement hydration. It is also presumed that if sawdust particles are in saturated surface dry condition, it could aid the hydration process of the cement by minimize the need for curing since water deposited in sawdust particles are being harvested by cement particles (37).

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 made with sawdust is a mixture of sawdust, sand, coarse aggregate and water. Sawdust concrete is light in weight and has satisfactory heat insulation (29). In the construction industry, sawdust has been used to develop sawdust concrete which consists of Portland cement, sand, sawdust and water. This kind of concrete has been found to bond well with ordinary concrete (38).

2.3.6 Sawdust Concrete

The concrete which is made by addition of sawdust is called sawdust concrete. In this type of concrete the sand is replaced partially with sawdust (6).

Benefit of sawdust concrete (38)

- Sawdust Concrete is light weight
- It is an economical alternative to conventional concrete Due to material's inert nature; it does not react with any ingredients of concrete and steel.
- It can save labour and natural resources. Since sawdust is lightweight material it saves the trouble of workers in carrying it.
- Larger volume of concrete can be handled by lighter equipment with less wear and tear on the equipment.

2.3.7 Availability of Wanza Sawdust in Ethiopia

Ethiopian forests provide significant benefits to Ethiopians through environmental protection and as a valuable, widely used resource base. Current use and demand for fuel wood and lumber exceeds the local forest capabilities and the industrial capacity to process and deliver lumber to the market (39)

Table 2.6 Total Wanza wood production in Sheka zone south western Ethiopia in 2016 (40)

Production	**Production in million m^3**	**Purpose**
Round wood	2.54	Furniture
Net export	0.02	Paper production
Total production	**2.56**	

Annual Wanza wood production in Sheka zone, south western Ethiopia was estimated 2.56 million cubic meters (40).About 10-13% of the total volume of round wood is reduced to fine sawdust in milling operations (44). Based on this, about 10-13% from 2.54 million cubic meter of rounded wood used for furniture production is reduced to fine sawdust. This indicates, total fine sawdust available in Sheka zone, south western Ethiopia is about 256, 000 to 332,800 cubic meters per year. Tepi is the town of Sheka zone.

2.4 Literature summary and gap identification

Sawdust is a by-product of cutting, grinding and drilling wood with a saw or other tool. The physical and chemical properties of sawdust vary significantly depending on several factors, especially the species of wood. The common physical properties of sawdust is their flammability and they are also hydroscopic. In addition to this chemically sawdust has silicon di oxide which makes its chemical properties comparable to sand.

If used in concrete, sawdust could have several advantage. By replacing the costly ingredient of concrete, sand, with sawdust the concrete price, thermal conductivity, and sound transmission could decrease. Since about 10-13% of the total volume of round wood is reduced to fine sawdust in milling operations. Based on this 256, 000 to 332,800 m^3 of sawdust is available per year in Tepi Ethiopia.

Research conducted on the use of sawdust as partial replacement of sand material shows effects on concrete properties. Ambiga K. in Enathur, India in 2015 the sand can be replaced up to 10% to produce C-20 concrete. Albert M Joy in Kanjirapally, India in 2016 the sand can be replaced up to 25% to produce C-25 concrete. Daniel Yaw Osier and Emmanuel Nana Jackson in Cape Coast, Ghana in 2016 the sand can be replaced up to 10% to produce C-25 concrete. Moreover, sawdust as replacement sand material in concrete production, has been found to show different effects on fresh and hardened properties of concrete; essentially on workability, compressive strength and water permeability of concrete.

The reviewed researches conducted in different countries shows different results and percentage replacement limits to produce. This is because of the difference in the species of wood used to replace sand.

The availability of Wanza sawdust is high in Tepi, Ethiopia. However there is no studies exist to explain the effect of replacing sawdust with sand on the production of concrete which is conducted in Ethiopia. Based on these gaps, this research study the possibility of replacing sand with sawdust to produce concrete and to study the workability, setting time , compressive strength and water penetration of concrete.

CHAPTER THREE

EXPERIMENTAL PROGRAM

3.1 Introduction

The main objective of this research is to study the possibility of using sand with sawdust replacement in concrete production. This include studying concrete by replacing sand with sawdust in 0%, 5%, 10, 15%, 20% and 25%.

The Experiment consists of material characterization, mix proportioning, concrete specimens preparation and laboratory tests on fresh and hardened concrete

Laboratory tests were made on concrete with specific compressive strength of C-20 using 42.5N OPC and 32.5R PPC cements. These tests are used to investigate the effect of sawdust on the property of concrete such as slump, setting time, density, compressive strength and water permeability.

3.2 Material characterization

3.2.1 Chemical composition of Wanza sawdust

The sample of sawdust is collected from Wanza furniture manufacturing firm and the chemical composition was tested in Ethiopia Geological Survey Geosciences Survey Laboratory to know the existence of reactive elements like alkali, chlorides, sulfate etc.

3.2.2 Physical properties of aggregates

Aggregates are important constituents in concrete. High percentage of the volume of concrete is occupied by aggregate; their impact on various characteristics and properties of concrete is undoubtedly considerable. Aggregates are natural materials and their proprieties vary because of this concrete made with different aggregates vary accordingly (17).

Different physical parameters of aggregates are required to be within certain limits by different standards so that concrete from a given aggregate will give the intended performance. Physical parameters are important as an input for mix design. Therefore, the following properties of aggregates were conducted.

- Gradation of fine and coarse aggregates was conducted as per ASTM C136 and both coarse and fine aggregates.
- Gradation of sawdust was conducted as per ASTM C330 since it is light weight aggregate.
- Density, relative density and absorption of fine and coarse aggregate were conducted as per ASTM C127 and 128.
- Relative density and absorption of sawdust was conducted as per ASTM C127 and 128 respectively.
- Density of sawdust was conducted by the method employed by Araki and Terazawa(39).

All these test results were used as input for mix proportioning.

3.3 Mix proportioning

The amount of water, cement, and fine aggregate and coarse aggregate was proportioned as per ACI 211.1 “Standard Practice for Selecting Proportion for Normal, Heavy weight and Mass concrete.”

Mix-proportioning was done following the procedures given in ACI211, 2002 report.

- **Step 1- Selecting slump**

The slump being fixed as 75mm and the specified 28day 150mm cubic specimen compressive strength (f’c) is 20MP, the equivalent cylindrical (150 mm dia. × 300 mm) compressive strength was calculated based on the conversion factor given in the researches related to ACI founds a conversion factor of 1.15 to 1.25 to convert 150x150x150mm cube strength to cylindrical strength. Whereas, EBCS 2 table 2.2 or Euro Code EN-206 recommends a conversion factor of 1.25 in order to convert 150mm cube strength to cylindrical 300x150mm. (42).

The respective required compressive strength was therefore calculated as follow:

$$f\text{'c (cylindrical)} = f\text{'c (cube)}/1.25 = 20/1.25 = 16\text{MPa}$$

$$f\text{'cr} = f\text{'c} + 8.5 = 16+7 = 23\text{ MPa}$$

Where: f'c - is specified compressive strength and;

f'cr – is required compressive strength

- **Step 2- Choice of nominal maximum size of aggregate**

As shown by sieve analysis test result the nominal maximum size of coarse aggregate was 25mm.

- **Step 3- Estimation of mixing water**

According to ACI211.1 table A1.5.3.3, for nominal maximum size of 25mm coarse aggregate and 75 slump, the estimated water content is 193 kg/m^3.

- **Step 4- Selection of w/c**

From ACI 211.1 table A1.5.3.4 (a) for 23MPa 28thday compressive strength, the w/c was estimated by interpolation and found 0.63.

- **Step 5- Calculation of cement content**

The respective estimated cement contents for 23MPa concretes were 305 kg per a cubic meter of concrete.

- **Step 6- Estimation of coarse aggregate content**

From ACI 211.1 table A1.5.3.6, for nominal maximum size of 25mm coarse aggregate and 3.00 fineness modulus of fine aggregate, the volume of dry-rodded coarse aggregate per a unit volume of concrete equals to 0.65.

Therefore, the weight of coarse aggregate= $0.65m^3 * 1630\ kg/m^3 = 1059.5$ kg

- **Step 7- Estimation of fine aggregate content**

With cement 305 kg, water 193 kg, and 0.65 m^3 coarse aggregate established, and, the sand content was calculated by dividing mass of an ingredient by density of water and its specific gravity as shown below:

Volume of water $= \frac{193}{1000} = 0.2\ m^3$

Volume of cement $= \frac{305}{1000*3.15} = 0.1\ m^3$

Volume of coarse aggregate $= \frac{1059.5}{1000*2.8} = 0.38\ m^3$

The Sum of known ingredients = 0 .680 m^3

The calculated absolute volume of fine aggregate is then

$1 – 0.68 = 0.32\ m^3$

The mass of dry fine aggregate is 0.32 x 2.56 x 1000 = 821 kg/m^3

Table 3.1 Proportion of ingredients in one meter cube of concrete

Ingredients	**By volume (m^3)**	**By mass (kg)**
Cement	0.1	305
Coarse aggregate	0.38	211
Fine aggregate	0.32	1063
Water	0.2	856

In this research there are two control mixes. The control mixes were C-20 OPC mix and C-20 PPC mix and designated as O and P. The special mixes of concrete mixes were made with partial replacement of sand with sawdust with various percentages (i.e. 5%, 10%, 15%, 20% and 25 %) using absolute volume method. The mix design was done for slump of 75 to 100 mm according to ACI 211.1.Altogether a total of 12 mixes were investigated to study the effect on workability, setting time, density, compressive strength and water permeability of concrete.

The proportion of cement, coarse aggregate and water are the same for concrete mixes with 5%, 10%, 15%, 20% and 25 % partial replacement of sand with sawdust. The only difference is the amount of sand and sawdust in one meter cube as shown in Table 3.2.

Table 3.2 Proportion of sand and sawdust in one meter cube

Replacement in percent (%)	Sand		Sawdust	
	By volume (m^3)	By mass (kg)	By volume (m^3)	By mass (kg)
0	0.32	821	0	0
5	0.30	780	0.02	9.6
10	0.29	738.2	0.03	19.7
15	0.27	699.3	0.05	29.8
20	0.25	658	0.06	39.3
25	0.24	616.4	0.08	49.2

3.4 Concrete specimens preparation

Light weight aggregate requires careful estimation of mix water since, additional water is required to achieve the desired workability level due to consumption of water for saturation of pores in the aggregates. This ensures an initial saturated surface dry condition before adding into the concrete mixer (13).

Each mix batch was $0.04m^3$ in volume and was subjected to 1 minute dry mixing of sand, coarse aggregate and cement for control mix and sand, coarse aggregate, sawdust and cement for mix with sawdust. Then followed by the addition of two third of the total mixing water. After two minutes of mixing, the remaining mixing water was added. Regarding placing and compaction, placing was started immediately after mixing is finished and compaction is held on table vibrator for 30 seconds for single 150mm cube mold and for 45 seconds for couple of 150mm cube molds.

The specimens for the testing of concrete properties in the hardened state, were cast in cube molds with 150mm dimension and wet inside using release agent then placed on a table vibrator.

The molds were left to cure for 24 hours. Once hardened, the specimens were carefully removed from the molds and placed in a curing tank for 7, 28 and 56 days for compressive strength tests for PPC concrete and 7 and 28 days for OPC concrete. The concrete specimens were prepared by replacing sand with sawdust from 0 to 25% replacement range with 5% increment to study the effects**.**

3.5 Laboratory tests on fresh and hardened concrete

3.5.1 Workability of concrete

In order to assess the effect of replacement of sand with sawdust on workability of fresh concrete, slump tests were conducted for each of concrete mixes using slump cone. This test was conducted according to ASTM C 143.

3.5.2 Setting time of concrete

There is no apparatus available in Addis Ababa Institution of Technology Construction Material Laboratory to measure the setting time of concrete as per ASTM C 403. Therefore, the slump loss of the control and the mix with sawdust were measured to know the retardation effect of sawdust in the concrete by taking the slump in 30 min interval until it became zero, which is the least workability. The stiffening of concrete can be recognized by a loss of workability (16).

3.5.3 Compressive strength

In this study one hundred five (105) pieces of 150mm cube samples were prepared for both control and mix with sawdust for C-20 concrete made with OPC and PPC for testing compressive strength after 7 and 28 days for OPC and 7, 28 and 56 curing days for PPC.

The compressive strength of each concrete was determined by testing the cubes in a compression machine. For each mix the average values were taken as average of three samples at 7 and 28 days for OPC concrete and 7, 28 and 56 days for PPC concrete. The mix codes and descriptions are shown below.

Table 3.3 Test specimens used in the research

No.	Specimens code	Sand (%)	Sawdust (%)	Compressive strength Test Days	Total Samples	Remarks
1	O	100	0	7 & 28	6	Control concrete mix made with OPC
2	O-5	95	5	"	"	Concrete mix made with OPC and partial replacement of sand with sawdust
3	O-10	90	10	"	"	
4	O-15	85	15	"	"	
5	O-20	80	20	"	"	
6	O-25	75	25	"	"	
7	P	100	0	7,28&56	9	Control concrete mix made with PPC
8	P-5	95	5	"	"	Concrete mix made with PPC and partial replacement of sand with sawdust
9	P-10	90	10	"	"	
10	P-15	85	15	"	"	
11	P-20	80	20	"	"	
12	P-25	75	25	"	"	

All cubes were cast for determination of compressive strength and water permeability of concrete. After 24 hours the molds were de-molded and subjected to water curing for 7 and 28 days for OPC concrete and 7, 28 and 56 days for PPC concrete. Before testing, the cubes were air dried for 2 hours. Crushing loads were recorded and average compressive strength of specimens was determined.

3.5.4 Water penetration

For assessing performance related to permeability due to the replacement of sawdust in different percentage in concrete production, non-steady water penetration test were conducted on 150mm cubes. Non steady water penetration of concretes made with OPC and PPC were carried out at 28 days and 56 days on cured 150 mm concrete cubes respectively because, researches done on OPC and PPC concrete showed that OPC concrete strength at 28 days equivalent to 56 days of PPC concrete strength. The steps followed for conducting water penetration test are shown as follows:-

- The test samples were assembled in the permeability apparatus and 3 bar (0.3MPa) pressure was applied for the first 24 hours.
- Then 5 bar (0.5MPa) water pressure were applied for the next 24 hours and
- The water pressure was increased to 7 bar (0.7MPa) for the third 24 hours to a total of 72 hours under pressure.
- At the end of 72 hours, the concrete cubes were removed from the permeability rig and split in to two using tensile splitting machine.
- Upon visual examination, the portion of specimens into which water penetrated appears darker than the rest. Then the darker zone was marked and water penetration depth measurements were taken.

CHAPTER FOUR

CHARACTERIZATION OF MATERIALS USED IN THE RESEARCH

4 Introduction

In this chapter, the materials used for the investigation are described with respect to their physical and chemical properties. All laboratory investigations on the materials used for concrete production were carried out in Addis Ababa Institution of Technology Construction Material Laboratory; whereas the chemical property of sawdust was conducted in Ethiopia Geological Survey Geosciences Laboratory.

4.1 Cement

The cements used for the research are;

- Portland pozzolana cement (PPC) and
- Ordinary Portland cement (OPC)

4.2 Aggregates

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

4.2.1. Silt content of fine aggregate

The presence of dust, loam and clay materials with sand decreases the bond between the materials to be bound together thereby decreases compressive strength of concrete. Therefore, the sand before use in all tests was washed until clear water came out. Then, the silt content of the sand was tested and was found to be 3.0 %.

According to the Ethiopian standard the silt content of sand is recommended not to exceed a limit of 6%.Therefore, the sand was within acceptable limit.

4.2.2 Gradation of fine and coarse Aggregate

Aggregate grain size distribution or gradation is one of the properties of aggregates which influence the compressive strength of concrete. Gradation of fine aggregate and coarse aggregate satisfy the grading requirement ASTM C33 as shown in Figure 4.1 and 4.2**.** The fineness modulus of sand was 3.00, which is between 2.3 to 3.2, specified fineness modulus range for sand according to ASTM C33.

Table 4.1 Fine aggregate gradation

Sieve Size (mm)	Weight Retained (g)	Percent Retained	Percent Passing	Cumulative Percent Retained	Percent Passing per ASTM C33
4.75mm	0	0	100	0	95-100
2.36mm	56	11.2	88.8	11.2	80-100
1.18mm	129	25.9	62.9	37.1	50 -85
600µm	169	33.9	29.1	70.9	25-60
300µm	80	16	13	87	5-30
150µm	48	9.6	3.4	96.6	0-10
pan	0	3.4	0	-	
Total	**499**			**302.8**	

Fineness modulus$=\frac{\sum Cumulative retained}{100}=\frac{302.8}{100}= 3.028\approx 3$

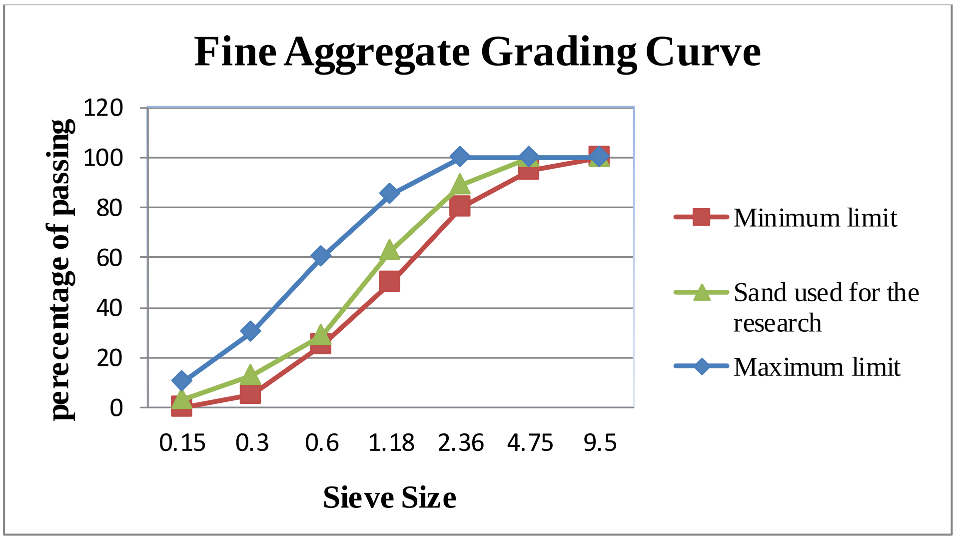


Figure 4.1 Fine aggregate grading curve

Table 4.2 Coarse aggregate gradation

Sieve Size (mm)	Weight Retained (g)	Percent Retained	Percent Passing	Cumulative Percent Retained	Percent Passing per ASTM C33
37.5	0	0	100	0	100
25	580	11.6	88.4	11.6	---
19	930	18.6	69.8	30.2	35-70
12.5	1570	31.4	38.4	61.6	---
9.5	1430	28.6	9.8	90.2	0-10
4.75	490	9.8	0	100	0-5
pan	0	0	0	100	
Total	**5000**	100		**393.6**	

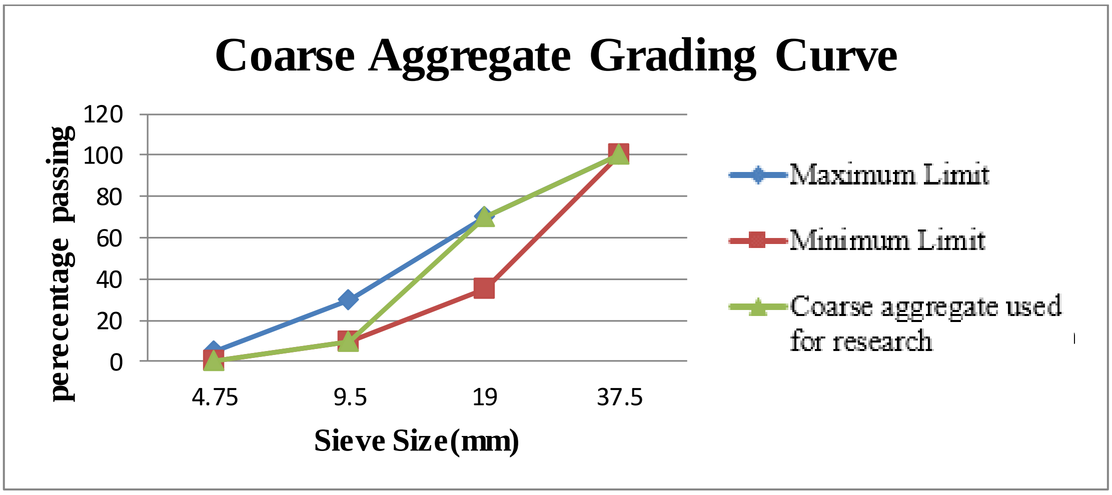


Figure 4.2 Coarse aggregate gradation curve

4.2.3 Unit weight, moisture content, specific gravity and water absorption capacity of fine and coarse aggregate

The unit weight, moisture content, specific gravity and water absorption capacity of aggregates affect compressive strength of concrete and these parameters are essential for mix design. These parameters were determined for coarse aggregate according to ASTM C29 and ASTM C127 test methods. The results of the tests are summarized on Table 4.3.

Table 4.3 Summary of test results on fine and coarse aggregate

Type of aggregate	**Unit weight (kg/m^3)**		**Specific gravity (Bulk SSD)**	**Absorption capacity (%)**	**Moisture content (%)**
	Compacted	**Loose**			
Fine aggregate	1690	1610	2.56	5.0	6.6
Coarse aggregate	1630	1470	2.8	0.7	0.28

4.3 Sawdust

The sawdust was collected from a wood workshop. It is byproduct of Wanza wood.

4.3.1 Gradation of lightweight aggregate

Sawdust satisfied the grading requirement ASTM C330 as shown in Figure 4.4. The fineness modulus of sawdust is 2.37, which is between 2.3 to 3.1, specified fineness modulus range recommended by ASTM C33.

Table 4.4 Sawdust gradation

Sieve Size (mm)	**Weight Retained (g)**	**Percent Retained**	**Percent Passing**	**Cumulative Percent Retained**	**Percent Passing per ASTM C330**
4.75mm	0	0	100	0	100
2.36mm	4.74	9.5	90.5	9.5	85-100
1.18mm	4.5	9	81.5	18.5	---
600µm	13.27	26.5	55	45	40-80
300µm	11.98	24	31	69	10-35
150µm	12.34	26	5	95	5-25
Pan	2.3	4	0	-	
Total	**49**	**100**		**237**	

$$\text{Fineness modulus}=\frac{\sum \text{Cumulative retained}}{100}= 237/100= 2.37$$

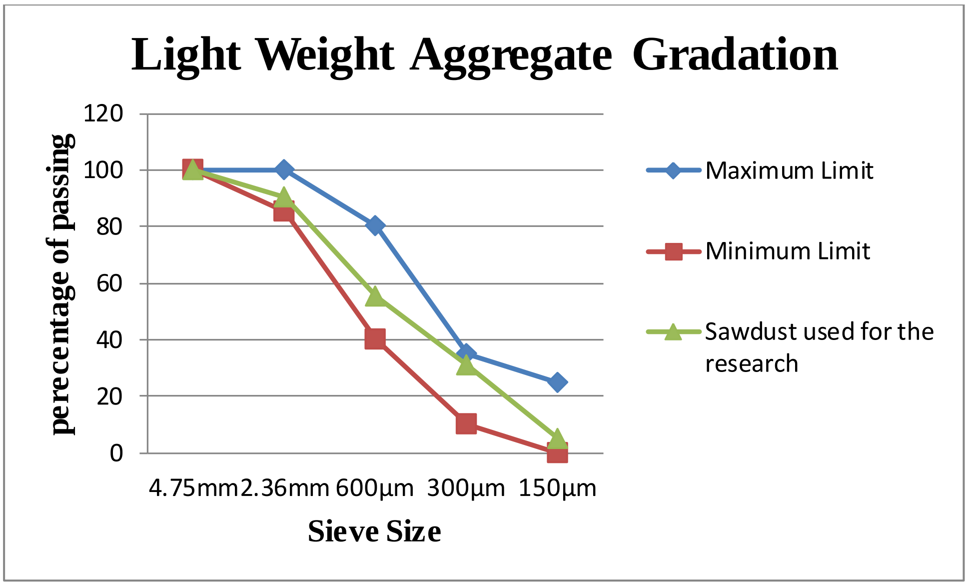


Figure 4.3 Light weight aggregate gradation curve

4.3.2 Sawdust finer than 75µm

Specifications usually limit the amount of material passing the 75µm which can adversely affect the dur ability and increase water requirement of concrete (16). According to the Ethiopian standard it is recommended to reject the material finer than 75µm if it exceeds a value of 6% and the sawdust was found to be 4% which is within the acceptable limit.

4.3.3 Unit weight, moisture content specific gravity and absorption capacity of sawdust

Moisture content, specific gravity and absorption capacity were determined for coarse aggregate according to ASTM C117and ASTM C127 test methods. However, the density of sawdust was measured using methods employed by Araki and Terazawa (39). The test results are summarized in Table 4.5.

Table 4.5 Summary of test results of sawdust

Type of aggregate	Unit weight (kg/m^3)	Specific gravity (Bulk SSD)	Absorption capacity (%)	Moisture content (%)
Sawdust	480	0.49	19.5	10

4.3.4 Chemical composition of sawdust

The chemical composition of Wanza sawdust is determined in Ethiopia Geological Survey Geosciences Laboratory as shown in the Table 4.6

Table 4.6 Chemical composition of Wanza sawdust

Chemical oxides	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_20	LOI
Composition (%)	40.44	11.85	0.01	2.32	5.62	0.01	0.01	0.01	0.05	0.1	14.6	25.1

Table 2.5 provided the chemical composition of pine sawdust. In relation to Table 4.6, the chemical composition Cordia Africana (Wanza) sawdust is not similar to the composition of sawdust of pine sawdust for instance, the silicon di oxide (SiO_2) of pine sawdust is 87% and SiO_2 of Wanza sawdust is 40%. This can proof for the idea that was raised in section 2.3.2 which is sawdust physical and chemical properties vary significantly depending on the species of wood.

Alkali contained within sawdust could lead to alkali silicate reaction which is potentially harmful when they produce significant expansion and hence cracking of concrete, leading to loss of strength. To control formation of such reaction ASTM C618 specifies the maximum content of alkali to be less 0.6 %. As shown in the Table 5.6 the percentage Na_2O and K_2O of Wanza sawdust used for this research is less than specified by ASTM C618. This result indicated that the alkali content in the sawdust will not produce alkali silica reaction. In addition to this, inside the sawdust no sulphate exists which affect the hydration of cement.

4.4 Mixing water and curing water

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

CHAPTER FIVE

TEST RESULTS AND DISCUSSIONS

5.1 Introduction

In this section the test results on the performance of concrete made with partial replacement of sand with sawdust are presented, analyzed and discussed.

5.2 Workability

In this study the slump were determined for each fresh concrete mix according to ASTM C143 standard test method for slump of hydraulic cement concrete at the end of mixing and prior to casting. The results are reported to the nearest of 5 mm as shown in Table 5.1.

Table 5.1 Slump of concrete

Specimen Code	Slump(mm)	Mix Code	Slump(mm)
O	75	**P**	80
O-5	75	**P-5**	75
O-10	70	**P-10**	70
O-15	65	**P-15**	70
O-20	65	**P-20**	65
O-25	60	**P-25**	65

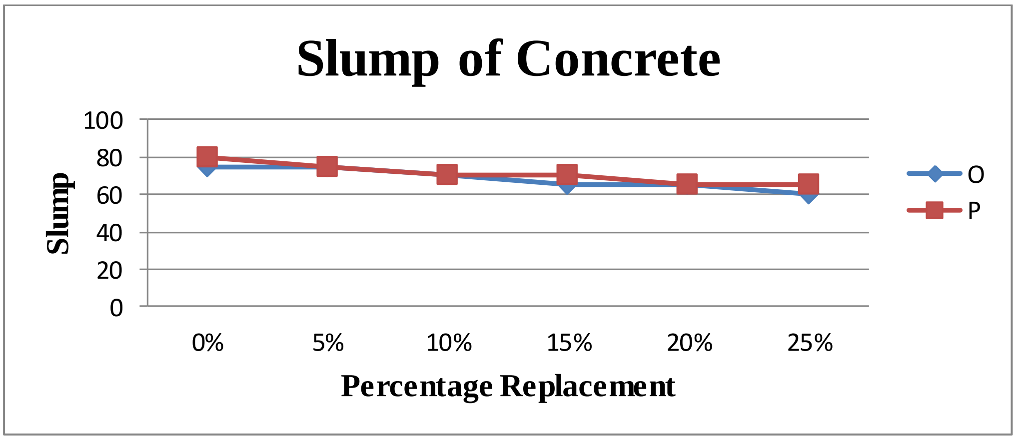


Figure 5.1 Slump of concrete

As shown in Table 5.1 and in the Figure 5.1 the concrete mixes which contain sawdust showed decrease in slump. Since, sawdust has larger surface area to volume ratio it needs more water than sand.

5.3 Slump loss

The stiffening of concrete can be recognized by a loss of slump that usually occurs during placing. The slump was measured every 30 min for each mix until it became zero (0) to know the retardation effect of sawdust in the concrete throughout replacement percentages. The results are reported to nearest of 5 mm Table 5.2. The comparison of slump loss of concrete throughout replacement percentages are illustrated using graph as shown in Figure 5.2 and Figure 5.3

Table 5. 2 Slump loss of OPC concrete

Time (min)	**Slump (mm)**					
	O	**O-5**	**O-10**	**O-15**	**O-20**	**O-25**
0	75	75	70	65	65	60
30	40	40	40	35	35	30
60	0	0	10	15	15	20
90	-	-	0	0	0	0

Table 5.3 Slump loss of PPC concrete

Time (min)	**Slump (mm)**					
	P	**P-5**	**P-10**	**P-15**	**P-20**	**P-25**
0	80	75	70	70	65	65
30	40	45	45	45	35	40
60	0	0	20	25	20	25
90	-	-	0	0	0	0

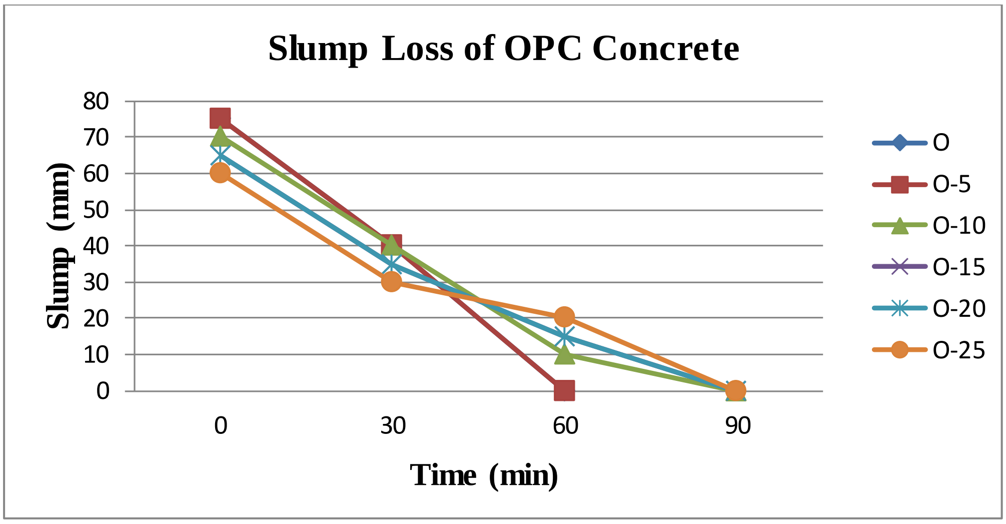


Figure 5.2 Slump loss of OPC concrete

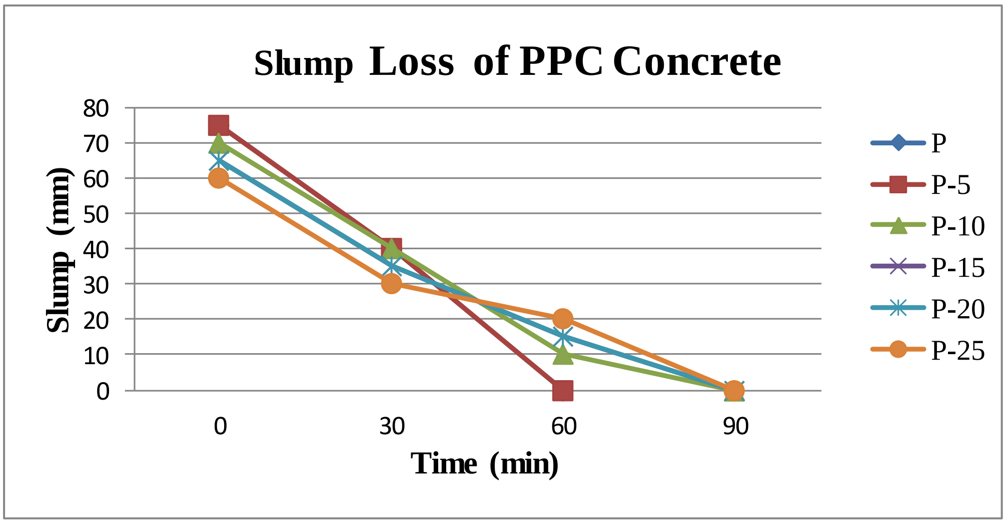


Figure 5.3 Slump loss of PPC concrete

The result shown in the Table 5-2 and Figure 5-2 the slump of concrete mix made with OPC for 0 and 5 % replacement of sand with sawdust became zero in one (1) hour and for 10 %, ,15% , 20% and 25 % replacement of sand with sawdust became zero in 1:30 hour.

As shown in the Table 5-3 and Figure 5-3 the slump of concrete made with PPC for 0% and 5 % replacement sand with sawdust became zero in one hour, for 10 %,15%, 20% and25% became zero in 1:30 hour.

The slump loss of concrete mixes made with OPC and PPC decreased when the percentage replacement of sand with sawdust increased; this means the concrete stiffening decreased when percentage of replacement increased. This indicated, the sawdust retarded the hydration reaction of cement. The probable reason for the retardation of concrete setting time with the increment in percentage replacement of sand with sawdust might be the existence of lignin inside the sawdust.

5.4 Density of concrete

At the end of the required curing days, 3 concrete cubes specimen were taken out for each mix from curing tank to measure the density of concrete before conducting compressive strength.

Table 5.4 Density of 150mm cubes OPC concrete on 28 days

Specimen Code	**Average Weight (kg)**	**Average Density (kg/m^3)**
O	7.893	2338.7
O-5	7.856	2327.8
O-10	7.843	2323.9
O-15	7.805	2312.6
O-20	7.761	2299.7
O-25	7.674	2273.8

Table 5.5 Density of 150mm cubes PPC concrete on 56 days

Specimen Code	**Average Weight (kg)**	**Average Density (kg/m^3)**
P	7.783	2305.9
P-5	7.762	2299.8
P-10	7.67	2272.6
P-15	7.625	2259.3
P-20	7.605	2253.2
P-25	7.588	2248.4

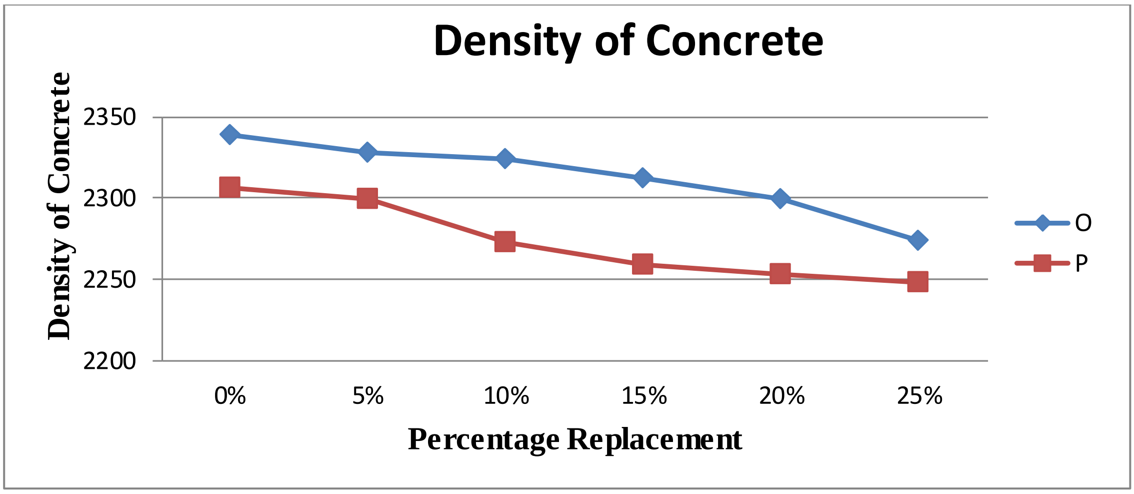


Figure 5.4 Density of concrete

Table 5.4 and 5.5 show the variation of density of concrete made with OPC and PPC at 28days and 56 days of curing. The results show that there was a decrease in the density of concrete made of OPC with increase in sawdust proportion with values ranging from2273.78Kg/m^3 to 2338.67Kg/$m^3$for 5%, 10%, 15%, 20% and 25 %.

Concrete made with PPC also shows decreased in density with increase in sawdust proportion with values ranging from2248.4 Kg/m^3 to2305.93 Kg/$m^3$for 5%, 10%, 15%, 20% and 25 %. The density of concrete decreased because, density of sawdust is less than density of sand. However, all the densities exceeded the 1850kg/m^3which is the maximum density required for lightweight aggregate concrete (13).

5.5 Compressive strength of concrete

In this study ACI 301 specification for structural concrete is used as compliance criteria to check the feasibility of using sawdust as partial replacement in concrete production. ACI 301 states that;

"*The strength level of concrete will be considered satisfactory When: the averages of all sets of three consecutive compressive strength test results molded and cured in accordance with the requirements of ASTM C31M equal or exceed fc´ (specified strength); and no individual* *strength test falls below fc′ by more than 3.5MPa when fc´ is 35MPa or less, or by more than 0.1times fc´ when fc´ is more than 35 MPa."*

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

$$f'cm(t) = f'c * \left(\frac{t}{4+0.85t}\right) \quad \text{[Eq.5.1]}$$

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

$f'c$ - Specified strength

According to Eq. 5.1 concretes made for this study are expected to attain 14.07MPa at 7 days of curing.

Tests for compressive strength of concrete made of OPC and PPC were carried out in this research after the cube samples were fully immersed in water for 7 and 28 days for OPC and for 7, 28 and 56 days for PPC. The mix design was prepared for C-20 according to ACI 211.1. The tests were performed on 150mm cubes due to the reliability and shortage of the available 300x150mm cylindrical molds.

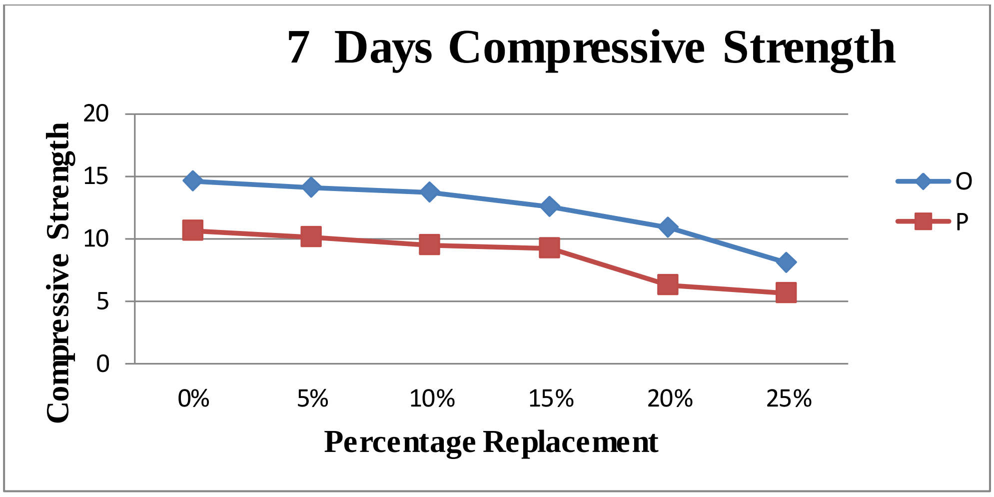
All of the 150mm cube strength test results obtained at 7, 28 & 56 days for PPC concrete and 7 and 28 days for OPC concrete are reported in the Appendixes'. In this section mean cube compressive strength results and percentages which compare loss of strength due to partial replacements of sand with sawdust are shown on Tables 5.6 and 5.7. Figures 5.5 demonstrate the relationship between compressive strength and replacement percentages for all concrete mixes.

Table 5.6 Average cube compressive strength result of OPC concrete

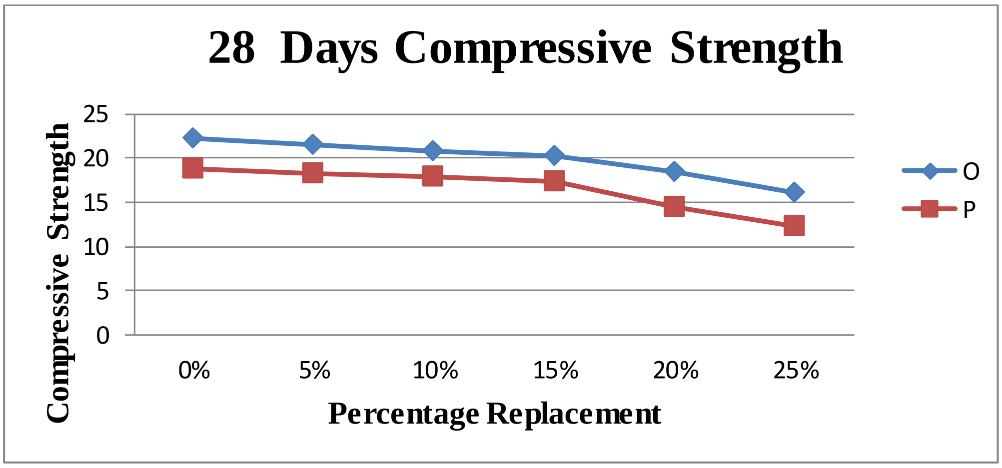
Specimen Code	7 days		28 days	
	Compressive Strength (MPa)	Reduction in Strength (%)	Compressive Strength (MPa)	Reduction in Strength (%)
O	14.61	0	**22.2**	0
O-5	14	4.2	**21.4**	3.6
O-10	13.73	6	**20.8**	6.31
O-15	12.5	14.5	**20.2**	9.01
O-20	10.9	25.4	18.5	16.67
O-25	8	45	16	27.93

Table 5.7 Average cube compressive strength result of PPC concrete

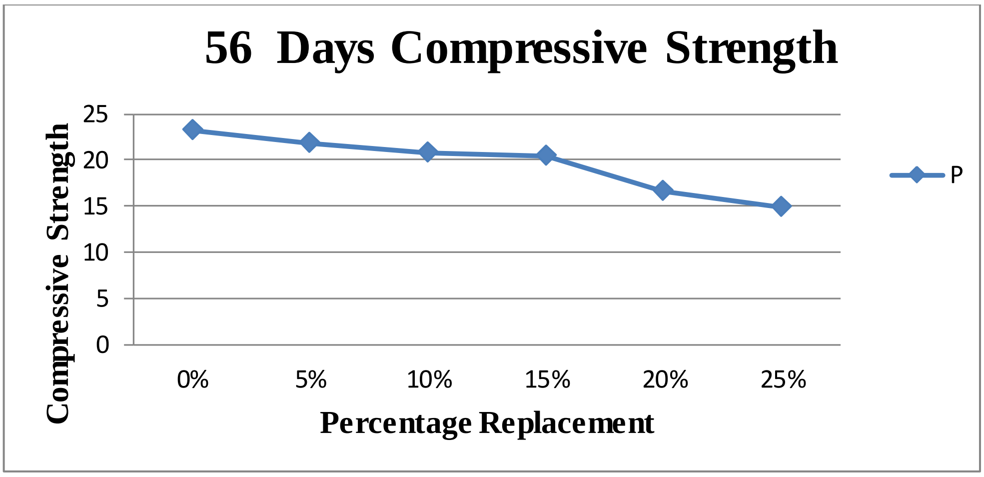
Specimen Code	7 days		28 days		56days	
	Compressive Strength (MPa)	Reduction in Strength (%)	Compressive Strength (MPa)	Reduction in strength (%)	Compressive Strength (MPa)	Reduction in Strength (%)
P	10.6	0	18.8	0	**23.2**	0
P-5	10.1	4.71	18.2	3.19	**21.8**	6.03
P-10	9.45	10.85	17.8	5.32	**20.8**	10.34
P-15	9.2	13.2	17.3	7.98	**20.4**	12.07
P-20	6.2	41.5	14.5	22.87	16.5	28.88
P-25	5.6	52.8	12.2	35.11	14.8	36.21



a)



b)



c)

Figure 5.5 Effect of sand with sawdust replacement at a) 7 days b) 28days c) 56days on the compressive strength of 20MPa cube compressive strength

As shown in the Table 5.6 the compressive strengths of OPC concrete mixes reduced up to 45% with 5%, 10%, 15%, 20% and 25% replacement of sand with sawdust at 7 days. Only 5% partial replacement of sand with sawdust satisfied ACI 209 criteria, which is for early day strength of moist cured concrete, the expected compressive strength to attain is 14.07MPa at 7 days of curing according to Eq. 5.1.

The 28 days compressive strength of OPC concrete made with 5%, 10%, 15%, 20% and 25% replacement of sand with sawdust also showed reduction in the strength from 3.6 to 27.93%.

At 28 days, the compressive strengths of OPC concrete mixes with 5%, 10% and 15% of sand with sawdust replacement satisfy the 20MPa compressive strength compliance criteria of ACI 301.The strengths achieved, 21.4, 20.8 and 20.2MPa respectively, are greater than the specified.

As shown in the Tables 5.7 the compressive strengths of PPC concrete mixes was reduced up to 52.8%, 35.11% and 36.2% at 7, 28 and 56 days respectively. At 7 days of curing, none of concretes cubes in this category satisfy compliance criteria of ACI 209, which is for early day strength of moist cured concrete; the expected compressive strength to attain is 14.07MPa at 7 days of curing according to Eq. 5.1.

At 56 days, the compressive strengths of PPC concrete mixes with 5%, 10% and 15% sawdust replacement satisfy the compliance criteria of ACI 301, the strengths achieved, 21.8MPa, 20.8MPa and 20.4MPa respectively, are greater than the specified.

From the compressive strength of concrete results made by replacing sand with sawdust using both OPC and PPC, the optimum replacement of sand with sawdust is found to be 15% to produce C-20 concrete. To a certain extent the strength of aggregate itself contribute to strength of the concrete. Therefore, the probable reason for low percentage replacement of sand with sawdust is because of sawdust has very low compressive strength compared to sand.

5.6 Water penetration of concrete

For assessing changes related to durability due to replacing of sand with sawdust in concrete production, non-steady state water permeability test was conducted. The maximum and average water permeability reading at28 days and 56 days for concrete made with OPC and PPC respectively are given in Table 5.8 and the changes in permeability through percentage replacement are demonstrated using graph as shown in Figure 5-9

Table 5.8 Water penetration depth of OPC concrete

Sample No.	Mix Code	Penetration Depth(mm)	
		Maximum	Average
1	O	29	24.5
2	O-5	40	38.5
3	O-10	50	45.5
4	O-15	55	50.5
5	O-20	85	75.5
6	O-25	93	88.5

Table 5.9 Water penetration depth of PPC concrete

Sample No.	Mix Code	Penetration Depth(mm)	
		Maximum	Average
1	P	25	22.5
2	P-5	38	34
3	P-10	45	42
4	P-15	54	49.5
5	P-20	78	74.5
6	P-25	87	81

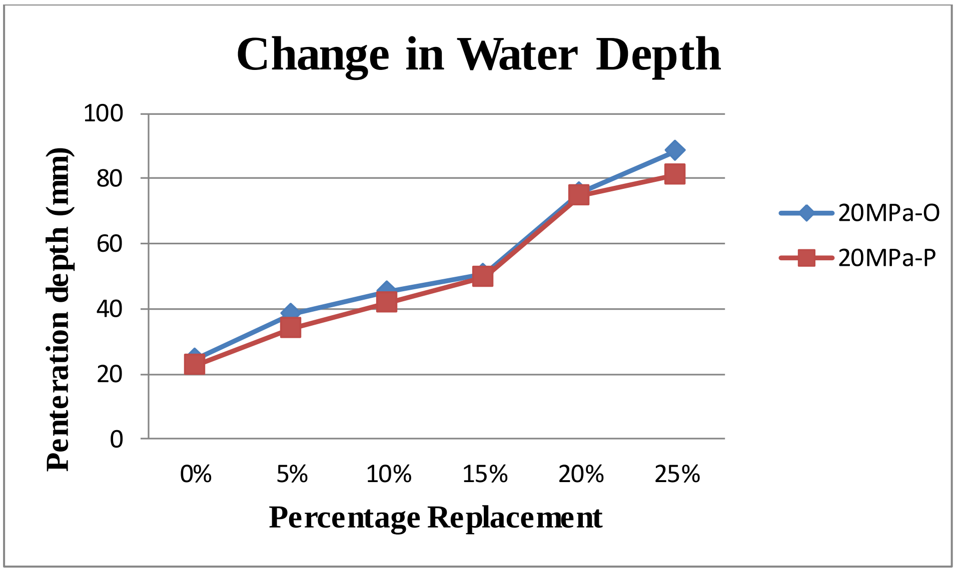


Figure 5.6 Average water penetration depth of concrete

As shown in the Figure 5.6 the replacement of sand with sawdust has significant effect on water permeability of concrete. The Permeability of water in concrete increased with increase percentage replacement of sand with sawdust. The permeability of concretes with the same water/cement ratio is affected by the permeability of the aggregate itself. So, sawdust is very porous material when compared to sand therefore, this might be the reason why permeability of concrete increased with the increase of percentage replacement of sand with sawdust. According to Neville A.M(1995), if water penetration depth in the concrete is less than 50mm the concrete is generally classified as impermeable; and if the penetration depth less than 30mm, it is classified as impermeable under aggressive conditions. Based on this, the concrete produced using sawdust with replacement up to 10% of sand is found to be impermeable concrete. Because maximum water penetration depth of concrete up to 10% replacement of sand with sawdust is less than 50mm; which is 45mm.

`

5.7 Cost Analysis

The production cost of concrete includes direct and indirect cost. The direct cost is material cost, labor cost and equipment cost. In indirect cost there is overhead cost. The major cost that makes a difference in this study is the material cost but both labor and equipment costs remain constant because the replacing of sand with sawdust has not effect on both labor cost and equipment cost.

Cost comparison was made between the control mix and mix with sawdust. The mix with 15% partial replacement of sand with sawdust is the optimum replacement, it satisfies the 20MPa compressive strength compliance criteria of ACI 301 .The strength achieved 20MPa is equal to the specified.

Table 5.10 Cost for control mix per meter cube

Ingredients	Unit	Birr/Unit	Control Mix	
			Quantity	Cost (Birr)
Fine aggregate	m^3	1100	0.317	348.7
Coarse aggregate	m^3	600	0.378	226.8
Cement (PPC)	Qtl	250	3.00	750
			1325.5 Birr/m³	

Table 5.11 Cost for mix with sawdust per meter cube

Ingredients	Unit	Birr/Unit	Mix with Sawdust	
			Quantity	Cost (Birr)
Fine aggregate	m^3	1100	0.27	297
Coarse aggregate	m^3	600	0.378	226.8
Cement (PPC)	Qtl	250	3.00	750
Sawdust	m^3	50	0.048	2.4
			1276.2 Birr/m³	

As shown in the Tables above the cost of special concrete mix decreased by 3.78 % or 49.8 birr per cubic meter than the control mix. This clearly shows that using sawdust in replacement of sand in Tepi can play significant role in the cost reduction during concrete production.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

The following conclusions are derived in line with the objective of this research.

1. Based on the compressive strength test results of the concrete mixes in this research, sand can be replaced by sawdust with an optimum replacement of 15% to produce 20MPa cube compressive strength of concrete.
2. In this research slump, setting time, density and water permeability tests were conducted on concrete produced with sawdust. Based on the results:
    - As the amount of sawdust increases the concrete becomes less workable. The reason could be attributed to the high water demand of sawdust resulting from the high area to volume ratio of saw dust compared to sand.
    - As the amount of sawdust increases the setting time of the concrete also increases.
    - As the amount of sawdust increase the density of the concrete decrease. The reason for this could be sawdust is very light weight compared to sand.
    - The water penetration of concrete increased with increased percentage replacement of sand with sawdust. This is because sawdust is porous material. In this research the concrete produced using sawdust with replacement up to 10% of sand is found to be impermeable concrete.
3. It is possible to save 49.8 Birr or 3.75% of cost for a meter cube of concrete in Tepi, Ethiopia using sawdust by replacing 15% of sand in the concrete without compromising the desired strength.

5.2 Recommendation for Further Studies

In this research, only study of using Sawdust waste in concrete production is investigated; therefore, further investigations are required on the following areas.

- Study on the use of sawdust in the production of Hollow Concrete Block (HCB) by replacing fine aggregate.
- Study on the application of sawdust as a retarding admixture.
- Study on the use of sawdust with Superplasticizers for more than 15% replacement with sand to produce C-20 concrete.

.

REFERENCES

1. G/Micheal A., Utilization of Crushed Jema Sandstones for Concrete Production as Alternative to River Sand. MSC thesis, Addis Ababa university.Addis Ababa, Ethiopia; 2017.
2. Chandana P., Study on Strength of Concrete by Partial Replacement of Fine Aggregate with Sawdust and Robosand. *International Journal & Magazine of Engineering Technology, Management and Research*. Kadapa, India. 2015; 2(9):338-346.
3. Albert M ., Partial Replacement of Fine Aggregate with Sawdust for Concrete production. *International Journal for Technological Research in Engineering*. Kanjirapally India. May2016; 3(9): 2439-2443.
4. Daniel Y and Emanuel N., Compressive Strength of Concrete Using Sawdust as Aggregate. *International Journal of Scientific & Engineering Research*. Cape Coast, Ghana. 2016;7(4): 1349-1353.
5. Getachew T., 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. MSc thesis, Jimma university, Jimma, Ethiopia ;2016.
6. Pervez R., Malaysia Faculty of Civil Engineering Universitiy. Mechanical and Thermal Properties of Sawdust Concrete. MSc Thesis. Malaysia; 2016.
7. Jian H., The Implementation of Waste Sawdust in Concrete. *International Journal of Advanced Science and Technology*. Singapore. 2014; 4(1):19-24.
8. Bdeir L., Study Some Mechanical Properties of Mortar with Sawdust as a Partially Replacement of Sand. *Anbar Journal for Engineering Sciences*. Pakistan. 2012; 5(1):22-30.

9. Taoukil D, Bouardi A, Ezbakhe H and Ajzoul., Thermal Proprieties of Concrete Lightened by Wood Aggregates. *Research Journal of Applied Sciences, Engineering and Technology*. Malaysia. 2011; 6:948-954.
10. Felix F., Sawdust Ash as Concrete Material. *Journal of Materials in Civil Engineering*. Singapore. 2002; 14:173-176.
11. Suji D., Experimental Study on Partial Replacement of Fine Aggregate with Quarry Dust and Sawdust. Department of Civil and Structural Engineering University. Enathur, India. 2016; 3(6):42-54.
12. American Society for Testing and Materials. ASTM C125. Terminology Relating to Concrete and Concrete Aggregates.West Conshohocken, PA 19428-2959, United States. ASTM International. 2003.
13. Neville A.M., Properties of Concrete. 5th Edition. Pearson Education Limited. London; 1996.
14. Mikiyas A. Construction materials, Teaching Material. AAU printing press. Addis Ababa Ethiopia. ;June 1987.
15. American Society for Testing and Materials. ASTM 403. Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance. West Conshohocken, PA 19428-2959, United States. ASTM International. 2003
16. Steven H., Design and Control of Concrete Mixtures. 4th Edtion, Illinois USA :Portland Cement Association;. 2003.
17. Abrar A., Using Marble Waste Powder in Cement and Concrete Production. Addis Ababa University. Addis Ababa, Ethiopia; March, 2011.
18. Illnston J. and Domone P., Construction Materials. 3rd Edition.New York: Spon Press; 2002.
19. Zongjin L., Advanced Concrete Technolgy. New Jersey: John wiley & Sons inc; 2011.

20. Mark A and Sidney M., Aggregate in Concrete. 4th ed. Madison Avenue New York: Taylor & Francis Group; 2010.

21. Bogale B., Comparison of Concrete Durability as Produced by Various Cements. MSc Thesis. Addis Ababa University. Addis Ababa, Ethiopia; 2007.

22. Dinku A., The Need for Standardization of Aggregates for Concrete Production in Ethiopia Construction Industry Report. Addis Ababa, Ethiopia; May 2005.

23. Abayneh M., Construction Materials Teaching Material. Addis Ababa University. Addis Ababa, Ethiopia ; June 1987.

24. G/egziabher N., Comparison of Concrete Properties Produced Using Muger, Messobo and Diredawa Cements. MSc Thesis. Addis Ababa University. Addis Ababa, Ethiopia; November 2005.

25. American Concrete Institute Committee. ACI Education Bulletin E1-07. Aggregates for Concrete. Farmington Hills, U.S.A; August 2007.

26. Negash B., The Importance of Standardization of Aggregate in Ethiopian Construction Industry MSc Thesis. Addis Ababa Univerisity Civil and Eniviromental Engineering. Addis Ababa, Ethiopia; 2014.

27. Gambhir M., Concrete Technology. 2nd Edition. Newdia India. MC Grawhill Book company; 2002.

28. Joseph T., Study on Feasibilty of Using Sawdust as partial Replacement for Sand in Concrete. Msc Thesis. University of Nairobi, Nairobi, Kenya; 2015.

29. Peter M., Glossary of Term in Soil Mechanics, Department of Agirculture. ENS Report 45. Canada; 1976

30. Kamar S., Mineral Perindustrian. Technical Report 12. India; 2004.

31. Addissie D., Handling of Concrete Making Materials in the Ethiopian Construction Industry. MSc Thesis, Addis Ababa University . Addis Ababa, Ethiopia; October 2005.

32. Dinku A., Construction Laboratory Manual. Addis Ababa University. Addis Ababa, Ethiopia; June 2002.
33. American Society for Testing and Materials. ASTM C33. Standard Specification for Concrete Aggregates. West Conshohocken, PA 19428-2959, United States. ASTM International. 2008.
34. Ambiga K., Studies on Strength of Concrete by Partial Replacement of Sand with sawdust. *International Journal of Advanced Engineering Research and Studies*. Enathur, India; June 2015.
35. Dilip K., Low Cost Construction Material for Concrete as Sawdust. *International Journal of Advanced Engineering Research and Studies*. Jhansi, India. October 2014; 4(5):3428-3430.
36. Araki and Terazawa., Physical properties of sawdust and soil (in Japan). Proceedings of the Hokkaido Branch of Japan Wood Research. Hokkiado, Japan; 2004.
37. Adebakin I., Uses of sawdust as Admixture in Production of Lowcost and Lightweight Hollow Sandcrete Blocks. MSc thesis. American jornal of scientific industrial research. Norway. 2012; 3(6):458-463.
38. Gopinath K., Utilization of Sawdust in Cement Mortar & Cement Concrete. *Authority of the State Board of Higher Education*. India. Augest 2015; 6(8):665-682.
39. Thomas T., Ethiopian Forest Action Program. Techincal Report. Ministry of Natural Resources. Addis Ababa, Ethiopia; 1994.
40. Gemedo D., Ethiopian Ministry of Enviroment. Forest and Climate change. Technical Report. Ministry of Environment, Forest and Climate Change. Addis Ababa, Ethiopia; 2017.

41. Rizki M., Scurtiny on Properties of Sawdust from Tropical Commercial Wood Species Effects of Diffrent Mills and Sawdust's Particle Size. *Journal of forestrey Research*. Hokkaido, Japan. 2010; 7(1):20-32.

42. American Society for Testing and Materials. ASTM C143., Standard Test Method for Slump of Hydraulic-Cement Concrete. West Conshohocken, PA 19428-2959, United States. ASTM International. 2003.

43. Ethiopian Building Code Standard., EBCS-2. Structural Use of Concrete. Addis Ababa, Etniopia. Ministry of works and urban development. 1995.

APPENDIX - A

Seven days compressive strength of OPC concrete specimens prepared by partial replacement of sand with sawdust

Specimen Code	Specimen no	Dimensions (m)			Weight (kg)	Failure load (KN)	Compressive strength (Mpa)
		L	W	H			
O	1	0.15	0.15	0.15	7.77	319.5	14..2
	2	0.15	0.15	0.15	7.76	335.3	14.9
	3	0.15	0.15	0.15	7.81	330.8	14.7
					Mean	**328.5**	**14.6**
O-5	1	0.15	0.15	0.15	7.73	293	13.02
	2	0.15	0.15	0.15	7.79	319.5	14.2
	3	0.15	0.15	0.15	7.765	333	14.8
					Mean	**315**	**14**
O-10	1	0.15	0.15	0.15	7.675	317.3	14.1
	2	0.15	0.15	0.15	7.65	301.5	13.4
	3	0.15	0.15	0.15	7.685	308.3	13.7
					Mean	**308.9**	**13.73**
O-15	1	0.15	0.15	0.15	7.63	261	11.6
	2	0.15	0.15	0.15	7.605	312.8	13.9
	3	0.15	0.15	0.15	7.64	270	12
					Mean	**281.3**	**12.5**
O-20	1	0.15	0.15	0.15	7.594	247.5	11
	2	0.15	0.15	0.15	7.62	265.5	11.8
	3	0.15	0.15	0.15	7.6	220.5	9.8
					Mean	245.3	**10.9**
O-25	1	0.15	0.15	0.15	7.573	216	9.6
	2	0.15	0.15	0.15	7.585	177.8	7.9
	3	0.15	0.15	0.15	7.58	146.8	6.5
					Mean	**180**	**8**

APPENDIX - B

Twenty eight days compressive strength of OPC concrete specimens prepared by partial replacement of sand with sawdust

Specimen Code	Specimen no	Dimensions (m)			Weight (kg)	Failure load (KN)	Compressive strength (Mpa)
		L	W	H			
O	1	0.15	0.15	0.15	7.925	468	20.8
	2	0.15	0.15	0.15	7.835	504	22.4
	3	0.15	0.15	0.15	7.83	526.5	23.4
					Mean	**499.5**	**22.2**
O-5	1	0.15	0.15	0.15	7.82	470.3	20.9
	2	0.15	0.15	0.15	7.87	474.8	21.1
	3	0.15	0.15	0.15	7.845	501.8	22.3
					Mean	**481.5**	**21.4**
O-10	1	0.15	0.15	0.15	7.83	461.3	20.5
	2	0.15	0.15	0.15	7.825	472.5	21
	3	0.15	0.15	0.15	7.824	468	20.8
					Mean	**468**	**20.8**
O-15	1	0.15	0.15	0.15	7.8	454.5	20.2
	2	0.15	0.15	0.15	7.789	452.25	20.1
	3	0.15	0.15	0.15	7.814	459	20.4
					Mean	**454.5**	**20.2**
O-20	1	0.15	0.15	0.15	7.78	445.5	19.8
	2	0.15	0.15	0.15	7.74	383.6	17.05
	3	0.15	0.15	0.15	7.72	416.3	18.5
					Mean	416.3	**18.5**
O-25	1	0.15	0.15	0.15	7.73	383.4	17.04
	2	0.15	0.15	0.15	7.63	364.5	16.2
	3	0.15	0.15	0.15	7.65	333	14.8
					Mean	**360**	**16**

APPENDIX - C

Seven days compressive strength of PPC concrete specimens prepared by partial replacement of sand with sawdust

Specimen Code	Specimen no	Dimensions (m)			Weight (kg)	Failure load (KN)	Compressive strength (Mpa)
		L	W	H			
P	1	0.15	0.15	0.15	7.77	263.3	11.7
	2	0.15	0.15	0.15	7.76	213.8	9.5
	3	0.15	0.15	0.15	7.81	238.5	10.6
					Mean	**238.5**	**10.6**
P-5	1	0.15	0.15	0.15	7.73	252.0	11.2
	2	0.15	0.15	0.15	7.79	207.0	9.2
	3	0.15	0.15	0.15	7.765	220.5	9.8
					Mean	**227.3**	**10.1**
P-10	1	0.15	0.15	0.15	7.675	241.9	10.75
	2	0.15	0.15	0.15	7.65	211.5	9.4
	3	0.15	0.15	0.15	7.685	184.5	8.2
					Mean	**212.625**	**9.45**
P-15	1	0.15	0.15	0.15	7.63	234.7	10.43
	2	0.15	0.15	0.15	7.605	210.2	9.34
	3	0.15	0.15	0.15	7.64	177.3	7.88
					Mean	**207**	**9.2**
P-20	1	0.15	0.15	0.15	7.594	160.2	7.12
	2	0.15	0.15	0.15	7.62	140.2	6.23
	3	0.15	0.15	0.15	7.6	119.3	5.3
					Mean	**139.5**	**6.2**
P-25	1	0.15	0.15	0.15	7.573	136.1	6.05
	2	0.15	0.15	0.15	7.585	121.5	5.4
	3	0.15	0.15	0.15	7.58	122.2	5.43
					Mean	**126.0**	**5.6**

APPENDIX - D

Twenty eight days compressive strength of PPC concrete specimens prepared by partial replacement of sand with sawdust

Specimen Code	Speci men no	Dimensions (m)			Weight (kg)	Failure load (KN)	Compressive strength (Mpa)
		L	W	H			
P	1	0.15	0.15	0.15	7.925	425.3	18.9
	2	0.15	0.15	0.15	7.835	429.8	19.1
	3	0.15	0.15	0.15	7.83	415.1	18.45
					Mean	**423.0**	**18.8**
P-5	1	0.15	0.15	0.15	7.82	402.5	17.89
	2	0.15	0.15	0.15	7.87	420.8	18.7
	3	0.15	0.15	0.15	7.845	403.4	17.93
					Mean	**409.5**	**18.2**
P-10	1	0.15	0.15	0.15	7.83	414.0	18.4
	2	0.15	0.15	0.15	7.825	384.8	17.1
	3	0.15	0.15	0.15	7.824	401.9	17.86
					Mean	**400.5**	**17.8**
P-15	1	0.15	0.15	0.15	7.8	375.1	16.67
	2	0.15	0.15	0.15	7.789	412.4	18.33
	3	0.15	0.15	0.15	7.814	382.5	17
					Mean	**389.25**	**17.3**
P-20	1	0.15	0.15	0.15	7.78	303.5	13.49
	2	0.15	0.15	0.15	7.74	329.0	14.62
	3	0.15	0.15	0.15	7.72	347.4	15.44
					Mean	**326.3**	**14.5**
P-25	1	0.15	0.15	0.15	7.73	267.1	11.87
	2	0.15	0.15	0.15	7.63	309.2	13.74
	3	0.15	0.15	0.15	7.65	247.3	10.99
					Mean	**274.5**	**12.2**

APPENDIX - E

Fifty six days compressive strength of PPC concrete specimens prepared by partial replacement of sand with sawdust

Specimen Code	Specimen no	Dimensions (m)			Weight (kg)	Failure load (KN)	Compressive strength (Mpa)
		L	W	H			
P	1	0.15	0.15	0.15	7.847	527.4	23.44
	2	0.15	0.15	0.15	7.80	509.4	22.64
	3	0.15	0.15	0.15	7.82	527.6	23.45
					Mean	**522.0**	**23.2**
P-5	1	0.15	0.15	0.15	7.775	492.8	21.9
	2	0.15	0.15	0.15	7.83	471.8	20.97
	3	0.15	0.15	0.15	7.805	504.0	22.4
					Mean	**490.5**	**21.8**
P-10	1	0.15	0.15	0.15	7.753	479.3	21.3
	2	0.15	0.15	0.15	7.737	456.8	20.3
	3	0.15	0.15	0.15	7.755	469.4	20.86
					Mean	**468**	**20.8**
P-15	1	0.15	0.15	0.15	7.715	467.8	20.79
	2	0.15	0.15	0.15	7.697	451.1	20.05
	3	0.15	0.15	0.15	7.727	460.8	20.48
					Mean	**459**	**20.4**
P-20	1	0.15	0.15	0.15	7.687	346.3	15.39
	2	0.15	0.15	0.15	7.68	402.5	17.89
	3	0.15	0.15	0.15	7.66	361.8	16.08
					Mean	**371.3**	**16.5**
P-25	1	0.15	0.15	0.15	7.652	338.2	15.03
	2	0.15	0.15	0.15	7.608	350.1	15.56
	3	0.15	0.15	0.15	7.165	312.8	13.9
					Mean	**333.0**	**14.8**

APPENDIX – F

Photo Attachments

F-1 Dividing the sand into two part using riffler

a) b)

F-2 Measuring weight a) fine aggregate b) sawdust

a) b)

F-3 Measuring of specific gravity a) sawdust b) sand

F-4 Sawdust inside the mixer

F-5 Measuring Slump of concrete

F-6 Concrete specimens after casting

F-7 Concrete specimens in curing pond

F-8 Concrete inside compression machine

F-9 Concrete on Water permeability testing apparatus

F-10 Measuring water penetration depth of the concrete

APPENDIX- G

Chemical composition of Wanza sawdust

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

Issue date: - 27/04/2018
Request No: GLD/TR/0241/18
Report No: GLD/TR/0264/18

Customer Name: - Getish Lemma Worku

Sample type: - Wanza Wood

Sample Preparation: - 200 Mesh

Date Submitted: - 18/04/2018

Number of Sample: Two (2)

Analytical Result: In present (%) Elements to be determined Major oxides & Minor oxides

Analytical Result: LiBO2 Fusion, HF attack, GRAVIMETERIC, COLORIMETRIC and AAS

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
G.00	40.44	11.85	<0.01	5.62	2.32	<0.01	<0.01	<0.01	0.05	0.1	14.6	25.1

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
G.01	39.2	9.85	<0.01	5.82	3.56	<0.01	<0.01	<0.01	0.05	0.1	15.3	26.25

Analysts	Checked By	Approved By	Quality Control
Tizita Zemene Dessie Abebe Tihitna Beletkachew Yohannes Getachew Nigist Fikadu	Tamiru Siraye	Gosa Haile	Awash Yirga