Utilization of Pine Wood Sawdust as Partial Replacement of Sand in Concrete Production

Teshale Daba Dandena

A Thesis Submitted to the Department of Civil Engineering, School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering (Construction Engineering and Management)

Office of Graduate Studies

Adama Science and Technology University

June 24, 2022

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DECLARATION

I hereby declare that this Master Thesis entitled "Utilization of Pine Wood Sawdust as Partial Replacement of Sand in Concrete Production" is my original work, that is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Teshale Daba Dandena	____________________	______________
Name of student	Signature	Date

RECOMMENDATION OF ADVISORS/ SUPERVISORS

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "Utilization of Pine Wood Sawdust as Partial Replacement of Sand in Concrete Production**"** prepared under my guidance by Teshale Daba Dandena submitted in partial fulfillment of the requirements for the degree of Masters of Science in Construction Engineering and Management. Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Meseret Getnet (PhD)______________ ___________________________ __________________

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ADVISOR'S APPROVAL

I, the advisor of the thesis entitled "Utilization of Pine Wood Sawdust as Partial Replacement of Sand in Concrete Production" and developed by Teshale Daba Dandena; hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Meseret Getnet (PhD)	______________________	_______________
Major Advisor/Supervisor	Signature	Date

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We, the undersigned, members of the Board of Examiners of the thesis by Teshale Daba Dandena have read and evaluated the thesis entitled "Utilization of Pine Wood Sawdust as Partial Replacement of Sand in Concrete Production" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Masters of Science in Construction Engineering and Management.

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ABSTRACT

The construction industry is which rapidly growing industry in Ethiopia and concrete is being widely used in construction of residential buildings, the world produces thousands of tons of sawdust annually from wood products and furniture. 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. This study was evaluated the effect of pine sawdust on concrete properties as well as durability property of concrete. Sets of concrete were produced with pine sawdust at the rate of 5%, 10%, 15% and 20% by volume of the fine aggregate. Conventional mix ratio of 1:2.56:3.43, and water to cement ratio (w/c) of 0.64 was also adopted for the concrete production. The slump of the fresh concrete, the setting time of concrete, density of concrete, compressive strength of concrete, flexural strengths of concrete, water absorption and water permeability of the hardened concrete were tested in accordance to ASTM procedures. Results obtained from the laboratory tests revealed that the pine sawdust had impact on the mechanical properties of the concrete. The compressive and flexural strengths of the concrete increase as quantity of sawdust increased from 5% to 10% and then it decreased, as the quantity of the pine sawdust increased from 10% to 20%. Water absorption and water permeability of concrete increase as the quantity of pine sawdust increased due to the fineness of sawdust increased. *When compared to the results obtained from concrete produced without pine sawdust, it was observed the pine sawdust enhanced the compressive and flexural strengths of the concrete produced. Regression analysis of the obtained results affirmed that pine sawdust can influenced the mechanical properties of concrete. Concrete produced with 10% pine sawdust had higher a Pearson correlation coefficient with concrete without pine sawdust (control mix). Results obtained from this study showed that it is possible to save 66.50 ETB or 1.8 % of cost for a meter cube of concrete in Ethiopia using sawdust by replacing 10% of sand in the concrete without compromising the desired strength. For further Study, this study recommends study on the use of pine sawdust with Super plasticizers to substitute sand in C-20 concrete which more than 10% replacements.*

Key words: - Compressive strength, Durability, Fine aggregate, pine sawdust, Sand.

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LIST OF ACRONYMS

ACI	American Concrete Institute
Al_2O_3	Aluminum Oxide
ASTM	American Society for Testing and Material
CA	Coarse Aggregate
CaO	Calcium Oxide
EBCS	Ethiopian Building Code Standard
ETB	Ethiopian Birr
FA	Fine Aggregate
Fe_2O_3	Iron oxide
MgO	Magnesium Oxide
MM	Millimeter
Mpa	Mega Pascal
OPC	Ordinary Portland cement
SD	Saw Dust
SiO_2	Silicon dioxide
TMCS	Target Mean Compressive Strength
WCA	Weight of Coarse Aggregate

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

The world produces thousands of tons of sawdust annually from wood products and furniture industry. Where these wastes accumulate and generate a serious environmental problem. To overcome this problem, researchers have found the possibility to use it in concrete (Abed and Khaleel 2019). Concrete is one of the most widely used construction material in the world. It is composed of coarse aggregate, fine aggregate, cement and water (Meko and Ighalo, 2021). It has been in use for over a century in all construction works. A new material in the field of concrete technology has been developed during the recent past with the ongoing demand of industries to meet the functional, strength, economical and durability requirements (Shameem et al., 2020).

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 (Molla, 2022).

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 (Ofuyatan and Adeniyi, 2021). In this changing time, sawdust might just be one of solutions for the increase in cost of concrete production by replacing sand (Lemma, 2019).

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 (Manoj et al., 2021).

In Ethiopia, the wood production is 69 million m3 of logs in 2020 (Girma et al., 2021). In the wood production industry about 15-20% waste is generated from total production although the reutilization of wood waste has been practiced. Construction industry can be the user of wood waste and this way can contribute to solve the environmental pollution (Khan et al., 2020).

This study were focus on using pine sawdust as partial replacement of sand in the production of concrete, which was use in building construction by ensuring the desired strength of concrete and durability as well as this study was determine the effects of pine sawdust on concrete properties and cost analysis were address.

1.2 Statement of the Problem

The construction industry is which 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 (Alsadey et al., 2021). Because, concrete is a composite mixture of binding material, filler material (coarse and fine aggregate) and water; which combines the whole mass. In the concrete, mix design is to achieve maximum durability and compressive strength as possible as without any compromise with the quality. Engineers and scientists are further trying to increase its limits with the help of innovative chemical admixtures and various supplementary binding and filler materials along with modified manufacturing techniques. Now a day's lot of technology is used in the field of concrete technology that modifies concrete properties.

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 (Lemma, 2019).

Sawdust is a 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. Generation of wood wastes in sawmill is an unavoidable environmental pollution and hence a great efforts are made in the utilization of such waste (Tilak and Singh, 2018). Wood Sawdust is waste which when burnt, produce lot of carbon emissions which pollutes the environment. If this waste is used in concrete, then there will be less emissions of carbon dioxide in environment; as it uses the saw dust material in concrete. The replacement of fine aggregates with saw dust can be beneficial for the building components (Sawant et al., 2018).

Thus, this research investigates the effect of pine wood sawdust wastes in concrete production to produce a fine aggregate for construction purpose. Now a day the cost of sand increasing from time to time and it became very expensive. So in this study the pines sawdust was partially replace the sand which is very expensive. The availability of pines wood in Ethiopia like jimma Zone, West shoa Zone, Chilimo plantation forest and in the Central Highlands of Ethiopia (Tesfaye et al., 2020). And also previous studies to date have focused on these byproducts and their effects on physical and mechanical properties, while the durability of pine sawdust on mechanical properties of concrete as well as the cost of natural sand has badly progressed at all. The pine sawdust concrete properties, durability of sawdust concrete, effects pine sawdust on sawdust concrete do not explained in detail. To answer this research problem this study have the objectives which was evaluated the effect of pine sawdust on concrete properties as well as durability property of concrete test and optimum replacement were determined, cost analysis of sawdust concrete was addressed in detail.

1.3 Objectives of the Study

1.3.1 General objective of the study

The main objective of this study was to investigate the utilization of pines wood sawdust as partial replacement of sand in concrete production.

1.3.2 Specific objectives of the study

1) Effect of pine sawdust on concrete properties; workability, compressive strength, flexural strength, setting time and density of concrete.
2) To determine the durability of concrete produce with pine sawdust in concrete production; based on water absorption and water permeability.
3) To determine the optimum utilization of pine sawdust as partial replacement of sand in the production of concrete based on cost analyses.

1.4 Research Questions

The research was answered the questions which rise as following:

1. What are the effects of using pines sawdust as partial replacement of sand on the properties of concrete?
2. What are the effects on durability of concrete as partial replacement of sand with pine sawdust?
3. How much the optimum amount of pines sawdust and cost of concrete would be improved by using pines sawdust as sand?

1.5 Scope of the Study

The scope of this research is focused on to produce concrete with strength class of C-20 with, using sawdust of pines wood as partial replacement of sand which is to be used for buildings in Ethiopia. And also it was focused on the effect of pine sawdust on the concrete properties as well as in addition to the durability properties of concrete. That means, this research mainly focuses on the workability, compressive strength of concrete, flexural strength of concrete, density of concrete, water absorption of concrete, water permeability of concrete and cost analysis of concrete made with pine sawdust as partial replacement of sand.

1.6 Limitation of the Study

The following were the paper work limitation:-

- The study is concerned with effect of pine sawdust on workability, mechanical and durability of concrete property only, and was not take in to account the chemical properties analysis (morphological structure).
- Embodied energy factor of sawdust does not include.

1.7 Significance of the Study

The main significance of this research is to use pines sawdust waste in construction to get as much benefit as possible. The significance of sawdust concrete production was to reduce the degradation. The use of sawdust not only reduces the natural degradation but also protects the concrete material from sacristy of natural resource. the most of sawmill sawdust was dumped at landfill which causing the landfill to pile up and increased its volume day to day since it is used in concrete it protects the natural material or rive sand. Another significance of this study is by using the sawdust in concrete mix it reduced the cost of fine aggregate because the sawdust can get cheaply. Besides, when the cost of fine aggregates are reduced, the overall cost of construction was decreased because sawdust can be obtained cheaply at sawmills or sometimes with cost-free and also the natural resource like sand was utilized wisely.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

2.1 Introduction

Sawdust technology has been investigated and utilized in areas of the United States, the United Kingdom, Germany, as well as Singapore and Malaysia, since at least the 1930s. The materials have been utilized for both flooring and walls in some cases (Plaza et al., 2015). Wood wastes, in the form of wood waste, can be used to replace sand in concrete without any prior treatment. The findings show that incorporating shavings into concrete not only reduces the density of the material, but also increases its thermal conductivity, all while maintaining a homogeneous structure and strong adherence of the wood to the concrete matrix (Afrifah et al., 2020).

Sawdust has been used in concrete before, but it hasn't been widely used. Although its low compressive strength limits it, it also has major restrictions that must be understood before it is put to use. Because sawdust is an organic material, it was alter the setting and hydration reactions 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 (Madrid et al., 2017). Sawdust also increased the thermal insulation of concrete by lowering the thermal conductivity of the material. The use of sawdust in the production of lightweight concrete has gotten a lot of attention in recent years. The structural qualities of sawdust concrete have been studied, and the results have been promising (Kabir et al. 2019).

2.2 Constituents of Concrete

2.2.1Cement

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. 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 (Ogunyemi and Ojo, 2019).

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) (Omopariola, 2020).

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

2.2.1.1Ordinary 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 (Huang et al., 2021).

2.2.1.2 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 (EB001, 2020).

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 (Omopariola, 2020).

2.2.2 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 (Nguyen et al., 2018).

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 (Mary, 2019).

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.(George, 2021)

2.2.3 Aggregates

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 (Chitra and Thendral, 2020). Aggregate properties significantly affect the workability of plastic concrete and also the durability, strength, thermal properties, and density of hardened concrete (Kabir et al., 2019).

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 economic and technical advantages in making concrete (Grâce et al., 2020).

In choosing aggregate for use in a particular concrete, attention should be given among other things to three important requirements (EB001, 2020). 1) Workability, when fresh for which the size and gradation of the aggregate should be such that undue labor in mixing and placing will not be required. 2) Strength and durability when hardened for which the aggregate should: 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 and 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 and well graded in order to minimize paste hence cement requirement.

2.2.4 Classification of aggregate and Properties

Aggregates can be divided into several categories according to different criteria (Ayende and Novianto, 2021).

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

In accordance with unit weight :- Lightweight aggregate: The unit weight of aggregate is less than 1120 kg/m3.The corresponding concrete have a bulk density less than 1800 kg/m3. Normal weights 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 weights aggregate: The unit weight is greater than 2100 kg/m3. The bulk density of the corresponding concrete is greater than 3200 kg/m3.

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.

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 (Mamo, 2019).

According to ASTM C33, (2010) 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.

2.2.4.1 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 (Factsheet, 2018)

2.2.4.2 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 (Nazari et al., 2018)

2.2.4.3 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 (Abed and Khaleel, 2019).

2.2.4.4 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 (Noratikah et al., 2021).

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 (Shameem et al., 2020).

2.2.4.5 Potential harmful materials

Various substances in aggregates can interact with the cement in concrete or have otherwise undesirable effects. Such as, sulphates may influence cement hydration, while excessive chlorides can incur corrosion of reinforcing steel (Huseien et al., 2018).

"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" (Huang et al., 2021)

Table 2.1 Deleterious substances in aggregates (Kirubakaran, 2019)

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 (Huang et al., 2021)

2.2.4.6 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 (Get et al., 2019).

2.2.4.7 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 (Get et al., 2019)

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 (Shamem et al., 2019).

2.3 Utilization of Locally Available Materials in Concrete

2.3.1 Origin of sawdust

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 woods into different sizes (Tilak and Singh, 2018).

2.3.2 Physical properties of saw dusts

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 properties of the sawdust will not be the same and it will vary from one tree to another tree (Molla, 2022).

2.3.3 Comparison between sand and sawdust

Sand is a loose granular material which available in beaches, riverbeds and deserts of the world. It composed of different materials which depending on its location and also various colors from white black and also pink. The general component of sand is silicon dioxide which is in form of quartz (Huseien and Kubba, 2018). The earth's land is made up from various types of rocks and minerals which include quartz, feldspar and mica. While, sawdust is composed of fine particles of wood (Sawant et al., 2018). There are several similarities between sawdust and sand in terms of density and particle sizes. The density of sawdust ranging from 650kg/m3 to 1650kg/m3 while the density of sand is from 1500 kg/m3 to 1600 kg/m3. A particle size of sawdust is between 30 to 600 microns while the particle size of sand is 70 to 800 microns. Thus, it is quite similar and the usage of sawdust to replace sand is suitable (Huda Suliman et al., 2019)

2.3.4 Chemical composition of soft wood 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.

Table 2.2 Chemical Composition of Sawdust of juniperus procera (Sawant et al., 2018)

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

2.3.5 Density of sawdust

Density of the sawdust can be determined by the method employed by Araki and Terazawa (Oi, Gg, and Uguru 2021). The sawdust density determine by:-

Density of sawdust (g/cm^3) = [Wb – Wa]/Vo

Where, Wb = weight of sawdust with volumetric cylinder

Wa = weight of empty volumetric cylinder

Vo = 100 cm^3

2.4 Properties of Sawdust Concrete

2.4.1 Properties of fresh 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 (Lemma, 2019). Fresh concrete is defined as concrete at the state when its components are fully mixed but its strength has not yet developed. This period corresponds to the cement hydration stages 1, 2, and 3. The properties of fresh concrete directly influence the handling, placing and consolidation, as well as the properties of hardened concrete. Some of important properties of fresh concrete are discussed as follows.

2.4.1.1 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 (Siddique et al., 2020).

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 (Harelimana et al., 2019).

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 (Agbi, 2021). 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(Awal and Memon, 2018).

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 (Skutnik et al., 2020).

2.4.1.2 Setting time of concrete

ASTM C403 defines time of setting as the elapsed time from addition of mixing water to a cementations' mixture until reaches a specified degree of rigidity as measured by a specific procedure. The development of rigidity in cementations' mixture is a gradual and continuous process. For cementations mixture development of rigidity is measured as the elapsed time to attain a specified level of resistance penetration by a probe.

According to 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) 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 (Huang et al., 2021).

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 (Zhang and Zong, 2019).

2.4.2 Properties of hardened 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 (Yakubu and Bukar, 2020). 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 (Prasetia and Pratiwi, 2022).

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 (Chitra and Thendral, 2020)

2.4.2.1 Compressive strength of concrete

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 (Shameem et al., 2020).

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 (Gambo et al., 2018).

According to Lemma,(2019) in Ethiopia, it investigate the study on the partial sand replacement with sawdust compressive strengths of OPC concrete mixes with 5%, 10% and 15% sand with sawdust replacement satisfy the 20Mpa(Mega Pascal) 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.

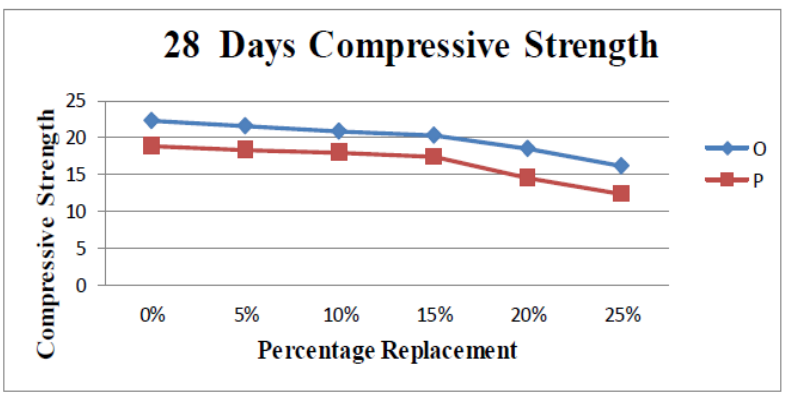

Figure 2-1 Compressive strength of sawdust concrete (Lemma 2019)

According to Shemam, (2021) Sand replaced by weight 0, 5, 10, 15, 20 and 25% with wood sawdust. Average results for compressive strength was detected as 30.13, 21.39, 13.46, 11.23, 8.02 and 6.49 N/mm2 respectively.

According to Noratikah et al, (2021) the concrete with 5% durian sawdust also exhibited an increment in strength from 13.78 Mpa on 7th day, to 16.31 Mpa on 14th day, to 21.41 Mpa on 28th day. This gradual increase in strength from concrete containing 5% durian sawdust gave the most acceptable result which the exceeded M20 strength limits (20 Mega Pascal). The suitability of the sawdust in concrete was completely tested to measure the possible changes and the causes. The optimum strength for durian sawdust can be achieved with the maximum replacement of only 5% durian sawdust.

2.4.2.2 Flexural strength of concrete

The unreinforced beam of 100 x 100mm x 500mm is used. Because of the concrete brittleness, the failure occurs suddenly and single crack will be obtained at the time of failure of a beam(ASTM ,2001).

According to Awal and Memon, (2018) in Ethiopia, the test was done by using 100x100x500 mm prism specimens. The maximum load sustained was recorded and the average flexural strength was calculated at the age of 7, 28 and 56 days. Figure below shows the gain in strength with 0.65, 1.00 and 1.40 water/cement ratio. Similar to compressive strength the flexural strength of concrete specimen also followed the same trend; the higher the amount of sawdust the lower the flexural strength. However, the graph shows rapid increase tendency of 1:1, 1:2 and 1:3 ratio of cement sawdust concrete at later ages. Highest strength of 5.77 Mpa was recorded for 1:1 ratio cement sawdust and lowest strength of 0.77 Mpa (Mega Pascal) was recorded for specimen containing 1:3 ratio cement sawdust at the age of 56 days**.**

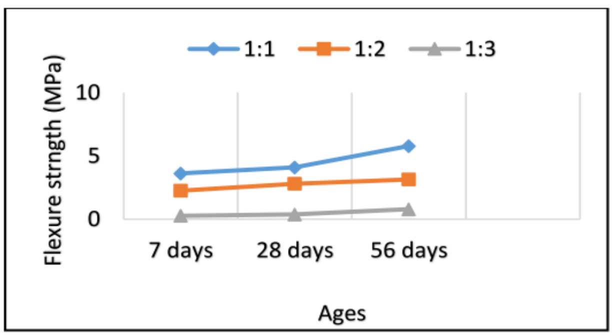

Figure 2-2 Flexural strength of sawdust concrete(source; (Awal and Memon ,2018))

2.4.2.3 Density of concrete

According to Harelimana and Nteziryayo, (2019) Concrete cubes made as a result of partial replacement of sand with sawdust were tested for density and the findings are presented and discussed in this study. It was discovered that the density kept on decreasing as sawdust content increased in the mix. In general, when curing days increased, the density did the reverse for each percentage of sawdust.

2.5 Durability of Concrete

According to Yakubu and Bukar, (2020) studies, different concretes require different durability depending on the conditions of the exposed environment. Concrete components, dosages of these components, interactions between components, and ingredient and hardening determine the durability and service life of concrete. Also, the durability of concrete depends mainly on the exposure conditions. The type of concrete used the quality of the material, and the degree of voids and pores in the concrete cover over the rebar also affect the durability of the concrete (Arivalagan and Sethuraman, 2020).

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

2.5.1 Permeability of concrete

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(Huseien et al., 2018).

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 (Lemma, 2019).

2.5.1.1 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. 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 (Ayende and Novianto, 2021). Water permeability of concrete can be evaluated under both steady state and non-steady state condition (Aleem et al., 2015).

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

K=e2v/2ht ……………………………………………………………………..…Equation 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 (Skutnik et al., 2020). 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 hours, 0.5MPa (5 bar) for the next 24 hours and 0.7MPa (7 bar) for the last 24 hours. At the last 24 hours the specimens was be removed from water penetration apparatus and will be split using tensile splitting machine. After Splitting, the maximum and average depths of water penetration was be measured (Skutnik et al., 2020)

2.5.2 Water absorption of concrete

The water absorption of the concrete following the incorporation of different amounts of sawdust, the concrete specimens with sawdust absorbed more water than the reference concrete as the amounts of the by-products increased (Ezeagu, 2020). The experimental results demonstrate that sawdust significantly increases the absorption of concrete. These results were expected due to the high hygroscopic behavior of this material compared to the reference concrete, the volumetric replacement of sand by sawdust at amounts of 5, 10 and 20% show absorption of 48.9, 87.7 and 112.2%, respectively (Madrid et al., 2017).

2.6 Cost Analysis of Sawdust Concrete

According to Chitra and Thendral, (2020) ,Cost comparison was made between the control mix and mix with sawdust. 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.so it has the great effect on material cost that means it decrease the material costs.

According to research in Ethiopia Lemma, (2019), price of wanza sawdust 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 can play significant role in the cost reduction during concrete production.

Table 2.3 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	Qtl	250	3.00	750
			1325.5 Birr/m^3	

Table 2.4 Cost for mix with wanza sawdust per meter cube

Ingredients	unit	Birr/unit	Control mix	
			quantity	Cost (Birr)
Fine aggregate	M^3	1100	0.27	297
Coarse aggregate	M^3	600	0.378	226.8
cement	Qtl	250	3.00	750
sawdust	M3	50	0.048	2.4
			1276.2 Birr/m^3	

2.7 Summary of Literature Review

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. Research conducted on the use of sawdust as partial replacement of sand material shows effects on concrete properties. (Lemma, 2019), in Ethiopia identify that the sand can be replaced up to 15% by Cordiana Africa sawdust to produce C-20 concrete (Molla, 2022). Sand replaced up to 20% to produce C-25 concrete (Noratikah et al., 2021) the sand can be replaced up to 5% to produce C-20 concrete. Moreover, sawdust as partial replacement of sand in concrete production has been found to show different effects on fresh and hardened properties of concrete; essentially on workability, compressive strength of concrete and also the material cost was decreased when sawdust partial replace the sand.

To identify the research gap, 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 pines saw dusts wastes are high in Ethiopia. However from the existed literature the study does not explain effect of pine sawdust on concrete properties as well as costs utilization of pine sawdust with sand on the production of concrete which is conducted in Ethiopia. And also previous studies to date have focused on these byproducts and their effects on physical and mechanical properties, while the analysis of durability properties and increasing cost of construction material has hardly progressed at all. To fulfill this research gap the study of utilization of pines sawdust as partial replacement of sand in concrete production is important. And also investigation on the physical, mechanical and durability properties of sawdust concrete are also part of interest.

CHAPTER THREE

RESEARCH MATERIALS AND METHODS

3.1 Introduction

This research was involved laboratory tests by preparing samples of concrete block mixes and the tests that was carried out on fresh concrete and harden concrete was to be conduct as per standard test for partial material replacement and conventional concrete. In addition to this, physical properties of sawdust, fine aggregate and coarse aggregate were be determined in the laboratory as per the standards. As well as, chemical composition of sawdust was tested to know the existence elements in the pine sawdust wood. Similarly, the effect of pine sawdust on the properties of concrete was determined. The type of this research is Quantitative experimental research. It used the descriptive and inferential statistical analysis. Descriptive were used for the first and second objectives as well as inferential were used for the first and second objectives. Prior to this, the way to understand different properties sand replacement material in concrete block and what is required to produce such type of concrete block were to be made possible by referring different literature written on properties concretes.

3.2 Research Materials

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

3.2.1 Cement

The cements used for this research is Ordinary Portland cement (OPC) which is available locally on market to be used for this research. Brand of the cement was Dangote class 42.5R and also which is conforming to the (ASTM C150/C150M, 2019) specifications was used for this research and the chemical and physical characteristics of cement were identified as specification.

3.2.1.1 Soundness test of cement

The cement samples tested for the soundness test has 1mm expansion after boiling the molded samples for about 3½ hours.

Table 3.1 Soundness Test of cement (Appendices H1)

Trial No	Initial distance between the indicator needles A mm	Final distance between the indicator needles B mm	Soundness Value	Average Soundness value
1	13	14	14mm -13mm	1mm
2	13	14	14mm -13mm	

3.2.1.2 Fineness of cement

Table 3.2 Fineness of cement by sieve (150 and 75 µm) (Appendices H4)

No	Sieve size	Cement sample gm	weight of residue gm	% of residue	Average of residue %
1	150 µm	50	3	6	6
2	75 µm	50	4.3	8.6	8.6

3.2.1.3 Normal consistency of cement test

The normal consistency of Dangote is the highest with water content of 29%

Table 3.3 Normal Consistency of cement test (Appendices H2)

No	Water gm	Cement Sample gm	Penetrated depth from the top surface of sample mm
1	145	500	9mm

Figure 3-1 Normal consistency of cement (Appendices H2)

3.2.1.4 Setting time of hydraulic cement

By taking 500g of cement and prepare cement paste of normal consistency. Insert the paste in to the conical ring and then remove the excess and after 30 seconds tighten the screw and set the indicators at the upper end of the scale or take the initial reading. Initial setting time was 49 minutes and final setting time was 4 hours and 30 minutes.

Table 3.4 Setting time of hydraulic cement (Appendices H3)

Penetration time minute	Penetration depth in mm
After 30 seconds	9
After 15 minutes	15
After 30 minutes	18
After 45 minutes	23
After 1 hour	31

Figure 3-2 Setting time of hydraulic cement (Appendices H3)

3.2.2 Fine and coarse aggregate

Throughout the experiment, River sand of Metahara Ethiopia used as fine aggregate and basaltic crushed stone as coarse aggregate which are available from local market were used. Gradation of fine and coarse aggregates were conduct as per ASTM C136 (ASTM C136 ,2001). And for fine aggregates replacing material (pine wood sawdust)(ASTM C330, 2009) was apply.

Figure 3-3 Aggregate used in the research (Appendices N)

3.2.2.1 Gradations 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 C136 (ASTM C136, 2001)as shown in Table 3.5 and 3.6**.** And for fine aggregates replacing material (pine wood sawdust)(ASTM C330, 2009) were apply.

The fineness modulus of sand was 2.66, which is between 2.3 to 3.1, specified fineness modulus range for sand according to ASTM C33.

Table 3.5 Fine aggregate gradation (Appendices)

Sieve Size	**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	31.6	6.32	93.68	6.32	80-100
1.18mm	71.66	14.33	79.35	20.65	50-85
600µm	165	33	46.35	53.65	25-60
300µm	173.33	34.66	11.69	88.31	10-30
150µm	45	9	3.69	97.31	2-10
Pan	5	1	2.69		
Total				266.24	

Fineness modulus$=\frac{\sum commulative\ retaiend}{100}$ =266.24/100= 2.66

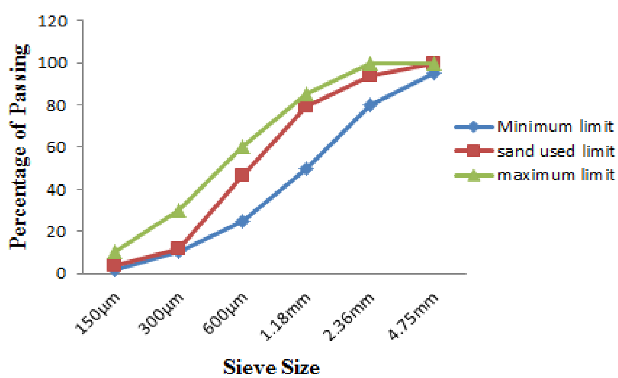

Figure 3-4 Fine aggregate gradation

Table 3.6 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	95-100
25	395	19.75	80.25	19.75	--------
19	902	45.1	35.15	68.85	35-70
12.5	482	24.1	11.05	88.95	------
9.5	192	9.6	1.45	98.55	10-35
4.75	18	0.9	0.55	99.1	0-5
Pan	0	0		0	
Total				675.2	

Fineness modulus$= \frac{\sum commulative\ retaiend}{100}$ =675.2/100= 6.75

Figure 3-5 Coarse aggregate gradation (Appendices N)

3.2.2.2 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. The silt content of river sand before washed it was found 7.4% which is above the limit 6%. 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 2.6 %. 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.

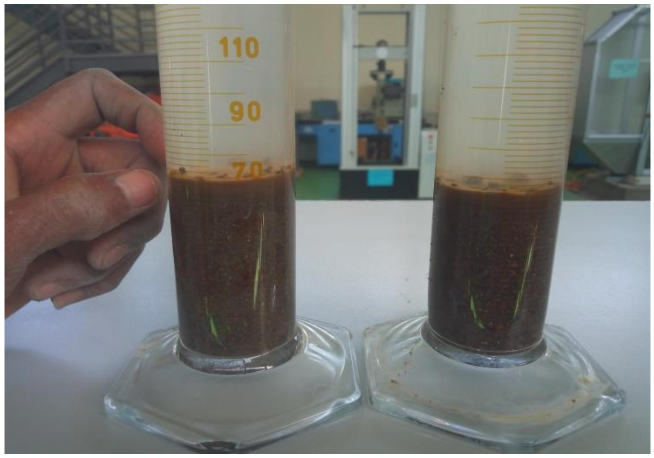

Figure 3-6 Silt content test of fine aggregate

Table 3.7 Moisture content of fine aggregate

No	Weight of fine aggregate wet test portion in gm = A	Weight of fine aggregate after oven dry test portion in gm= B	Moisture contents In %	Average moisture contents in %
1	500	495	(A-B)/B*100 (500-495)/495 *100	1.01

Table 3.8 Moisture content of coarse aggregate

No	Weight of coarse aggregate wet test portion in gm = A	Weight of coarse aggregate after oven dry test portion in gm= B	Moisture contents in %	Average moisture contents in %
1	2000	1985	(A-B)/B*100 (2000-1985)/1985 *100	0.75

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

The unit weight (Appendices B), moisture content (Appendices C1 and C2), specific gravity (Appendices D2 and D1) 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 3.9

Table 3.9 Summary of test results on fine and coarse aggregate

Type of aggregate	Unit weight (kg/m3)		Specific gravity (Bulk SSD)	Absorption capacity (%)	Moisture content (%)
	compacted	loose			
Fine aggregate	1310	1160	2.41	5.0	1.01
Coarse aggregate	1624	1571	2.88	0.50	0.755

Figure 3-7 Summary of test results on fine and coarse aggregate (Appendices C and D)

3.2.3 Pine sawdust

The pine sawdust were sourced from sawmills and furniture firms in Ambo, Ethiopia. In this study the wood species called pine (softwood) sawdust were used. The sawdust was collected in plastic bags and sundry for 24 hours to expel all moisture. To ensure uniform drying, they were thoroughly agitated and then used in this laboratory study.

Figure 3-8 Pine sawdust (Appendices N)

3.2.3.1 Gradation of pine sawdust's

Sawdust satisfied the grading requirement ASTM C330 as shown in figure 3.9. 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 3.10 Pine sawdust gradation

Sieve Size	Weight Retained (g)	Percent Retained	Percent Passing	Cumulative Percent Retained	Percent Passing per ASTM C330
4.75mm	0	0	100	0	100
2.36mm	46.4	9.3	90.7	9.3	85-100
1.18mm	45	9	81.7	18.3	------
600µm	141.7	28.34	53.36	46.64	40-80
300µm	119.8	23.96	29.4	70.6	10-35
150µm	122	24.4	5	95	5-25
Pan	23	4.6		-	
Total				239.84	

Fineness modulus$=\frac{\sum commulative\ retaiend}{100}$ =239.84/100=2.40

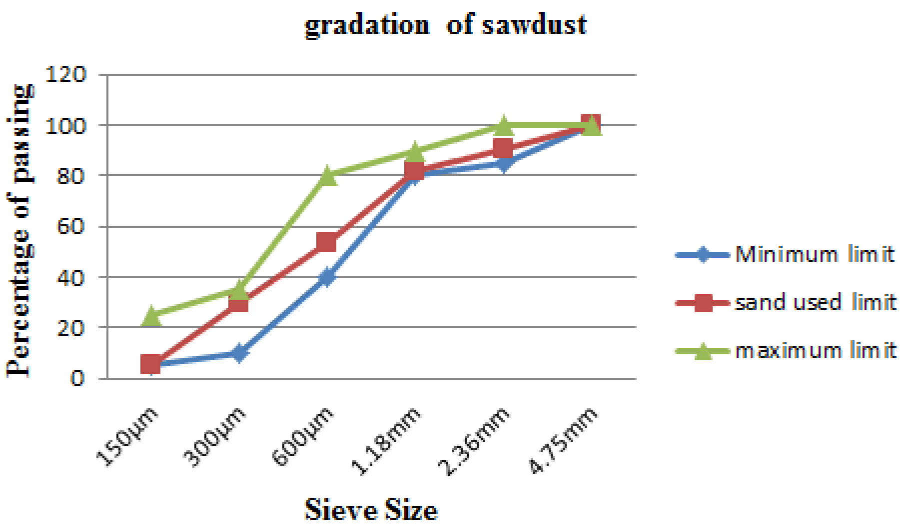

Figure 3-9 Gradation of pine sawdust

3.2.3.2 Sawdust finer than 75µm

Specifications usually limit the amount of material passing the 75µm which can adversely affect the durability and increase water requirement of concrete (Huang et al. 2021). 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 5% which is within the acceptable limit.

3.2.3.3 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 (Get et al., 2019) . The test results are summarized in Table 3.11.

Table 3.11 Summary of test results of sawdust (Appendices G)

Type of aggregate	**Unit weight (kg/m3)**	**Specific gravity (Bulk SSD)**	**Absorption capacity (%)**	**Moisture content (%)**
Pine Sawdust	468	1.05	17.2	9

3.2.3.4 Chemical Composition of Pine Sawdust

The chemical composition of pine sawdust is determined in Ethiopia Geological Survey Geosciences Laboratory as shown in the Table 3.12

Table 3.12 Chemical composition of pine sawdust (Appendices M)

Chemical oxides	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	MnO	P2O5	TiO2	H_2O	LOI
Composition (%)	49.62	<0.01	0.24	0.04	2.26	<0.01	1.08	0.02	<0.03	0.01	7.37	38.71

3.2.3.5 Availability of pine 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 furniture in the industry and the industrial capacity to process and deliver furniture to the market is more increase (Asresu, 2017). The pine wood what it call in Amharic language yelimat t'idi wood plants are available in Ethiopia like, Jimma Zone, West Shoa zone, Chilimo plantation forest and in the Central Highlands of Ethiopia. Due to that the total availability of pine sawdust production in Ethiopia is high (Tesfaye et al., 2020)

3.2.4 Water

The water used for this tests to be following ASTM (C1602, 2012) which defines sources of mixing water that used as batch water. Batch water is discharged into the mixer from municipal water supply, reclaimed water, or water resulting from concrete production operation. The water that is drinkable and has no pronounced taste or odor can be used as mixing water for making concrete. The PH value of water is not less than 6 (Lemma, 2019).

3.2.4.1 Mixing and curing water

Throughout the laboratory investigation, tap water supplied for drinking consumption at Addis Ababa Science and Technology University Construction Materials Laboratory was used for concrete mixing and curing since it fulfill the ASTM C1602.

Figure 3-10 Curing method (Appendices N)

3.3 Research Methods

3.3.1 Introduction

To achieve the objective successfully, the method of this research is very important. These methods were containing research design, Laboratory test procedure, Mix design, Specimen preparation, Laboratory Tests procedure on Fresh and Hardened Concrete and Data analysis method. The first objective of the study was depends on the workability and compressive strength, flexural strength, setting time of concrete and density. The second objective of this study was determined based on the water absorption and water permeability tests. Lastly, the third objective was determined under the improved properties to utilize the pine sawdust in concrete production price analysis of one meter cubic concrete which have the sawdust and not have sawdust (conventional) concrete as partial replacement of sand.

3.3.1.1 Research design

This study was following this research design to be achieving the objective and solve the existing problem, first start with problem identification. Then set the objective and take experimental study and conduct laboratory, based on the results collected from the laboratory from time to time, the analysis were done and lastly conclusion and recommendation was drawn based on the result and discussions. In detail the study were following research design shown below.

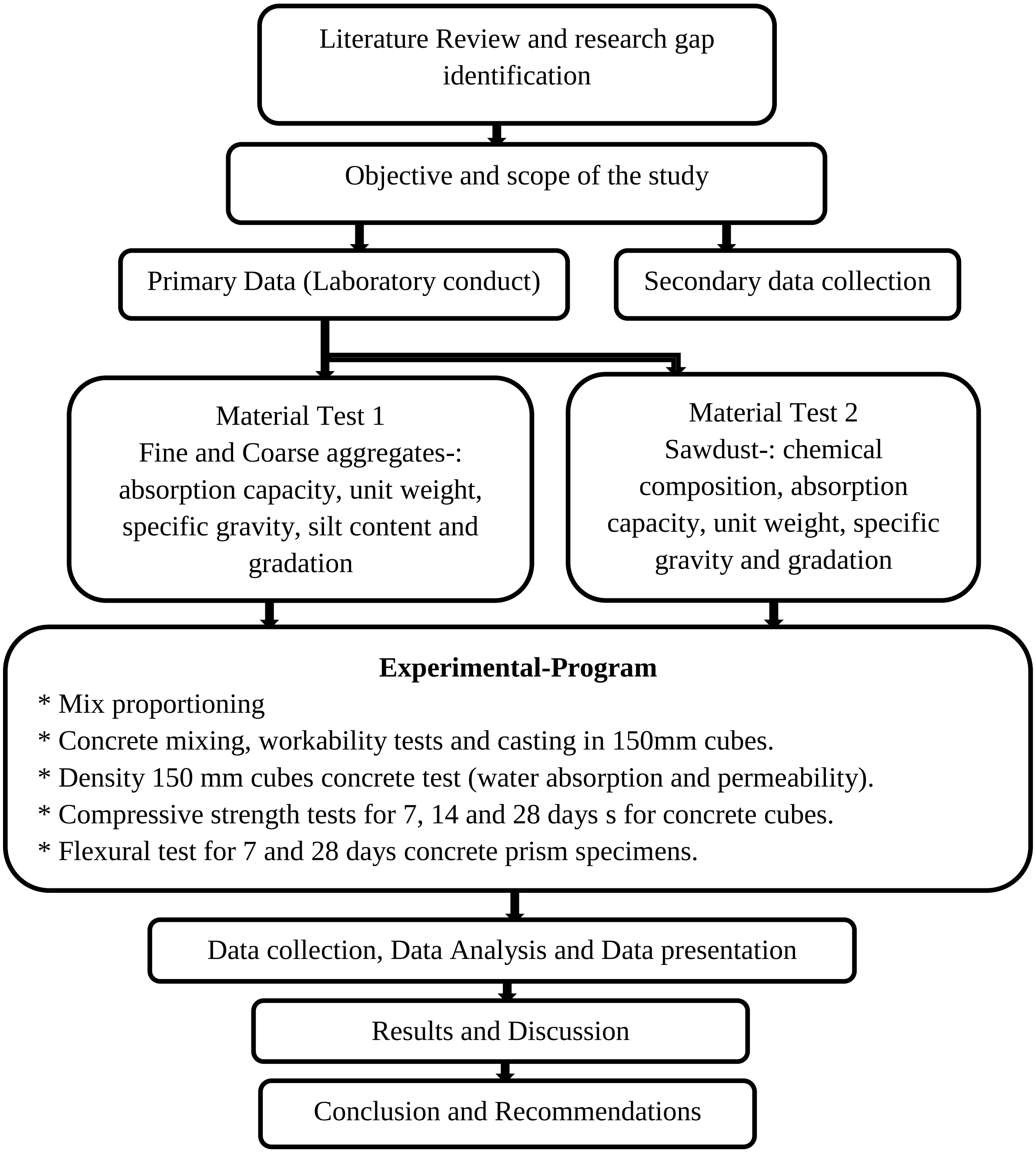

Figure 3-11 Research Design

3.3.1.2 Concrete mix design for C-20

In this research to achieve the objective successfully, sample of concrete blocks units were determined which is needed for casting and tests for various physical, mechanical and durability properties as per the standards.

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.” The amount of pine wood saw dusts added were calculated from the amount of fine aggregate use for one sample according to the percent of partial replacement. Mix-design was done following the procedures given in ACI211, 2002 report. The ACI method and IS methods were easier to proportion compared to the DOE method which was cumbersome. The compressive strength of the ACI method and IS methods met the targeted mean compressive strength (TMCS) but the DOE method did not meet the TMCS for the C15, C20, C25, C30 and C40 grades of concrete. The ACI method was more cost effective than the IS method. The ACI method was cheaper than the IS method by; 14.94%, 12.18%, 12.55%, 12.93% and 4.10% for the C15, C20, C25, C30 and C40 concrete grades respectively (Molla 2022). The ACI method was thus, recommended as first choice proportioning method of concrete Mix design for this study.

Steps 1- Selecting slump

The slump being fixed as 75mm and the specified 28day 150mm cubic specimen compressive strength (f‟c) is 20MP,

Ƒ’cr = ƒ’c +7 = 20 + 7=27 Mpa.

Where: ƒ’c - is specified compressive strength and; ƒ’cr – is required compressive strength

Step 2- Specifying minimum cement content

From durability considerations cement content should not be reduced below 300Kg/m^3 for RCC. IS 456 –2000 recommends higher cement contents for more severe conditions of exposure of weathering agents to the concrete.

Minimum cement content = 300 kg/m3

Step 3 Choice of nominal maximum size of aggregate

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

Step 4- Estimation of mixing water and air content

According to ACI211.1 table A1.5.3.3, for nominal maximum size of 25mm coarse aggregate and 75 slumps, the estimated water content is 193 kg/m3.

Step 5- Selection of water to cement ratio (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 0.64.

Step 6- Calculation of cement content

The respective estimated cement contents for 27MPa concretes were 302 kg per a cubic meter of concrete.

Cement content= water contents/water to cement ratio=193/0.64=302kg/m3

Step 7- Estimating the bulk volume of dry rodded as per unit volume of concrete

From ACI 211.1 table A1.5.3.6, for nominal maximum size of 25mm coarse aggregate and 2.66 fineness modulus of fine aggregate, the volume of dry-rodded coarse aggregate per a unit volume of concrete equals to 0.642.

Step 8 Calculating the weight of coarse aggregate (WCA) per m3 of concrete

WCA = bulk volume of dry rodded aggregate. Per unit volume of concrete * bulk density C.A

Where; volume of dry rodded aggregate. = 0.642

Assume bulk density C.A = 1624 kg/m3

WCA= bulk volume*bulk density

WCA = 0.642 m3 * 1624 Kg/m3,   WCA = 1043kg

Step 9- Determining the solid volume of the coarse aggregate

Solid volume of C.A. = WCA /1000. Sp. gravity

Solid volume of C.A. = 1042.6 kg / 2.88, =362 liter/m3

Where; Specific gravity of C.A.: 2.88

Step 10 Calculating the solid volume of cement, water and volume of air.

Volume of cement = weight of cement / unit weight of cement

Volume of cement = 302 / 3.12 =96.79 liter/m3, where unit weight of cement taken from lab test

Volume of water = 193 liter/ M^3 and Volume of air = 3% or 30 liter/ m3**,** where taken by interpolating

Step 11 determining solid volume of sand (Solid volume of sand is then calculated by subtracting from the data volume of concrete).

Solid volume of sand = 1000 – (362 (VCA) +96.79 (VC) +193 (VW) +30(VA))

Solid volume of sand = 318.21 liter or 0.32 m3

Solid weight of sand = 0.32* 2.41 * 1000

Weight of sand = 771.20kg/ m3

Table 3.13 Summary of mix design (Appendices A)

Ingredients	Volume in (lit)	Weight (kg)
Cement	96.79	302
Water	193	
Coarse aggregate	362	1043
Fine aggregate	318.21	771.20
Air	30	-
Total	1000 lit	2116.2kg/m3

Step 12 Adjustment for moisture in the aggregate.

From lab test results, 0.5% of moisture absorption by coarse aggregate, 1.01% of moisture adsorption by fine aggregate. The amount of water absorbed by coarse aggregate 1043kg/m3 * 0.0075 = 7.82 kg/m3 the amount of water supplied by fine aggregate 771 kg/m3 * 0.0101 = 7.77kg/m3. Therefore, the estimated amount of water needed for the mix is;

(193 kg/m3 + 7.82 kg/m3) – 7.77 kg/m3 = 193.05 kg/m3

Therefore, the estimated batch weights for cubic meter of concrete are;

Table 3.14 Estimated batch weights for one meter cubic concrete (Appendices A)

Ingredients	Units/M^3
Cement	302 Kg/m3
Coarse aggregate 1043-7.82	1035.18 kg/m3
Fine aggregate771.2+7.77	778.97 kg/m3
Water (free water)	193.05 Lit/m3

The above results in mix design ratio was summarized as follows table

Table 3.15 Mix design ratio (Appendices A)

Ingredients	Cement	Fine aggregate	Coarse aggregate
Quantities/m3	302/302	778.97/302	1035.18/302
Ratio	1	2.56	3.43

In this research there is one control mix. The control mix was C-20 OPC mix and designated as O. The special mixes of concrete mixes were made with partial replacement of sand with sawdust with various percentages (i.e. 5%, 10%, 15 and 20 %,) 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 5 mixes were investigated to study the effect on workability, setting time, density, compressive strength ,water absorption and water permeability of concrete.

The proportion of cement, coarse aggregate and water are the same for concrete mixes with 0%, 5%, 10%, 15 and 20 % partial replacement of sand with sawdust. The only difference is the amount of sand and sawdust in one meter cube as shown in Table 3.16.

Table 3.16 Proportion of sand and sawdust in one meter cube

Replacement in percent (%)	Sand		Sawdust	
	By volume (m3)	By mass (kg)	By volume (m3)	By mass (kg)
0	0.32	771	0	0
5	0.30	732	0.02	10
10	0.29	694	0.03	16
15	0.27	655	0.05	26
20	0.26	617	0.06	31

3.3.1.3 Specimen preparation for Test

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. Each mix batch was 0.07m3 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, 14 and 28 days for compressive strength tests for OPC concrete. The concrete specimens were prepared by replacing sand with sawdust from 0 to 20% replacement range with 5% increment to study the effects**.**

3.3.1.4 Casting and curing method of samples

Based on the pilot study, the number of mix was determined because of sawdust content can affect the mixing efficiency and compressive strength of concrete. It is important to achieve a uniform sawdust concrete mix therefore; all concrete batches have tests under the slump test. When proven the credibility of the fresh mix concrete of its workability, all mixed concrete then have been casted into concrete cube by pour into the mold by several layers and follows with compaction processes in between those layers to make sure the concrete is well compacted and fill the mold fully in avoiding any defects such as honeycombs and avoid any air traps inside the concrete layers which eventually reduce the strength and weakens the concrete. After casting, the concrete cubes then undergo curing process whereby it was cured by putting into curing tank up to 28 days to allow it to hydrate to reach the required strength before further testing.

3.3.2 Method of laboratory tests procedures for fresh concrete

3.3.2.1Workability test

In this study, workability test were follow ASTM C143/C143M procedure. This enabling high structural efficiency and ease of construction, in addition to providing the freedom of shape advantage is made available by appropriate workability. In this study the slump was 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 and the results were report.

3.3.2.1.1 Slump test

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.

3.3.2.2 Setting time of concrete test

Following ASTM C403 standard, samples were tested for setting time of concrete. This test method was used to determine the effects of variables, such as water content, amount of cement, material used as fine aggregate replacement; upon the time of setting of concrete.

3.3.3 Laboratory tests procedures for hardened concrete

3.3.3.1 Compressive strength test of concrete

In this study forty five (45) pieces of cube samples were prepared for both control and mix with sawdust for C-20 concrete. All concrete blocks units which dimensions 150 mm x 150 mm x 150 mm, the loaded-face were capped according to ASTM C109/C109M Apply the load rate at a relative rate of movement between the upper and lower platens corresponding to a loading on the specimen with the range of 200 to 400 lbs/s [900 to 1800 N/s]. Top and bottom steel plates with a thickness of 12 mm and, length and width of the steel plate were 7 mm greater than the length and width of the tested concrete blocks units. A 3000 KN Universal Testing Machine used to determine compressive strength. Average of three concrete blocks units of compressive strength for each group has reported at the age of 7, 14 and 28 days. The mix codes and description are shown below

Table 3.17 Test specimens used in the research

No	Specimen code	Sand (%)	Pine Sawdust (%)	Compressive strength test (days)	Total Sample	Remarks
1	O	100	0	7,14 and 28	9	Control mix with OPC
2	SD-5	95	5	7,14 and 28	9	Concrete mix made with OPC and partial replacement of sand with sawdust
3	SD-10	90	10	7,14 and 28	9	
4	SD-15	85	15	7,14 and 28	9	
5	SD-20	80	20	7,14 and 28	9	

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, 14 and 28 days for OPC concrete. Before testing, the cubes were air dried for 1 hour. Crushing loads were recorded and average compressive strength of specimens was determined. The possibility of using sawdust as a partial replacement in concrete production is investigated using the ACI 301 specification for structural concrete as compliance criteria. "The concrete strength level would be judged good," according to ACI 301 When: the averages of all sets of three consecutive compressive strength test results molded and cured in accordance with ASTM C31M equal or exceed fc' (specified strength); and no single 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." ACI 209 provides a formula for calculating the predicted compressive strength of damp cured concrete at specific dates.

$f'cm\ (t) = f'c * (t/4+0.85t)$……………………………………………………Equation 3-1

Where: -f ′ c (t) – Expected mean strength at specified curing date (t)

f'c- Specified strength

3.3.3.2 Flexural strength test of concrete

The flexural strength were tested according to ASTM C78(ASTM, 2001) by using 100x100x500 mm prism specimens. In this study thirty (30) pieces of flexural samples were prepared for both control and mix with sawdust for C-20 concrete. The maximum load sustained was recorded and the average three concrete blocks flexural strength was calculated at the age of 7and 28 days.

Flexural Strength (S) = $3WL/2bd^2$ ………………………………………….Equation 3-2

Where:

W = Maximum load indicated by the testing machine (N),

L = Concrete beam Span (mm),

b = Average width of the concrete beam at the plane of failure (mm),

d = Average depth of the concrete beam at the plane of failure (mm).

Table 3.18 The mix codes and description are shown below.

No	**Specimen code**	**Sand (%)**	**Pine Sawdust (%)**	**Flexural strength test (days)**	**Total Samples**	**Remarks**
1	O	100	0	7 and 28	6	Control mix with OPC
2	SD-5	95	5	7 and 28	6	Concrete mix made with OPC and partial replacement of sand with sawdust
3	SD-10	90	10	7 and 28	6	
4	SD-15	85	15	7 and 28	6	
5	SD-20	80	20	7 and 28	6	

3.3.3.3 Density of concrete

Three concrete cubes specimens were taken from the curing tank at the end of the required curing days for each mix to measure the density of concrete before conducting compressive strength testing.

The density of the concrete was determined by Gravimetrical method, in accordance with ASTM C138, (2017) procedures, and calculated with the expression shown in Equation 3.3.

Density (p) =M/V…………………………………………………………..Equation 3-3

Where M=mass of concrete

V= volume of concrete

3.3.4 Durability test of concrete

The durability of concrete is a function of permeability and water absorption. 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. So in this study the water permeability and water absorption tests are used for durability tests.

3.3.4.1 Water penetration test of concrete

Following ASTM C803/803M, 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 was carrying out at 28 days on cured 150 mm concrete cubes. The steps are follow for conducting water penetration test are shown as follows:-

The test a sample was 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 was 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 zones were mark and water penetration depth measurements were taken.

3.3.4.2 Water absorption test of concrete

According to ASTM C140 standard, water absorption were carried out, concrete blocks units was completely immersed in water at 25°C for 24 hours. The samples were drained on paper towels for 10 min to remove excess water. The samples were dried in oven up to 110°C for 24 hours until reaching constant weights. The increases in weight of the specimen during submersion represent the water absorption (Ayende and Novianto, 2021).

3.3.5 Cost analysis of sawdust concrete

Cost analysis was determined based on the cost of control mix and mix with sawdust. That means the mix with partial replacement of sand with sawdust which to be the optimum replacement, and satisfy the 20MPa compressive strength compliance criteria of ACI 301.this was done for one meter cubic of concrete with sawdust and concrete without sawdust that means control mix. Then based on this analysis the total construction cost was determined.

3.3.6 Method of data analysis technique and tools

To analysis the data collected by primary and Secondary data collection methods, since the secondary data was not need the analysis it is present in a literature review part and the Primary Data (Laboratory tests on construction material) collect on materials and sawdust concrete specimen (slump, Setting time, compressive strength, flexural strength, density, water absorption test and water permeability test on concrete produced with sawdust) from Laboratory result from time to time were be recorded carefully. Then the data was going to analyses by different techniques and tools. The techniques of data analyses used for this research was Descriptive and inferential statistics analyses method.

The data collect in the primary data collection process were be analyzed by descriptive to determine the effects of sawdust concrete production and slump, Setting time, compressive strength, flexural strength, density, water absorption test and water permeability test was be analyzed by using the data analysis tools like Origin pro 2021, which is to answer the first objective and the second objective of this study based on the parameters like dependent and independent variables such as density, flexural and compressive, water absorption and water permeability tests results then inferential by correlation and regression analyses were used by using the analysis tools Origin pro 2021 software to achieve objective. Then, the results were presented by different system like using excels charts, graphs and tables to answer the study question/objective. Lastly based on the optimum replacement of sawdust in this study the cost analysis of the one meter cubic concrete cost were determined. Finally, conclusions and recommendations are going to be forwarded based on the analyzed results and brief discussions.

3.3.6.1 Regression analyses procedures

The concept of linear regression was first proposed by Sir Francis Galton in 1894. Linear regression is a statistical test applied to a data set to define and quantify the relation between the considered variables linear regression can be tested through the origin pro 2021 statistical software in five steps to analyze data using linear regression. The procedure are followed in this study (Kumari and Yadav, 2018).

Click Analyze > Regression > Linear > then select Dependent and Independent variable > OK (enter).

Coefficient of Determination, R^2 the coefficient of determination is the portion of the total variation in the dependent variable that can be explained by variation in the independent variable(s). When R^2 is + 1, there exists a perfect linear relationship between x and y, i.e., 100% of the variation in y is explained by variation in x. When it is 0< R2 <1, there is a weaker linear relationship between x and y, i.e., some, but not all of the variation in y is explained by variation in x (Taiwo and Olatayo, 2019). to label the strength of the association, for absolute values of R, 0-0.19 is regarded as very weak, 0.2-0.39 as weak, 0.40-0.59 as moderate, 0.6-0.79 as strong and 0.8-1 as very strong correlation, but these are rather arbitrary limits, and the context of the results should be considered.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

The performance of concrete made with pine sawdust as a partial replacement of sand results are given, analyzed, and discussed in this section to answer the research questions which is reflect the specific objectives of this study.

4.2 Effect of Pine Sawdust on Concrete Properties

4.2.1 Workability of concrete

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.

4.2.1.1 Slump test of fresh concrete

According to ASTM C143, the fresh concrete testing was conducted in order to determine the workability of all five concrete mixes. The slump test is the methods which were employed in this study for measuring consistency of the mix. Based on the slump test results in Figure 4.1, the slump value of control sample is 75 mm which is being classified as True Slump and has a high workability.

On the other hand, the slump value for control mix is actually 75 mm based on mix design calculations which are classified under slump class S2. Moreover, 5% and 10% partial replacement of sand with pine sawdust has a true slump since the slump value determined is 73 and 70 mm respectively but it has a low workability. This is because pine sawdust had absorbed the water content for the mix design. After that, it was measured that 15% partial replacement of sand with pine sawdust produced a slump value of 65 mm which being classified as a shear slump with low workability. Finally, it was measured that 20% partial replacement of sand with pine sawdust produced a slump value of 60 mm which being classified as a shear slump with low workability. The results are reported to the nearest of 4 mm as shown in Table 4.1.

Table 4.1 Slump of concrete

Specimen Code	Slump (mm)
O	75
SD-5	73
SD-10	70
SD-15	65
SD-20	60

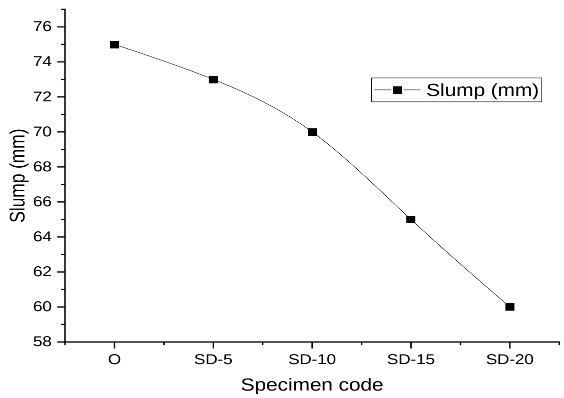

Figure 4-1 Slump of concrete

True slump is the most desirable result since the concrete mix was able to maintain the form of the mold and not significantly subsidize. Based on the observation, the control mix 5% and 10% pine sawdust replacement are the only concrete mix achieved true slump. The other two mix designs shown low workability since there is a significant increase of pine sawdust in the concrete mix which increases the rate of water absorption in concrete mix.

4.2.1.2 Setting time of concrete

A loss of slump, which normally occurs during placing, is a sign of concrete stiffening. The slump of each mix was measured every 30 minutes until it reached zero (0) to determine the effect of sawdust in the concrete at various replacement percentages. The results are reported to nearest of 5 mm Table 4.2. The comparison of slump loss of concrete throughout replacement percentages are illustrated using graph as shown in Figure 4.2

Table 4.2 Slump loss of control mix and sawdust mix concrete

Time (minute)						
Slump mm		**0**	**30**	**60**	**90**	**120**
	O	75	50	0	-	-
	SD-5	73	48	0	-	-
	SD-10	70	45	10	0	-
	SD-15	65	40	15	0	-
	SD-20	60	35	17	5	0

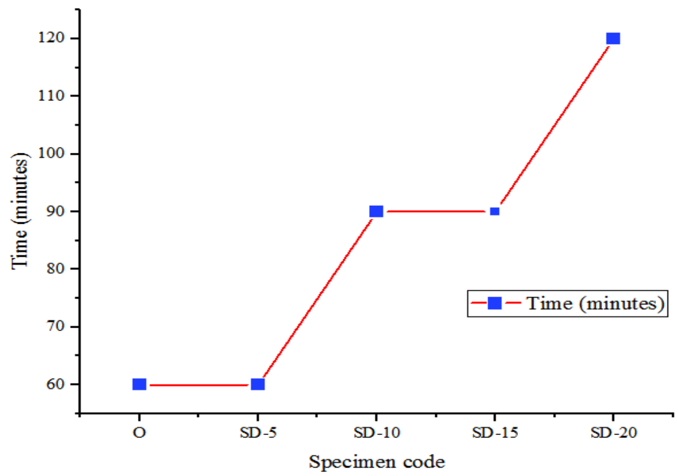

Figure 4-2 Slump loss

The result shown in the Table 4-2 and Figure 4-2 the slump of concrete mix made with 0 and 5 % replacement of sand with pine sawdust became zero in 60 minutes and for 10 %, and ,15% , it takes one(1) hour and 30 minutes, for 20% replacement of sand with sawdust became zero in two (2) hour. When the quantity of sand replaced with pine sawdust was increased, the slump loss of concrete mixes decreased; this means that the stiffening of the concrete decreased. This shows that the sawdust retarded the cement's hydration reaction. The presence of lignin in the sawdust could be the reason for the retarding concrete setting time as the percentage of sand replaced with pine sawdust increases.

4.2.2 Density of concrete

The density of concrete before conducting compressive strength testing was done and The density of the concrete was determined by Gravimetrical method, in accordance with ASTM C138 (2017) procedures. The result was presented as follows.

Table 4.3 Density of 150mm cubes of concrete on 28 days

Specimen Code	Average Weight (kg)	Average Density (kg/m3)
O	8.262	2448
SD-5	8.062	2388.7
SD-10	7.638	2263.1
SD-15	7.281	2157.3
SD-20	6.905	2045.9

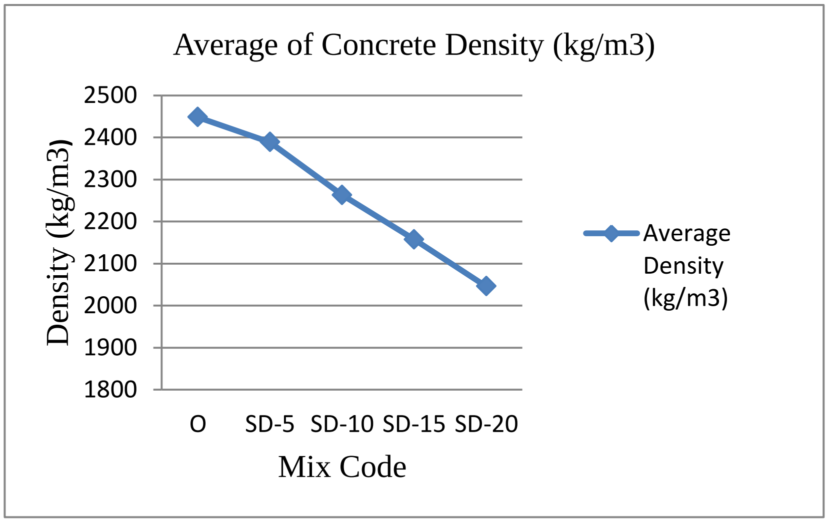

Figure 4-3 Average of concrete Density

The above figure shows that, the density of concrete decreased as the proportion of sawdust increased, with values ranging from 2448Kg/m^3 to 2045.9Kg/m^3 for 5 %, 10%, 15%, and 20%. Because sawdust has a lower density than sand, the density of concrete has decreased. Based on that the weight loss of sawdust concrete increases with increase in the proportion of sawdust volume in concrete. This is due to the low density/specific gravity of the sawdust. Since the pine sawdust batch by volume it becomes lightweight the concrete. All of the densities, however, exceeded the maximum density required for lightweight aggregate concrete, which are 1850kg/m^3.

4.2.3 Compressive strength of concrete

The possibility of using sawdust as a partial replacement in concrete production is investigated using the ACI 301 specification for structural concrete as compliance criteria. According to

Equation 3.1 concretes made for this study are expected to attain 14.07MPa at 7 days, 17.61 Mpa at 14 days and 20.14Mpa at 28 days of curing.

The compressive strength of concrete was tested in this study after the cube samples were totally immersed in water for 7, 14 and 28 days, respectively. The Appendices - I contains all of the 150mm cube strength test results for concrete obtained at 7, 14, and 28 days. Tables 4.4 exhibit mean cube compressive strength results and percentages of strength loss due to partial replacements of sand with sawdust in this section. For all concrete mixes, Figures 4.5 show the relationship between compressive strength and replacement percentages.

Figure 4-4 Results of compressive strength at 28 days curing (Appendices I)

Table 4.4 Average cube compressive strength result of concrete

Specimen Code	**7 days**		**14 days**		**28 days**	
	Compressive Strength (Mpa)	Reduction in Strength (%)	Compressive Strength (Mpa)	Reduction in Strength (%)	Compressive Strength (Mpa)	Reduction in Strength (%)
O	15.75	0	17.26	0	23.48	0
SD-5	15.36	2.4	17.10	0.9	23.03	1.9
SD-10	14.92	5.2	17.13	0.7	23.42	0.2
SD-15	11.09	29.5	14.61	15	19.23	18
SD-20	8.86	43.7	13.08	24	17.20	26.7

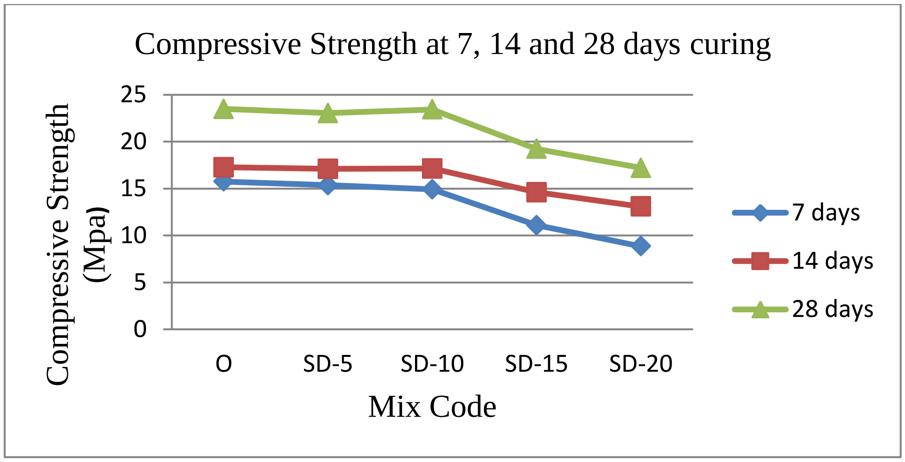

Figure 4-5 Compressive strength at 7, 14 and 28 curing days

The results obtained from compressive strength test for all the mixes are given in figure 4.5. It was observed that the compressive strength of concrete with pine saw dust as partial replacement notably dropped as more sawdust is being replaced with respect to sand. The control specimen shows a rise in compressive strength conforming to achieving the target mean strength from 15.75 Mpa on 7th day, to 17.26 Mpa on 14th day, to 23.48 Mpa on 28th day. The above figure shows that, the compressive strength of concrete mixes was reduced up to 43.7% with 5% to 20% replacement of sand with sawdust at 7 days as indicated in table 4.4 and also The 28 days compressive strength of concrete made with 5%, 10%, 15% and 20% replacement of sand with sawdust also showed reduction in the strength from 1.9 to 26.7%.

On the same hand, the concrete with 10% pine sawdust also exhibited an increment in strength from 14.92 Mpa on 7th day, to 17.13 Mpa on 14th day, to 23.42 Mpa on 28th day. This gradual increase in strength from concrete containing 10% pine sawdust gave the most acceptable result which the exceeded C-20 strength limits (20 Mpa).only 10% replacement of sand with pine sawdust met ACI 209 standards for early day strength of moist cured concrete; according to equation 3.1 the expected compressive strength to attain is 14.07Mpa after 7 days of curing.

In contrast, the concrete with 15% pine sawdust as a partial replacement for sand which exhibited compressive strength results that is significantly decreased from 11.09 Mpa on 7th day, to 14.61 Mpa on 14th day, and 19.23 Mpa on 28th day. Lastly, concrete with 20% pine sawdust partial replacement shows the exact trend as 15% pine sawdust replacement but had the least compressive strength results from 8.86 Mpa on 7th day, to 13.08 Mpa on 14th day, to

17.20 Mpa on 28th day. Based on the compressive result for 15% and 20% pine sawdust replacement concrete, both samples only can be used as a non-structural component for construction since it is not following the requirement of the target M20 strength.

This issue occurred because of the pine sawdust has a characteristic of high-water absorption, which definitely reduced the strength and workability of concrete. There are higher water absorption levels which weaken the bond between concrete constituents. Therefore, the origin of its strength through the hydration cycle from the water-cement paste should exhibit a significant decrease in compressive strength.

This study shows that the compressive strength is directly affected by the amount of pine sawdust replacement. In order to reduce environmental degradation associated with mining of river sand, pine saw dust can be used to replace rive sand up to 10% replacement since they have exceeded the target M20 strength at 28 days (20 Mpa), which have enough strength and density to be used as a structural component but at 15% of replacing sand results shows it was decrease in strength may due to increase the pine sawdust and absorb more water, when the pine sawdust in a concrete absorb the water the compressive strength was deceased since the water is needed for the chemical reaction between the cement particles and sand.

4.2.4 Flexural strength of concrete

Another common test to assess the tensile strength of concrete is the flexural strength test. Flexural strength is expressed as modulus of rapture and is tested using ASTM C78 standard specimen sizes (500 mm, 100 mm, 100 mm). Figure 4.7 depicts the flexural strength results. The results show that by increasing the amount of sawdust, the flexural strength has reduce from 4.71MPa at 28 days for control mix to 2.35 Mpa at 28 days for 20% of sawdust replacement. But for all replacement percentages by increasing the time of curing flexural strength has increased. For example, for 5% of sand replacement flexural strength was 2.08 Mpa at 7 days while it has increased to 4.11 Mpa at 28 days.

Based on the results 10% sand replacement flexural strength was 4.30 Mpa at 28 days which is the maximum of flexural strength of pine sawdust concrete according to this study.

Figure 4-6 Results of flexural Strength of concrete results (Appendices J)

Table 4.5 Flexural strength of concrete at 7 and 28 days

Mix code	Dimension			Flexural strength (N/mm^2) at 7 days	Flexural strength (N/mm^2) at 28 days
	L(mm)	B(mm)	D(mm)		
O	500	100	100	2.37	4.71
SD-5	500	100	100	2.08	4.11
SD-10	500	100	100	1.93	4.30
SD-15	500	100	100	1.25	3.50
SD-20	500	100	100	0.81	2.35

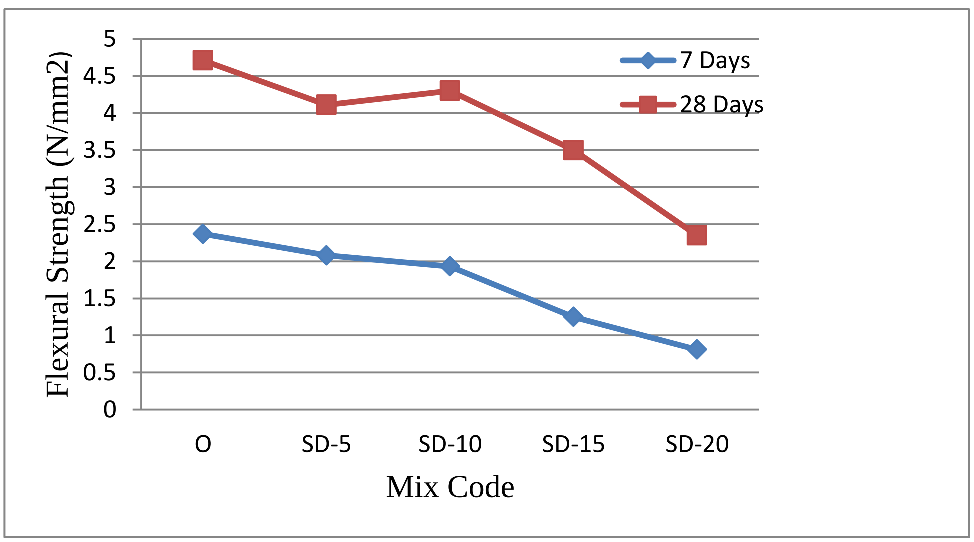

Figure 4-7 Flexural strength of concrete at 7 and 28 days

4.2.5 Statistical analysis of mechanical properties of concrete

4.2.5.1 Regression analysis between compressive strength and density of concrete

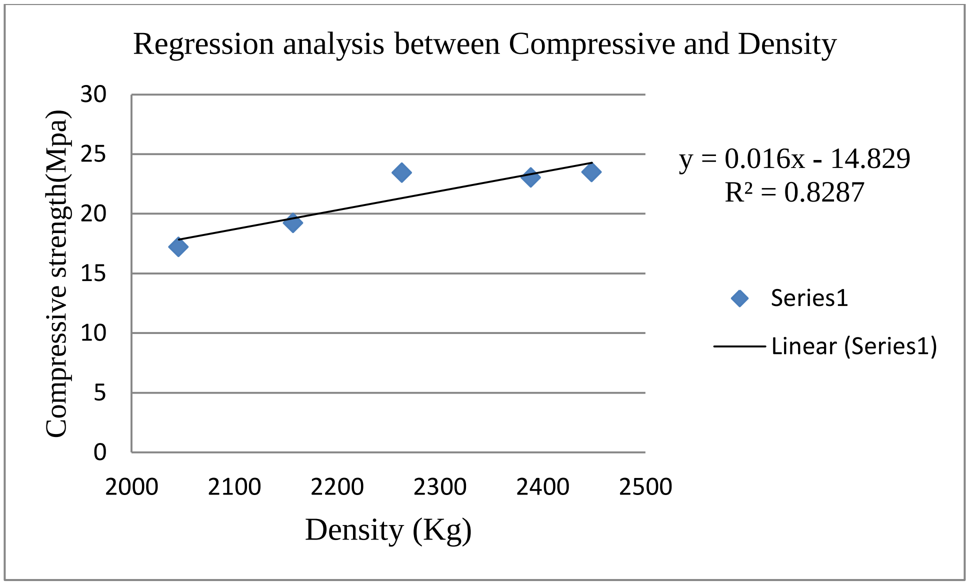

Figure 4-8 Relationships between Compressive strength and Density of concrete

Concrete produced with sawdust

Y=0.016X + 14.829 R^2 = 0.8287 ……………………………Equation 4.1

Where,

R^2 - is the coefficient of determination,

r- Is the Pearson correlation coefficient

Y- Means compressive strength and x- means density of concrete

The above figure shows that, the statistical relationship between the concrete compressive strength and its density, with respect to the quantity of wood shavings incorporated into the concrete was further buttressed by correlation evaluations. The correlation line and co-efficient presented in Figures 4.8; and equations 4.1

As presented in Table 4.3, the density of the concrete was greatly influenced by the quantity of the pine sawdust incorporated into the concrete; hence the high coefficient of determination values ($r \geq 0.80$) recorded in Equations 4.1. This further affirmed the earlier accretion that high quantity wood sawdust in the concrete was lead to poor compressive strength development in concretes. Furthermore, as displayed by Figures 4.8, and represented by the correlations values in equations 4.1, the concrete produced with sawdust had a better compressive strength at 10% partial replacement and density relationship, than that of its counterpart produced without sawdust revealed that there is a very strong relationship between the density of the concrete and its compressive strength.

4.2.5.2 Regression analysis between compressive strength of concrete and quantity of sawdust

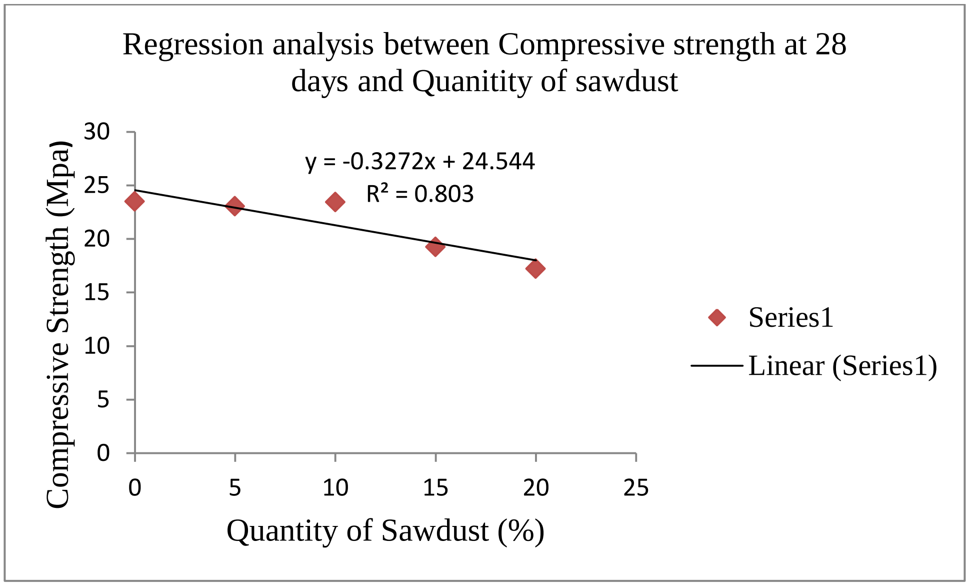

Figure 4-9 Relationship between Compressive strength and Quantity of Sawdust

Y= -0.3272X + 24.544 R^2 = 0.803 r = 0.89611 ……………………Equation 4-2

Where,

R^2 - is the coefficient of determination,

r - Is the Pearson correlation coefficient

Y- Means Compressive strength and x- means quantity of sawdust

The results of the compressive strength of the concrete cubes are presented in Figure 4.9. As seen in the results, the compressive strength of concrete containing sawdust decreased as the quantity of wood shavings increased after some optimum, regardless of the presence of sawdust introduced. This generally signified that quantity of cement, fine and coarse aggregates in the concrete mixture impacted positively on the compressive strength of the concrete produced. The findings of this study showed a significant statistical relation between quantity of sawdust and the compressive strength of the concrete (Pearson r = 0.89611) for concrete reported similar observations, in which the compressive strength of concrete produced with sawdust decreased after gradual increasing the strength with increase in the quantity of sawdust. (Ayende and Novianto, 2021) stated that wood particulates helped to retard the cement hydration, through the absorption some water from the fresh mortar; hence, decreasing the compressive strength of the concrete during aging. But the compressive properties of the concrete produced with wood sawdust particulates, can be enhanced through the incorporation of appropriate admixture into the concrete.

4.2.5.3 Regression analysis between flexural strength and quantity of sawdust

The results of the flexural strength of the concrete beams are presented in Figure 4.10. As portrayed by the results, at curing day 28, the flexural strength of the concrete generally decreased with increase in the volume of sawdust. The flexural strength of the concrete declined from 4.71 Mpa to 2.35 Mpa, in the concrete produced with sawdust, as the sawdust increased from 0% to 20%. This revealed that the pine sawdust enhances the flexural strength of the concrete produced with it, irrespective of the decline in strength. The statistical relationship of the concrete flexural strength (y) as a function of quantity of sawdust (x) was evaluated by means of regression Equations 4.3.

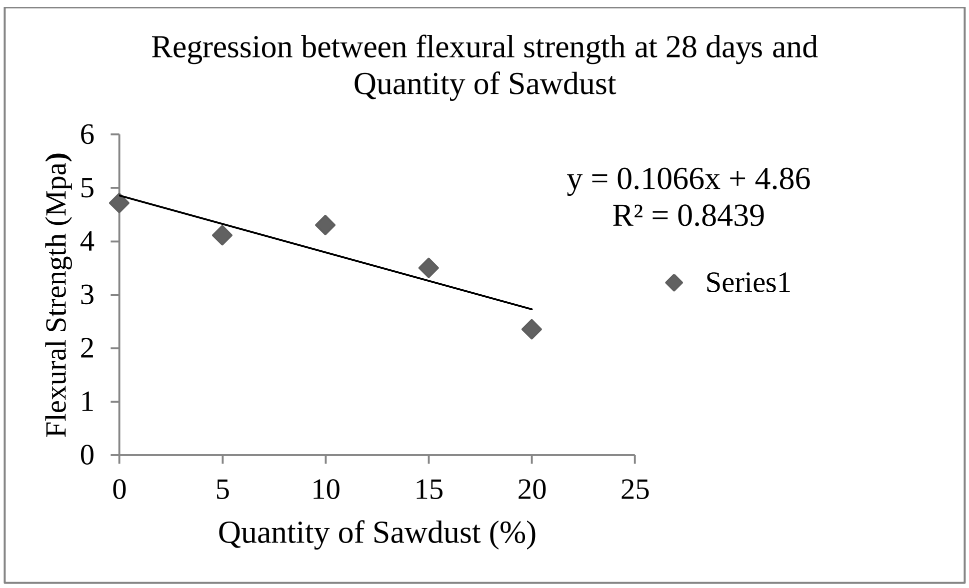

Figure 4-10 Regression Analysis between Flexural strength and Quantity of Sawdust

Y=0.1066X + 4.86 R^2= 0.8439 r = 0.91864 ……..Equation 4-3

Where,

R^2 - is the coefficient of determination,

r - Is the Pearson correlation coefficient

Y- means Flexural strength and x - means Sawdust

The results further revealed a significant statistical relationship (Pearson r = 0.91864) for concrete with sawdust between the sawdust quantity and the flexural strength of the concrete produced. Similar results were reported by (OGg and Uguru, 2021), where a strong regression existed between the flexural strength of concrete produced and the quantity of wood materials incorporated into the concrete.

4.2.5.4 Regression analysis between control mix and 10 % pine sawdust mix (optimum)

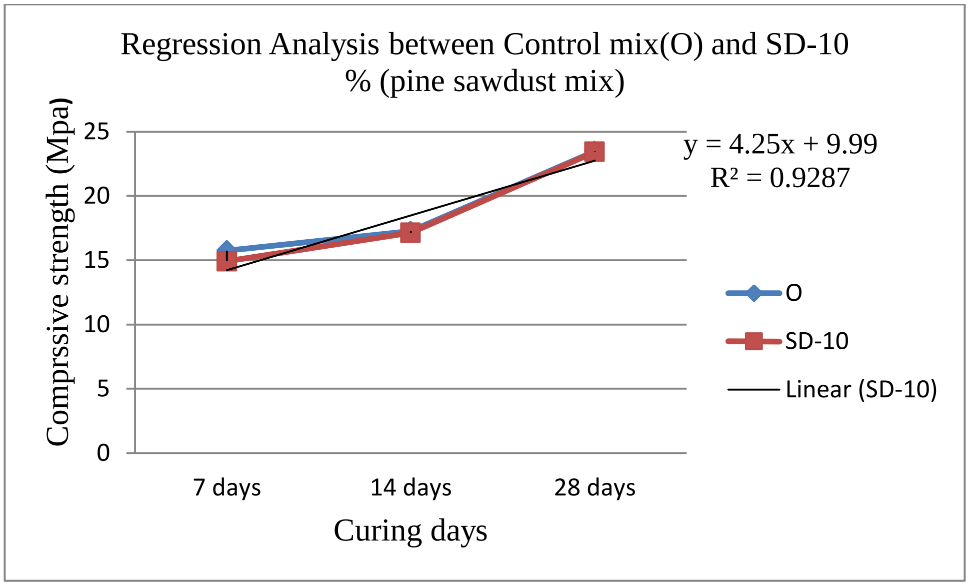

Figure 4-11 Regression Analysis between control mix and 10 % pine sawdust mix

Concrete produced with sawdust

Y=4.25X + 9.99 R^2= 0.9287……………………….………..Equation 4.4

Where,

R^2 - is the coefficient of determination,

Y- Means Compressive strength and x – 10 % pine sawdust mix

The results further revealed a significant statistical relationship (the coefficient of determination R = 0.9287) for concrete with sawdust between the control mix and the 10 % of pine sawdust replacement of the concrete produced.

Similar results were reported by (Zhang and Zong, 2019), where a strong relation existed between the control mix of concrete produced and the optimum sawdust incorporated into the concrete have 92.87% correlate .

4.3 Effect of Pine Sawdust on the Durability Properties of Concrete

4.3.1 Water absorption of concrete

According to ASTM C140 standard, water absorption were carried out, the following table presents the water absorption of the concrete samples results.

Table 4.6 Water absorption of concrete (Appendices K)

Mix code	Percent of Absorption Average (%)
O	1.1
SD-5	5.2
SD-10	9.8
SD-15	15.4
SD-20	20.6

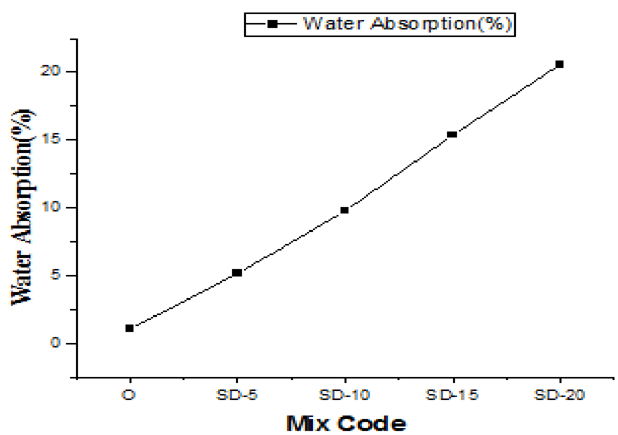

Figure 4-12 Water absorption of concrete

Figure 4.12 presents the water absorption tests results of the control mix and the mixes containing pine sawdust waste aggregate for various replacement ratios. The general behavior of all five mixes was that the higher replacement ratio of sawdust waste aggregate, the greater the water absorption rate. Generally, mixes of SD-5 showed better performance for water absorption, which means less voids in the structure of concrete blocks units. This was due to the needs of cement more water to complete the process of hydration, as well as its high fineness affect the absorption of water. The fine aggregate (sawdust) aggregate in SD-15 and SD-20 seems to have been absorbed more water than sand and cement. This was due to the fact that the shape of sawdust aggregate has great effect on the absorption when the amount of sawdust increase the water absorption was increase, due to the fineness of sawdust increased. This increased the water absorption ratio.

4.3.2 Water penetration of concrete

A non-steady state water permeability test was used to assess changes in durability as a result of replacing sand with pine sawdust in concrete production. Table 4.7 shows the average water permeability measurements after 28 days for concrete casted with pine sawdust, and Figure 4.13 shows the changes in permeability by using percentage of replacement.

Table 4.7 Water penetration depth of concrete (Appendices L)

Sample number	Mix code	Penetration depth Average (mm)
1	O	13
2	SD-5	20
3	SD-10	34.3
4	SD-15	50.7
5	SD-20	94

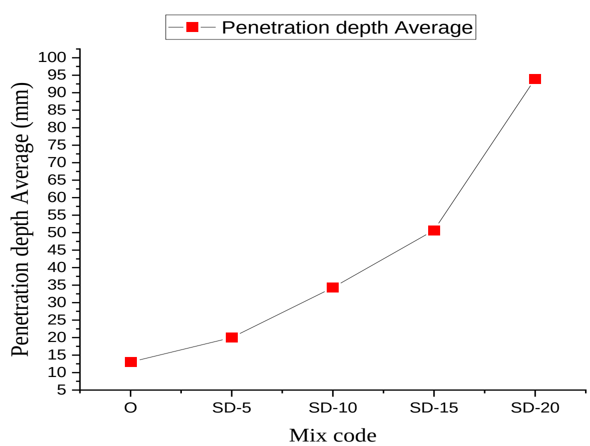

Figure 4-13 Relationship between water penetration and amount of sawdust

As shown in the Figure 4.13 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, (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 34.3mm.

4.3.3 Statistical analysis of durability properties of concrete

Relations between water absorption and water permeability are analyzed for durability of concrete. Relationship between permeability and water absorption was analyzed, as shown in Figure 4.14. From the figures 4.14, we can see that there was, a linear correlation exists between water absorption and permeability depth. The permeability depth increased with the increase in water absorption. As we know, both of permeability and water absorption were affected by the pore structure of cement paste, and liquid transfers from surface into interior. So, it indicated that water absorption provides great influence on permeability. In addition, the high correlation coefficients of 0.957 indicated that there was a 95.7% significant linear correlation between permeability and water absorption of concrete.

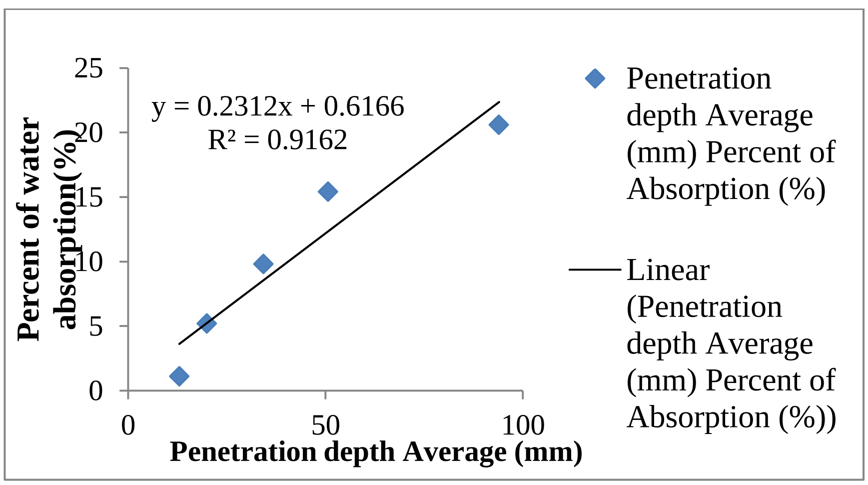

Figure 4-14 Relationship of water absorption and water penetration depth

Concrete produced with sawdust

Y=0.2312X + 0.6166 $\quad$ R^2= 0.9162 $\quad$ r = 0.957162 ……..Equation 4.5

Where,

R^2 - is the coefficient of determination, r - Is the Pearson correlation coefficient

Y- Means percent of water absorption and x - means water penetration depth

4.4 Cost Analysis of Concrete

River sand is preferred for construction because it requires less processing and has better quality than other sources. But it comes at a huge cost to the river and those living around it. Excessive sand mining can alter the river bed, force the river to change course, erode banks and lead to flooding. It also destroys the habitat of aquatic animals and micro-organisms besides affecting groundwater recharge. Cost analysis in construction is even more important than in many other industries. The nature of construction projects and bidding for work makes understanding costs and margin critical to sustainable materials. The cost includes:

Table 4.8 Cost analysis for 1m^3 of river sand (Molla, 2022)

Cost description	Value of costs	Benefit description
Impact on the environmental degradation	15.5 ETB /M^3	Avoid mining river sand
Material depletion per year	8.25 ETB /M^3	Avoid resource scarcity
Labor cost, for mining River Sand	3.00 ETB /Labour	Minimizing labour costs
	= **26.75 ETB/**year	

Based on the above table the concrete production costs include both direct and indirect costs. Material, labor, and equipment costs are all included in the direct cost. Overhead costs are included in indirect costs. The material cost is the significant variable in this study, while labor and equipment costs remain constant because the substitution of sawdust for sand has no influence on labor or equipment costs. The cost of the control mix and the sawdust mix were compared. The maximum replacement is a mix with 10% partial replacement of sand with sawdust, which meets ACI 301's 20MPa compressive strength compliance criteria. The realized strength of 20MPa is the same as the specified value.

Table 4.9 Cost for control mix per meter cube

Concrete Ingredients	Unit	Birr/Unit	Quantity M^3	Cost (Birr)
Cement	Qtl	950	3.00	2850
Coarse Aggregate	M^3	1000	0.362	362
Fine Aggregate	M^3	1400	0.32	448
			Total	**3660 +26.75 = 3686.75 ETB**

Table 4.10 Cost for mix with pine sawdust per meter cube (SD-10)

Concrete Ingredients	**Unit**	**Birr/Unit**	**Quantity M^3**	**Cost (Birr)**
Cement	Qtl	950	3.00	2850
Coarse Aggregate	M^3	1000	0.362	362
Fine Aggregate	M^3	1400	0.29	406
Pine Sawdust	M^3	75	0.03	2.25
			Total	**3620.25 ETB**

Based on the results, comparative cost analysis were made between the control mix and SD-10, the cost of the unique concrete mix reduced by 1.8 percent or 66.50 ETB per cubic meter, as compared to the control mix which are shown in the tables above. Because of the river sand mining has great impact on depletion of source and natural degradation, but pine sawdust was the waste which is cheapest. This clearly demonstrates that in Ethiopia, replacing sand with sawdust can significantly reduce the cost of concrete production.

5 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

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

1. In this research slump, setting time of concrete, compressive strength of concrete, flexural strength of concrete and density of concrete tests were conducted on concrete produced with pine sawdust. Based on the results:

- ✓ Concrete becomes less workable as the proportion of sawdust increases at a constant water to cement ratio. This could be attributed to the high water demand resulting from the absorbent nature of sawdust
- ✓ As the amount of sawdust increases the setting time of the concrete also increases. The reason could be the presence of lignin inside the sawdust.
- ✓ As the amount of sawdust increase the density of the concrete decrease. The reason for this could be pine sawdust is very light weight compared to sand.
- ✓ The compressive strength of the concrete increased gradually up to 10% replacement of sand then it decreases monotonically as the quantity of pine sawdust incorporated into the concrete's increased.
- ✓ The flexural strength of the concrete decreases monotonically as the quantity of pine sawdust incorporated into the concrete's increased.

2. In this research durability of concrete tests results of water absorption and water permeability tests were conducted on concrete produced with pine sawdust. Based on the results:

- ✓ The water penetration of concrete increased with increased percentage replacement of sand with pine 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. Permeability mainly depended on the surface water absorption of concrete, and there was a significant linear correlation between permeability and water absorption of concrete.
- ✓ Water absorption of concrete increase as the addition of pine sawdust increased in replacement of sand due to the fineness of sawdust increased.

3. 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 10% to produce 20MPa strength

of concrete. It is possible to save 66.50 ETB or 1.8% of cost for a meter cube of concrete in Ethiopia using sawdust by replacing 10% of sand in the concrete without compromising the desired strength.

5.2 Recommendations for Further Studies

Only the use of pine sawdust in concrete production is explored in this study; consequently, more research is needed in the following areas:-

- ✓ Study on the use of pine sawdust with Super plasticizers to substitute sand in C-20 concrete which more than 10% replacements.
- ✓ Sawdust as partial replacement of sand in Hollow concrete Block production.

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APPENDICES - A

MIX DESIGN

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

Steps 1- Selecting slump

The slump being fixed as 75mm and the specified 28day 150mm cubic specimen compressive strength (f"c) is 20MP,

Ƒ'cr = ƒ'c +7 = 20 + 7=27 Mpa.

Where: ƒ'c - is specified compressive strength and; ƒ'cr – is required compressive strength

Step 2- Specifying minimum cement content

From durability considerations cement content should not be reduced below 300Kg/m3 for RCC. IS 456 –2000 recommends higher cement contents for more severe conditions of exposure of weathering agents to the concrete.

Minimum cement content = 300 kg/m3

Step 3 Choice of nominal maximum size of aggregate

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

Step 4- Estimation of mixing water and air content

According to ACI211.1 table A1.5.3.3, for nominal maximum size of 25mm coarse aggregate and 75 slumps, the estimated water content is 193 kg/m3.

Step 5- Selection of water to cement ratio (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 0.64.

Step 6- Calculation of cement content

The respective estimated cement contents for 27MPa concretes were 302 kg per a cubic meter of concrete.

Cement content= water contents/water to cement ratio=193/0.64=302kg/m3

Step 7- Estimating the bulk volume of dry rodded as per unit volume of concrete

From ACI 211.1 table A1.5.3.6, for nominal maximum size of 25mm coarse aggregate and 2.66 fineness modulus of fine aggregate, the volume of dry-rodded coarse aggregate per a unit volume of concrete equals to 0.642.

Step 8 Calculating the weight of coarse aggregate (WCA) per m3 of concrete

WCA = bulk volume of dry rodded agg. Per unit volume of concrete * bulk density C.A

- ✓ Where; volume of dry rodded agg. = 0.642
- ✓ Assume bulk density C.A = 1624 kg/m3
- ✓ WCA= bulk volume*bulk density
- ✓ WCA = 0.642 m3 * 1624 Kg/m3
- ✓ WCA = 1043kg

Step 9- Determining the solid volume of the coarse aggregate

Solid volume of C.A. = WCA /1000. Sp. gravity

Solid volume of C.A. = 1042.6 kg / 2.88, =362 liter/m3

Where; Specific gravity of C.A.: 2.88

Step 10 Calculating the solid volume of cement, water and volume of air.

Volume of cement = weight of cement / unit weight of cement

Volume of cement = 302 / 3.12 =**96.79 liter/m3,** where unit weight of cement taken from lab test

Volume of water = **193 liter/ m3**

Volume of air = 3% or **30 liter/ m3,** where taken by interpolating

Step 11 determining solid volume of sand (Solid volume of sand is then calculated by subtracting from the data volume of concrete).

From table 7

- ✓ Solid volume of sand = 1000 – (362 (VCA) +96.79 (VC) +193 (VW) +30(VA))
- ✓ Solid volume of sand = 318.21 liter or 0.32 m3
- ✓ Solid weight of sand = 0.32* 2.41 * 1000
- ✓ Weight of sand = <u>771.20kg/ m3</u>

Ingredient	Volume in (lit)	Weight (kg)
Cement	96.79	302
Water	193	
Coarse aggregate	362	1043
Fine aggregate	318.21	771.20
Air	30	-
Total	1000 lit	2116.2kg/m3

Step 12 Adjustment for moisture in the aggregate.

From laboratory test results 0.5% of moisture absorption by coarse aggregate. 1.01% of moisture adsorption by fine aggregate. The amount of water absorbed by coarse aggregate 1043kg/m3 * 0.0075 = 7.82 kg/m3 the amount of water supplied by fine aggregate 771 kg/m3 * 0.0101 = 7.77kg/m3

Therefore, the estimated amount of water needed for the mix is;

(193 kg/m3 + 7.82 kg/m3) – 7.77 kg/m3 = 193.05 kg/m3

Therefore, the estimated batch weights for cubic meter of concrete are;

Cement	**302 Kg/m3**
Coarse aggregate 1043-7.82	1035.18 kg/m3
Fine aggregate771.2+7.77	778.97 kg/m3
Water (free water)	193.05 Lit/m3

The above results in mix design ratio will be

Ingredients	**Cement**	**Fine aggregate**	**Coarse aggregate**
Quantities/m3	302/302	778.97/302	1035.18/302
Ratio	1	2.56	3.43

APPENDICES - B

Tests on Coarse and fine aggregate

Unit weight of coarse aggregate and fine aggregate

Trial	**Coarse aggregate**		**Fine aggregate**	
	Compacted	**Loose**	**Compacted**	**Loose**
1	8165	7525	6805	5590
2	8160	7235	6805	5970
3	8040	7355	6790	5850
Mean	8121.66 kg	7371 kg	6800 kg	5803.33 kg
Unit weight	8121.66kg/0.005m3 =1624	7371kg /0.005m3 =1471	6800 kg/0.005 m3= 1360	5803.33kg/ 0.005 m3=1160.6

APPENDICES - C

1) <u>Moisture content of coarse aggregate</u>

Weight of coarse aggregate sample 2000g = A

Weight of sample after 24 hours oven dry at 105’c =B=1985g

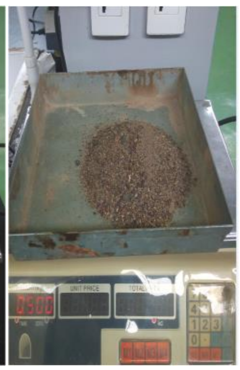
Moisture contents W (%) = (A-B)/B*100 = (2000-1985) g/1985 g * 100 = <u>0.755%</u>

2) <u>Moisture content of Fine aggregate</u>

Weight of fine aggregate sample 500g = A

Weight of sample after 24 hours oven dry at 105’c = B =495g

Moisture content of sand w (%) = (A-B)/B * 100 = (500g-495g)/495g *100 =<u>1.01%</u>

APPENDICES - D

1) <u>Specific gravity and Absorption capacity of coarse aggregate</u>

Sample of coarse aggregate 5000g, washed and dry for 3hours and then immersed in water for 24 hours at room temperature.

Weight the sample in the saturated surface dry-condition record = B =5010g

Weight in Water = C =3283.4g

Weight of oven dry = A = 4975g

Bulk specific gravity = A/ (B-C) = 4975/ (5010-3283.4) = <u>2.88</u>

Absorption % = (B-A)/A = (5010 g – 4975g / 4975g *100 = <u>0.50</u>

2) <u>Specific gravity and Absorption capacity of fine aggregate</u>

- ✓ Sample of fine aggregate 500g, washed and dry for 3hours and then immersed in water for 24 hours at room temperature.
- ✓ Weight of water and picknometer record = B =1557.4g
- ✓ Weight of picknometer + sand +water = C =1872.6g

- ✓ Weight of oven dry = A = 476g

Bulk specific gravity = A/ (B+500-C) = 476g / (1557.4g +500 – 1872.6) = 2.41

Absorption % = (500-A)/A *100 = (500 – 476g) / 476g *100 = 5%

APPENDICES - E

Silt content of sand

The silt content of the sand was done by taking 500ml jar /graduated cylinder capacity and pours 30g of sand into the jar then fills the cylinder by water up to the ¾ of cylinder with water and shakes for a minute. After that leave for an hour to allow the silt to settle on the layer of the sand.

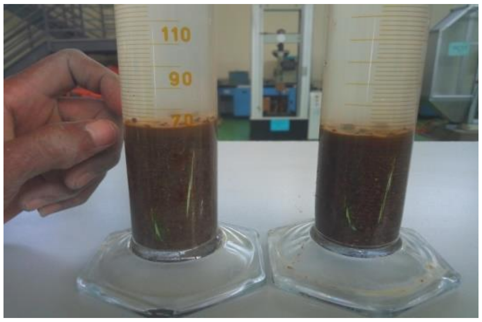
A=Amount of silt content deposit above the sand=7.1ml

B=Amount of clean sand=95ml

Silt content (%) =A/B*100 then, 7.1ml/95ml *100 = 7.4

According to Ethiopian standard, if the silt content of sand is more than 6% it should be rejected unless it washed. Therefore after it washed it becomes

A = 2.5, B = 95 then, Silt contents (%) = 2.5ml/95ml = 2.6, since it's less than 6% it's acceptable.



APPENDICES - F

1) Silt content of pine sawdust

The silt content of the pine sawdust was done by taking 500ml jar /graduated cylinder capacity and pours 30g of sand into the jar then fills the cylinder by water up to the ¾ of cylinder with water and shakes for a minute. After that leave for an hour to allow the silt to settle on the layer of the sawdust.

A=Amount of silt content deposit above the sand=4.75ml

B=Amount of clean sand=95ml

Silt content (%) =A/B*100 then, 4.75ml/95ml *100 = 5%

According to Ethiopian standard, if the silt content of sand is more than 6% it should be rejected unless it washed. Therefore since it's less than 6% it's acceptable.

2) Specific gravity and Absorption capacity of pine sawdust aggregate

Sample of fine aggregate 500g, washed and dry for 3hours and then immersed in water for 24 hours at room temperature.

Weight of water and picknometer record = B =1557.4g

Weight of picknometer + sawdust +water = C =1651.8g

Weight of oven dry = A = 426.5g

Bulk specific gravity = A/ (B+500-C) = 426.5g / (1557.4g +500 – 1652.8) = 1.05

Absorption % = (500-A)/A *100 = (500 – 426.5g) / 426.5g *100 = 17.2%

APPENDICES - G

Type of aggregate	Unit weight (kg/m3)	Moisture content (%)
Pine Sawdust	468	9

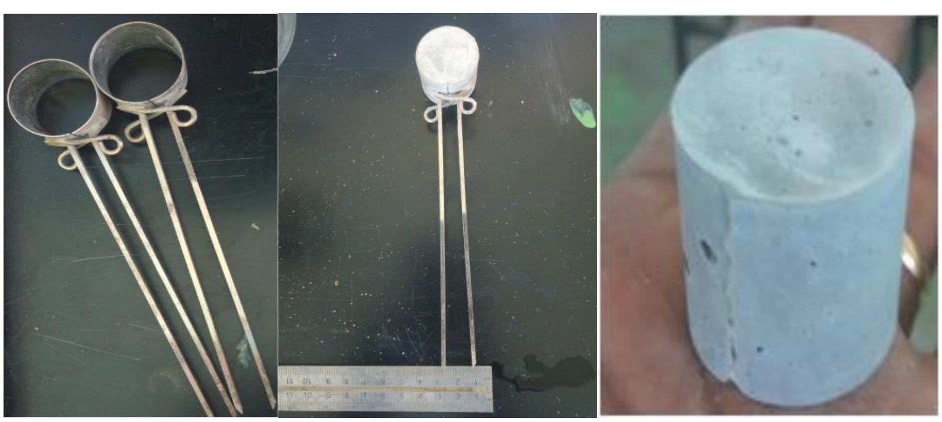
APPENDICES - H

Tests on cement

1) Soundness of cement

By using Le chateliers apparatus and glass plate, fill the paste in the cylinder mould placed on glass plate then put in after for 24 hours, after that measure the distance between indicator needle taking out which = 13 mm and submerge it again in water and boiling up to 30'c for 1 hour and 30 minutes then taking to out and measure it becomes 14 mm

Soundness = 14mm-13mm = 1mm which is less than 10mm and acceptable.



2) <u>Normal Consistency of hydraulic cement</u>

Consistency is done by taking:- cement = 500g and taking water cement ratio starting from 26% and trial mix and put in vicat apparatus then at 29% of water cement ratio the penetration depth become 9mm that means since the standard allows 9 -11mm its acceptable. So, 29*9= 145 ml water is needed.

% water = weight of water/ weight of cement =145ml/500 g =29%

3) <u>Setting time of hydraulic cement</u>

By taking 500g of cement and prepare cement paste of normal consistency. Insert the paste in to the conical ring and then remove the excess and after 30 seconds tighten the screw and set the indicators at the upper end of the scale or take the initial reading.

Penetration time (minutes)	Penetration depth in mm
After 30 seconds	9
After 15 minutes	15
After 30 minutes	18
After 45 minutes	23
After 1 hour	31

There the initial setting time was calculated by interpolation between 23mm and 31 mm to find the at 25mm what the time of initial setting which is 49 minutes it’s acceptable because the minimum time of initial setting time is 45 minutes.

4) <u>Fineness of cement</u>

Fineness of cement by sieve (150 and 75 µm)

No	Sieve size	Cement sample gm	weight of residue gm	% of residue	Average of residue %
1	150 µm	50	3	6	6
2	75 µm	50	4.3	8.6	8.6

APPENDICES - I

Result of Compressive strength tests of concrete.

O-specimen (control mix)

No	Test age (days)	Dimension (mm)			Weight (gm)	Volume	Compressive strength (Mpa)	Unit weight (gm/cm3)
		L	W	D				
1	7	150	150	150	8500	0.003375	16.80	
2		150	150	150	8450	0.003375	14.95	2503704
3		150	150	150	8235	0.003375	15.50	2440000
Mean							**15.75**	
1	14	150	150	150	8403	0.003375	17.15	2489778
2		150	150	150	8355	0.003375	16.88	2475556
3		150	150	150	8200	0.003375	17.76	2429630
Mean							**17.26**	
1	28	150	150	150	8366	0.003375	21.97	2478815
2		150	150	150	8303	0.003375	23.93	2460148
3		150	150	150	8117	0.003375	24.56	2405037
Mean							**23.48**	

SD-5% (5% partial replacement of with sawdust)

No	Test age (days)	Dimension(mm)			Weight (gm)	Volume Cm^3	Compressive strength (Mpa)	Unit weight (gm/cm^3)
		L	W	D				
1	7	150	150	150	8210	0.003375	16.5	2432593
2		150	150	150	8125	0.003375	14.05	2407407
3		150	150	150	8300	0.003375	15.54	2459259
Mean							**15.36**	
1	14	150	150	150	8177	0.003375	16.54	2422815
2		150	150	150	8050	0.003375	17.53	2385185
3		150	150	150	8195	0.003375	17.22	2428148
Mean							**17.10**	
1	28	150	150	150	8104	0.003375	24.69	2401185
2		150	150	150	8005	0.003375	22.38	2371852
3		150	150	150	8078	0.003375	21.94	2393481
Mean							**23.03**	

SD-10% (10% partial replacement of with sawdust)

No	Test age (days)	Dimension (mm)			Weight (gm)	Volume	Compressive strength (Mpa)	Unit weight (gm/cm3)
		L	W	D				
1	7	150	150	150	7660	0.003375	17.34	2269630
2		150	150	150	7800	0.003375	14.02	2311111
3		150	150	150	7930	0.003375	13.40	2349630
Mean							**14.92**	
1	14	150	150	150	7609	0.003375	17.23	2254519
2		150	150	150	7692	0.003375	16.60	2279111
3		150	150	150	7880	0.003375	17.57	2334815
Mean							**17.13**	
1	28	150	150	150	7550	0.003375	25.81	2237037
2		150	150	150	7601	0.003375	22.05	2252148

3		150	150	150	7764	0.003375	22.42	2300444
Mean							**23.42**	

SD-15% (15% partial replacement of with sawdust)

No	Test age (days)	Dimension (mm)			Weight (gm)	Volume	Compressive strength (Mpa)	Unit weight (gm/cm3)
		L	W	D				
1	7	150	150	150	7465	0.003375	11.79	2211852
2		150	150	150	7410	0.003375	10.98	2195556
3		150	150	150	7397	0.003375	10.50	2191704
Mean							**11.09**	
1	14	150	150	150	7430	0.003375	15.44	2201481
2		150	150	150	7365	0.003375	13.80	2182222
3		150	150	150	7301	0.003375	14.60	2163259
Mean							**14.61**	
1	28	150	150	150	7293	0.003375	18.45	2160889
2		150	150	150	7311	0.003375	19.30	2166222
3		150	150	150	7240	0.003375	19.11	2145185
Mean							**19.23**	

SD-20% (20% partial replacement of with sawdust)

No	Test age (days)	Dimension (mm)			Weight (gm)	Volume	Compressive strength (Mpa)	Unit weight (gm/cm3)
		L	W	D				
1	7	150	150	150	7250	0.003375	10.23	2148148
2		150	150	150	7308	0.003375	8.42	2165333
3		150	150	150	7270	0.003375	7.95	2154074
Mean							**8.86**	
1	14	150	150	150	7210	0.003375	13.78	2136296
2		150	150	150	7245	0.003375	13.44	2146667
3		150	150	150	7250	0.003375	12.03	2148148

Mean							**13.08**	
1	28	150	150	150	7189	0.003375	16.89	2130074
2		150	150	150	6720	0.003375	16.90	1991111
3		150	150	150	6805	0.003375	17.83	2016296
Mean							**17.20**	

Results of compressive strength at 28 days curing

APPENDICES - J

Flexural strength of concrete results at 7 days of curing

No	Mix code	Dimension			Max load (KN)	Flexural strength (Mpa) at 28 days
		L(mm)	B(mm)	D(mm)		
1	O	500	100	100	5.88	2.65
2		500	100	100	4.25	1.97
3		500	100	100	6.11	2.51
Mean						**2.37**
1	SD-5	500	100	100	5.11	2.35
2		500	100	100	4.15	1.95
3		500	100	100	4.18	1.96
Mean						**2.08**
1	SD-10	500	100	100	4.87	2.2
2		500	100	100	4.01	1.83
3		500	100	100	3.84	1.78
Mean						**1.93**
1	SD-15	500	100	100	4.44	2.1
2		500	100	100	3.61	1.54
3		500	100	100	3.06	1.13
Mean						**1.25**

1	SD-20	500	100	100	2.90	1.03
2		500	100	100	2.68	0.8
3		500	100	100	2.2	0.6
Mean						**0.81**

Flexural strength of concrete results at 28 days of curing

No	Mix code	Dimension			Max load (KN)	Flexural strength (Mpa) at 28 days
		L(mm)	B(mm)	D(mm)		
1	O	500	100	100	10.98	4.98
2		500	100	100	9.74	4.53
3		500	100	100	9.87	4.61
					Mean	**4.71**
1	SD-5	500	100	100	8.54	3.84
2		500	100	100	9.49	4.31
3		500	100	100	8.92	4.20
					Mean	**4.11**
1	SD-10	500	100	100	10.46	4.71
2		500	100	100	8.93	3.96
3		500	100	100	9.33	4.22
					Mean	**4.30**
1	SD-15	500	100	100	7.44	3.35
2		500	100	100	8.55	3.85
3		500	100	100	7.29	3.28
					Mean	**3.50**
1	SD-20	500	100	100	5.88	2.65
2		500	100	100	5.45	2.43
3		500	100	100	4.25	1.97
					Mean	**2.35**

APPENDICES -K

Water Absorption Tests after 28 days curing

Mix code	No Sample	Saturated weight of specimen in (g)	Oven dry weight of specimen in (g)	Percent of Absorption (%)	Percent of Absorption Average (%)
O	1	3878	3843	0.9	1.1
	2	3852	3808	1.2	
	3	3855	3811	1.2	

SD-5	1	3830	3645	5.1	5.2
	2	3801	3613	5.2	
	3	3788	3597	5.3	
SD-10	1	3850	3515	9.5	9.8
	2	3822	3504	9.1	
	3	3864	3489	10.7	
SD-15	1	3930	3385	16.1	15.4
	2	3910	3370	16	
	3	3865	3385	14.2	
SD-20	1	3969	3312	19.8	20.6
	2	3958	3292	20.2	
	3	3906	3207	21.7	

APPENDICES - L

Water Penetration Tests after 28 days curing which is done in ASTU Construction Material Laboratory

Mix code	No Sample	Penetration depth (mm)	Penetration depth Average (mm)
O	1	12	13
	2	14	
	3	13	
SD-5	1	20	20
	2	18	
	3	22	
SD-10	1	31	34.3
	2	34	
	3	38	
SD-15	1	45	50.66
	2	49	
	3	58	
SD-20	1	82	94
	2	94	
	3	106	

APPENDICES - M

Chemical composition of pine sawdust was done in Ethiopian Geological Survey Geosciences Laboratory.

	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:- 21/02/2022

Customer Name:- Teshal Daba

Request No:- GLD/RQ/663/22

Report No:- GLD/RN/174/22

Sample type : Powder

Sample Preparation: - 200 Mesh

Date Submitted:-07/02/2022

Number of Sample:-One (01)

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

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

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI	Weight of Sample
T-D-01	49.62	<0.01	0.24	0.04	2.26	<0.01	1.08	0.02	0.03	<0.01	7.37	38.71	300.00gm

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

Analysts	Checked By	Approved By	Quality Control
Elisa Fiseha Lidet Endeshaw Nigist Fikadu	Tizita Zemene	Yohannes Getachew	Gosa Haile

APPENDICES - N

Photo attachments