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Experimental Investigation on the use of Sawdust as Partial Replacement of Sand on Concrete Production

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A Thesis in Structural Engineering

By Kidist Assefa

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A Thesis

Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science

The undersigned have examined the thesis entitled '**Experimental Investigation on the use of Sawdust as Partial Replacement of sand on Concrete Production**' presented by **KIDIST ASSEFA**, a candidate for the degree of **Master of Science** and hereby certify that it is worthy of acceptance.

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UNDERTAKING

I certify that research work titled "Experimental Investigation on the use of Sawdust as Partial Replacement of sand on Concrete Production" is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

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ABSTRACT

Sawdust concrete technology was first introduced in industrialized nations, where it was used as a flooring and wall system. Sawdust and clay have been used to build houses in the West Indies. Without any prior treatment, sawdust may be used to replace sand in concrete mixes. The weight of concrete may be reduced by using sawdust, which also solves the problems of a lack of raw materials, safe waste disposal and cost efficiency. In this research partial replacement of sawdust with sand is investigated. Different strength of concrete grades with sawdust ratios of 0%, 5%, 10%, and 15% were studied with their physical and mechanical characteristics. The results of this study show that compressive strengths of C16/20 concrete grade mixes sawdust substitution up to 15% meet the ACI 301 cylindrical compressive strength compliance criteria. Sawdust replacements satisfy cylindrical compressive strength up to 10% for C30/37, C45/55, and C60/65. The slump of the concrete was decreased by partially replacing sand with sawdust, and the concrete's density was lowered as well. The tensile strength of concrete using sawdust as partial replacement of sand improved by up to 5%, indicating that the sawdust acts as a fiber in the concrete.

Keywords: Sand, Sawdust, Partial replacement, Concrete grade

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LIST OF ABBREVIATIONS

HRWRA	High range water reducing admixture
OPC	Ordinary Portland cement
RCC	Reinforced Cement concrete
SD	Sawdust
SDA	Saw dust ash
SSD	Saturated surface drying

1 INTRODUCTION

1.1 Background

Since its discovery and advancement, concrete and the technology that surrounds it have gone a long way. Concrete is a composite material that is made up of fine and coarse aggregates that are bound together with fluid cement and solidify over time. Concrete is one of the most often used building materials and is claimed to be the world's second most utilized substance after water. Because of its excellent compressive strength and its ability to be molded, it is widely used in a variety of project.

Because of the massive use of non-renewable natural resources in the production of structural concrete, natural resources such as aggregate, which are mined in the production of concrete, are depleting. As a result, alternative material resources are being discovered through considerable research efforts to address this issue. The use of waste materials as cement or aggregate replacements in concrete can help to reduce the negative effects of the concrete industry, such as raw material shortages, waste disposal safety, cost efficiency, and, more importantly, improving concrete quality [1].

Among the waste products accessible, wood waste (sawdust) is the one that is readily available everywhere at no cost. According to a researcher, sawdust is fabricating in thousands of tons in a year from wood items and furniture, and these wastes build up and become a severe environmental issue. Researchers have discovered a way to employ it in concrete to solve this problem. Sawdust is described as loose particles or wood chippings that are produced as a by-product of sawing wood into conventional usable sizes [2]. Timber is one of man's first structural materials. Temples and monuments created many years ago that are still in outstanding shape demonstrate the endurance and use of wood. Because of its lesser weight, saw dust was chosen for this investigation.

It was demonstrated that with 0% to 50% replacement ratio of sawdust, light-weight concrete block units with sufficient compressive strength may be produced. The optimal replacement ratio was 10%, resulting in good physical and mechanical qualities. Because of its light weight, this might be seen as a solution not just to the environmental challenge, but also to the problem of economics in building design [5].

When compared to normal weight concrete, lightweight concrete has a number of advantages, including a lower dead load and lower construction costs. The use of lightweight aggregates is one of the most frequent techniques of making structural lightweight concrete. According to the findings of the study, environmentally friendly structural lightweight aggregate concrete may be manufactured by partially replacing sawdust as fine or coarse aggregate [7].

Workability, setting time, density, compressive strength, and water penetration were investigated and C-20 class concrete was achieved by substituting 5%, 10%, 15%, 20%, and 25% by volume of sand with sawdust, with the optimal replacement of 15% producing 20MPa cube compressive strength of concrete [13].

Replacing fine and coarse aggregates in reinforced concrete slabs with saw dust and palm kernel shells (PKS) was studied. When the amount of sawdust or palm kernel shells in concrete slabs is increased, the compressive strength values are reduced. SD can manufacture lightweight reinforced concrete slabs with a low replacement value of 25% sawdust and may be utilized where minimal stress is required at a reasonable cost savings of up to 7.43 percent for each cubic meter of slab manufacturing [2].

The influence of concrete grades in substituting sand with sawdust in the production of concrete will be investigated in this study. The water-to-cement ratio decreases as the concrete grade rises. Sawdust, on the other hand, has a large capacity for absorbing water. As a result, the impact of concrete grade on partial replacement sawdust will be examined in this study. And also it will be discovered if sawdust may be used to replace sawdust in standard and higher compressive strength concrete grades.

1.2 Statement of the problem

The increasing number of development projects throughout the world has prompted the construction sector to look for alternative materials to replace conventional resources in concrete production. The construction sector is dealing with a scarcity of raw materials, rising costs, environmental issues, and other challenges. Aside from that, human activity on the earth generates an endless amount of waste. Among the waste resources, sawdust is a readily accessible item [6].

Recycling waste material has a positive impact on sustainable building by enhancing the concrete's behavior. Industrial and residential waste can be used to improve the characteristics of concrete [4]. Sawdust is a low-density substance. According to various studies, replacing sawdust with cement or aggregate reduces the weight of concrete significantly. As a result, sawdust is a well-timed substance that may lighten the concrete and solve the concrete's shortcoming of being heavy in comparison to its strength.

Because of its light weight, sawdust is the best material for high-rise buildings because it reduces the dead load of the structure, the cross section of structural elements, and the foundation will be minimized. As a result, it can help with the economics of building design.

The water-to-cement ratio decreases as the concrete grade rises. Sawdust, on the other hand, has a large capacity for absorbing water. As a result, the impact of concrete grade on partial replacement sawdust will be studied in this study.

1.3 Objective of the study

1.3.1. General objective of the study

The main objective of this study is to investigate how different concrete grades affect the partial substitution of sand with sawdust.

1.3.2. Specific Objective

The specific objective of this study is

- To investigate how different concrete grades affected the partial substitution of sand with sawdust.
- To determine the best level of sawdust partial substitution as sand in concrete mixtures for four different concrete grades.
- To study the compressive and tensile strength of concrete containing sawdust as a partial substitute.
- To study physical properties and PH value of the sawdust.

1.4 Scope of the study

In this study, the effect of sawdust for partial replacement of sand for different concrete grades was investigated. Normal and high compressive strength concrete grades are included in the research. The concrete grades were 16/20, C30/37, C45/55 and C60/75 for a 0%, 5%, 10%, and 15% partial replacement of sand with sawdust. The PH value of sawdust, workability, density, compressive and tensile strength of concrete were performed.

1.5 Significance of the Study

Sawdust concrete can lower the weight of concrete. While simultaneously addressing challenges such as a scarcity of raw materials, proper waste disposal, cost efficiency, and increased air pollution [4].

Sawdust is a light-weight material. According to various studies, partial replacement of sawdust in place of cement or aggregate reduces the weight of concrete by a significant amount. Sawdust is a well-timed material that might help lighten the load on high-rise buildings. As a result, it can forego the possibility to create a large number of high-rise structures for developing nations by addressing the issue of overall building cost and land scarcity owing to population growth.

1.6 Methodology of the Study

This study includes conducting slump, density, compressive, and tensile strength tests on concrete samples containing varied quantities of sawdust and concrete grades. The physical properties of sawdust, fine aggregate, and coarse aggregate have already been established in the lab. Furthermore, the PH level of sawdust was examined in order to predict the decomposing behavior of the saw dust.

1.7 Organization of the Thesis

The thesis is divided into five chapters, which are ordered as follows.

Chapter one gives a basic introduction to the thesis with a brief amount of background information and discusses the justification of the research by highlighting the primary challenges related with partial substitution of sawdust as sand, as well as the thesis's aims, scope, and organization. The second chapter covers the relevant literature and quotes from several related publications in the field. The materials, techniques, and testing procedures are presented in the third chapter. The fourth chapter tries to summarize the outcomes of the tests in detail, followed by a discussion of the findings. Finally, the study's conclusion and recommendation are presented in Chapter 5.

2 LITERATURE REVIEW

2.1 Introduction

The growing use of natural resources in concrete production has resulted in a lack of raw materials, cost increases, environmental concerns, and other challenges for the building industry. Due to a scarcity of raw materials, the building industry is looking for alternative materials to replace the practical concrete with less expensive and more readily available alternatives. Numerous wastes, including agricultural and industrial wastes, are produced as a result of human activities on the planet. According to the researchers, waste materials may be used to make concrete. Rice husk ash, fly ash, bottom ash, marble powder, copper slag, sawdust and other waste elements were discovered during the research of concrete preparation. Saw dust is freely obtainable material among waste materials [6].

Saw dust technology was first introduced in developed nations, where it was used as a flooring and wall system [11]. In the West Indies, sawdust and clay are used to build houses [6].

Because of its organic character, sawdust requires more investigation into its decomposition property, which might impact the hydration and setting response of cement. Within this range, investigations have discovered promising results in the creation of light-weight concrete utilizing sawdust as a partial replacement for concrete components. Because of its light weight, cost effectiveness compared to the production of normal concrete, prolongs formwork life due to its light weight, makes workmanship in handling and casting easier, and also enhances sound absorbent property of the concrete due to its high volume of void to the space occupied by solids, sawdust concrete provides significant reduction in dead load of the structure [8]. Saw dust improves thermal insulation by lowering heat conductivity [9].

2.2 Sawdust

Sawdust is described as loose particles or wood chippings that are produced as a by-product of sawing wood into standard usable sizes. Timber is one of man's first structural materials. Temples and monuments created many years ago that are still in outstanding condition demonstrate the strength and use of wood.

2.2.1 Fresh concrete properties under replacement of sawdust

2.2.1.1 Workability

The workability of concrete has been investigated, and it has been found to decrease significantly as the amount of SDA in concrete mixtures increases [11]. Workability reduced when the amount of sawdust substitution of sand in the mix increased up to 50%, according to [26]. Slump values increased when the percentage of sand replaced with sawdust was increased to 100%. Slump values of 40mm, 9mm, and 5mm were achieved for workability when sawdust was used as a partial substitute for sand at 0%, 25%, and 50%, respectively, but at 75% and 100% replacement of sand with sawdust, the workability increased to 6mm and 15mm, respectively. Though they recognized this behavior to the work's substantially greater water-cement ratio, it is clear that additional research is required to corroborate this behavior.

2.2.2 Weight loss

An experiment was conducted to evaluate the cost of sand-used concrete blocks to sawdust-used concrete blocks, as well as the weight reduction of the two blocks. They made 6 test specimens of control concrete with 10%, 15%, and 20% fine aggregate substituted with saw dust by volume each in this experiment. The following results are reached from a study on the strength behavior of saw dust: during the beginning ages, as the percentage replacement of saw dust grows, the strength as well as compressive strength increases. Furthermore, the use of saw dust decreases the weight of concrete, making it lighter and suitable for use as a light building material in a variety of civil engineering purposes [6].

The optimal amount of river sand to be substituted with Quarry dust and saw dust in order to get the best results was found, and the characteristic strength of normal concrete and concrete with Quarry dust and Saw dust was compared. The test was done for M30 mix including Quarry dust ranging from 0 to 10%, 20%, 30%, and 40% coupled with Saw dust ranging from 0 to 10%, 10%, 15%, and 20% remaining percentage river sand. The compressive strength of quarry dust and saw dust up to 30 percent and 15 percent, respectively, is practically similar to that of the control mix, according to the experimental investigation. Quarry dust and saw dust have split tensile strengths of up to 30% and 15%, respectively, and are essentially matching with that of control mix. The initial crack load for both control mix and quarry dust and saw dust concrete is practically the same, according to the results of a two-point loading test. As a result of this experiment, quarry dust and saw dust with weight contents of 30% and 15% produced the best 6 outcomes. As a result, quarry dust and saw dust can be used as a partial replacement for fine aggregate up to this point. Weight loss of up to 20% is possible [8].

2.2.2.1 Water-to-cement ratio

In concrete, sawdust can be used in place of fine aggregate. For the m-20 mix, saw dust was substituted for fine aggregate in the proportions of 0%, 5%, 10%, and 15% by weight. For this experiment, M20 grade concrete with a mix percentage of 1:1.60:2.78 and a water cement ratio of 0.45 were used. Cement, coarse aggregate, fine aggregate, and sawdust chemical and physical qualities were examined in this study. When the percentage of saw dust in the concrete is increased, the concrete's compressive strength is reduced. The compressive strength of concrete is reduced when the water cement ratio rises. With a higher amount of sawdust, water absorption increased. As a result, it can be concluded that sawdust can be utilized in the field at a maximum of 10% [9].

2.2.2.2 Fineness modulus, Specific gravity and Moisture content

The experiment has been carried out by substituting natural sand with SDA (5%, 10%, 15%, 20%, 25% and 30%). Fineness modulus, specific gravity, moisture content, water absorption, bulk density, percent voids, and percent porosity (loose and compact) condition for sand and SDA are all included in this study. He discovered compressive, tensile, and flexural strength tests of concrete samples for 28, 45, 60, 90, and 180 days. Sawdust ash was discovered to have fineness modulus, specific gravity, moisture content, uncompact bulk density, and compacted bulk density. In addition, it was discovered that when the SDA content rises, the amount of water required rises as well.

The compressive strength of concrete cubes and cylinders increases with age of curing and decreases as the SDA content increases [10].

2.2.3 Strength of concrete under different level of sawdust

2.2.3.1 Compressive Strength

Concrete compressive strength is significant because it influences the design of structural concrete and is a quality that is specified by standards and rules for compliance. All other structural parameters, including flexural strength, splitting tensile strength, and modulus of elasticity, are directly proportional to the concrete's compressive strength.

The experiment was carried out by substituting 5%, 10%, and 25% of the volume of sand with sawdust. Different parameters of sawdust and sand (moisture content, specific gravity, fineness modulus, aggregate grading) were evaluated in this article, as well as compressive, tensile and flexural strength tests after 7 and 28 days. Lowering the amount of sawdust in the concrete mixture increases the strength in 28 days, whereas increasing the amount of sawdust in the concrete mixture increases the strength in 7 days. The compressive strength of the material declined as the sawdust content increased, with replacements above 10% leading in a significant reduction in strength. There is a clear conception in this work that sawdust may be used in field purposes if 10% of total fine aggregate is sawdust [11].

Chitra, R. was experimented on using sawdust ash as a fine aggregate substitute in concrete. The test findings show that it is feasible to make concrete using sawdust ash that has qualities similar to natural sand aggregate concrete if the amount of sawdust ash in the fine aggregate is limited to 10-20% [4].

Gettish Lemma has carried out an experiment by replacing 5%, 10%, 15%, 20%, and 25% of the volume of sand with sawdust, compressive strength C-20 class concrete was produced, with the optimal replacement of 15% producing 20MPa cube compressive strength of concrete [13].

Pervez R. studied strength of concrete tested by partially replacing rivers with sawdust and robosand. Fineness modulus, bulk density, specific gravity, and moisture content of sawdust, robosand, and river sand, as well as other physical characteristics of cement and coarse aggregate, were investigated in this article. Compressive and tensile strength were measured over a period of seven to twenty-eight days. At 7 days, 70% of the typical compressive strength is achieved. For increasing replacement percentages, the concrete's 28-day characteristic strength steadily falls. As a result, these improvements will be beneficial for 7 days strength but not for 28 days strength [11].

The compressive strength of sawdust when partially replaced with cement or aggregate is represented in the below.

Table 2- 1: Compressive strength of partial replacement of sawdust by different Authors

Authors	Max. 28^{th} day's compressive strength (MPa)	Replacement of Sawdust (%)
Chowdhury et al. [40]	31.7 – 35 .3 29.0 – 33.3	5 – 20 5 – 20
Ogork and Ayuba [37]	20	10
Marthong [38]	32.5	10
Subbaramaiah [39]	24-39.74	40
Raheem et al [41]	15	10
Ettu et al. [35]	20.90	10
Adamu et al [21]	22-28	15
Abhishek and Kumbar [36]	25-36	15
Getish Lemma [13]	22	15

2.2.3.2 Tensile Strength

The strength of concrete under tension is important in the design of constructions. Tensile strains can make cracks in concrete that are severe enough to endanger the material's durability. Splitting tests (splitting tensile strength) and modulus of rupture tests are commonly used to measure it (flexural tensile strength) [24].

Split tensile strengths of concrete using sawdust as a partial substitution for fine aggregate seem to be contradictory. Olutoge [2] found that when the addition of saw dust increased, the flexural tensile strength fell. The 28-day findings were 2.24, 1.67, 1.12, 0.81, and 0.55 at 0, 25, 50, 75, and 100% replacement levels. Albert et al [25] found the opposite. Flexural tensile strengths were reported to be 4.38, 4.38, 4.44, 4.44, and 4.5 at 0, 15, 20, 25, and 30% replacement levels, respectively. At all degrees of replacement, these data showed an improvement above control specimens. The apparent improvement in the flexural characteristics of concrete using sawdust as a partial substitute for fine aggregate, according to [25], is due to the fiber in the sawdust.

Moin, S. et al. investigated the physical characteristics and chemical composition of saw dust ash (SDA) in quantities of 5%, 10%, 15%, 20%, 25%, and 30%.The concrete's workability and compressive strength were investigated. The Split Tensile strength of M25 concrete improves when the percentage of Fine Aggregate replaced with Quarry Dust increases from 5% to 10%, 15% to 20%, 25% to 30%, while Saw Dust Ash remains constant at 15% [34].

2.2.4 PH of Sawdust

The PH values of sawdust concrete were in between 10.0 and 12, which is in the alkali region. According to the Portland Cement Association, an alkaline atmosphere will preserve the reinforcing bar more effectively, but an acidic environment will accelerate the corrosion process in steel [17].

2.2.5 Relationship of Sand and Sawdust

Sand is a granular substance found on beaches, riverbeds, and deserts all over the world. It is made up of numerous materials that vary based on its location, as well as a variety of colors. Silicon dioxide, in the form of quartz, is the most common component of sand [30]. Quartz, feldspar, and mica are among the rocks and minerals that make up the earth's surface. Sawdust, on the other hand, is made up of tiny wood particles.

When it comes to density and particle size, sawdust and sand have a lot in common. Sawdust has a density of 650 to 1650 kg/m3, but sand has a density of 1500 to 1600 kg/m3 [30, 31]. Sawdust particles range from 30 to 600 microns in size, whereas sand particles range from 70 to 800 microns in size [30, 31]. As a result, it's very comparable, and replacing sand with sawdust is a good idea.

2.2.6 Effect of Adding HRWRA Admixture in Sawdust Concrete

The results revealed that a maximum dose of 5% sawdust should be used to avoid an excessive loss of mortar mechanical strength and a 25% drop in thermal conductivity. On the other hand, even with 10% sawdust, appropriate mechanical performance can be achieved if a water reducing admixture is used [19].

2.2.7 Sawdust in Ethiopia

Ethiopian forests help Ethiopians by protecting the environment and providing a valuable and frequently used resource base [18]. In Table 2-2, the wood production in south Ethiopia is presented.

Table 2- 2: Total wood production in south Ethiopia in 2016 [16]

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

2.2.8 Availability of Sawdust in Wanza Furnishing Industry

Wanza Furnishing Industry, a member of the MIDROC Technology Group, was founded in July 2003 and specializes in the manufacture and sale of wooden and metallic furniture for the construction, household, office, hotel, and school markets in Ethiopia. Due to the high capacity of furniture manufacture, a large amount of sawdust is produced. Figure 2-1 shows waste sawdust at Wanza Furnishing Industry

Figure 2- 1: Waste Sawdust at Wanza Furnishing Industry

2.3 Concrete Grades

Concrete grade according to European standard, Euro code 2 and EN 206-1, concrete grade represented as C12/15, C16/20, C20/25, C30/37, C35/45, C40/50, C45/55, C50/60, C55/67, C60/75, C70/85, C80/95 and C90/105. For example, C16/20, It is indicated as C, which C is stand for concrete strength class followed by a numerical figure 16, which is compressive strength of concrete is 16MPa after 28 days of mixing on axial compression test on cylinder shape with 15cm diameter and 30cm length cylinder follow by numerical figure 20, which is compressive strength of concrete is 20MPa after 28 days of mixing on axial compression test on cube concrete block shape with cube size 15cm × 15cm × 15cm [43, 44].

Characteristic strength of concrete is their compressive strength which can be determined by axial compression test on cubic concrete block or cylinder shape. If Compression test is carried on cubic concrete block, when tested with cube size 15cm × 15cm × 15cm, that's known as Cubic test and their strength is called cubic strength. And compression test is carried on cylinder shaped concrete block, when tested with 15cm diameter and 30cm length of cylinder, that is known as cylinder test and their strength is called cylinder strength.

For the same combination, the cube and cylinder strengths are substantially different. The strength of the cube is greater than that of the cylinder. Cube strength is around 1.25 times that of a cylinder, according to a rule of thumb.

European Standard (EC2) codes concrete grade generally refers both, cube test and cylinder test, for finding out compressive strength of different mix of concrete at 28 days after mixing. The types of concrete grades and their compressive strengths as defined by European Standard are discussed in this research [43].

2.3.1 International codes and their Concrete Grades

International design codes pertain to the strength of a cube or a cylinder. It's preferable to keep to the code's strengths. Table 2-3 indicates which code considers concrete strength to be cube strength and which considers concrete strength to be cylinder strength.

Table 2- 3: International codes and their concrete strength used in the design

Codes/Standards	Concrete Strength used in the Design
Indian Code (IS)	Cube strength
American Code (ACI)	Cylinder strength
Canadian Code (CSA)	Cylinder strength
European Code (EC2)	Cylinder Strength and Cube strength
British Standards(BS)	Cube strength
Australian Standards (AS)	Cylinder strength

2.3.2 Types of Concrete Grades

According to the EC2 (European standard), normal concrete grades are C12/15, C16/20, C20/25, C30/37, C35/45, C40/50, and C50/60, whereas C55/67, C60/75, C70/85, and C80/95 are high strength concrete grades.

2.3.2.1 C16/20 concrete grade

This is normal grade of concrete, according to European standard. In C16/20 concrete grade, C indicates concrete strength class, numerical figure 16 represent it's characteristics of compressive strength (f_{ck}) on cylinder test that is 16MPa and numerical figure 20 represent it's characteristics of compressive strength (f_{ck}) on cube test that is 20MPa. So compressive strength value of C16/20 concrete grade is 16MPa based on cylinder test and 20MPa based on cube test.

2.3.2.2 C30/37 Concrete Grade

This is normal grade of concrete, it is recommended for construction of load bearing building structure member of beam, column, foundation and basement, according to European standard. Strength of concrete is according to cube test and cylinder test. In C30/37 concrete grade, C indicates concrete strength class, numerical figure 30 represent characteristics of compressive strength (f_{ck}) on cylinder test and numerical figure 37 represent characteristics of compressive strength (f_{ck}) on cube test that is 37MPa.

2.3.2.3 C45/55 and C60/75 Concrete Grades

C45/55 and C60/75 Concrete Grades are used in extreme environmental condition, sea side condition, formation of septic tank and water tank, and basement formation, bridge & dams formation and heavy loaded structural commercial and industrial building, mostly high rise building, it is used for special uses.

2.3.3 Factors Affecting Concrete Grades

Many variables influence the strength of concrete, including the quality of the raw materials, the water/cement ratio, the coarse/fine aggregate ratio, the age of the concrete, the compaction of the concrete, the temperature, the relative humidity, and the curing of the concrete.

2.3.3.1 Quality of Raw Materials

- Cement

Cement should be acceptable for use in concrete if it meets the relevant standards and has been kept properly (i.e. in dry conditions).

- Aggregates:

The strength of concrete is determined by the quality of aggregates, including their size, shape, texture, and strength. Concrete's strength is additionally reduced by the presence of salts (chlorides and sulphates), silt, and clay.

- Water

The water should be appropriate for drinking. This requirement, however, is not absolute, and testing of water construction should be done in accordance with the relevant rules.

2.3.3.2 Water / Cement Ratio

If the water/cement ratio is reduced, the workability of the concrete is reduced for given cement content. A lower water cement ratio indicates that there is less water, or more cement, and therefore the workability is reduced. However, if the workability of the concrete is too low, it becomes difficult to compact and the strength of the concrete suffers. The water-cement ratio determines the strength at any age for a particular combination of materials and environmental circumstances, as long as full compaction is accomplished.

2.3.3.3 Coarse / fine aggregate ratio

The following points should be kept in mind while calculating the coarse/fine aggregate ratio:

- Increasing the amount of fines in ratio to coarse aggregate will increase the overall aggregate surface area.
- As the aggregate's surface area grows, so does the amount of water required.
- Assuming that the demand for water has risen, the water cement ratio will rise as well.
- The compressive strength will decrease as the water cement ratio rises.

2.3.3.4 Aggregate / Cement Ratio

- If the volume remains constant but the percentage of cement to sand increases, the solid's surface area increases.
- If the solids' surface area has risen, the water requirement will remain constant for continuous workability.
- The water cement ratio will decrease assuming no increase in cement content and no increase in water consumption.
- As the water cement ratio decreases, the concrete's strength increases.

Increases in cement percentage have little influence on water consumption and result in a reduction in the water/cement ratio for a given workability. Concrete's strength improves as the water/cement ratio is reduced. As a result, if the cement content is increased at a certain workability, the strength of the concrete increases.

2.3.3.5 Age of concrete

The degree of hydration is synonymous with the age of concrete provided the concrete has not been allowed to dry out or the temperature is too low. In theory, provided the concrete is not allowed to dry out, and then it will always be increasing in ever reducing rate. For convenience and for most practical applications, it is generally accepted that the majority of the strength has been achieved by 28 days.

2.3.3.6 Compaction of concrete

Any entrapped air caused by insufficient compaction of the plastic concrete will result in a loss of strength. If there is 10% trapped air in the concrete, the strength will be reduced by 30 to 40%.

2.3.4 Chemical Admixtures

Higher strength can be achieved by using chemical admixtures to improve the efficiency of cementitious materials by lowering water requirements and/or distributing the cementitious materials. Chemical admixtures should meet ASTM C494/C494M requirements.

Dosage rates for chemical admixtures are measured in fluid ounces per 100 pound (oz/cwt) of total cementitious material. Dosage rates for powdered admixtures are calculated on a dry mass basis. Chemical admixtures can help manage slump loss and hardening rate, resulting in better workability, longer time between batching and placement (especially in hot weather concrete), faster strength gain, and longer durability.

HRWRAs (high-range water-reducing admixtures) operate best in concrete mixes with a lot of cement and other cementitious materials. HRWRAs enhance cement particle dispersion and can cut mixing water requirements by up to 30%, resulting in greater concrete compressive strengths.

Admixtures that can be used in high-strength concrete include water-reducing/retarding additives, high-range water-reducing admixtures, and hydration stabilizers. Admixture dosage rates for normal-strength concrete mixes will almost probably differ from the manufacturer's published guidelines. It is recommended that the additive producer be consulted before using certain admixtures and admixture combinations for high strength concrete mixes.

Although there is minimal information available, high-strength concrete has been produced using a combination of chemical admixtures, such as a high dosage rate of a normal-set water-reducer and a set accelerator. The performance of the admixtures is affected by the type of cementitious materials used. To determine the optimum dose of an admixture or combination of admixtures, trial mixes with varying quantities of admixtures should be utilized [15].

2.3.5 Constituent of concrete

2.3.5.1 Cement

Cement is an excellent natural component with suitable and coherent qualities that binds particles together. Cement is a substance that can maintain its strength and stability in the presence of water and can be molded, but it finally maintains and strengthens solid weight [14].

Cements are finely powdered inorganic compounds with adhesive and cohesive qualities that enable them to unite or link solid matter fragments or particles into a compact whole. Cements are materials that create a paste that sets and hardens by hydration reactions, and that after hardening keep their strength and stability even when submerged, and that can be shaped or deformed before setting and hardening to a rigid mass. [14]

2.3.5.2 Aggregate

Aggregates are materials used as filler with binding material in the making of concrete, and they serve to increase the completed product's dimensional stability and wear resistance. They can be found in igneous, sedimentary, and metamorphic rocks, or manufactured from blast furnace slag. Because aggregates make up 60 to 75 percent of the concrete volume (70 to 85 percent by mass) and have a considerable influence on the concrete's newly mixed and cured qualities, mixing proportions, and economy, getting the optimum kind and quality of fine and coarse aggregates is crucial. Certain aggregate properties that influence the paste requirement of fresh concrete, such as shape and texture, size gradation, moisture content, specific gravity, and bulk unit weight, must be known in order to proportion suitable concrete mixes.

Aggregates should also be hard, dense, durable, clear, and free of veins and adhering covering, as well as devoid of harmful quantities of disintegrating pieces, alkali, vegetable matter, and other harmful chemicals.

Aggregates can be divided into fine and coarse categories based on the number of particles retained or passed through a 4.75 mm sieve, but most specifications, such as Ethiopian, Indian, and South African standards, divide aggregates into fine and coarse categories based on the number of particles retained or passed through a 4.75 mm sieve.

The British standard, on the other hand, categorizes with a 5 mm sieve size. Aggregates can also be classified as light weight, standard weight, or heavy weight based on their unit weight [12].

Aggregates can also be classified according to their size. Coarse aggregates are aggregates that are mostly retained on the No. 4 (4.75 mm) sieve. The most often available coarse aggregates in a particular location are normal weight crushed basaltic rocks. The size of coarse aggregate is commonly 19 mm to 25 mm. A 9.5mm intermediate size aggregate is occasionally used to improve overall aggregate gradation. Fine aggregates are those that pass the No. 4 (4.75 mm) sieve and are mostly retained on the No. 200 (75 m) sieve. Sand is one of the materials that may pass through this series of sieves. It comes in a variety of forms, including natural, crushed stone sand, crushed gravel sand, and a mix of the three. The fine aggregate grading has a significant impact on the workability of a concrete mix. Silica (silica dioxide or SiO_2) is the most frequent component in sand. Silica is the term given to a collection of minerals made up of the two most prevalent elements in the earth's crust, silicon and oxygen. Silica is often found in crystalline form, with amorphous forms occurring rather infrequently. It has the chemical formula SiO_2 because it contains one silicon atom and two oxygen atoms [12].

2.3.5.3 Requirement of Sand for concrete

Aggregate gives concrete a technical benefit because it has higher volume stability than cement paste alone. Before employing aggregate as a concrete-making material, it is necessary to determine whether the aggregates are suitable for the purpose for which they are intended, and to conduct testing on-site and in the laboratory. Some of the requirements for sand used for concrete are discussed as follows:

- Grading of fine aggregate

Fine particle grading affects concrete workability more than coarse aggregate grading. The amount of cement paste required for workable concrete is determined by the amount of void in the concrete mixture [20].

- Fineness Modulus

A numerical index called the fineness modulus (FM) is commonly computed using the sieve analysis findings. According to ASTM C 125, the fineness modulus (FM) of fine or coarse aggregate is computed by combining the cumulative percentages by mass retained on each of a set of sieves and dividing the total by 100 [20].

9.5 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600μm, 300μm, and 150μm are the sieves that have been defined. The 150μm (No. 100) sieve is the lowest in the specified series of sieves, and the openings in each bigger sieve are twice the size of the sieve below. The FM is higher the coarser the aggregate size. According to ASTM C 33 [20], the FM for fine aggregate used in concrete is typically between 2.3 and 3.1. Sand with a fineness modulus of higher than 3.2 is inappropriate for concrete production. [12].

- Silt Content

Sand is created through the disintegration of rocks and minerals, which can occur naturally or artificially. Glacial, river, lake, marine, residual, and wind-blown (extremely fine sand) deposits are all sources of sand. However, these sand formations do not contain pure sand. Dust, loam, and clay, which are finer than sand, are frequently found in them. Therefore, a silt content test and comparisons to allowed limits are required [12].

The 'field settling' test is a simple on-site test that may be used to estimate how much silt is present in natural sand. For broken rock sands, this test is not appropriate. If the silt content of the sand surpasses a value of 6%, the Ethiopian Standard recommends washing it or rejecting it [22].

- Deleterious substance of fine aggregate

Aggregates should not be used in Portland cement concrete if they contain elements that are harmful to the environment. As a result, the Specifications limit the amount of potentially harmful elements to a level that meets ASTM C33 [22] quality standards.

2.3.5.4 Water

In concrete, water plays an important role. It combines chemically with cement to give concrete its desired characteristics. A quantity of water that comes into contact with cement, affects the slump of concrete, and is used to estimate the water to cementation materials ratio of concrete mixes is known as mixing water. The water cement ratio influences the strength and durability of concrete to a larger extent. When less water is utilized in the mix preparation, the strength of the concrete rises. Wet concrete contains more water than is necessary for the hydration processes, despite the fact that the hydration process consumes a particular amount of water.

Concrete must be workable in order to be shaped into the correct form and consolidated to the necessary density. The water to cement ratio is calculated by dividing the amount of water used by the amount of cement. A low water-cement ratio generates great strength but poor workability, whereas a high water-cement ratio produces low strength but excellent workability. When producing the mix, a precise balance of cement to water is necessary.

Concrete mixing necessitates the use of high-quality water. Natural water that is consumable and does not have a strong flavor or odor can be utilized as a concrete mixing water. When mixing concrete, salt water should not be used since it reduces strength and creates substantial fluctuations in setting time.

2.3.6 Properties of fresh concrete

Fresh concrete is described as concrete that has not yet established its strength despite its components being fully mixed. The handling, laying, and consolidation qualities of fresh concrete, as well as the properties of hardened concrete, are all influenced by its properties. Some of important properties of fresh concrete are discussed in this section.

2.3.6.1 Workability

Workability is defined by ASTM C 143 as the attribute that determines the effort necessary to handle a freshly mixed quantity of concrete with the least amount of homogeneity loss. The early age operations of putting, compacting, and completing are included in the phrase "manipulate." A workable concrete enables for thorough compaction with a minimum of effort. This aids in getting the highest possible density (i.e. the fewest possible voids) in concrete, resulting in increased strength and durability. [28].

The amount of water in concrete is the most critical element impacting its workability. Concrete's workability will improve when the amount of water is increased. However, increasing the amount of water in the mix would reduce its strength and cause segregation and bleeding. The workability of concrete is affected by the amount of aggregate, the percentage and fine aggregate, as well as the form and texture of the aggregate particles. Increasing the amount of aggregate while keeping the water and cement content constant lowers the workability of concrete. [28].

2.3.7 Properties of hardened concrete

2.3.7.1 Compressive Strength

The compressive strength of concrete is the characteristic that receives the most attention among the numerous strength qualities of concrete since it is this property that is used in developing structural or basic load bearing building units. It also has a significant practical and economic value since it determines the sections and sizes of concrete constructions. Because most concrete buildings are built to withstand compressive stress, rules or standards frequently specify this feature.

Other strengths, such as flexural and tensile, can also be linked to this feature. A conventional uniaxial compression test will be used to measure the concrete's compressive strength after 3, 7, and 28 days. This test is commonly acknowledged as a general index of concrete strength [24].

2.4 Literature summary and gap identification

Studies have shown that using sawdust as fine and coarse aggregate in concrete mixtures has acceptable physical and mechanical properties. The compressive, tensile, and flexural strength of sawdust partially replaced as fine or coarse aggregate in concrete is comparable to concrete control for optimal sawdust replacement. Almost all studies used normal concrete grades and bricks to perform their investigation. Given its light weight and other benefits, it is preferable to investigate the feasibility of partial substitution of sawdust for structural components, particularly for normal and high compressive strength concrete grades. As a result, the influence of concrete grades on the partial replacement of saw dust as sand will be investigated in this study.

3 MATERIALS AND METHODS

3.1 Introduction

The properties and types of materials utilized in the study, as well as all laboratory experiments, sample preparations, experimental techniques, and test settings, are briefly discussed in this chapter. The materials were prepared, tested, and the experimental program was carried out in the Addis Ababa Institute of Technology's building material laboratory (AAiT). Each material's properties and tests are compared to ASTM standards and specifications to see if they meet the criteria.

3.2 Materials

The material used for this research includes; cement, fine aggregate, coarse aggregate, water, high range water reducing admixture and sawdust.

3.2.1 Cement

In this research, ordinary Portland cement from the local market was used. The cement utilized in this study was Type-1 Dangote ordinary Portland cement with a CEM 42.5 R grade, and the physical properties of the cement were investigated, with a relative density of 3.15g/cm^3.

3.2.2 Aggregate

Aggregate refers to both coarse and fine aggregates. Aggregate must cover at least three quarters of the concrete. To eliminate any changes owing to a different source, the aggregate was given from the same source in this study. To guarantee that the material fits the standard for concrete work, all essential laboratory tests such as bulk density, specific gravity, and aggregate moisture content have been performed. Before the aggregate qualities were determined, it was washed to eliminate impurities such as silt, organic debris, and any other particles that might degrade its quality. Aside from that, the aggregate was stored in a plastic bag after it dried until mixing time to keep the moisture level consistent.

3.2.2.1 Fine Aggregate

Fine aggregate was prepared from locally accessible river sand that passes through a 4.75mm sieve and is retained on the 0.075mm sieve. The physical properties of fine aggregate were studied in the lab, and the results are described in Table 3-1.

Table3- 1 Physical properties of fine aggregate

No.	Test description	Test result
1	Silt content	1.33%
2	Moisture Content	1.52%
3	Absorption capacity	2.27%
4	Fineness modulus	2.71
5	Unit weight	1490.97 kg/m^3
6	Bulk specific gravity (SSD)	2.45g/cm^3

The fine aggregate was washed to reduce the amount of silt in it, and it now has a silt percentage of 1.33 percent. The local fine aggregate utilized in this investigation complies with ASTM C-33-01 [22].

Table3- 2: The particle size distribution of fine aggregate

Sieve size (mm)	Weight Retained (g.)	Percent of retained (%)	Cumulative retained (%)	Cumulative passing (%)	ASTMC33 standard passing (%)
9.5	0	0	0	100	100
4.75	0.6	0.12	0.12	99.88	95-100
2.36	21.9	4.38	4.5	95.5	80-100
1.18	69.8	13.96	18.46	81.54	50-85
0.6	177.8	35.56	54.02	45.98	25-60
0.3	201.9	40.38	94.4	5.6	5-30
0.15	25.9	5.18	99.58	0.42	0-10
Pan	2.1	0.42	100	0	0

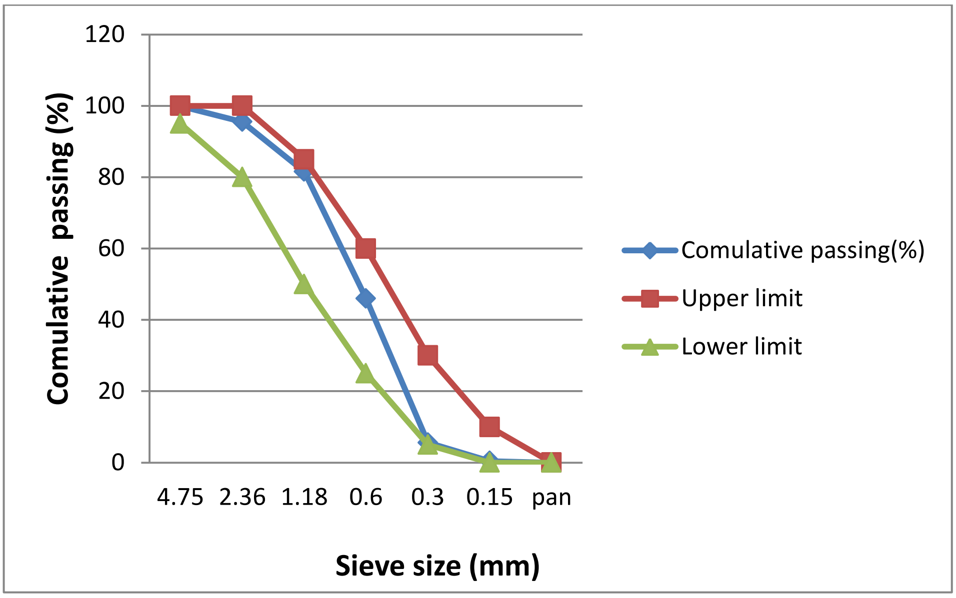

Figure 3- 1: Gradation curve of fine aggregate

3.2.2.2 Coarse Aggregate

To keep the gradation within the range required by the ASTM standard, basaltic crushed rock aggregates with a nominal maximum size of 19 mm were employed in this study. The aggregates were tested for physical properties such as gradation, specific gravity, water absorption, moisture content, and unit weight.

Table3- 3: Physical properties of coarse aggregate

No	Test description	Test result
1	Moisture content	1.28%
2	Water absorption capacity	1.27%
4	Bulk Specific gravity	2.73g/cm^3
5	Unit weight	1660 kg/m^3
6	Finesse modulus	6.99

Table3- 4: The particle size distribution of coarse aggregate

Sieve size (mm)	Weight Retained (g.)	Percent of retained (%)	Cumulative retained (%)	Cumulative passing (%)	ASTM C33 standard passing (%)
25	0	0	0	100	100
19	231.2	11.56	11.56	88.44	90-100
12.5	882	44.1	55.66	44.34	35-80
9.5	636.2	31.81	87.47	12.53	20-55
4.75	247	12.35	99.82	0.18	0-10
Pan	3.6	0.18	100	0	0

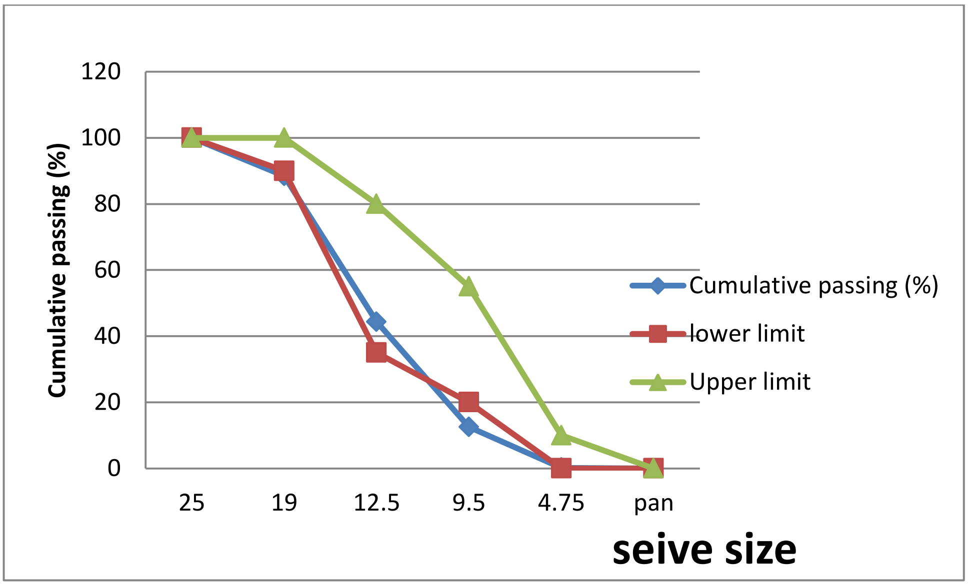

Figure 3- 2: Gradation curve of coarse aggregate

3.2.3 Sawdust

Sawdust is made up of tiny wood particles and is produced as a by-product of cutting or drilling wood with a saw or other instrument. Sawdust was gathered for this investigation from wanza furnishing industry located at Semit around Pepsi.

3.2.3.1 Physical properties of sawdust

The physical properties of sawdust obtained from laboratory test results are summarized in below.

Table3- 5: Physical property of sawdust

No	Test description	Test result
1	Moisture content	8%
2	Water absorption capacity	16.3%
3	Unit weight	536.9 Kg/m3
4	Finesse modulus	2.57
5	Bulk Specific gravity	0.91 g/cm3

Table3- 6: The particle size distribution of sawdust

Sieve size (mm)	Weight Retained (gm)	Percent of retained (%)	Cumulative retained (%)	Cumulative passing (%)	ASTM C33 standard passing (%)
9.5	0	0	0	100	100
4.75	0	0	0	100	100
2.36	5.64	11.28	11.28	88.72	85-100
1.18	6.8	13.6	24.88	75.12	-
0.6	12.38	24.76	49.64	50.36	40-80
0.3	11.78	24	73.64	26.36	10-35
0.15	9.5	23.56	97.2	2.8	5-25
Pan	1.9	3.8	-	0	0
Total	48		256.64		

$$\text{Fineness modulus} = \frac{\sum(\text{cumulative percent of retained})}{100} = \frac{256.64}{100} = 2.57$$

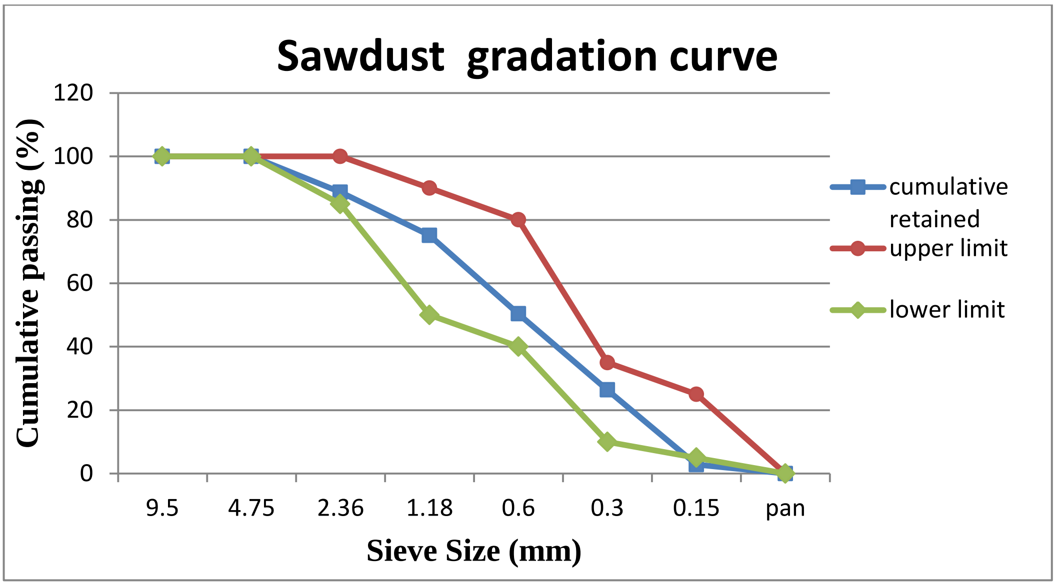

Figure 3- 3: Gradation curve of sawdust

3.2.3.2 Sawdust finer than 75μm

Specifications normally limit the quantity of material that passes over the 75-meter mark, which can reduce the durability of concrete and increase the amount of water it requires [20]. According to the Ethiopian standard, material finer than 75m should be rejected if it has a value greater than 6%, while sawdust had a value of 4%, which was within the allowed range.

3.2.4 Water

Water is an important component of concrete since it is involved in the chemical interaction between cement and water. Furthermore, water was used to mix the concrete, cure the concrete, and wash the aggregate. As a result, water must be free of pollutants that cause quality degradation, such as alkalis, suspended particles, acids, silt, clay, and dissolved salt. As a result, the water utilized in this study was tap water from the Addis Ababa Institute of Technology's construction material laboratory's water supply pipe.

3.2.5 Admixture

The chemical admixture acts as high range water reducer and promotes high plasticity and good slump keeping properties of concrete. Chemical admixtures should meet the requirements of ASTM C494/C494M. For this study Sikament NN high range water reducing admixture was used.

3.2.6 Specimens

Specimens are made based on the concrete grades and the replacement ratio. A total of 192 specimens are available. The mechanical characteristics were tested on the 7th and 28th days for all of the mechanical properties. The specimens were cast for concrete grades C16/20, C30/37, C45/55, and C60/75 with a sawdust content of 0%, 5%, 10%, and 15%, computed by volume using the ACI mix design procedure. Sawdust was used as sand in the mixture. The compression strength test was performed on 150mm x 150mm x 150mm cubes, while the split tensile strength test was performed on 300mm long x 150mm diameter cylinders. For each of the four concrete grade tests, four different percentages of sawdust were obtained, with three specimens taken in each case for average purposes. Then 96 specimens were used for the compressive test of partial replacement of wanza sawdust, as well as the tensile strength test. Then totally, 192 specimens were cast. Table 3-7 describes the mix notation.

Table3- 7: Mix Notation of Sawdust

Mix Code	Mix Notation
SD-0	0% Replacement of sawdust
SD-5	5% Replacement of sawdust
SD-10	10% Replacement of sawdust
SD-15	15% Replacement of sawdust

3.3 Methods

All constituent materials required to make concrete samples have been prepared, and their physical properties have been tested to ensure their suitability.

3.3.1 PH Value of Sawdust

In this investigation, a PH meter was used to assess the PH value of sawdust.

Figure 3- 4: Measuring the PH value of Sawdust using the PH meter.

The PH value of sawdust was determined using a PH meter in three samples for an average purpose. The PH values of the samples are shown in Table 3- 8.

Table3- 8: PH value of the Samples.

Mix Code	PH value of the Sawdust
SD-1	7.62
SD-2	7.61
SD-3	7.5
Average	7.57

3.3.2 Mix Design

The proportions of C16/20, C30/37, C45/55 and C60/75 are indicated in the tables below, and the mix designs for each concrete grade were conducted in accordance with ACI specification.

3.3.2.1 Mix Design of C16/20

The mix design for C16/20 was performed in accordance with ACI 211.1. Table3- 9 shows content of ingredients for unit volume of C16/20 concrete grade. Appendix A has the detailed calculations.

Table3- 9: Content of ingredients for unit volume of C16/20 concrete grade

No	**Ingredients**	**Weight per unit volume (kg/m^3)**
1	Cement	306.45
2	Fine aggregate	760.43
3	Coarse aggregate	1045.8
4	Water	201.03

3.3.2.2 Mix Design of C30/37

Mix design of C30/37 was completed in accordance with ACI 211.1-91. The quantity of each component is listed in the table 3-10 below. Appendix B has the detailed calculations.

Table3- 10: Content of ingredients for unit volume of C30/37 concrete grade

No	Ingredients	Weight per unit volume (kg/m^3)
1	Cement	431.82
2	Fine aggregate	662.31
3	Coarse aggregate	1044.14
4	Water	200.29

3.3.2.3 Mix Design of C45/55

Mix design of C45/55 was completed in accordance with ACI 211.1-91. The quantity of each component is listed in the table 3-11 below. Appendix C has the detailed calculations.

Table3- 11 : Content of ingredients for unit volume of C45/55 concrete grade

No	Ingredients	Weight per unit volume (kg/m^3)
1	Cement	470.2
2	Fine aggregate	605.15
3	Coarse aggregate	1188
4	Water	181.02
5	High range water reducing admixture (HRWRA)	7.053

3.3.2.4 Mix Design of C60/75

The mix design for C60/75 was accomplished according to ACI 211-4R-08. Detailed calculation is presented in appendix D. Table 3-12 shows content of ingredients for unit volume of C60/75 concrete grade.

Table3- 12: Content of ingredients for unit volume of C60/75 concrete grade

No	Ingredients	Weight per unit volume (kg/m^3)
1	Cement	629.03
2	Fine aggregate	477.75
3	Coarse aggregate	1195.2
4	Water	178.56
5	High range water reducing admixture (HRWRA)	9.44

3.3.3 Specimen and material preparation

3.3.3.1 Surface dry condition for sawdust

Saturated-surface-dry (SSD) is a method that involves filling all pores with water but leaving no water film on the surface. Sawdust requires a saturated surface drying due to its high water absorption capacity. Figure 3- 5 shows the sawdust being soaked and then saturated surface dried.

Figure 3- 5: Soaking the sawdust for 24 hours and Saturated surface drying the sawdust

Figure 3- 6: Cube and cylinder molds for casting sealed by wax

3.3.4 Concrete mix

The mixer shown in Figure 3-7 was used to mix the concretes in the laboratory. Concrete test specimens were made and cured in the laboratory according to ASTM C192 [27]. The coarse aggregate was put first, followed by cement and fine aggregate (sand and sawdust), and then it was dry mixed. After adding two-thirds of the water, the mixing was maintained for another minute. The final step is to add the remaining water. For a high-strength concrete grade, the high range water reducing admixture (HRWRA) was added around 15 minutes after the first mixing. In a mixer machine, the materials were carefully combined until they had a homogeneous consistency. The concrete on cube and cylinder samples was compacted using a table shake vibrator. After the concrete was poured, standard troweling was used to finish the top surface.

Figure 3- 7: The mixer used and mixing the concrete

To verify the workability of fresh concrete, slump tests were performed soon after mixing. ASTM C143 [28] is used to measure the slump of all freshly mixed concrete.

Figure 3- 8: Concrete casting and curing the samples

3.4 Test Setup

3.4.1.1 Compressive strength test

The concrete was surface dried and tested according to ASTM C39 [29], weighed, and then tested with the Universal Testing Machine at seven and twenty-eight days after being taken out of the curing tank. Compressive strength was measured in three cubes of each mix after seven and twenty-eight days. Appendix D contains the complete findings of the compressive strength test. Figure 3- 9 shows compressive strength test setup.

Figure 3- 9: Compressive strength test setup

3.4.1.2 Splitting tensile test

The fracture tensile strength test on concrete cylinders is a method of determining the tensile strength of concrete. Due to its brittle nature, concrete performs poorly in tension and was not meant to resist direct tension. When tensile forces are applied to concrete, cracks appear. After 7 and 28 days of curing, the split tensile strength of cylindrical samples with a 30cm height and 15cm diameter was measured using ASTM C496 standard testing methods. Figure 3- 10 shows splitting tensile testing setup.

Figure 3- 10: Splitting tensile testing setup

4 RESULT AND DISCUSSION

4.1 Introduction

In this chapter, a summary of all experimental test findings will be offered, along with a discussion; the finding of an experimental program will address the fresh and hardened properties of concrete made with sawdust as a partial replacement for sand. The findings are fully discussed in relation to previous work and globally recognized standards.

4.2 PH Value of Sawdust

PH is a critical factor in the chemistry of concrete. The components of concrete are Portland cement, fine and coarse aggregates and water. Portland cement is the "binding" component in concrete and has a pH approaching 11, which is very alkaline In order for the cement to hold together the other components, it is important for it to remain at or near a pH of 11. When acids are introduced onto the concrete, they enter into the small pores and micro-cracks of the concrete and attack the surrounding materials, lowering their PH. The cement's capacity to hold things together reduces when the pH decreases. Only sand and rock will remain once the concrete has been exposed to acidic surroundings for a long enough amount of time. When the lowered pH reaches below that of the steel reinforcement, it attacks the reinforcement's thin protective coating of iron oxide, causing corrosion. When steel corrodes, it expands up to 6 times its original size, causing the surrounding concrete to fracture and break under the pressure. This can cause structural collapse in concrete [17].

In this investigation, a PH meter was used to assess the PH value of sawdust, which was found to be 7.57 on average, which is in the weak base range.

4.3 Fresh Concrete Properties

4.3.1 Slump test

A slump test is used to determine the workability of fresh concrete. At the completion of mixing and before casting, slump tests were performed on C16/20 and C30/37 concrete grades using the ASTM C143 standard test technique for slump of hydraulic cement concrete. The slump test results are shown in figure 4-1.

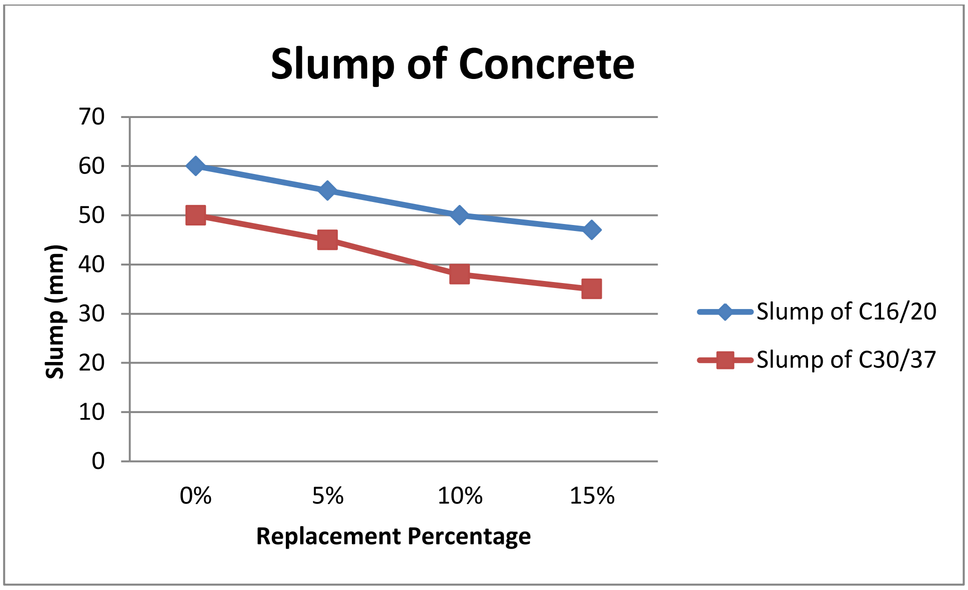

Figure 4- 1: Slump of Concrete

The concrete mixes that contain sawdust demonstrated a reduction in slump, as indicated in figure 4.1. When compared to the control mix, mix SD-5, SD-10, and SD-15 demonstrate reductions of 8.3 %, 16.7%, and 21.7% in C16/20 concrete grade. In addition, when compared to C30/37 concrete mix, mix SD-5, SD-10, and SD-15 had workability reductions of 10%, 24%, and 30%, respectively. When comparing the workability of C16/20 and C30/37 concrete grades, the concrete grade of C30/37 concrete grade mix of SD-5, SD-10, and SD-15 drops by 16.7%, 30.6 percent, and 27.8%, respectively, when compared to C16/20 concrete grade. Because the C30/37 mix design has a lower water-to-cement ratio than the C16/20 mix design, sawdust has a higher surface area-to-volume ratio and requires more water than sand, resulting in a decrease in concrete workability.

4.4 Hardened Property of Concrete

Compressive strength and splitting tensile strength tests were performed at 7th and 28th days to evaluate the mechanical properties of partial replacement of sawdust as sand in concrete for C16/20, C30/37, C45/55, and C60/75 concrete grades. Concrete density comparisons were also performed.

4.4.1 Density of Concrete

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

The density of concrete has a significant impact on its mechanical properties. Denser concrete has more strength and less voids and porosity than less dense concrete.

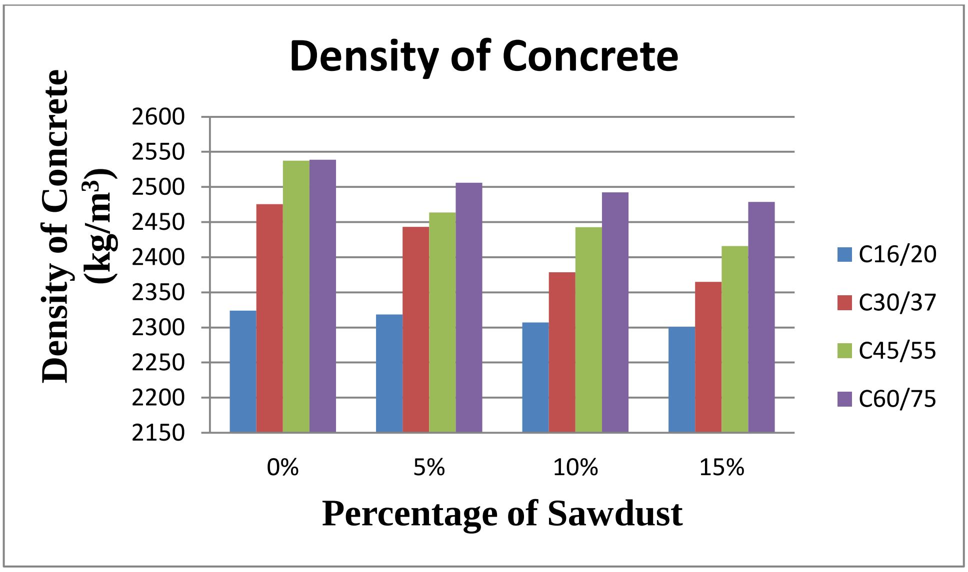

Figure 4- 2: Density of Concrete

The difference in density of concrete made with C16/20, C30/37, C45/55, and C60/75 concrete grades at 28 days of curing is shown in Figure 4.2. The results demonstrate that as the quantity of sawdust in concrete increased, the density of the concrete decreased. Because sawdust has a lower density than sand, the density of concrete has dropped. All of the densities, however, were higher than the maximum density needed for lightweight aggregate concrete, which is 1850kg/m^3 [24].

4.4.2 Compressive Strength Test Result

The compressive strength of concrete grades C16/20, C30/37, C45/55, and C60/75 were measured and analyzed. The viability of using sawdust as a partial substitute in concrete production is checked using a 95 percent confidence interval calculation and the ACI 301 structural concrete specification as compliance criteria.

The Appendices contain all of the cube and cylinder strength test data for concrete grades C16/20, C30/37, C45/55, and C60/75 at 7th and 28th days. Figure 4-3 and figure 4-4 show the relationship between cylindrical compressive strength and replacement percentages of sawdust as sand for the illustrated concrete grades at 7th and 28th days respectively.

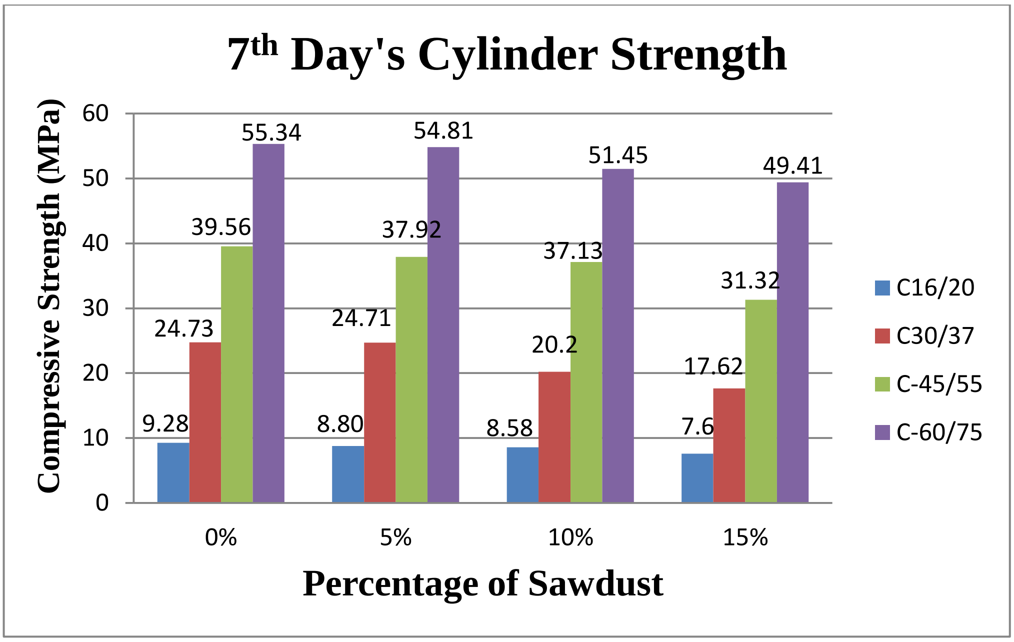

Figure 4-3: 7th Days cylindrical compressive strength

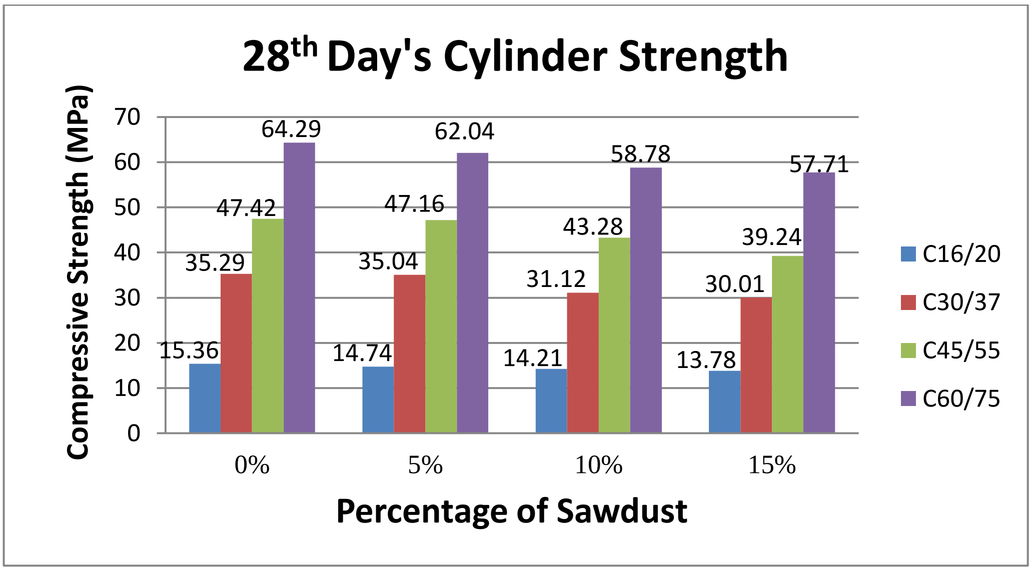

Figure 4- 4: 28th Days cylindrical compressive strength

For each concrete grade, the 95 percent confidence interval was determined using 0%, 5%, 10%, and 15% replacements. Based on the mean and standard deviation, an upper and lower limit was established. Depending on the confidence interval and ACI 301 specification, the comparative strength of C16/20 concrete allows for up to 15%

substitution of sawdust with sand. For C30/37, C45/55, and C60/75 concrete grades, sawdust concrete substitution up to 10% is permissible. The pattern of compressive strength test results demonstrates that increasing the amount of sawdust has a negative impact on the cement-sawdust bond. Show that adding more sawdust to concrete reduces its strength [1]. Figure 4-5 shows the result comparisons.

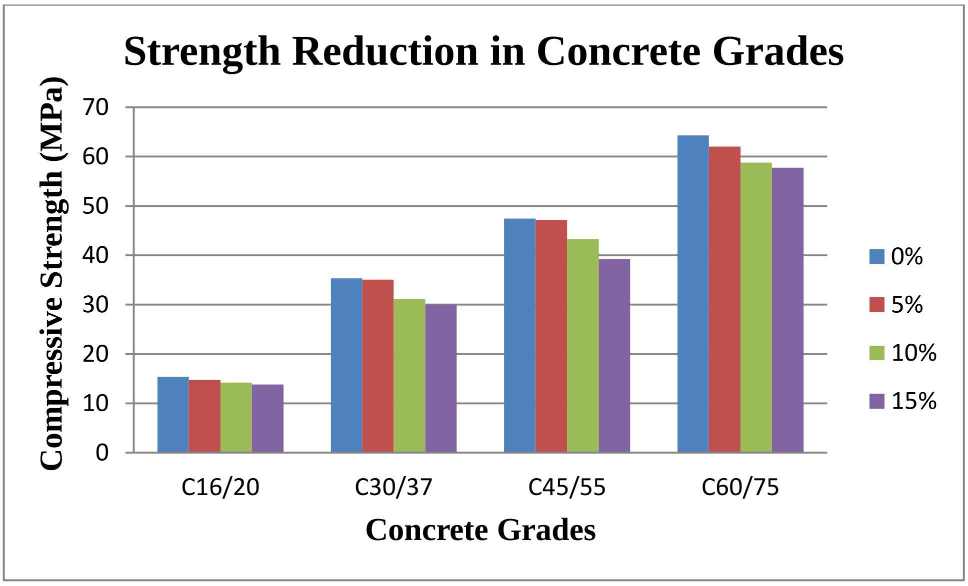

Figure 4- 5: comparison of strength reduction within C16/20, C30/37, C45/55 and C60/75 concrete grades under replacement of sawdust

The effect of substituting sawdust as sand for C30/37, C45/55, and C60/75 concrete grades on their compressive strength is greater than in C16/20 concrete grade. The reason for this reduction is that, in C16/20 strength concrete, compression failure almost exclusively involves debonding of the cement paste from the aggregate particles at the paste aggregate interface, whereas in increasing concrete grade, both the aggregate particles and the interface fail, clearly contributing to overall strength [32]. Therefore, the low percentage substitution of sand with sawdust in C30/37, C45/55, and C60/75 strength is most likely due to sawdust's poor compressive strength when compared to sand.

4.4.3 Splitting Tensile Strength Test Result

The splitting tensile strength test for concrete is an indirect tension test. It's done on a standard cylindrical specimen that has been examined in diametric compression on its side. For each partial replacement of sawdust in sand, three cylindrical samples were evaluated. Figure 4-6 and figure 4-7 demonstrate the relation between sawdust concrete tensile split strength in comparison to the control concrete.

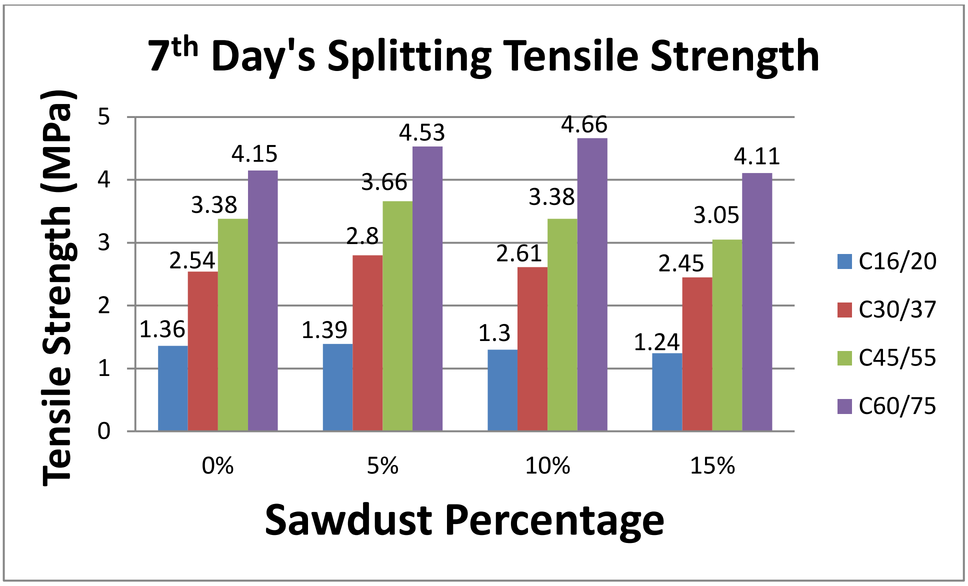

Figure 4- 6: 7th Day's Splitting Tensile Strength

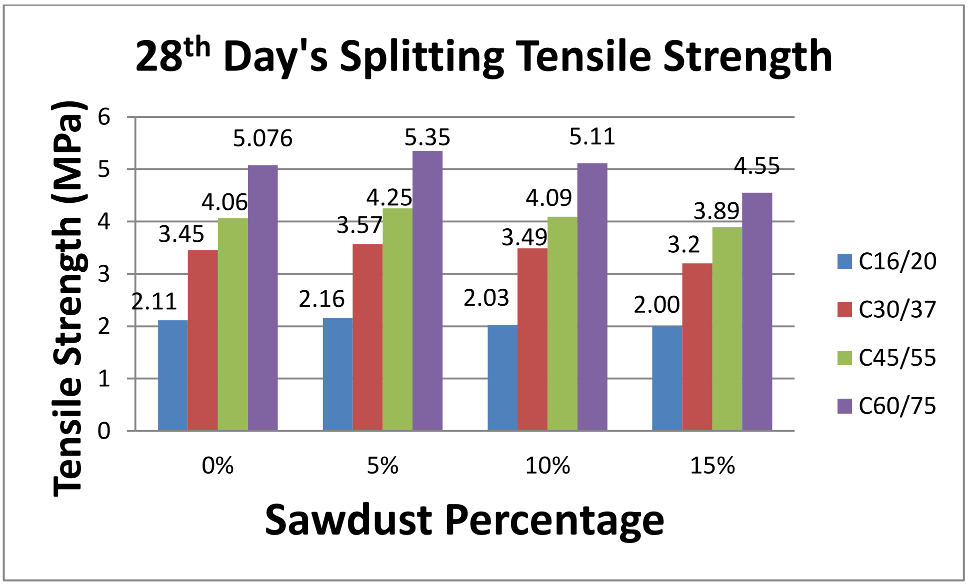

Figure 4- 7: 28th Day's Splitting Tensile Strength

The fact that sawdust acts as a fiber in the concrete, increased the splitting tensile strength of concrete through percentage replacement of sand with sawdust, showing improvement in the flexural properties of concrete with sawdust as partial replacement of fine aggregate.

5 CONCLUSIONS AND RECCOMENDATIONS

5.1 Conclusions

Based on the experimental works, the following conclusions are drawn.

- Based on the compressive strength test results of the concrete mixes, in the case of C16/20 concrete grade, sand can be replaced with sawdust up to 15%.
- Sawdust replaces sand in concrete grades C30/37, C45/55, and C60/75 with a maximum replacement of 10%.
- As the concrete grade rises, the maximum percentage replacement of sawdust as sand decreased.
- Concrete becomes less workable as the amount of sawdust increases. This might be due to sawdust's high water consumption, which is caused by its higher area-to-volume ratio than sand.
- Partial replacement of sawdust increases the tensile and flexural strength of all grades considered in this research.
- The density of the concrete decreases as the amount of sawdust increases.
- The average PH value of sawdust is 7.5, which is in the weak base range. And it is in a good agreement with that of sand.

5.2 Recommendations

Based on the study, sawdust usage as a structural concrete ingredient is undeniable. More research is needed, bending behavior and associated properties such as

- cracking and stiffness,
- Shear behavior,
- Sawdust concrete strength development, and
- Bond characteristics are some of the properties of concrete containing saw dust that need to be understood in order to capture its complete structural response.

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APPENDIX

Appendix A - Mix design procedure of C16/20

The following procedures are used for the mix design of C16/20 concrete grade.

Step 1. Material property

a. Cement type 1; specific gravity=3.15

b. Coarse aggregates

- Bulk specific gravity =2.73
- Absorption capacity =2.54%
- Moisture content = 2.03%
- Compacted unit weight =1660 kg/m^3

c. Fine aggregate

- Bulk specific gravity =2.45
- Absorption capacity =2.27%
- Moisture content = 1.52%
- Compacted unit weight =1490.97 kg/m^3
- Fineness modulus = 2.71

Step 2. Choice the slump

From the recommended slump value of ACI 211 Table 6.3.1, to address the most common constructions of concrete we considered beams, reinforced walls and columns with the slump ranges (25- 100) mm, minimum slump =25mm and maximum slump = 100mm.

Step 3. Choice the maximum aggregate size

Coarse aggregate = 19mm

Step 4. Estimation of Mixing water & Air content

Considered non-air-entrained concrete, from ACI 211 table 6.3.3, for non-air entrained and slump of 25-50, the water in 1m^3 of concrete is 190 Kg.

Step 5. Water-Cement ratio (W/C)

To change the cylindrical to the cube compressive strength, it considered as 19 MPa so the water to cement ratio is nearly 0.6

W/C = 0.62

Step 6: - Cement content calculation

Water content = 190kg

w/c =0.62

Cement content (Kg) for 1m^3 of concrete =190/0.62= 306.45kg

Step 7. Estimation of Coarse aggregate (CA) content

From ACI table, for fineness modulus = 2.71of Fine aggregate and Maximum aggregate Size of coarse aggregate = 19 mm the volume of dry-rodded coarse aggregate per unit volume of concrete is 0.63.

Coarse aggregate content = 0.63×1660kg/m^3 = 1045.8kg

Step 8. Estimation of Fine aggregate content

By absolute volume method

In absolute volume method the volume of fine aggregate is determined by subtracting the volume of all known ingredients from unit volume of concrete.

Volume = $\frac{\text{mass(kg)}}{\text{specific gravity} * \text{density of water}}$

Volume of Water = $\frac{190}{1*1000}$ = 0.19m^3

Volume of Cement = $\frac{306.45}{3.15*1000}$ = 0.097m^3

Volume of Coarse aggregate = $\frac{1045.8}{2.73*1000}$ = 0.383m^3

Volume of air = 2%

Therefore -

Volume of fine aggregate = unit volume of concrete - volume of (coarse aggregate +cement + water + air)

= 1 – (0.383 + 0.097 + 0.19 +0.02) = 0.31m^3

Mass of fine aggregate = 0.31×2.453×1000 = 760.43 kg

The content of ingredients for unit volume of concrete

No	Ingredients	Weight per unit volume (kg/m^3)
1	Cement	306.45
2	Fine aggregate	760.43
3	Coarse aggregate	1045.8
4	Water	190

Step 9. Moisture adjustment

If absorption capacity of aggregate is greater than the moisture content, we need add the mixed water to get better workability of the concrete.

C.A water = 2.54 -2.03 = 0.51%

F.A water = 2.27 -1.52 = 0.75%

Total required water = 190 + ((mass C.A ×0.51%) + (mass F.A×0.75%)

Total required water = 190 + ((1045.8× 0.51%) + (760.43×0.75%)) = 201.03 kg

Therefore content of ingredients for unit volume of concrete is

No	Ingredients	Weight per unit volume (kg/m^3)
1	Cement	306.45
2	Fine aggregate	760.43
3	Coarse aggregate	1045.8
4	Water	201.03

Mass of Sawdust = (%)*F.A volume *specific gravity of SD *1000

Like, SD-15 = 15% * 0.27* 0.91 *1000 =

No	Ingredients	Weight per unit volume (kg/m^3)			
		SD-0	SD-5	SD-10	SD-15
1	Cement	306.45	306.45	306.45	306.45
2	Fine aggregate	760.43	629.20	596.08	562.96
4	sawdust	0	12.29	24.57	36.86
3	Coarse aggregate	1045.8	1045.8	1045.8	1045.8
5	Water	200.03	200.03	200.03	200.03

Appendix B – Mix design procedure of C30/37

The following procedures are used for the mix design of C30/37 concrete grade.

Step 1. Material property

a. Cement type 1; specific gravity=3.15

b. Coarse aggregates

- Bulk specific gravity =2.73
- Absorption capacity =2.54%
- Moisture content = 2.03%
- Compacted unit weight =1660 kg/m^3

c. Fine aggregate

- Bulk specific gravity =2.45
- Absorption capacity =2.27%
- Moisture content = 1.52%
- Compacted unit weight =1490.97 kg/m^3
- Fineness modulus = 2.71

Step 2. Choice the slump

From the recommended slump value of ACI 211 Table 6.3.1, to aslump ranges (25- 50) mm, minimum slump =25mm and maximum slump = 50mm.

Step 3. Choice the maximum aggregate size

Coarse aggregate = 19mm

Step 4. Estimation of Mixing water & Air content

Considered non-air-entrained concrete, from ACI 211 table 6.3.3, for non-air entrained and slump of 25-50, the water in 1m^3 of concrete is 190 Kg.

Step 5. Water-Cement ratio (W/C)

To change the cylindrical to the cube compressive strength, it considered as 38 MPa so the water to cement ratio is nearly 0.44.

W/C = 0.44

Step 6: - Cement content calculation

Water content = 190kg

w/c =0.44

Cement content (Kg) for 1m^3 of concrete =190/0.44 =431.82kg

Step 7. Estimation of Coarse aggregate (CA) content

From ACI table, for fineness modulus = 2.71of Fine aggregate and Maximum aggregate Size of coarse aggregate = 19 mm the volume of dry-rodded coarse aggregate per unit volume of concrete is 0.629.

Coarse aggregate content = 0.629 ×1660kg/m^3 = 1044.14kg

Step 8. Estimation of Fine aggregate content

By absolute volume method

In absolute volume method the volume of fine aggregate is determined by subtracting the volume of all known ingredients from unit volume of concrete.

Volume = $\frac{\text{mass(kg)}}{\text{specific gravity}*\text{density of water}}$

Volume of Water = $\frac{190}{1*1000}$ = 0.19m^3

Volume of Cement = $\frac{431.82}{3.15*1000}$ = 0.137m^3

Volume of Coarse aggregate = $\frac{1044.14}{2.73*1000}$ = 0.383m^3

Volume of air = 2%

Therefore -

Volume of fine aggregate = unit volume of concrete - volume of (coarse aggregate +cement + water + air)

= 1 – (0.383 + 0.137 + 0.19 +0.02) = 0.27m^3

Mass of fine aggregate = 0.27×2.453×1000 = 662.31 kg

The content of ingredients for unit volume of concrete

No	Ingredients	Weight per unit volume (kg/m^3)
1	Cement	431.82
2	Fine aggregate	662.31
3	Coarse aggregate	1044.14
4	Water	190

Step 9. Moisture adjustment

If absorption capacity of aggregate is greater than the moisture content, we need add the mixed water to get better workability of the concrete.

C.A water = 2.54 -2.03 = 0.51%

F.A water = 2.27 -1.52 = 0.75%

Total required water = 190 + ((mass C.A ×0.51%) + (mass F.A×0.75%)

Total required water = 190 + ((1044.14× 0.51%) + (662.31×0.75%)) = 200.29 kg

Therefore content of ingredients for unit volume of concrete is

No	Ingredients	Weight per unit volume (kg/m^3)
1	Cement	431.82
2	Fine aggregate	662.31
3	Coarse aggregate	1044.14
4	Water	200.29

Mass of Sawdust = (%)*F.A volume *specific gravity of SD *1000

Like, SD-15 = 15% * 0.27* 0.91 *1000 =

No	Ingredients	Weight per unit volume (kg/m^3)			
		SD-0	SD-5	SD-10	SD-15
1	Cement	431.82	431.82	431.82	431.82
2	Fine aggregate	662.31	629.20	596.08	562.96
4	sawdust	0	12.29	24.57	36.86
3	Coarse aggregate	1044.14	1044.14	1044.14	1044.14
5	Water	200.29	200.29	200.29	200.29

Appendix C – Mix design procedure of C45/55

The following procedures are used for the mix design of C45/55 concrete grade.

Step 1. Material property

a. Cement type 1; specific gravity=3.15

b. Coarse aggregates

- Bulk specific gravity =2.73
- Absorption capacity =2.54%
- Moisture content = 2.03%
- Compacted unit weight =1660 kg/m^3

c. Fine aggregate

- Bulk specific gravity =2.45
- Absorption capacity =2.27%
- Moisture content = 1.52%
- Compacted unit weight =1490.97 kg/m^3
- Fineness modulus = 2.71

Step 1:- Calculation for weight of coarse aggregate

From ACI 211.4R Table 4.3.3 for 19mm maximum aggregate size,

Volume of coarse aggregate = 0.72

$$weight\ of\ coarse\ aggregate = 0.72 * 1660 = 1188\ Kg/m3$$

Step 2:- Calculation for quantity of water from ACI 211.4R Table 4.3.4

Slump = 25- 50

Coarse aggregate size = 19 mm

Water = 140 Kg

Void content of fine aggregate = 35.5

Void content of fine aggregate (V)

$$V = \left[1 - \left(\frac{1491}{2.453} * 1000\right)\right] * 100 = 39.22\ \%$$

$$Adjustment\ in\ mixing\ water = (V - 35) * 4.55$$

$$= (39.22 - 35) * 4.55 = 19.99$$

$$Total\ water\ required = 166.124 + 18.99 = 188.08\ liter$$

Step 3:- Calculation for weight of cement

From ACI 211.4 (table 4.3.5), take w/c = 0.4 (using interpolation)

$$Weight\ of\ cement = \frac{188.08}{0.4} = 470.2\ Kg$$

Step 4:- Calculation for weight of fine aggregate

$$cement = \frac{470.2}{3.15} * 1000 = 0.1493$$

$$water = 188.08/1 * 1000 = 0.188$$

$$C.A = \frac{1188}{3} * 1000 = 0.396$$

$$Entrapped\ air = \frac{2}{100} = 0.02$$

$$Total = 0.7533$$

$$volume\ of\ F.A = 1 - 0.7533 = 0.2467$$

$$= 0.243 * 2.45 * 1000 = 605.16kg$$

Step 5:- High Range Water Reducing Admixture

HRWRA = 2(1.5) from ACI 211.4 Table 6.4.

$$\frac{1.5}{100} * 470.2 = 7.053\ liter$$

Step 6:- Correction for water

$$weight\ of\ water = 188.08 - 7.053 = 181.02$$

Requirements of materials per cubic meter

$$Cement = 470.2\ Kg$$

$$Water = 181.02\ Kg$$

$$F.A = 605.15\ Kg$$

$$C.A = 1188\ Kg$$

$$HRWRA = 7.053\ Kg$$

The content of ingredients for unit volume of concrete

No	**Ingredients**	**Weight per unit volume (kg/m^3)**
1	Cement	470.2
2	Fine aggregate	605.15
3	Coarse aggregate	1188
4	Water	181.02
5	HRWRA	7.053

Appendix D – Mix design procedure of C60/75

The following procedures are used for the mix design of C60/75 concrete grade.

Step 1. Material property

a. Cement type 1; specific gravity=3.15

b. Coarse aggregates

- Bulk specific gravity =2.73
- Absorption capacity =2.54%
- Moisture content = 2.03%
- Compacted unit weight =1660 kg/m^3

c. Fine aggregate

- Bulk specific gravity =2.45
- Absorption capacity =2.27%
- Moisture content = 1.52%
- Compacted unit weight =1490.97 kg/m^3
- Fineness modulus = 2.71

Step 1:- Calculation for weight of coarse aggregate

From ACI 211.4R Table 4.3.3 for 19mm maximum aggregate size,

Volume of coarse aggregate = 0.72

$$weight\ of\ coarse\ aggregate = 0.72 * 1660 = 1195.2\ Kg/m3$$

Step 2:- Calculation for quantity of water from ACI 211.4R Table 4.3.4

Slump = 25- 50

Coarse aggregate size = 19 mm

Water = 169.08 kg

Void content of fine aggregate = 35.5

Void content of fine aggregate (V)

$$V = \left[1 - \left(\frac{1490.97}{2.453 * 1000}\right)\right] * 100 = 39.22\ \%$$

$$Adjustment\ in\ mixing\ water = (V - 35) * 4.55$$

$$= (39.22 - 35) * 4.55 = 18.99$$

$$Total\ water\ required = 169.08 + 18.99 = 188.08\ liter$$

Step 3:- Calculation for weight of cement

From ACI 211.4 (table 4.3.5), take w/c = 0.299(using interpolation)

$$Weight\ of\ cement = \frac{188.08}{0.299} = 629.03\ Kg$$

Step 4:- Calculation for weight of fine aggregate

$$cement = \frac{629.03}{3.15 * 1000} = 0.199$$

$$water = 188.08/1 * 1000 = 0.188$$

$$C.A = \frac{1195.2}{2.73 * 1000} = 0.398$$

$$Entrapped\ air = \frac{2}{100} = 0.02$$

$$Total = 0.845$$

$$volume\ of\ F.A = 1 - 0.805 = 0.195$$

$$= 0.195 * 2.45 * 1000 = 477.75\ kg$$

Step 5:- High Range Water Reducing Admixture

HRWRA = 2(1.5) from ACI 211.4 Table 6.4.

$$\frac{1.5}{100} * 629.03 = 9.44\ liter$$

Step 6:- Correction for water

$$weight\ of\ water = 188.08 - 9.44\ = 178.56$$

Requirements of materials per cubic meter

$$Cement = 629.03\ kg$$

$$Water = 178.56\ kg$$

$$F.A = 477.75kg$$

$$C.A = 1195.2\ \ kg$$

$$HRWRA = 9.44\ kg$$

The content of ingredients for unit volume of concrete

No	**Ingredients**	**Weight per unit volume (kg/m^3)**
1	Cement	629.03
2	Fine aggregate	477.75
3	Coarse aggregate	1195.2
4	Water	178.56
5	HRWRA	9.44

Appendix E – Compressive strength of C16/20 for the partial replacement

Sawdust Ratio (%)	Days	Mass(g)	Failure Load (kN)	Cubic Strength	Average Cube Strength (MPa)	Average Cylinder Strength (MPa)
0%	7th	7750	319.5	11.2	11.6	9.28
		7746	335.3	11.9		
		7740	330.8	11.7		
	28th	7905	468	17.8	19.2	15.36
		7815	504	19.4		
		7810	526.5	20.4		
5%	7th	7710	293	10.02	11.00	8.80
		7770	319.5	11.2		
		7745	333	11.8		
	28th	7800	270	17.9	18.43	14.74
		7850	474.8	18.1		
		7825	501.8	19.3		
10%	7th	7655	317.3	11.1	10.73	8.58
		7630	301.5	10.4		
		7665	308.3	10.7		
	28th	7785	461.3	17.5	17.76	14.21
		7785	472.5	18		
		7790	468	17.8		
15%	7th	7610	261	8.6	9.5	7.6
		7585	312.8	10.9		
		7620		9		
	28th	7760	454.5	17.2	17.23	13.78
		7759	452.25	17.1		
		7774	459	17.4		

Appendix F - Compressive strength of C30/37 for the partial replacement

Sawdust Ratio (%)	Days	Mass(g)	Failure Load (kN)	Cubic Compressive Strength	Average Cube Strength (MPa)	Average Cylinder Strength (MPa)
0%	7th	8390	629.77	32.99		
		8339	728.77	32.39		
		8339	728.77	32.39	32.39	25.91
	28th	8390	992.25	44.1		
		8303	978.3	43.48		
		8370	1007.77	44.79	44.12	35.29
5%	7th	8188	689.85	30.66		
		8228	702.225	31.21		
		8364	693	30.8	30.89	24.712
	28th	8226	982.8	43.68		
		8281	986.85	43.86		
		8230	987.3	43.88	43.80	35.04
10%	7th	8041	549.9	24.44		
		8022	609.3	27.08		
		7966	545.17	24.23	25.25	20.2
	28th	8003	893.7	39.72		
		8012	882.225	39.21		
		8070	850.5	37.8	38.91	31.128
15%	7th	7961	518.17	23.03		
		8016	516.37	22.95		
		7934	456.525	20.29	22.09	17.672
	28th	8020	832.5	37		
		8009	835.65	37.14		
		8015	864.22	38.41	37.51	30.01

Appendix G - Compressive strength of C45/55 for the partial replacement

Sawdust Ratio (%)	Days	Mass (g)	Failure Load (kN)	Compressive Strength (MPa)	Average Cube Strength (MPa)	Average Cylinder Strength (MPa)
0%	7th	8464	1192.5	53.00	53.71	42.97
		8504	1224.2	54.41		
		8493	924.6	49.00*		
	28th	8592	1316.2	58.48	59.28	47.42
		8572	1370.3	60.89		
		8527	1372.9	58.48		
5%	7th	8339	1071.5	47.62	47.40	37.92
		8330	1087.5	48.33		
		8318	1040.9	46.26		
	28th	8357	1333.4	59.24	58.96	47.168
		8322	1341.1	59.6		
		8265	1351.3	58.04		
10%	7th	8129	1006.2	44.72	46.41	37.13
		8178	1069	47.51		
		8217	1057.8	47.02		
	28th	8283	1142.1	50.76	54.11	43.28
		8249	1217.7	54.12		
		8203	1292.7	57.45		
15%	7th	8049	653	39.02	39.15	31.32
		8049	648.5	38.82		
		8019	666.8	39.63		
	28th	8143	796.1	49.06	49.05	39.24
		8153	856.4	49.06		
		8163	855.7	49.03		

* The value is neglected, according to ACI 318-19 compliance criteria.

Appendix H - Compressive strength of C60/75 for the partial replacement

Ratio (%)	Days	Mass(g)	Failure Load (kN)	Cube strength (MPa)	Cylinder Strength (MPa)	Average Cylinder Strength (MPa)
0%	7th	8541	1534.21	68.18	54.55	
		8555	1556.71	69.18	55.35	
		8545	1578.93	70.17	56.14	55.34
	28th	8626	1864.40	82.86	66.29	
		8548	1789.03	79.51	63.61	
		8533	1771.59	78.73	62.99	64.29
5%	7th	8392	1549.12	68.85	55.08	
		8458	1545.46	68.68	54.95	
		8437	1530.28	68.01	54.41	54.81
	28th	8452	1638.84	72.83	58.27	
		8466	1821.37	80.95	64.76	
		8456	1774.68	78.87	63.1	62.04
10%	7th	8423	1405.68	62.47	49.98	
		8423	1405.68	62.47	49.98	
		8423	1530.28	68.01	54.41	51.45
	28th	8438	1676.81	74.52	59.62	
		8452	1680.18	74.67	59.74	
		8344	1602.56	71.22	56.98	58.78
15%	7th	8333	1405.68	62.47	49.98	
		8310	1357.59	60.33	48.27	
		8315	1405.68	62.47	49.98	49.41
	28th	8388	1603.12	71.25	57	
		8364	1586.53	70.51	56.41	
		8344	1680.18	74.67	59.74	57.71

Appendix I -Tensile strength of C16/20 for the partial replacement

Ratio (%)	Days	Failure Load (kN)	Splitting Tensile Strength (MPa)	Average Tensile Strength (MPa)
0%	7th	94.15	1.33	1.36
		96.76	1.36	
		98.04	1.38	
	28th	138.40	1.95*	2.19
		150.84	2.13	
		158.61	2.244	
5%	7th	94.01	1.33	1.39
		99.66	1.41	
		101.08	1.43	
	28th	151.26	2.14	2.16
		157.62	2.23	
		150.06	2.12	
10%	7th	88.35	1.25	1.3
		91.89	1.3	
		95.42	1.35	
	28th	144.19	2.04	2.03
		142.07	2.01	
		144.19	2.04	
15%	7th	86.23	1.22	1.24
		91.89	1.3	
		84.82	1.2	
	28th	142.07	2.01	2.00
		139.95	1.98	
		143.49	2.03	

*The value is neglected, according to ACI 318-19 compliance criteria.

Appendix J - Tensile strength of C30/37 for the partial replacement

Specimen	Sawdust Ratio (%)	Days	Failure Load (kN)	Splitting Tensile Strength (Mpa)	Average Splitting Tensile Strength (MPa)
C30/37	0%	7th	179.54	2.54	
			180.95	2.56	
			178.12	2.52	2.54
		28th	250.22	3.54	
			238.21	3.37	
			243.15	3.44	3.45
	5%	7th	195.79	2.77	
			193.67	2.74	
			204.28	2.89	2.8
		28th	235.38	3.33	
			278.50	3.94	
			243.15	3.44	3.57
	10%	7th	182.36	2.58	
			185.19	2.62	
			187.31	2.65	2.61
		28th	243.86	3.45	
			246.69	3.49	
			250.93	3.55	3.49
	15%	7th	171.76	2.43	
			176.00	2.49	
			172.47	2.44	2.45
		28th	226.19	3.2	
			228.31	3.23	
			224.07	3.17	3.2

Appendix K - Tensile strength of C45/55 for the partial replacement

Specimen	Sawdust Ratio (%)	Days	Failure Load (kN)	Splitting Tensile Strength (Mpa)	Average Tensile Strength (MPa)
C45/55	0%	7th	241.03	3.41	
			243.15	3.44	
			233.96	3.31	3.38
		28th	299.00	4.23	
			320.20	4.53	
			243.15	3.44	4.06
	5%	7th	272.14	3.85	
			254.46	3.6	
			249.52	3.53	3.66
		28th	288.39	4.08	
			311.01	4.4	
			302.53	4.28	4.25
	10%	7th	233.96	3.31	
			247.40	3.5	
			235.38	3.33	3.38
		28th	286.27	4.05	
			245.98	3.48	
			299.00	4.23	3.92
	15%	7th	215.59	3.05	
			214.88	3.04	
			216.29	3.06	3.05
		28th	255.17	3.61	
			228.31	3.23	
			226.90	3.21	3.35

Appendix L - Tensile strength of C60/75 for the partial replacement

Specimens	Sawdust Ratio(%)	Days	Failure Load (kN)	Tensile Strength (Mpa)	Average Tensile Strength (MPa)
C60/75	0%	7^{th}	290.51	4.11	4.15
			291.22	4.12	
			299.00	4.23	
		28th	355.54	5.03	5.07
			359.79	5.09	
			361.20	5.11	
	5%	7^{th}	320.20	4.53	4.53
			313.13	4.43	
			327.98	4.64	
		28th	393.01	5.56	5.35
			349.894	4.95	
			393.01	5.56	
	10%	7^{th}	318.79	4.51	4.56
			331.51	4.69	
			317.37	4.49	
		28th	401.49	5.68	5.11
			349.89	4.95	
			332.93	4.71	
	15%	7^{th}	290.51	4.11	4.11
			290.51	4.11	
			290.51	4.11	
		28th	302.53	4.28	4.55
			325.86	4.61	
			337.17	4.77	

Appendix M – Photo attachments of the laboratory work

Measuring Sawdust for the Specific Gravity Calculation

Measuring Sand for Specific Gravity Calculation

Sieving Sawdust

Slump test

Split tensile test