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COLLEGE OF TECHNOLOGY AND BUILT ENVIROMENT

SCHOOL OF CIVIL AND ENVIROMENTAL ENGINEERING

Suitability of Crushed Hintalo Wejerat Sandstone as a River Sand Alternative for Normal Grade Concrete Production

A Thesis in Structural Engineering

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A Thesis

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

Approval page

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Undertaking

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ABSTRACT

The potential of substituting Hintalo Wejerat Sandstone for regular river sand in the production of regular grade concrete is investigated in this study. The building industry of Ethiopia is expanding rapidly,, with the resultant increased demand for concrete. River sand has been the main fine aggregate: however, overexploitation has resulted in environmental degradation in the form of riverbank erosion and loss of habitat. The study examines particle size distribution, specific gravity, water absorption and strength of concrete that consists of Hintalo Wejerat sandstone and compares it with the properties of natural river sand. River sand substitution with different percentage of Hintalo Wejerat Sandstone was used to produce concrete mix, C-25.The workability of the fresh concrete was checked by slump tests, and the compressive and flexural strength of hardened concrete was checked at 7,14 and 28 days.

Results indicate that Hintalo Wejerat Sandstone can be used successfully as a river sand substitute in the production of concrete with all replacement levels satisfying the compressive strength requirement. Although concrete mix containing 100% river sand was indicated to possess higher compressive strength, use of Hintalo Wejerat Sandstone also facilitated proper workability, and hence, its suitability towards sustainable construction. The flexural strength tests indicated that higher percentage of Hintalo Wejerat Sandstone had a positive influence on the bending strength of the concrete, demonstrating improved durability.

In conclusion, this study recommends Hintalo Wejerat sandstone as a substitute to river sand in concrete production to construction sector's need for green operations. The study recommends the establishment of standard practices in Hintalo Wejerat sandstone quarrying and processing to further enhance its usefulness as a building material. Additional studies should also involve the long term strength of Hintalo Wejerat Sandstone concrete under different environmental conditions and its use performance in practice.

Key Words: Hintalo wejerat Sandstone, River sand, Concrete, Compressive and flexural strength

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LIST OF ABBREVIATIONS

ES	Ethiopian standard
Gm	Gram
Gm/cm3	Gram per cubic meter
Kg/m^3	Kilo gram per cubic meter
KN	Kilo newton
Mm	Millimeter
W/C	Water to cement ratio
µm	Micro meter
Mpa	Mega pascal
C.A	Coarse Aggregate
F.A	Fine Aggregate
W/C	Water/Cement Ratio
CHWSS	Crushed Hintalo Wejerat Sandstone
RS	River Sand
ASTM	American Society for Testing and Materials
ACI	American Concrete Institute
SSD	Saturated Surface Dry
F.M	Fines modulus
CSS	Crushed Sandstone
EBCS	Ethiopian building code standard
N	Normal cement setting
OPC	Ordinary Portland cement
ASFA	Ambo Sandstone fine aggregate

BS	British standard
SSD	saturated surface dry
Fck	Characteristic compressive strength
MOE	Ministry of education
CTBE	College of technology and built environment
EiT-M	Ethiopian institute of technology mekelle

Chapter One: Introduction

1.1. Background of the Study

Building industry in Ethiopia is spearheading growth, and country is currently one of the fastest-growing in Africa [1].

The most important projects in the industry include roads, bridges, buildings, and dams, all of which are important to the growth of the country [1]. Concrete is now more widely used than any other man-made material and is an essential component of construction[2]. Around 65%-70% of concrete making used an aggregate[3]. They are two types coarse and fine. Fine aggregate can be sourced from various quarries which produce coarse aggregate by crushing basaltic stone. Fine aggregate can also be traditionally gathered from river basins. Crushed basaltic stone converted into small pebbles can also produce it. “Concrete is a composite construction material and is primarily used worldwide, its quality depending greatly on the qualities of the constituents that comprise it” [4]. Concrete's mechanical properties are found based on the combined action of these materials, and aggregates contribute to a substantial percentage of overall volume.

River sand has long been a traditional source of fine aggregate because it is readily available and usually possesses acceptable qualities for the building of concrete. However, the availability of this natural element is decreasing more recently as a result of extensive urbanization and costly transportation, which has increased costs and created environmental issues like habitat degradation and riverbank erosion.

The construction industry is searching for a different source of fine aggregate to solve the rising demand for concrete and the declining cost of transporting aggregate. The Sandstone of Hintalo Wejerat is one such locally accessible source. Because this material is readily available and may be used as an alternative to river sand, people have started using it. The strength characteristics and general acceptability of Hintalo Wejerat Sandstone as affine aggregate for use in the formation of concrete are still not well understood in scientific research, despite its increasing use in building. By closely examining the mechanical and physical characteristics of Hintalo Wejerat Sandstone fine aggregate, this work seeks to fill this information gap. The study will assess the feasibility of the substitute material by contrasting the strength characteristics of concrete created using Hintalo Wejerat sandstone with those made with regular river sand. To check if the Hintalo Hintalo Wejerat sandstone can successfully replace river sand without losing the performance and durability of concrete, core strength characteristics like compressive and flexural strength will be investigated. Finally, the study aims to encourage ecologically friendly building practices in the region and contribute to environmental conservation by lowering dependency on river sand resources.

1.2. Problem of the Statement

Ethiopia's building industry faces significant challenges due to unsustainable exploitation of natural river sand and rising demand for concrete, especially in the Tigray region surrounding Mekelle city. Degradation of the environment, including erosion of riverbanks and the loss of regional ecosystems, has resulted from this dependence on river aggregate. As building construction activity is thriving, even river sand of good quality is increasingly becoming scarce and impacting the supply of concrete, driving prices upward. Alternate materials like Hintalo Wejerat sandstone are now in use, but adequate studies assessing their strength properties and applicability as a fine aggregate for making concrete are still not available in plenty.

Although available, little actual evidence exists on the degree to which Hintalo Wejerat sandstone can meet the demands of normal grade strength concrete production. Such a lack of knowledge not only limits the awareness of its potential for sustainable construction practice but also discourages the effort for reducing environmental degradation caused by traditional sand mining.

Accordingly, the exclusive features of Hintalo Wejerat sandstone fine aggregate affect concrete strength and durability, hence the present work attempts to examine its physical and mechanical properties and contrast its behavior in concrete with river sand. To provide sustainable future-proof utilization of local material resources due to exponential infrastructure demands and promote environmentally sustainable alternatives within the construction industry, the problem must be explored.

1.3. Overall Objective of the Study

1.3.1. General Goal of the Study

The overall aim of the study is to explore and evaluate several strength properties of Hintalo Wejerat Sandstone fine aggregate as an environmentally friendly substitute for natural river sand in concrete production.

1.3.2. Specific Study Objectives

- To determine the physical properties of Hintalo Wejerat crushed Sandstone fine aggregates, like particle size distribution, specific gravity, and water absorption.
- To compare the workability of Hintalo Wejerat Sandstone concrete mixtures against river sand at plastic state.
- To observe the strength properties of concrete made with Hintalo Wejerat Sandstone against that made from conventional river sand at a hardening state.
- To provide recommendations in the field for the use of Hintalo Wejerat crushed Sandstone in concrete, its value addition to sustainable construction in the country.

1.4. Research Question

1. What are the physical characteristics of Hintalo Wejerat crushed Sandstone sand?

2. What is workability of concrete mixtures made with crushed Hintalo Wejerat Sandstone compared with mixtures made with river sand in the fresh condition?

3. How does the strength characteristics of concrete produced with Hintalo Wejerat sandstone differ from those produced with natural river sand under the condition of hardening?

4. What are the practical suggestions that can be provided for applying crushed Hintalo Wejerat crushed sandstone in concrete construction, and what are the potential advantages it offers for sustainable construction in the region? With Hintalo Wejerat sandstone compared to that produced with natural river sand in the hardening state?

1.5. Relevance of the Research

This research is extremely high significance to a very large number of very significant fields like transport cost, environmental impact, and material availability. The degree of significance of this study is very high in the Mekelle construction industry, particularly in terms of transport cost in aggregate supply. Currently, river sand use is usually associated with high-cost, long-distance transportation and logistical problems, such that in studying Hintalo Wejerat Sandstone as an alternative for river sand, the study considered transportation costs involved in aggregate procurement. Local availability of sandstone can reduce transportation costs and distances significantly and thus ensure production of concrete to be economically viable for Tigray construction.

The study is significant from the perspective of environmental sustainability, as it indicates the bad effects caused by sand mining on riverbeds, including erosion, habitat loss, and biodiversity depletion, the finding of which supports resource conservation and nature's preservation through encouraging the use of Hintalo Wejerat Sandstone.

Further, as the demand for concrete continues to grow due to flourishing up urbanization and infrastructure development, substitute sources of fine aggregates are vital for sustainable supply. Studies on Hintalo Wejerat sandstone reduce not only lack of river sand but also provide an avenue material source diverging to further strengthen the building sector as a whole.

1.6. Scope of the Study

The scope of this study mainly focuses on the evaluation of Hintalo Wejerat Sandstone sand aggregate as a substitute for river sand in the production of C-25 grade strength within the Tigray region of Ethiopia, particularly around Mekelle city. This research included physical properties of crushed Hintalo Wejerat stone sand such as particle distribution, specific gravity, and moisture content. It will primarily investigated the strength characteristics of C-25 concrete made With Hintalo Wejerat Sandstone compared to concrete made with conventional river sand, and analyzing compressive, and flexural strength. While the research will give valuable insights into the performance of Hintalo Wejerat Sandstone in concrete applications, it will not involve into aspects such as permeability and long-term durability consequences. By focusing on these parameters, the study aims to assess the direct continuity of Hintalo Wejerat Sandstone as a viable alternative to river sand in normal concrete production, addressing the critical issues of material existence and environmental sustainability in the region's construction industry.

Chapter Two: Literature Review

2.1. General 2.1.

Scholars have searched the substitution of river sand with different types of manmade or crushed sand. This part discusses a review of the literature and investigation related to concrete materials, sand aggregates, the influence of river sand on concrete production, the environmental and technical issues associated with river sand properties of both hardened and fresh concrete, and ultimately presents potential substitution to river sand with crushed sandstone. “Concrete is among the most commonly used construction materials worldwide” [5]. “Historically, river fine aggregate has served as the main fine aggregate in concrete production” [6]. However, the diminishing availability of river fine aggregate and the environmental impact of its extraction have prompted the search for alternative material. One successful option is crushed sandstone, especially Hintalo Wejerat sandstone, which is recognized as locally available material and potential effectiveness in concrete applications.

2.2. Concrete Making Material

“Concrete is a composite material that comprises several chief constituents which mix to create a long-lasting and strong construction material” [3]. The chief ingredients of concrete are Cement, water, fine aggregates (like sand), and coarse aggregates (like crushed stone or gravel). Portland cement is the binder which holds the aggregate particles collectively when it sets and hydrates. “Water is a key point because it initiates the chemical reaction with cement, leading to the setting and curing process” [7]. The choice of fine aggregates significantly affects the workability, strength, and durability of the concrete; river sand is most commonly used, but alternatives like crushed sandstone have come into prominence because of environmental concerns and resource depletion. The strength capacity of the concrete is from coarse aggregates; however, shape and size affect the capacity of concrete. Additional admixtures may also be included to modify some characteristics of the product, such as increasing workability, reducing water content, or curing time. Such materials are precisely balanced in mix designs to achieve some performance criteria so that the concrete can withstand target loads and environments. The characteristics and interactions of these components must be known in order to produce high-quality concrete capable of achieving the demands of modern construction methods.

2.2.1. Cement

The key ingredient in concrete is cement, which, when moistened, bonds the particles to create the usable, hard, and monolithic whole. Portland cement in its different forms accounts for well over 95% of the cement used in concrete worldwide; the amounts and characteristics of the components that make up concrete determine its characteristics [8]. Since cement is the most active ingredient in concrete and typically costs the most per unit, choosing and using it correctly is crucial to getting the best possible balance of desired qualities for a given concrete mixture.

2.2.2. Water

Impurities in water can lead to surface discoloration, hinder the setting of cement, or negatively impact concrete strength, and water quality is therefore imperative. Whether water is suitable for mixing and curing operations should therefore be taken into consideration. "As some of the latter types may be innocuous or even desirable when used in mixing water, it is required to distinguish between mixing water action and aggressive water attack on hardened concrete" [3].

2.2.3. Aggregate

"The concrete aggregates are critical ingredients that have a major role in indicating the durability, strength, and performance of the material" [9]. They are in two types: fine aggregates and coarse aggregate. Although particles in fine aggregations, typically containing sand, are small in size, those in coarse aggregations, such as crushed stone or gravel, are greater than 4.75 mm. Due to the reason that fine aggregates have effects on cohesiveness and also workability of concrete, they are of extremely important nature. Filling spaces in between larger-sized particles, fine aggregates introduce a homogenous dense mix to the concrete. On the other hand, coarse particles provide the structural reinforcement to the concrete, which enhances its weight-carrying capacity and resistance to cracking. The shape, size, and purity of the particles have a profound influence on concrete.

Concrete with an assortment of particle sizes and a well-graded aggregate is more durable and of a lower water-to-cement ratio. The choice of the aggregate is equally crucial in building, as it will determine the sound and heat conducting characteristics of the concrete. As a result of environmental reasons against the quarrying and removal of natural material, it is becoming more significant to use responsibly sourced aggregates. Alternatives are being researched to minimize the environmental impact without lowering the performance standards, for instance, recycled concrete aggregates of crushed concrete.

2.2.3.1. Physical Properties of Aggregate

Aggregates constitute 60-75% of the concrete mixture, significantly influencing its overall properties. The physical characteristics of aggregates play a great role in determining the behavior of concrete as a whole [10] . A factor such as chemical composition, specific gravity, porosity, and thermal properties are comes from the original material used for aggregates [11] . In addition to that, the production process affects critical attributes like form, size, and surface roughness, which are vital for ensuring workability and establishing strong bonds between the aggregate and cement paste. Consequently, understanding the physical properties of aggregates and their formation is essential for producing high-quality concrete at minimal cost.

A. Strength

When determining the performance and durability of concrete, a critical parameter is undoubtedly the overall strength [12] .

Compression strength in concrete, which contributes to the stability of a structure, depends on strong aggregate assets. A number of parameters influence the strength of the aggregate, such as its size, shape, and mineral composition, but also on the type of material.

Heavy, interlocking crystal jambs like granite and basalt are renowned for their extreme strength. On the other hand, weaker rocks such as limestone and chalk can have lower strength values, influencing negatively on the performance of concrete. Finally, structure, texture, and composition of an aggregate are accomplices for its strength: weak grains or badly linked strong grains lead to a decrease in overall strength.

B. Particle Shape and Texture

The attributes of both fresh and cured concrete depend heavily on the aggregates external characteristics, particularly the form and surface roughness of the particles [13]. The aggregate particles for regular concrete should ideally be nearly equidimensional with reasonably smooth surfaces, like the majority of natural sands and gravels, in order to reduce the amount of cement paste needed to give appropriate workability of the fresh concrete. Crushed stone can utilize in places where natural sands and gravels are not accessible.

The surface of crushed stone is usually rougher and more angular in shape. Because of this, it usually needs a lot more cement paste to be workable. Whether utilizing natural gravels or crushed stone, however, either flat or elongated particles should be avoided, as they will contribute workability and finishing problems.

The elongation and flakiness tests useful for assessing aggregate overall; however, they are not very good at characterizing the shape of the particles[14]. Although there are no established restrictions, it is generally undesirable to river elongated particles that make up more than 10 to 15% of the mass of coarse aggregate [3].

The amount of water required to produce the mix with the required aggregate needs is significantly influenced by the texture and form of the fine aggregate. The influence on the water requirement is quite clear if the packing of fine aggregate, or the ratio of voids in a loose state, is used to indirectly describe these characteristics. In coarse aggregate, the influence of the voids is not so clear. The shape and flakiness of the coarse particles have a very marked influence on the workability of concrete [3].

C. Grading of Fine and Coarse Aggregate

The distribution of grading of aggregate sizes is a crucial component of the concrete mix design [15]. Given the sectional dimensions of the concrete structural member and the spacing of the reinforcements, it is generally recommended to use the greatest size of aggregate.

The maximum size and grading are important because they affect [16]:

- The proportional volume that aggregate occupies in the production of concrete determines the economy.
- The aggregate's surface area determines how much water is needed to wet all the solids.
- The workability of the mixtures
- The tendency of segregation
- The porosity and shrinkage

“Coarse aggregate typically has a maximum size of 19 or 25 mm, although occasionally an intermediate-sized aggregate, about 9.5 mm, is used to improve the overall aggregate gradation” [17]. “Fine aggregate (sand and/or crushed stone) are less than 4.75 mm in size” [18].They could be crushed stone made by crushing stones or natural sand left by rivers [3].

D. Bonding

“The bond between aggregate and cement paste is a significant aspect in the strength of concrete, however, the nature of bond is not entirely understood” [19]. A rougher surface, such as that of crushed particles, results in a better binding due to mechanical interlocking.

Other physical and chemical characteristics of the aggregate, including as its chemical and mineralogical makeup and the electrostatic state of the particle surface, also have an impact on the bond. In any event, a clean aggregate surface free of adhering clay particles is essential for a successful connection to form[3].

“The determination of the quality of bond of aggregate is difficult and no accepted tests exist” [20].

In addition to the more common aggregate particles torn out of their sockets, a crushed specimen of average strength concrete should typically have some aggregate particles broken clear through when the bond is strong.

2.2.3.2. **Characteristics of Fine Aggregate**

The presence of fine aggregate in the concrete mixture has a significant impact and gives concrete a technical advantage over cement paste alone, such as higher volume stability. Therefore, before using fine aggregate as a material for concrete, it is important to determine whether the fine aggregates are suitable for the intended use and to conduct laboratory and on-site tests. Some of the characteristics will be discussed below:

A. Specific Gravity & Water Absorption

According to ASTM C 128-97, the specific gravity is expressed in terms of bulk specific gravity or apparent specific gravity (also known as saturated surface dry, or SSD). Fine aggregate is employed as a reference for bulk specific gravity (SSD) and absorption after 24+4 hours immersion in water.

B. Sieve Analysis

According to [21], "It's a fundamental procedure in geology and engineering to determine the particle size distribution, or "grading," of a granular material by mechanically separating it into various size fractions using a series of sieves with progressively smaller openings". Since the same amount of cement paste must be used to fill the void in a concrete mixture, the grading establishes the amount of paste needed for workable concrete [22]. Using sieve analysis, a grading curve for aggregate will be the grading requirements for fine aggregate, as stated by ASTM, BS882, and ES C.D3.201, are compiled in table 2.1.

Table2. 1. BS and ASTM grading requirement

Sieve size (mm)	Percentage of passing%				
	BS882:1973				ASTM (C33-78)
	Grading zone 1	Grading zone2	Grading zone3	Grading zone4	
9.5mm	100	100	100	100	100
4.75mm	90-100	90-100	95-100	95-100	95-100
2.36mm	60-95	75-100	85-100	95-100	80-100
1.18mm	30-70	55-90	75-100	90-100	50-85
600µm	15-34	35-59	60-79	80-100	25-60
300µm	5-20	8-30	12-40	15-20	10-30
150µm	0-10	0-10	0-10	0-15	2-10

C. Fineness Modulus

The fineness modulus is calculated by dividing the total percentage of material retained on the standard series sieves by 100 [3].

The sieves (No. 4, 8, 16, 30, 50, and 100) that are mentioned are 9.5 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600 µm, 300 µm, and 150 µm. The 150 µm (No. 100) sieve is the lowest of the designated series of sieves, and the actual size of the apertures in each larger sieve is double that of the sieve below. The FM increases with the coarseness of the aggregate size. According to ASTM C 33, the FM for fine aggregate used in concrete typically falls between 2.3 and 3.1 [23].

It serves as a measurement for aggregate homogeneity, coarseness, and fineness. These aggregate characteristics have a major impact on the concrete's properties, but they are not a grading indicator because there might be an endless number of grading schemes that result in a particular fineness modulus. The following restriction can be used as a guide.

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

It will not be possible to make good concrete with sand that has a fineness modulus more than 3.2. Nonetheless, it is evident that a single parameter, the average, cannot accurately depict a distribution; as a result, an endless number of completely distinct size distributions or grading curves can be represented by the same fineness modulus. So that, fineness modulus cannot be used to detect slight variations in the aggregate from the same source which could affect the workability of the fresh concrete.

D. Bulk Density

Bulk density is also known as unit weight, or the weight of a specific volume of graded aggregate. By taking into consideration the solid aggregate particles as well as the interstitial spaces, the volume that the graded aggregate will occupy in concrete may be accurately calculated. Simply fill a specified capacity container and weigh it to determine the unit weight. However, the amount of space that remains empty will depend on how long the vibration or tamping continues. The moisture content of the aggregate must remain constant because it affects its weight. This test employed an aggregate sample that was oven-dried [24].

The typical aggregate used in normal-weight concrete has a relative bulk density (unit weight) of between 1200 and 1750 kg/m3 (75 and 110 lb/ft3)) [25].

The aggregate's packing density, and thus the size distribution and particle shape, determine the bulk density. Therefore, the degree of compaction must be set for optimal results [26].

E. Silt Content

Silt is defined as a material in tiny aggregates that are less than 75 µm. The amount of silt in the concrete sand has causes its strength to decrease. "According to the Ethiopian Standard, it is recommended to wash the sand or reject if the silt content exceeds a value of6%" [27].

F. Moisture Content

The moisture content must be taken into account when calculating batch quantities and the mixes over all water requirements because aggregates exposed to rain pick up significant amounts of moisture on their surface and retain it for a long time, with the exception of the stockpiles surface [3].

It is considered that the aggregates in concrete are inert substances. However, by releasing water into the mix (wet aggregates) or absorbing it (dry aggregates), the majority of aggregates fail to meet this premise. This aggregate feature causes a change in the mix's design water to cement ratio.

Determining the aggregates moisture content and absorption capacity is therefore crucial. The moisture content of fine aggregates was calculated by oven drying a 500g sample of fine aggregate at 110^0 C for 24 hours and dividing the weight change by the oven dry weight.

2.3. Environmental Effect of River Sand

2.3.1. General

The environmental impacts of natural river sand mining can be broadly categorized as follows: "The cumulative effects of unmanaged sand mining have significantly changed the physical and social environment" [28].These may include,

- Reduction of farm and grazing land
- Landscape destruction
- Deforestation
- Water pollution

2.3.2. The Need River Sand Replacement

For any building sector, cement, sand, and aggregate are essential components. Sand is a key component that is required to prepare concrete and mortar and is crucial to mix design. “River sand is in short supply these days due to river erosion and environmental concerns” [29]. “It is required to identify a new alternative material to replace river sand to prevent too much river erosion and environmental damage because the construction industry will be impacted by its shortage” [30].

According to the United Nations Environmental Programme (UNEP), which lists water, sand, and gravel as the most frequently used raw materials worldwide, river sand is the second most used natural resource after fresh water. River sand's natural renewal rates are greatly exceeded by the demand for it in building. States should look into alternatives to river sand, according to the 2018 sand mining framework, particularly to re address the mismatch between supply and demand. In addition to potentially lowering costs, offering [31].

2.4. Crushed (manufactured) Sand

Researchers have confirmed that crushed sand, in comparison to natural sand, can make concrete acquire the same or higher compressive, tensile, and flexural strength. Because manufactured sand improves particle bonding and interlocking, concrete mixtures containing it tend to show notable improvement in compressive and tensile strength. Furthermore, in various applications, produced sands can improve flexural strength. Particularly where the natural sand is limited or severely controlled, the manufactured sand might be more cost-effective and consequently a better and viable substitute for natural sand used for construction purposes [32]. The findings reached are as indicated below:

- Synthetic sands, unlike natural sands, are capable of producing the compressive strength of concrete mixes that are equivalent to or more.
- Because of their enhanced bonding and particle interlocking strengths, manufactured sands increase the tensile strength of concrete.
- In concrete, factory-produced sands tend to provide more flexural strength; some mixes are even superior to those that can be made using natural sand.

- It is more economical from a financial point of view, especially where natural sand is limited or illegal.
- Providing artificial sand could make natural sand less relied on, which would be cost-effective and lead to the preservation of resources.

2.4.1. Waste Foundry Sand

Manufactured sands can accomplish similar or better results. It is preferable to replace up to 15% of the sand with waste foundry sand because it has no negative effects on the concrete's strength characteristics. When the percentage of WFS increases and as concrete ages, there is a noticeable rise in concrete shrinkage. Very high shrinkage was observed in mixtures that contained more than 30% leftover foundry sand. Based on the results, it can be said that concrete with up to 15% leftover foundry sand can be used effectively for structural purposes. Concrete pavements are one example of a non-structural use where higher replacements can be tested [33].

2.4.2. Granite Powder

Granite fines are a result of cutting large granite rocks into the appropriate shapes in granite industries [34]. When granite fines are used as an additive to concrete, they fill up the pores and boost the concrete's strength. This material is also often used to stud the strength behavior of concrete [35]. Some of granite powder characteristics are as follows:

- The particle size of granite powder varies based on the processing method, although it usually has a fine texture. In general, it is inert and has a high specific gravity.
- The main minerals it includes are silica (SiO_2), iron oxide (FeO_3), alumina (AlO_3), and trace amounts of other minerals.

2.4.3. Stone Powder

According to the study [36], it might be concluded that

- Compressive and flexural strength of concrete is improved on partial replacement of stone dust with fine particles, and it becomes an appropriate option for various applications.
- The concrete mixes with stone dust are more workable, and handling and placement during construction are easier.

- Natural sand, being more expensive and in shorter supply, can be replaced by stone dust to save material costs.

Stone dust blends may have lower shrinkage rates than cement mixes made up of pure natural sand and thus may add years to the life of a structure and reduce cracking.

2.4.4. Quartzite Sand

Quartzite is a hard, metamorphic rock composed primarily of quartz grains and thus a durable and highly desired material for use in many aspects of construction.

"Quartzite sand is a synthetic fine aggregate acquired from the treatment and crushing of quartzite stone" [37].

According to research, it is evident that:

- Introduction of quartzite sand in concrete mixtures increases compressive and tensile strength considerably, making it an appropriate alternative to regular fine aggregates.
- While mixing and placing, concrete with quartzite sand is more workable and consistent; therefore, it is easy to use at construction sites.
- Owing to its durability to weather and chemical degradation, the quartzite sand extends the durability of concrete, especially in applications that experience intense weather conditions.
- Using quartzite sand to reduce reliance on natural sand resources will conserve resources and reduce the environmental impacts, which will benefit sustainable building practices.

2.5. Sandstone

2.5.1. Introduction

Sandstone is a classic-origin sedimentary rock made up primarily of sand-sized (0.0625 to 2 mm) mineral particles or rock pieces, as opposed to organic rocks like chalk or coal [38]. The most prevalent minerals in the earth's crust are quartz and feldspar, which make up the majority of sandstone, which can have any color. The colors white, grey, red, yellow, and tan are the most prevalent. Sandstone beds frequently generate prominent cliffs and other geographical features; therefore, certain sandstone colors can be strongly associated with specific regions [39].

The suitability of crushed stone sand for various applications is predicated upon the chemical makeup of the material. Crushed sandstone material consists of quartz and feldspar with the following characteristics:

- Silica content: its stability and resistance to chemical weathering are also thanks to high silica content.
- Impurities: Clay or organic impurities can influence the permeability of crushed sandstone. Heavy washing and grading to improve quality have been suggested by research

2.5.2. Sandstone in Ethiopia

Notable sandstone formations in Ethiopia include the Adigrat and Enticho Sandstones. The latter is a significant Mesozoic unit in northern and central Ethiopia, distinguished by its thick cross-bedded sandstone sequences.

A. Addigrat Sandstone

"At 700 meters thick, the Addigrat Sandstone formation is the oldest of the Mesozoic sedimentary succession in the Mekelle outlier" [40]. It is mainly made up of medium-grained sandstone with a range of colors from yellowish to red and pink. It has different units, such as fine- to medium-grained interbedded sandstone, cross-bedded coarse-grained sandstone with ferruginous lenses, and poorly sorted ferruginous sandstone with quartz pebbles and wood fragments. It is well-sorted, well-rounded, and ripple-marked.

While the upper portion of the formation is usually white, extremely friable, and well-sorted, the lower portion is soft and friable and exhibits variegated colors and some clay. The bottom and middle parts contain *Paleosols* with a high clay percentage and characteristics like rootlets and slickensides. The lower boundary may be Triassic in age, suggesting that the formation was deposited in an intermountain basin or piedmont. The boundaries of the formation are probably diachronous [41].

B. Hintalo Wejerat Sandstone

One of the Ethiopian districts in the Tigray area is Hintalo Wajirat. “It is called for the Wajirat Mountains and Hintalo, its main town Situated in the eastern border of the Ethiopian highlands in the southern eastern zone” [42].Hintalo Wajirat is bordered to the south by the southern zone, to the west by Samre to the north by Enderta, and to the east by the Afar region[42]. Hintalo Wejerat is located at ~40km south of mekelle city and dolerite and sandstone are the dominant geological formation[43].

The region of Hintalo Wejerat is known for its abundant supply of sandstone, which is found in many different places. The Amba Aradom, May Derhu, Geragam, and Mekiden Dawit sandstones are notable examples. Known for its upper sandstone layers, the Amba Aradom formation is a prominent Cretaceous sandstone formation in Ethiopia that can reach thicknesses of up to 200 meters. These sandstone formations are abundant because of the region's distinct geological past, which has encouraged the gradual buildup and preservation of sedimentary elements. Fluviatile sandstone and shale make up the majority of the sedimentary rocks in the Amba-Aradam Formation. These rocks are colored purple, violet, white, red, and yellow, and they comprise compact, coarse-grained sandstone mixed with quartz conglomerate lenses that contain a calcite binding agent [41]. The strength properties of concrete made with Sandstone is affected by the amount of silica content in sandstone. Hence, according the Ethiopian geological survey bellow in table2.2, crushed hintalo wejerat sandstone has shown high silica content.

Table2. 2.Chemical composition of crushed hintalo wejerat sandstone from Appendix C

Constituent	Oxide composition	of the chemical composition
Silica	SiO2	94.36%
Alumina	Al2O3	1.84%
Iron(III) oxide	Fe_2O_3	0.94%
Calcium oxide	CaO	<0.01
Magnesium oxide	MgO	<0.01
Sodium oxide	Na_2O	<0.01
Potassium oxide	K_2O	<0.01
Manganese (II) oxide	MnO	0.04
Phosphorus pentoxide	P_2O_5	0.70
Titanium dioxide	TiO_2	0.22
Water (or Hydration)	H_2O	0.22

2.5.3. Concrete Performance Studies

Several study the performance of concrete incorporating crushed sandstone as an alternative to river sand:

[44] Investigated the potential for sandstone to replace river sand in his thesis, "A study on high-performance concrete using sandstone aggregate," in Malaysia. His investigation leads him to the conclusion that concrete can be made from locally accessible sandstone aggregate.

Sandstone cutting waste as partial replacement of fine aggregates in concrete was studied based on A mechanical strength perspective [45].According to the results of the research, the mechanical characteristics of concrete are greatly improved by incorporating sandstone cutting waste in partial replacement of certain natural river sand. In particular, at a w/c ratio of 0.35, compressive strength had significant improvements up to 10% replacement, while at higher ratios of 0.40 and 0.45, strengths kept increasing with up to 30% replacement.

The inclusion of sandstone cutting waste significantly improved flexural strength, with ideal strength values noted at replacement levels of 25–30% for w/c ratios of 0.40 and 0.45. These results demonstrate that sandstone cutting waste can successfully increase compressive and flexural strengths, confirming its potential as a sustainable substitute fine aggregate in the manufacturing of concrete.

In the "Experimental Investigation of Partially Replaced Fine Aggregate with Sandstone Powder in Concrete" study concluded that replacement of river sand by sandstone powder up to 50% is effective without compromising the strength and workability of the concrete. Particularly, 50% replacement of river sand by sandstone powder resulted in 11.91% greater compressive strength and 47.06% greater tensile strength compared to conventional concrete. Powder of sandstone also showed improvement in flexural strength, and hence it is a promising replacement material [46].

“Suitability of Ambo Sandstone Fine Aggregate as an Alternative River Sand Replacement in Normal Concrete Production” was studied [1].The study says that river sand can effectively be substituted by Ambo Sandstone Fine Aggregate when producing concrete. Although the original silt concentration was higher than permissible, washing lowered it to 5.3%, and hence ASFA was usable. The fineness moduli of the two quarry samples were also within tolerable limits, and therefore they were properly graded. The C-25 grade criterion was met by compressive strengths of 16.61 Mpa, 19.62 Mpa, and 25.60 Mpa at 7, 14, and 28 days, respectively. Its attractiveness as a sustainable building material was further enhanced by the fact that ASFA turned out to be substantially less expensive than river sand.

“Use of Crushed Sandstone near Adigrat as a Substitution Material for Sand” was investigated [47]. The study compared the performance of utilizing crushed sandstone near Adigrat as a substitute for construction sand in the manufacturing of hollow concrete blocks. The highest compressive strength and highest density were observed in white sandstone blocks to serve Ethiopia's load-bearing demands. All the sandstone blocks met the requirements for applications that were at least non-load-bearing. As the study comes to a conclusion, river sand can be effectively replaced by crushed sandstone, presenting a viable alternative to overcome sand shortages and minimize waste. Some of the suggestions include maintaining the fine content within acceptable boundaries and assessing the feasibility of producing sand from sandstone for commercial purposes.

The thesis of fitsum Reda discusses the use of idaga hamus crushed sandstone (css) as river sand (RS) alternative for reinforced concrete and hollow concrete block (HCB) production. The following are the key findings:

- Strength improvement: the findings demonstrated that CSS can replace RS to a great degree, which leads to improved compressive strength and flexural strength of concrete. Optimum compressive strength was observed at 100% replacement with CSS, where an increase of 15.49% with respect to normal concrete was observed.
- Physical characteristics: CSS had better grade quality and less clay and silt content than RS. Specifically, CSS had 5.2% silt, which was within the permissible limit as per Ethiopian standard.

Chapter Three: Material Used and Methods

3.1. Sample Location

"Hintalo Wejerat has a rugged terrain, and its altitude ranges from 2000 to 2600 meters above sea level" (Abay & Hirvonen, 2016).The sample of Crushed Hintalo Wejerat Sandstone was taken from Hintalo Wejerat Mountains which is located at 40 km south of Mekelle city, and the experiment was conducted at Mekelle institute of Technology University material Laboratory.

3.2. Data Collection

Information from primary and secondary sources was used. During the literature review, secondary data was gathered from various journals, books and websites, and primary data sources were used to document the results of each laboratory test.

3.3. Material for Experimental works

3.3.1. Cement: Grade 42.5 KN is assigned to Messobo Ordinary Portland Cement, which is made in Mekelle. This grade of cement is appropriate for a range of construction uses, such as high-rise structures, foundations, and structural work. The cement is widely utilized in Ethiopia's building industry and is renowned for its high quality, especially in the northern regions where it is manufactured.

3.3.2. Crushed Hintalo Wejerat Sandstone: by sieving 4.75mm maximum nominal size that was produced using Hintalo Wejerat Sandstone that was taken from the Geriegam quarry site.

3.3.3. Natural Coarse Aggregate: "Debrie" crushed stone, which is a 19mm maximum nominal size that was commonly available in (from a nearby village to the Mekelle city site).

3.3.4. River Sand: - "Gelebeda" sand which was commonly transported from Temben to Mekelle city.

3.3.5. Water: - Drinkable water (potable water) obtained from mekelle institute of technology University material Laboratory water supply.

3.4. Mix Proportions

Mix proportion is done according to ACI method to examine the impact of crushed Hintalo Wejerat Sandstone and combination with natural fine aggregate (river sand) at various replacement levels on the properties of concrete. Mixes were prepared with a characteristic strength of normal strength (C-25) were created to meet target mean strength of 33.6 Mpa after 28 curing day.

3.4.1. Concrete Mix Design

The ACI method of mix design was used to create the mix proportions in this investigation. Based on this, five different mix-proportion types were created using the replacement levels of crushed Hintalo Wejerat Sandstone, which are as follows: 0%CSS, 25%CSS, 50%CSS, 75%CSS, 100%CSS.Nine cubes and six flexural beams were to be cast for each batch of concrete produced in order to allow for seven, fourteen, and twenty-eight days of testing for compressive strength and seven and twenty-eight days of testing for flexural strength after a decision was made. This resulted in the manufacture of thirty flexural beam specimens and forty-five concrete cube specimens. To make sure that any variations in the properties of the concrete were due to the crushed Hintalo Wejerat Sandstone and not due to any other external influences, the same water-to- cement ratio was utilized for every mix.Table4.4 below provides an overview of the mix proportions for 1m^3 of concrete mixes from Appendix.

Table3. 1. Summarized mix proportions.

Replacement level of crushed sandstone	Cement type	W/C ratio	W ter (kg)	ment (kg)	F.A (kg)	C.A (kg)
0%CSS	Messobo OPC	0.49	202.96	418.37	726.13	999.09
25%CSS	Messobo OPC	0.49	204.04	418.37	708.01	1003.73
50%CSS	Messobo OPC	0.49	204.25	418.37	702.87	1014.69
75%CSS	Messobo OPC	0.49	202.92	418.37	698.45	1022.51
100%CSS	Messobo OPC	0.49	201.639	418.37	691.89	1030.31

3.4.2. Preparation of Specimens and Mixing Procedures

Throughout the mixing procedure, Messobo Cement was utilized, and graded aggregate that meet Ethiopian standards ES142 and ASTM C33 specifications was also employed to prepare the samples mixes.

The component materials were prepared using weight measurement. Following the determination of the proportions of materials to be utilized for the specimens, mixer was used to mix the aggregates and cement dry for one minute. After adding water, the mixture was swirled for a further two minutes. The workability of the concrete is next assessed right after mixing by pouring three levels into a conventional slump cone and rodding each layer 25 times in accordance with ASTM C143. The specimens were then placed on a level and firm surface of the molds that had been made, and they were well compacted in three layers using a tamping rode. Each layer was rodded 25 times; and trowel is used to polish the top surface following compaction.

For the first twenty- four hours, the concrete mixture was poured into the molds. The concrete was then taken out of the molds and allowed to cure in a water bath set at 23 ± 1^0C until it reached the testing age. Following 7, 14, and 28 days of curing, the concrete cubes and flexural beam specimens were taken out of the water bath and placed on a dry surface until they were surface dried. In the end, the specimens were examined using universal testing equipment for flexural beams and a conventional compression testing machine for cubes.

3.5. Procedures for Laboratory Experimental Works

The procedures used for the laboratory experimental works are illustrated using photos in stage by stage manner.

Stage 1:- Sample preparation

Sample preparation involved the collection of various aggregates from specific locations. Sandstone was sourced from the wejerat region, particularly from The Geragam quarry site, known for its high-quality materials. Coarse aggregate was obtained from debrie near mekelle. River sand was collected from Gelebeda Temben and ordinary Portland cement from Messobo. Figure 3.1 illustrated that the source of Crushed sand stone used for sample preparation.

Figure3. 1. Hintalo Wejerat (Geragam) Crushed Sandstone

Stage2: Laboratory tests on the property of aggregates

Tests conducted on both coarse and fine aggregates according to ASTM C136-96a and ES2000-2004 .First, the measurement of silt content is performed to assess the presence of fine particles that could negatively impact the performance of concrete. Next, data recording of material weight is crucial for accurate calculations in further analyses. Sieve analysis follows, which determines the particle size distribution and ensures the aggregates meet required grading specifications. Additionally, specific gravity and water absorption tests are conducted to evaluate the density and porosity of the aggregates, essential for informed mix design. The unit weight is measured to estimate the overall density of the concrete mix, while assessing moisture content is important for maintaining the proper water – to – cement ratio during mixing. The above idea is illustrated further by the pictures below in figures 3.2 to 3.7.

Figure3. 2. Measuring silt content

Figure3. 3.Data recording material weight

Figure3. 4.Sieving for graduation

Figure3. 5.Specific gravity for C.A

Figure3. 6.Specific gravity for F.A

Figure3. 7.Unit weight

Stage 3: Concrete mix design, mixing and specimen preparation of concrete

According to the ACI methods C-25 concrete mix design prepared for each aggregate replacement ratio to meet the 33.6 MPa target mean strength after a 28-day curing period. Nine samples of concrete cubes and six flexural beams were cast for each replacement percent of crushed Hintalo Wejerat Sandstone fine aggregate, in which forty-five cube and thirty flexural beam samples were cast by using 150mm*150mm*150mm cubes and 100mm*100mm*500mm flexural beams, for a total of 75 specimens cast. To prepare concrete sample specimens for beams and cubes, the process begins with mixing ingredients, which includes accurately measuring and combining cement, aggregates, and water to achieve the desired consistency. After mixing, the workability is assessed by measuring the slump test to ensure it meets the specified requirements. The concrete is then poured into molds for casting the beam and cube specimens. Each specimen is carefully coded to facilitate proper identification during subsequent testing. Once the concrete has adequately set, the specimens are demolded, revealing their defined shapes. Following demolding, the samples undergo a curing process, crucial for developing strength and durability, as it allows the concrete to hydrate fully and reach its intended properties over time. The procedure is properly illustrated in the figures 3.8, 3.9, 3.10, 3.11, as well as in Appendix D, which depict the various stages of specimen preparation for concrete strength testing.

Figure3. 8.Casting specimen

Figure3. 9.Coding specimen

Figure3. 10. De-molding

Figure3. 11.Curing

Stage4: Compressive and flexural strength test

In case of compressive strength test, compressive testing machine was used after the concrete cube samples had been cured for 7, 14, and 28 days. Additionally, a universal testing machine was used to perform the flexural strength test after the concrete flexural beam samples had been cured for seven and twenty-eight days. Bellow figure3.12 and 3.13 describe the process of strength testing specimen.

Figure3. 12.Compressive strength test

Figure3. 13. Flexural strength test

Chapter Four: Results and Discussion

4.1. Physical Properties of Coarse Aggregate

The coarse aggregate included in the experimental mixes featured a maximum diameter of 37 mm and was used over all concrete mix designs. The test findings are presented in Table 4.1, with an overview of gradations illustrated in figure 4.1.

Table4. 1. Summarized test results for C.A from appendix (A)

tem no.	Description		Test results
1	Maximum aggregate size (mm)	Max.	37.5
		Nominal	19
2	Specific gravity	Bulk	2.69
		Bulk (SSD)	2.70
		Apparent	2.71
3	Unit weight (kg/m^3)	Loose	1343.56
		Compacted	1556.56
4	Absorption capacity		0.23%
5	Moisture content		0.29%
6	Shape		Angular
7	Texture		Rough

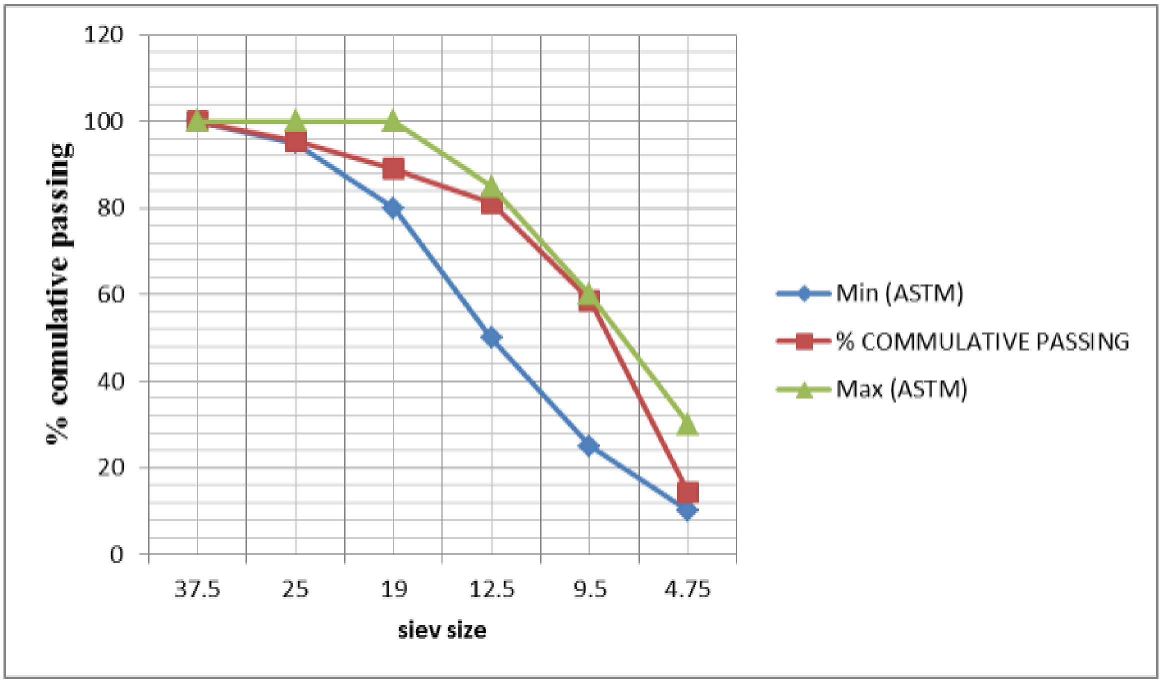


Figure4. 1.Graduation Curve (C.A)

The assessment of the physical characteristics of coarse aggregate was conducted following ASTM C136-96a (Standard Test Method for Sieve Analysis of Fine and C.A), which confirm the established criteria.

4.2. Physical Properties of River Sand

A range of tests was performed on the materials to formulate and produce a concrete mix. Tests included sieve analysis, bulk and dry density measurements, moisture content assessment, absorption capacity evaluation, unit weight determination, and chemical analysis such as silicate examination. All experiments' on aggregates met to Ethiopian standards and complied with ASTM specifications. The results from these tests across with the gradation curve are presented in table 4.2 and Fig 4.2 below.

Table4. 2. Generalized test findings of F.A

no.	Description		Test findings (With Different Replacement Levels)				
			0%CSS	25%CSS	50%CSS	75%CSS	100%CSS
1	Specific gravity	Bulk	2.65	2.61	2.63	2.64	2.64
		Bulk (SSD)	2.66	2.64	2.66	2.65	2.65
		Apparent	2.70	2.66	2.70	2.68	2.67
2	Unit Weight (kg/m^3)	Loose	1629.00	1607.33	1607.33	1603.67	1475.54
		Compacted	1755.00	1751.67	1719.6	1685.44	1609.78
3	Absorption capacity		0.54%	0.42%	0.8%	0.51%	0.4%
4	Moisture content		0.74%	0.47%	0.47%	0.6%	0.8%
5	Silt content		2.41%	3.6%	4.42%	5.2%	5.8%
6	Fineness modulus		2.60	2.57	2.50	2.45	2.4

Based on, ASTM standards (C33-78), the gradation results for the initial sand sample fall outside the acceptable limits for the 150µm and 600µm sieves. Figure4.2 illustrates both the grading requirements for F.A as per ASTM standards (C33-78) and the particle size distribution of aggregates utilized in this experiment. Additionally, Appendix "A" contains details on each replacement level of fine aggregate gradations along with their respective curves.

Table4. 3. Summary of cumulative passing percentage for F.A

sieve size	min(ASTM)	0% CSS	25%CSS	50%CSS	75%CSS	100% CSS	max(ASTM)
9.5	100	100	100	100	100	100	100
4.75	95	95.35	95.9	95.5	95.35	95.45	100
2.36	80	89.05	88.15	89.05	88.6	88.25	100
1.18	50	81.15	80.9	82.25	82	81.05	85
0.6	25	58.65	58.9	61.9	64.75	65.6	60
0.3	10	14.1	16.4	20.75	22.35	28.7	30
0.15	2	1.3	2	2.9	3.25	4.1	10

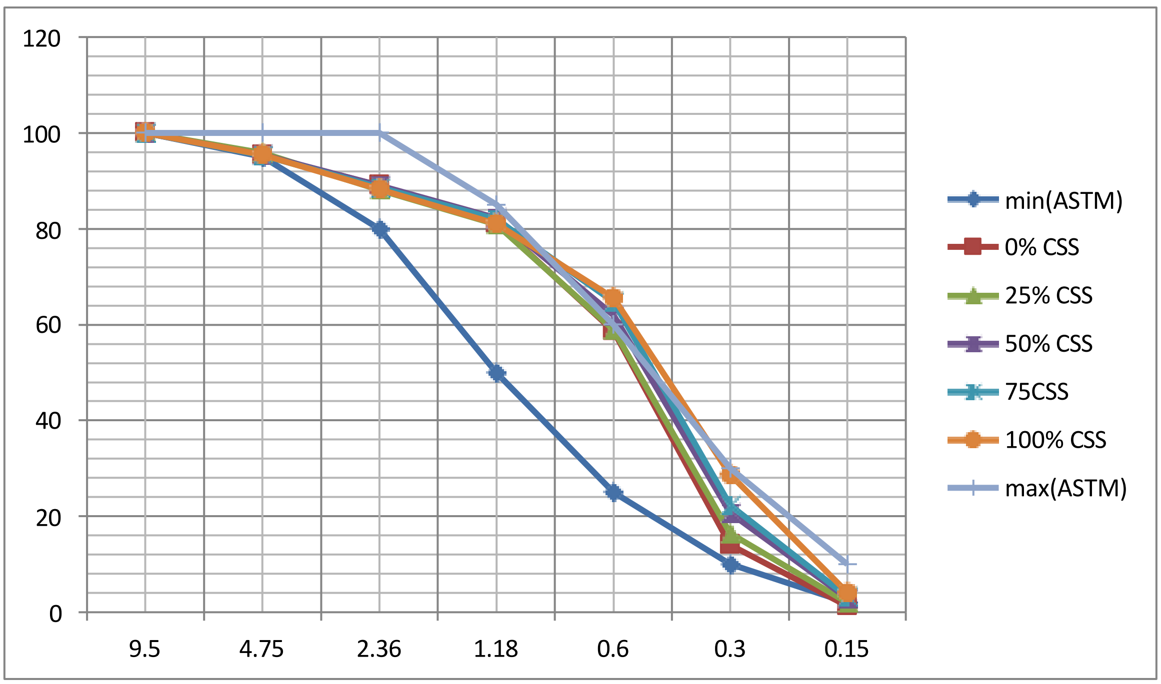


Figure4. 2. Summary of cumulative passing of F.A

4.3. Hintalo Wejerat Sandstone Sand

4.3.1. Sieve Analysis

Aggregate sieve analyses were conducted in accordance with ASTM. Sieve analysis results indicate that crushed Hintalo Wejerat sandstone has a higher concentration of fine components than natural sand. Hintalo wejerat sandstone and natural sand have varying grades, necessitating variable aggregate combining. ASTM C33-03 states that the fine aggregate's fines modulus must not be less than 2.3 and not be less than 45% to pass through any sieve and be kept on subsequent sieves Greater than 3.1. According to ASTM C33, all the sieve analysis results except sieve number 150 and 600 μm meet the grading requirement of ASTM standards (C33-78). The fines modulus falls within the range according to ASTM. The material is therefore standardized for the mix in this study. All the sieve analysis findings of each aggregate samples utilized in the concrete mix shown in Appendix.

4.3.2. Silt Content

It was discovered that the initial sample had a silt percentage of 12.6%, which was higher than permitted. According to the Ethiopian standard, sand with a silt percentage of more than 6% should be washed or rejected. As a result, washing was required to lower the silt content. Following the process, the crushed Hintalo Wejerat Sandstone's fine aggregate's silt concentration was below the permitted 6%. Appendix A has the silt content results.

4.3.3. Specific Gravity and Absorption Capacity

Based on, ASTM C 127-88, the specific gravity (relative density) and absorption capacity of natural and coarse aggregates were measured. Table 4.3 displays the findings from a number of tests of aggregate characteristics. CSS specific gravity was comparable to that of fine aggregate found in nature. Appendix A is a record of the specific gravity, absorption, and moisture content test results of all aggregate samples used in the mix.

4.4. Concrete Test Result

4.4.1. Plastic Concrete Properties

.Table4.4 below presents the slump value of fresh concrete properties at laboratory. This table demonstrates that incorporating Hintalo Wejerat sandstone was comparable to that of traditional river sand. The slump values measured for different replacement levels (25% to 100% Hintalo Wejerat sandstone) remained within acceptable limits for concrete production. This indicates that the sandstone does not negatively affect the simplicity of mixing, placement, and finishing of concrete, making it a practical option for construction applications.

Table4. 4. Characteristic of Plastic concrete

No	F.A replacement levels	Slump (mm)
mix-1	0%CSS	79
mix-2	25%CSS	78
mix-3	50%CSS	77
mix-4	75%CSS	76
mix-5	100%CSS	75

4.4.2. Hardened Concrete Properties

4.4.2.1. Compressive Strength Test

Cubes concrete of 150 mm were tested in based on ASTM C39-90 to find the specimen's compressive strength. Each specimen was weighed and measured in order to get the concrete density and cube area. The hardened concrete qualities were examined after 7, 14 and 28 days. To assure the reliability of test findings, minimum three specimens were tested for every age. Compressive strength of concrete has been found to be influenced when Hintalo Wejerat Sandstone is used as a partial or total replacement for natural river sand. The results are displayed in Figure4.3 and Table4.5. Compare to the control concrete mix, the compressive strength of the concrete with Hintalo Wejerat Sandstone experienced less than to control mixes, particularly at 7 and 14 days, with losses between approximately 0.77% and 24.60%. However, by 28 days, all mixes met the requirements for normal strength concrete (C-25), with reductions of 4.31% to 5.98%.The test results below shown that all different replacement level of crushed hintalo wejerat sandstone achieve the desired compressive strength, although a concrete containing 100% river sand achieve a better compressive strength. It is more beneficial to utilize Crushed Hintalo Wejerat Sandstone for making normal strength concrete. Findings of compressive strength test are presented in Appendix.

Table4. 5. Summary of Mean Compressive Strength findings of Concrete mix

mix-no	**F.A replacement level**	**Age (days)**					
		7 day strength (Mpa)		**14 day strength (Mpa)**		**28 day strength (Mpa)**	
mix-1	0%CSS	26.87	Control	33.43	control	40.61	Control
mix-2	25%CSS	23.21	-13.62%	31.63	-5.38%	38.56	-5.05%
mix-3	50%CSS	25.88	-3.68%	33.17	-0.77%	38.18	-5.98%
mix-4	75%CSS	26.05	-3.05%	33.01	-1.26%	38.54	-5.10%
mix-5	100%CSS	20.26	-24.60%	32.62	-2.42%	38.86	-4.31%

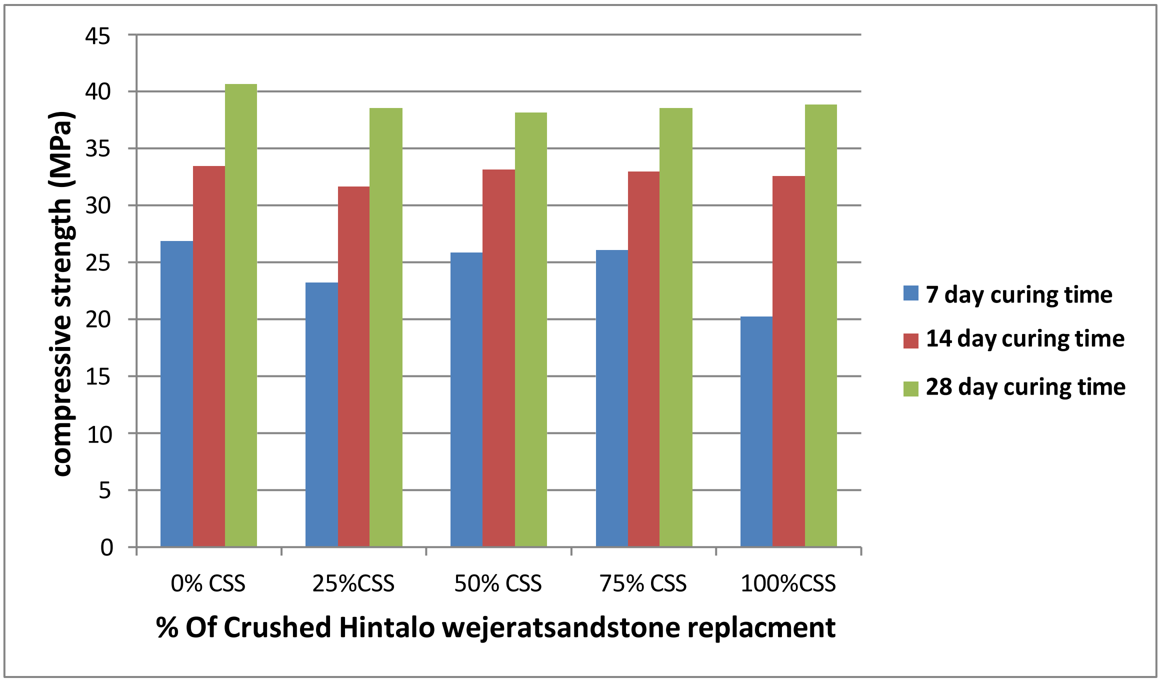


Figure4. 3. Compressive Strength of Concrete

4.4.2.2. Flexural strength Test

A 100mm*100mm*500mm size concrete beam flexural was tested based on ASTMC39-90 to find the flexural strength of the sample. Findings are illustrated in Table4.6 and Figure4.4. The following test results validated flexural strength at 7 days of curing in Hintalo Wejerat Sandstone mixed with concrete mixes showed acceptable findings. The mixes all generally had flexural strengths equal to or greater than the control mix using river sand. This would indicate that replacing Hintalo Wejerat Sandstone with river sand can enhance the flexural properties of the concrete at early age, which is crucial for not cracking and having structural integrity.

Flexural strength at 28 day of curing was improved in Hintalo Wejerat sandstone mixes, particularly under high replacement levels. Mixes showed considerable improvement in flexural strength from 1.91% to 6.98% over the control mix.

Table4. 6. Summary of mean flexural strength findings of mixes

no	F.A replacement level	age			
		7 day strength (Mpa)		28 day strength (Mpa)	
mix-1	0%CSS	6.50	control	6.79	Control
mix-2	25%CSS	6.54	0.61%	6.92	1.91%
mix-3	50%CSS	6.57	1.07%	7.00	3.09%
mix-4	75%CSS	6.59	1.38%	7.06	3.98%
mix-5	100%CSS	6.62	1.84%	7.24	6.63%

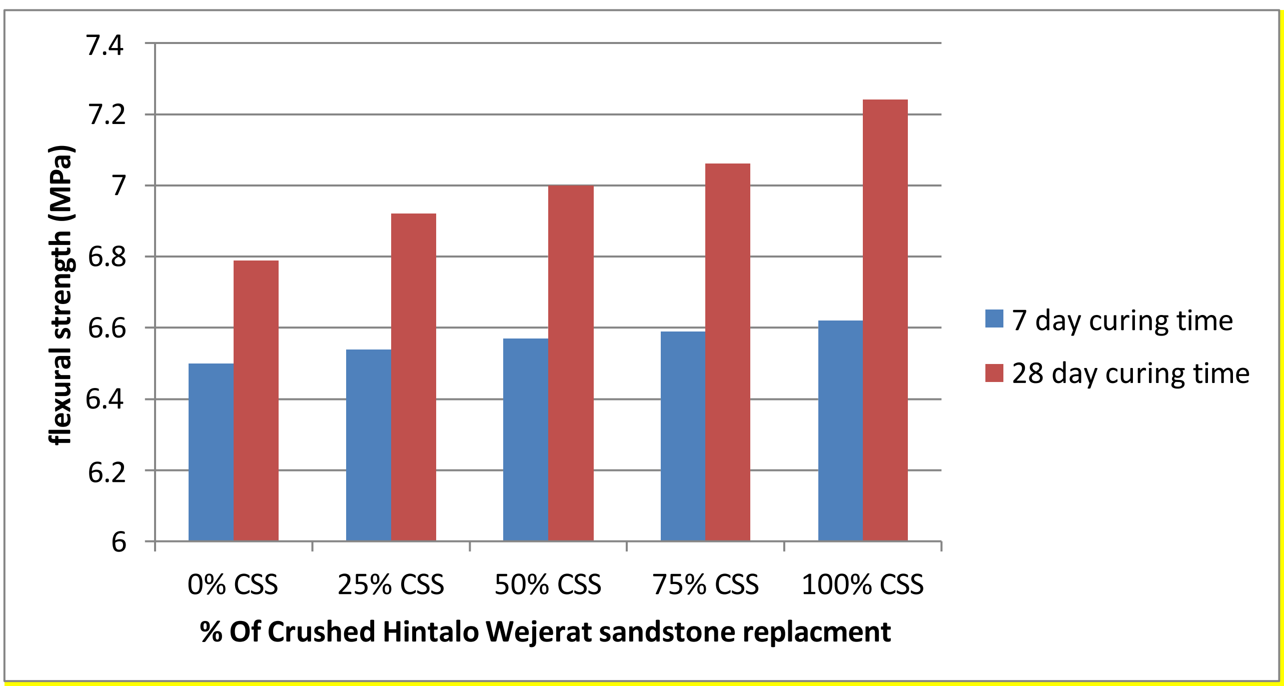


Figure4. 4. Flexural Strength of Concrete

Fig. 4.3 has shown variability in compressive strength results observed in concrete mixes containing Crushed Hintalo Wejerat Sandstone (CSS) can be due to several interrelated factors that influence the material performance. One major factor is the influence of aggregate size and distribution. Effectiveness of CSS to achieve uniform compressive strength is affected by particle sizes and their distribution in the mix. Mixture size variation would lead to vary in packing densities, which can create voids within the concrete matrix. Although mechanical interlock of angular aggregate is beneficial for bending strength, the compressive strength is more susceptible to aggregates distribution uniformity. It has been established that well-graded aggregates yield higher compressive strength through optimum packing efficiency[3].

Apart from that, curing conditions are also very essential in the development of the compressive strength. Temperature and humidity are two factors from the surrounding environment that play a significant role in the hydration of the cement, an important process in the development of the required strength. Changes in these conditions can give rise to inconsistent test results, as noted by [48], that temperature and humidity fluctuation of environmental conditions could greatly affect compressive strength throughout curing. Curing is also important to ensure that concrete attains the intended strength because it can make hydration of cement particles possible [49].

An additional central element is the bonding characteristic among aggregates and cement paste. Bond strength is most critical in the realization of ultimate compressive strength; interface weakening through adverse mixing or curing will prevent the anticipated benefits of CSS from being achieved. Inconsistency of this bonding quality will result in variable compressive strength results even when bending strength trends are positive [19]. In addition, the testing method used to determine compressive strength can also introduce variability. Differences in specimen preparation and in sample handling can all lead to differences in measured strength. Compliance with strict test standards is important to obtaining reliable consistent data [50].

Additionally, hydration in concrete is naturally a complex process, and the addition of other aggregates can affect this process. While CSS can be a supplement to bending strength based on physical properties, its impact upon compressive strength may be more complicated. Not all mix will be equal when it comes to level of hydration or bonding effectiveness, and this could create variability in compressive strength yield [4].

Over all, the observed lack of a clear trend in compressive strength can be due to a combination of factors including, aggregate distribution, curing conditions, bonding quality, testing methodology, and the complexities of hydration dynamics.

Fig4.4 has shown of increasing flexural strength with higher CSS replacement over both 7 and 28 curing days. One significant contributor is high silica content of CSS plays a crucial role in its performance. According to complete silicate analysis of CSS in Appendix C, crushed Hintalo Wejerat Sandstone has 94.36% silicates. Silica contributes to the pozzolana activity of the aggregate, which enhances the bonding between the cement paste and aggregates. This results in a denser microstructure, improving the overall mechanical performance of the concrete. Studies have shown that pozzolana materials can be used to improve hydration reactions in concrete mixtures, which in turn lead to increased strength and durability. The interaction between the CSS particles and cement paste increases bonding and aids in effective hydration, important in achieving increased flexural strength.

Apart from high silica content of CSS, filler effect of the finer particles of CSS is also contributing towards the improvement in flexural strength being noted. The finer particles have the ability to fill the gaps between the bigger aggregates and thus create a denser and more uniform concrete structure. This type of densification decreases the possibility of the formation of cracks under bending loads confirms that "fine aggregates can significantly improve the performance of concrete" through enhancing its bending stress resistance [48].

Mechanical interlocking in CSS also contributes additional role toward the observed increase in flexural strength. This surface improves the interlocking between the cement matrix and aggregate, thus increasing load transfer mechanisms within the concrete. Literature reports that angular aggregates are very efficient in developing tensile and flexural properties since they generate a strong interlocking effect created by bending forces[51].

In summary, the increment in flexural strength with CSS replacement can be scientifically justified through a combination pozzolana activity, the filler effect of finer particles and mechanical interlocking.

4.5. Economic Impact

The major source of sand for building industry nearby mekelle is the Gelebeda (Temben) river placed about 63.2km West of Mekelle city. The transport cost of river sand is high from Temben to mekelle city in comparison to use Hintalo wejerat sand stone. But the economic impact of Hintalo Wejerat Sandstone has not been deeply investigated and it was difficult to get the exact figure about its production cost. Table4.7 has shown the cost distribution of F.A in 2025 year and taken from Tigray construction burro.

Table4.7. distribution cost of F.A per m^3 from source to mekelle city

Sand Type	Cost per (m^3)	one Sino truck (16m^3) pick-up price	Location
Crushed Hintalo wejerat Sandstone	1437.5-1875 Birr	23000-30000 birr	Hintalo Wejerat (Gerygam quarry site)
River sand originally from (Gelebeda)	3000-3250 Birr (at site)	48000-52000 birr	Temben (Gelebeda)

The information in Table 4.7 is based on the fact that distance between the Hintalo Wejerat Sandstone quarry site and Mekelle is roughly 40 Kilometers. In comparison to river sand, Hintalo Wejerat Sandstone is more cost-effective, as shown in Table4.7. In addition to generating jobs in mining, processing, and transportation, the extraction and processing of Hintalo Wejerat Sandstone can enhance regional economies.

4.6. Environmental Impact

Concrete production by using Hintalo Wejerat sandstone from local sources has several positive environmental impacts. Firstly, it reduces the carbon footprint by less transportation distance from Mekelle to the production site as compared to Temben and hence less fuel is consumed and less greenhouse gas emitted. It conserves aquatic habitat and biodiversity as riverine habitats are commonly susceptible to the disturbance that results from sand extraction. Moreover, use of crushed sandstone on land can enhance land stability and reduce erosion on land next to the quarry, resulting in expanded land use practice. Low-carbon production and extraction of Hintalo sandstone can also create job opportunities around the vicinity, supporting the economic growth of the people while lowering the environmental impact. Additional research indicates that recycling or reuse of by-products applied in sandstone processing eliminates waste and enhances circular economy further aiding in the production of more environmentally friendly construction processes. All this contributes to making Hintalo Wejerat sandstone an environmentally friendly product to utilize in producing concrete.

Chapter five: Conclusion and Recommendation

5.1. Conclusion

In C-25 concrete, crushed Hintalo wejerat sandstone was studied as a potential partial or total substitute for river sand. The research's conclusions and recommendations are as follows.

- Hintalo Wejerat sandstone has a sound workability of the concrete, and with appropriate slump values adequate to provide mass concrete production.
- Concrete mixes containing 100% conventional sand have more compressive strength than mixes of Hintalo Wejerat sandstone. However, all replacement percentages were acceptable from the point of required compressive strength.
- Concrete flexural strength improved with higher ratios of Hintalo Wejerat sandstone, which indicates its beneficial effect on the bending strength of the concrete.
- Utilization of crushed hintalo wejerat sandstone can minimize environmental issues associated with Mining.
- All replacement levels meet the required target mean compressive strength (33.6 MPa) of C-25 concrete grade at 28 curing period; hence, crushed Hintalo Wejerat Sandstone is viable alternative for concrete production.

At the end, crushed hintalo wejerat sandstone test is in line with standard specification but requires proper cleaning to lower its silt content. It may be a viable substitute for the use of river sand in concrete manufacture with economic and environmental benefits.

5.2. Recommendation

According to the study, replacement of crushed Hintalo wejerat sandstone with natural river sand in the production of C-25 concrete, bellow recommendation is put forward to the building industry.

- Promote use of crushed Hintalo Wejerat sandstone as a green substitute for river sand to reduce material shortages and reduce environmental impacts.
- Establish standard methods to wash Crushed Hintalo wejerat sandstone to minimize silt and clay content according to the specifications of the construction material.
- Promote research activity that will attempt to alter the properties of Crushed Hintalo wejerat sandstone and other alternative materials in a manner that will make them exhibit better performance when used in concrete.
- The results support the promotion of CSS in the construction sector, particularly in regions facing sand shortages.

5.3. Future Research Directions

- Examine the long-term durability of crushed Hintalo Wejerat sandstone based concrete subjected to moisture exposure, freeze thaw cycling, and chemical attack.
- explore the supplementary cementitious properties of CHWSS
- Investigate the tensile strength of concrete with different CHWSS ratio.
- Investigate permeability of concrete made with crushed hintalo wejerat sandstone.
- Conduct field studies to compare the performance of structures constructed using CHWSS under actual conditions, obtaining actual facts regarding service life and structural condition.

References

[1] H. Hailu, “Crushed Ambo Sandstone as a Partial Replacement of Sand for C-25 Concrete Production,” Jan. 2018, Accessed: Apr. 20, 2025. [Online]. Available: https://www.academia.edu/96192636/Crushed_Ambo_Sandstone_as_a_Partial_Replacement_of_Sand_for_C_25_Concrete_Production

[2] R. Courland, *Concrete planet: the strange and fascinating story of the world’s most common man-made material*. Rowman & Littlefield, 2022. Accessed: May 21, 2025. [Online]. Available: https://books.google.com/books?hl=en&lr=&id=tTFxEAAAQBAJ&oi=fnd&pg=PA5&dq=Concrete+is+now+more+widely+used+than+any+other+man-made+material+and+is+an+essential+component+of+construction+&ots=w4h7ZvPioH&sig=deNahBXO4pC8oscvHuim73XlgEk

[3] A. M. Neville and J. J. Brooks, *Concrete technology*, vol. 438. Longman Scientific & Technical England, 1987. Accessed: Mar. 28, 2025. [Online]. Available: https://www.academia.edu/download/36900631/_A.M_Neville__J_J_Brooks_Concrete_Technology_2nd_ed_Engineersdaily.com_.pdf

[4] S. Mindess, “Concrete constituent materials,” in *Concrete Construction Engineering Handbook, Second Edition*, 2008, pp. 1–28.

[5] Autodesk, “The 5 Most Common Construction Materials,” Digital Builder. Accessed: Apr. 22, 2025. [Online]. Available: https://www.autodesk.com/blogs/construction/common-construction-materials/

[6] R. Cepuritis, S. Jacobsen, and T. Onnela, “Sand production with VSI crushing and air classification: Optimising fines grading for concrete production with micro-proportioning,” *Miner. Eng.*, vol. 78, pp. 1–14, Jul. 2015, doi: 10.1016/j.mineng.2015.03.025.

[7] K. C. Hover, “The influence of water on the performance of concrete,” *Constr. Build. Mater.*, vol. 25, no. 7, pp. 3003–3013, Jul. 2011, doi: 10.1016/j.conbuildmat.2011.01.010.

[8] D. Peter and I. John, “Construction materials: Their nature and behaviour.” Spon Press, New York, USA, 2010.

[9] P. G. Fookes, “An introduction to the influence of natural aggregates on the performance and durability of concrete,” *Q. J. Eng. Geol.*, vol. 13, no. 4, pp. 207–229, Nov. 1980, doi: 10.1144/GSL.QJEG.1980.013.04.02.

[10] A. Dehghan, M. L. J. Maher, and M. Navarra, “The Effects of Aggregate Properties on Concrete Mix Design and Behaviour,” in *Proceedings of the Canadian Society of Civil Engineering Annual Conference 2021*, vol. 248, S. Walbridge, M. Nik-Bakht, K. T. W. Ng, M. Shome, M. S. Alam, A. El Damatty,

and G. Lovegrove, Eds., in Lecture Notes in Civil Engineering, vol. 248. , Singapore: Springer Nature Singapore, 2023, pp. 457–468. doi: 10.1007/978-981-19-1004-3_38.

[11] A. Dinku, “The need for standardization of aggregates for concrete production in Ethiopian construction industry,” 2005, Accessed: May 21, 2025. [Online]. Available: https://scholarworks.wmich.edu/africancenter_icad_archive/90/

[12] D. L. Bloem and R. D. Gaynor, “Effects of aggregate properties on strength of concrete,” in *Journal Proceedings*, 1963, pp. 1429–1456. Accessed: May 21, 2025. [Online]. Available: https://www.concrete.org/publications/internationalconcreteabstractsportal.aspx?m=details&id=7900&m=details&id=7900

[13] P. N. Quiroga, *The effect of the aggregates characteristics on the performance of Portland cement concrete*. The University of Texas at Austin, 2003. Accessed: May 21, 2025. [Online]. Available: https://search.proquest.com/openview/0bf74435120c6154e2fc2cc04489c215/1?pq-origsite=gscholar&cbl=18750&diss=y

[14] M. R. Ponnada, “Combined effect of flaky and elongated aggregates on strength and workability of concrete,” *Int. J. Struct. Eng.*, vol. 5, no. 4, p. 314, 2014, doi: 10.1504/IJSTRUCTE.2014.065915.

[15] A. Dehghan, M. L. J. Maher, and M. Navarra, “The Effects of Aggregate Properties on Concrete Mix Design and Behaviour,” in *Proceedings of the Canadian Society of Civil Engineering Annual Conference 2021*, S. Walbridge, M. Nik-Bakht, K. T. W. Ng, M. Shome, M. S. Alam, A. el Damatty, and G. Lovegrove, Eds., Singapore: Springer Nature, 2023, pp. 457–468. doi: 10.1007/978-981-19-1004-3_38.

[16] R. Chudley and R. Greeno, *Construction technology*. Pearson Education, 2005.

[17] S. H. Kosmatka, W. C. Panarese, and B. Kerkhoff, *Design and control of concrete mixtures*, vol. 5420. Portland cement association Skokie, IL, 2002. Accessed: Mar. 28, 2025. [Online]. Available: https://www.researchgate.net/profile/Steven-Kosmatka/publication/348676262_Design_and_Control_of_Concrete_Mixtures/links/600a61c8299bf14088b1a784/Design-and-Control-of-Concrete-Mixtures.pdf

[18] M. U. Aswath, “Technical specifications for fine aggregates,” *Altern. RIVER SAND*, vol. 24, 2013, Accessed: Sep. 30, 2025. [Online]. Available: http://icikbc.org/docs/ICI-Seminar2013-ARS-Souvenir.pdf#page=26

[19] D. P. Bentz *et al.*, “Influence of aggregate characteristics on concrete performance,” National Institute of Standards and Technology, Gaithersburg, MD, NIST TN 1963, May 2017. doi: 10.6028/NIST.TN.1963.

[20] A. R. Tarrer, “The effect of the physical and chemical characteristics of the aggregate on bonding,” 1991, Accessed: May 21, 2025. [Online]. Available: https://books.google.com/books?hl=en&lr=&id=j3MiN-

5pfpMC&oi=fnd&pg=PA1&dq=The+determination+of+the+quality+of+bond+of+aggregate+is+difficult+and+no+accepted+tests+exist&ots=savT2LI-MN&sig=c0bVVD1Ur7NmnWxZyUUJTCWnahI

[21] W. D. Kemper and W. S. Chepil, “Size Distribution of Aggregates,” in *Agronomy Monographs*, C. A. Black, Ed., Madison, WI, USA: American Society of Agronomy, Soil Science Society of America, 2015, pp. 499–510. doi: 10.2134/agronmonogr9.1.c39.

[22] C. Astm, “Standard test method for sieve analysis of fine and coarse aggregates,” *ASTM C136-06*, 2006.

[23] C. Astm, “Standard test method for sieve analysis of fine and coarse aggregates,” *ASTM C136-06*, 2006.

[24] B. HAILU, “ADDIS ABABA INSTITUTE OF TECHNOLOGY DEPARTMENT OF CIVIL ENGINEERING,” PhD Thesis, ADDIS ABABA UNIVERSITY, 2011. Accessed: May 21, 2025. [Online]. Available: https://www.researchgate.net/profile/Biruk-Tekle/publication/305281723_Bagasse_ash_as_a_cement_replacing_material/links/5786c6f008ae36ad40a69a15/Bagasse-ash-as-a-cement-replacing-material.pdf

[25] S. H. Kosmatka, W. C. Panarese, and B. Kerkhoff, *Design and control of concrete mixtures*, vol. 5420. Portland cement association Skokie, IL, 2002. Accessed: May 21, 2025. [Online]. Available: https://www.researchgate.net/profile/Steven-Kosmatka/publication/348676262_Design_and_Control_of_Concrete_Mixtures/links/600a61c8299bf14088b1a784/Design-and-Control-of-Concrete-Mixtures.pdf

[26] S. H. Kosmatka, W. C. Panarese, and B. Kerkhoff, *Design and control of concrete mixtures*, vol. 5420. Portland cement association Skokie, IL, 2002. Accessed: Mar. 31, 2025. [Online]. Available: https://www.researchgate.net/profile/Steven-Kosmatka/publication/348676262_Design_and_Control_of_Concrete_Mixtures/links/600a61c8299bf14088b1a784/Design-and-Control-of-Concrete-Mixtures.pdf

[27] W. Ararsa, E. Quezon, and A. Aboneh, “Suitability of Ambo Sandstone Fine Aggregate as an Alternative River Sand Replacement in Normal Concrete Production,” *Am. J. Civ. Eng. Archit.*, vol. 6, Apr. 2018, doi: 10.12691/ajcea-6-4-2.

[28] T. A. Ako *et al.*, “Environmental effects of sand and gravel mining on land and soil in Luku, Minna, Niger State, North Central Nigeria,” 2014, Accessed: Mar. 28, 2025. [Online]. Available: https://www.academia.edu/download/56738238/Egila1.pdf

[29] K. K. Kumar, Dr. J. Premalatha, R. Sangeetha, and S. Vishwa, “A Review on Usage of Waste Materials as Replacement for Natural Sand in Concrete,” *Int. J. Res. Publ. Rev.*, vol. 4, no. 11, pp. 2453–2459, Nov. 2023, doi: 10.55248/gengpi.4.1123.113133.

[30] A. C. Sankh, P. M. Biradar, S. J. Naghathan, and M. B. Ishwargol, “Recent trends in replacement of natural sand with different alternatives,” in *Proceedings of the international conference on advances*

in engineering and technology, 2014, pp. 59–66. Accessed: May 21, 2025. [Online]. Available: https://www.researchgate.net/profile/Praveen-Biradar/publication/323239519_Recent_Trends_in_Replacement_of_Natural_Sand_With_Different_Alternatives/links/5a87c3c1aca272017e5ac3c6/Recent-Trends-in-Replacement-of-Natural-Sand-With-Different-Alternatives.pdf

[31] S. K. Singh, V. Srivastava, V. C. Agarwal, R. Kumar, and P. K. Mehta, "An experimental investigation on stone dust as partial replacement of fine aggregate in concrete," *J. Acad. Ind. Res. JAIR*, vol. 3, no. 5, p. 229, 2014.

[32] S. Prasanth, S. P. Chandar, and K. Gunasekaran, "Influence of manufactured sand on fresh properties, strength properties and morphological characteristics of self-compacting coconut shell concrete," *Buildings*, vol. 14, no. 8, p. 2281, 2024.

[33] P. Smarzewski, "Mechanical Properties of Ultra-High Performance Concrete with Partial Utilization of Waste Foundry Sand," *Buildings*, vol. 10, no. 1, Art. no. 1, Jan. 2020, doi: 10.3390/buildings10010011.

[34] S. Chowdary, "Granite waste as replacement", Accessed: Apr. 27, 2025. [Online]. Available: https://www.academia.edu/6089716/EXPERIMENTAL_INVESTIGATION_ON_BEHAVIOUR_OF_CONCRETE_WITH_THE_USE_OF_GRANITE_FINES_Address_for_Correspondence

[35] A. Ramesh, "Experimental Study on Granite Powder as a Replacement of Fine Aggregate in Concrete," *Int. J. Adv. Res. Innov. Ideas Educ.*, Jan. 2019, Accessed: Mar. 28, 2025. [Online]. Available: https://www.academia.edu/85320803/Experimental_Study_on_Granite_Powder_as_a_Replacement_of_Fine_Aggregate_in_Concrete

[36] F. Eric, V. Srivastava, V. Agarwal, A. Denis, and E. Ali, "Stone Dust as Partial Replacement of Fine Aggregate in Concrete," vol. 3, pp. 148–152, Aug. 2014.

[37] E. G. Collares, I. F. Júnior, and L. A. Motta, "Evaluation of the aggregate produced from wastes of quartzite mining sites to use in concrete," *Soils Rocks*, vol. 35, pp. 251–266, 2012.

[38] "Sandstone - Wikipedia." Accessed: Sep. 29, 2025. [Online]. Available: https://en.wikipedia.org/wiki/Sandstone

[39] "Sandstone," *Wikipedia*. Mar. 22, 2025. Accessed: Mar. 28, 2025. [Online]. Available: https://en.wikipedia.org/w/index.php?title=Sandstone&oldid=1281737320

[40] M. Beyth, "Paleozoic-Mesozoic sedimentary basin of Mekele outlier, northern Ethiopia," *AAPG Bull.*, vol. 56, no. 12, pp. 2426–2439, 1972.

[41] T. Gebreyohannes *et al.*, "Large-scale geological mapping of the Geba basin, northern Ethiopia." VLIR-Mekelle University IUC Programme, 2010. Accessed: May 21, 2025. [Online]. Available: https://core.ac.uk/download/pdf/55812716.pdf

[42] "Hintalo Wajirat," *Wikipedia*. Oct. 31, 2024. Accessed: Nov. 05, 2024. [Online]. Available: https://en.wikipedia.org/w/index.php?title=Hintalo_Wajirat&oldid=1254629872

[43] K. Gebremeskel, K. Teka, E. Birhane, and E. Negash, "The role of integrated watershed management on soil-health in northern Ethiopia," *Acta Agric. Scand. Sect. B — Soil Plant Sci.*, Nov. 2019, Accessed: Nov. 17, 2024. [Online]. Available: https://www.tandfonline.com/doi/abs/10.1080/09064710.2019.1639806

[44] P. S. Kumar, "A study on high performance concrete using sandstone aggregates," 2006. Accessed: Nov. 04, 2024. [Online]. Available: https://www.semanticscholar.org/paper/A-study-on-high-performance-concrete-using-Kumar/45e99f4aadbdd36892d4b9961e996c158bfce623

[45] S. Mundra, V. Agrawal, and R. Nagar, "Sandstone cutting waste as partial replacement of fine aggregates in concrete: A mechanical strength perspective," *J. Build. Eng.*, vol. 32, p. 101534, Nov. 2020, doi: 10.1016/j.jobe.2020.101534.

[46] K. R. Chandar, B. C. Gayana, and V. Sainath, "Experimental investigation for partial replacement of fine aggregates in concrete with sandstone," *Adv. Concr. Constr.*, vol. 4, no. 4, p. 243, 2016.

[47] A. Yihune, "Using Crushed Sandstone around Adigrat as a Sand Replacement Material", Accessed: Sep. 14, 2024. [Online]. Available: https://www.academia.edu/32377156/Using_Crushed_Sandstone_around_Adigrat_as_a_Sand_Replacement_Material

[48] R. Alizadeh, P. Ghods, M. Chini, M. Hoseini, M. Ghalibafian, and M. Shekarchi, "Effect of Curing Conditions on the Service Life Design of RC Structures in the Persian Gulf Region," *J. Mater. Civ. Eng.*, vol. 20, no. 1, pp. 2–8, Jan. 2008, doi: 10.1061/(ASCE)0899-1561(2008)20:1(2).

[49] P.-C. Aitcin, *Binders for Durable and Sustainable Concrete*. London: CRC Press, 2007. doi: 10.1201/9781482265767.

[50] A. ASTM, "ASTM C39/C39M-18 standard test method for compressive strength of cylindrical concrete specimens," *ASTM Int. West Conshohocken PA ASTM AI*, vol. 192, 2018.

[51] P. K. (Povindar K.) Mehta and P. Monteiro, *Concrete : microstructure, properties, and materials*, 4th ed. McGraw-Hill, 2014. Accessed: Jun. 04, 2025. [Online]. Available: https://cir.nii.ac.jp/crid/1130000797867624064

Appendix A

Appendix A. Material Properties and Test findings

A.1. Properties of C.A

A.1.1. Graduation of C.A

Sieve diameter in (mm)	(gm) mass retained	(%) retained	(%) cumulative coarser	(%) cumulative passing	ASTM LIMIT	
					Min	Max
37.5	0	0	0.00	100	100	100
25	916	18.32	18.3	95.35	95	100
19	2124	42.48	60.8	89.05	80	100
12.5	1506	30.12	90.9	81.15	50	85
9.5	425	8.5	99.4	58.65	25	60
4.75	23	0.46	99.9	14.1	10	30
Pan	6	0.12	00.00	0		
Total	5000		369.3			
		F.M=	**3.7**			

$$F.M = \sum \frac{\%\,Cumulative\ Coarser}{100} \qquad F.M = \frac{(369.3)}{100} = 3.7$$

A.2. properties of F.A

A.2.1. properties of F.A 0% CSS

A.2.1.1. Graduation test for F.A 0 % CSS

Sieve diameter (mm)	**Mass retained (gm)**	**Retained (%)**	**Cumulative coarser (%)**	**(%) Cumulative passing**	**ASTM Limit**	
					Min	**Max**
9.50	0	0.00	0.00	100	100	100
4.75	93	4.65	4.65	95.35	95	100
2.36	126	6.30	10.95	89.05	80	100
1.18	158	7.90	18.85	81.15	50	85
0.60	450	22.50	41.35	58.65	25	60
0.30	891	44.55	85.90	14.1	10	30
0.15	256	12.80	98.70	1.3	2	10
0.75	26	1.30	0.00	0		
Pan	0	1.30	0.00	0		
TOTAL	2000		260.4			
		F.M=	**2.6**			

$$F.M=\sum\frac{\%\,Cumulative\ Coarser}{100} \qquad F.M=\frac{(260.4)}{100}=2.6$$

A.2.3. 25%CSS

A.2.3.1. Gradation test for F.A 25%CSS

Sieve diameter (mm)	**(gm) mass retained**	**(%) retained**	**(%)cumulative coarser**	**(%)cumulative passing**	**ASTM Limit**	
					Min	**Max**
9.50	0	0.00	0.00	100	100	100
4.75	82	4.1	4.1	95.9	95	100
2.36	149	7.45	11.55	88.15	80	100
1.18	151	7.55	19.10	80.9	50	85
0.60	440	22.00	41.10	58.9	25	60
0.30	850	42.55	83.60	16.4	10	30
0.15	288	14.40	98.00	2	2	10
0.75	40	2.00	00.0	0		
Pan	0		0.00	0		
TOTAL	2000		257.45			
		F.M=	**2.57**			

$$F.M=\sum\frac{\%\ Cumulative\ Coarser}{100}$$

$$F.M=\frac{(257.45)}{100}=2.57$$

A.2.4. 50%CSS

A.2.4.1. Gradation test for F.A 50%CSS

Sieve diameter (mm)	Mass retained (gm)	Retained (%)	Cumulative coarser (%)	Cumulative passing (%)	ASTM Limit	
					Min	Max
9.50	0	0.00	0.00	100	100	100
4.75	90	4.50	4.50	95.5	95	100
2.36	129	6.45	10.95	89.05	80	100
1.18	136	6.80	17.75	82.25	50	85
0.60	407	20.35	38.10	61.90	25	60
0.30	823	41.15	79.25	20.75	10	30
0.15	357	17.85	97.10	2.9	2	10
0.75	58	2.90	00.0	0		
Pan	0	0	0	0		
TOTAL	2000		247.65			
		F.M=	**2.5**			

$$F.M=\sum\frac{\%\,Cumulative\ Coarser}{100}\quad,\qquad F.M=\frac{(247.65)}{100}=2.5$$

A.2.5.75%CSS

A.2.5.1.Gradation test for Fine Aggregate 75%CSS+25%R.S

Sieve diameter (mm)	**Mass retained (gm)**	**Retained (%)**	**(%) cumulative coarser**	**(%) cumulative passing**	**ASTM Limit**	
					Min	**Max**
9.50	0	0.00	0.00	100	100	100
4.75	113	5.65	5.65	95.35	95	100
2.36	115	5.75	11.40	88.60	80	100
1.18	132	6.60	18..00	82.00	50	85
0.60	345	17.25	35.25	64.75	25	60
0.30	848	42.40	77.65	22.35	10	30
0.15	382	19.10	96.75	3.25	2	10
0.75	65	3.25	00.0	0		
Pan	0		0	0		
TOTAL	2000		244.7			
		F.M=	**2.447**			

$$F.M=\sum\frac{\%\,Cumulative\ Coarser}{100}\quad , \qquad F.M=\frac{(244.7)}{100}=2.45$$

A.2.2. 100%CSS

A.2.2.1. Gradation test for F.A 100% CSS

Sieve diameter (mm)	Mass retained (gm)	Retained (%)	Cumulative coarser (%)	Cumulative passing (%)	ASTM Limit	
					Min	Max
9.50	0	0.00	0.00	100	100	100
4.75	91	4.55	4.55	95.45	95	100
2.36	144	7.2	11.75	88.25	80	100
1.18	144	7.2	18.95	81.05	50	85
0.60	309	15.45	34.40	65.6	25	60
0.30	738	36.90	71.30	28.7	10	30
0.15	492	24.60	95.90	4.1	2	10
0.75	82	4.10	100.00	0.00		
Pan	82	4.10	0.00	0.00		
TOTAL	2000		237.85			
		F.M=	**2.4**			

$$F.M=\sum\frac{\%\,Cumulative\ Coarser}{100} \qquad F.M= \frac{(237.85)}{100}=2.4$$

Appendix B. Design Mix

B.1. Mix design of C-25 Concrete Grade

B.1.1. Mix design-1 (0% CSS)

Required material properties

No	Material properties	C.A	F.A
1	unit weight	1556.56kg/m^3	1755 kg/m^3
2	fineness modulus		2.6
3	Specific gravity	2.69	2.65
4	absorption	0.23	0.54%
5	moisture content	0.29%	0.74%

Step 1: determining target mean strength

Cube strength: design strength is 25Mpa

Cylindrical Strength = 0.8 x cubic strength = 0.8 x 25Mpa = 20Mpa

fck = fc' +ks = $f$cm = fc' + 6.9Mpa where according ACI 214R-02 table 4.2minimum required strength without sufficient historical data $f$cm = fc' + 6.9Mpa when fc'≤20.7Mpa.

fck = 20Mpa + 6.9Mpa=26.9MPa when the compressive strength change to cube strength is $f$ck = 26.9 x 1.25 = 33.6Mpa

Step2: choice of slump based on ACI

According to ACI211.1-91, slump values for different types of construction are provided.

Mix design is selected for beam and reinforced wall concrete; the recommended slump requirement is the range between the slumps 25 to 100 mm.

Step3: choice of the nominal maximum size of aggregate

Based on the retained weights given on the sieve analysis findings:

- Maximum aggregate size 37.5mm
- Maximum nominal aggregate size 19mm

Step4: Calculation of mixing water and air content

- Assume concrete with non – air entrained

According the table for requirements of mixing water and air content, for the given slump 75 to 100mm, maximum aggregate size of 19mm non- air entrained concrete, the water content is 205kg/m^3 and air content from table 2% for 19 nominal maximum size of aggregate.

Step5: Estimation of water/cement ratio

From the table6.of ACI211.1-91, the recommended water cement ratio for the target mean compressive strength, will be read. But this compressive strength has not direct readable value from the table. Thus have to extrapolate the water cement ratio is 0.49

W/C=0.49, C=W/0.49= (205kg/m3)/0.49 =418.37kg/m3

Step6: Calculation of C.A content

For the 19 mm maximum size of C.A having fines modules of sand 2.6, from the table of ACI211,1-91 for bulk volume of C.A, Thus the dry rodded bulk volume of C.A per unit volume * dry rodded bulk density. C.A=0.64 x 1556.56kg/m3= 996.20kg/m3

Step7: Calculation of F.A by using absolute volume method

The amount of all ingredients without F.A is known. In the absolute volume method, the volume of F.A is calculated by subtracting the absolute volume of the known ingredient from cubic meter.

Assuming air =2%=0.02M3

No	Ingredients	Using Absolute volume ($1M^3$)	Result
1	Water	205/(1*1000)	$0.205m^3$
2	Cement	418.37/(3.15*1000)	$0.133m^3$
3	Coarse aggregate	996.2/(2.69*1000)	$0.370\ m^3$
4	Entrapped air 2%	2/100	$0.020m^3$
	Total volume		$0.728m^3$
5	The volume of F.A	1-0.728	$0.272m^3$
6	Weight of F.A (kg/m^3)	$G_{FA}*V_{FA}*1000=2.65*0.272*1000$	720.8

Step8: Adjustment for moisture Amount

Water =205-[720.8(0.74%-0.54%)]-[996.2(0.29%-0.23%)] =202.96kg

Coarse aggregate=996.2(1+moisture content (%)) =996.2(1+0.29%) =999.09kg

Fine aggregate= 720.8*(1+m.c (%)) =720.8(1+0.74%) =726.13kg

Step 9: Weight adjustment in laboratory

The total laboratory trial batch production (9cube+6 flexural beams)

Total volume = Total volume of cube + total volume of flexural beam

Total volume = [(0.15*0.15*0.15*9) + (0.1*0.1*0.5*6)]*1.2=$0.07245m^3$

`

Material Type	Adjusted quantity(kg/m^3)	Weight(kg)
Water	202.96kg	14.61
Cement	418.37	30.12
C.A	999.09	71.93
F.A	726.13	52.28

Compressive and flexural strength test findings

no	Test age (days)	dimensions (c.m)			weight (gm)	volume (cm^3)	failure load (KN)	comp. strength (Mpa)	unite weight (gm/cm^3)
		L	L	L					
1	7	15.00	15.00	15.00	8650	3375	560.4	24.91	2.56
2		15.00	15.00	15.00	8490	3375	610.4	27.13	2.52
3		15.00	15.00	15.00	8460	3375	643.1	28.58	2.50
						mean	604.63	26.87	2.53
1	14	15.00	15.00	15.00	8260	3375	750.9	33.37	2.45
2		15.00	15.00	15.00	8510	3375	722.5	32.11	2.52
3		15.00	15.00	15.00	8670	3375	783.3	34.81	2.57
						mean	752.23	33.43	2.51
1	28	15.00	15.00	15.00	8540	3375	935.3	41.57	2.53
2		15.00	15.00	15.00	8490	3375	896.4	39.84	2.51
3		15.00	15.00	15.00	8460	3375	909.5	40.42	2.50
						mean	913.73	40.61	2.45

no	Test age (days)	dimensions (cm)			weight (gm)	volume (cm^3)	Failure load (KN)	Flexural. Strength (Mpa)
		L	D	B				
1	7	50.00	10.00	10.00		5000	14.36	6.46
2		50.00	10.00	10.00		5000	14.45	6.50
3		50.00	10.00	10.00		5000	14.55	6.55
						Mean	14.45	6.50
1	28	50.00	10.00	10.00		5000	15.14	6.81
2		50.00	10.00	10.00		5000	15.10	6.79
3		50.00	10.00	10.00		5000	15.06	6.77
						Mean	15.10	6.79

Mix design-2 (25%CSS)

Required material properties

No	Material properties	C.A	F.A
1	unit weight	1556.56 kg/m^3	1751.67kg/m^3
2	fineness modulus		2.57
3	Specific gravity	2.69	2.61
4	Absorption	0.23%	0.42%
5	moisture content	0.29%	0.47%

Laboratory weight adjusted weight

Material Type	Adjusted quantity	Weight(kg)
Water	204.04kg	14.69
Cement	418.37	30.12
Coarse Aggregate	1003.73	72.27
Fine Aggregate	708.01	50.97

Compressive and flexural strength test result

no	test age (days)	dimensions (m)			weight (gm)	volume (cm^3)	failure load (KN)	comp. strength (Mpa)	unite weight(gm/cm^3)
		L	W	H					
1	7	15.00	15.00	15.00	8510	3375	533.5	23.71	2.52
2		15.00	15.00	15.00	8340	3375	511.3	22.72	2.47
3		15.00	15.00	15.00	8490	3375	521.6	23.18	2.51
						mean	522.13	23.21	2.50
1	14	15.00	15.00	15.00	8260	3375	680.3	30.23	2.45
2		15.00	15.00	15.00	8620	3375	710.60	31.58	2.55
3		15.00	15.00	15.00	8390	3375	744.4	33.08	2.48
						mean	711.76	31.63	2.49
1	28	15.00	15.00	15.00	8571	3375	858.4	38.15	2.54
2		15.00	15.00	15.00	8574	3375	877.6	39.00	2.54
3		15.00	15.00	15.00	8796	3375	866.8	38.52	2.60
						mean	867.6	38.56	2.56

no	Test age (days)	dimensions (cm)			weight (gm)	Volume(cm^3)	Failure load (KN)	Flexural. Strength (Mpa)
		L	W	H				
1	7	50.00	10.00	10.00		5000	14.49	6.52
2		50.00	10.00	10.00		5000	14.55	6.55
3		50.00	10.00	10.00		5000	14.57	6.56
						mean	14.53	6.54
1	28	50.00	10.00	10.00		5000	14.99	6.75
2		50.00	10.00	10.00		5000	15.59	7.02
3		50.00	10.00	10.00		5000	15.54	6.99
						Mean	15.37	6.92

Mix design3 (50%CSS)

Required material properties

No	material properties	C.A	F.A
1	unit weight	1556.56kg/m^3	1719.6 kg/m^3
2	fineness modulus		2.5
3	specific gravity	2.69	2.63
4	Absorption	0.23	0.8%
5	moisture content	0.29%	0.47%

Laboratory Adjusted weight for concrete mix

Material Type	Adjusted quantity	Weight(kg)
Water	204.25kg	14.75
Cement	418.37	30.37
Coarse Aggregate	1014.69	73.06
Fine Aggregate	702.87	50.61

Compressive and flexural strength test findings

no	test age (days)	dimensions (CM)			weight (gm)	volume (cm^3)	failure load (kN)	comp. strength (MPa)	unite weight (gm/cm^3)
		L	W	H					
1	7	15.00	15.00	15.00	8790	3375	570.4	26.91	2.60
2		15.00	15.00	15.00	8330	3375	590.9	27.28	2.47
3		15.00	15.00	15.00	8440	3375	585.5	28.80	2.50
						Mean	582.27	25.88	2.52
1	14	15.00	15.00	15.00	8670	3375	730.3	32.46	2.57
2		15.00	15.00	15.00	8520	3375	725.9	32.26	2.52
3		15.00	15.00	15.00	8500	3375	783.1	34.80	2.52
						Mean	746.43	33.17	2.54
1	28	15.00	15.00	15.00	8693	3375	812.9	36.12	2.57
2		15.00	15.00	15.00	8611	3375	867.6	38.56	2.55
3		15.00	15.00	15.00	8663	3375	897.1	39.87	2.56
						Mean	859.2	38.18	2.56

no	Test age (days)	dimensions (cm)			weight (gm)	volume (cm^3)	failure load (KN)	Flexural. Strength (Mpa)
		L	B	D				
1	7	50.00	10.00	10.00		5000	14.16	6.37
2		50.00	10.00	10.00		5000	14.65	6.59
3		50.00	10.00	10.00		5000	14.98	6.74
mean							14.59	6.57
1	28	50.00	10.00	10.00		5000	15.52	6.98
2		50.00	10.00	10.00		5000	15.57	7.00
3		50.00	10.00	10.00		5000	15.56	7.00
Mean							15.55	7.00

Mix design -4 (75% CSS)

Required material property

No	material properties	C.A	F.A
1	unit weight	1556.56kg/m^3	1685.44 kg/m^3
2	fineness modulus		2.45
3	specific gravity	2.69	2.64
4	Absorption	0.23	0.51%
5	moisture content	0.29%	0.6%

Laboratory Adjusted weight for concrete mix

Material Type	Adjusted quantity(kg/m^3)	Weight(kg)
Water	202.92	14.61
Cement	418.37	30.12
Coarse Aggregate	1022.51	73.62
Fine Aggregate	698.45	50.29

Compressive and flexural strength test findings

no	test age (days)	dimensions(m)			weight (gm)	volume (cm^3)	failure load (KN)	comp. strength(MPa)	Unite weight (gm/cm^3)
		L	W	H					
1	7	15.00	15.00	15.00	8540	3375	615.9	27.37	2.53
2		15.00	15.00	15.00	8420	3375	550.5	24.47	2.50
3		15.00	15.00	15.00	8560	3375	592.1	26.32	2.54
						mean	586.17	26.05	2.52
1	14	15.00	15.00	15.00	8610	3375	725.1	32.23	2.55
2		15.00	15.00	15.00	8390	3375	759.5	33.75	2.49
3		15.00	15.00	15.00	8530	3375	743.5	33.04	2.53
						mean	742.7	33.01	2.52
1	28	15.00	15.00	15.00	8467	3375	880.6	39.14	2.51
2		15.00	15.00	15.00	8697	3375	875.2	38.90	2.57
3		15.00	15.00	15.00	8722	3375	845.5	37.58	2.58
						mean	867.1	38.54	2.55

No	test age (days)	dimensions (cm)			weight(gm)	volume(cm^3)	failure load (KN)	Flexural. Strength (MPa)
		L	B	D				
1	7	50.00	10.00	10.00		5000	14.63	6.58
2		50.00	10.00	10.00		5000	14.67	6.60
3		50.00	10.00	10.00		5000	14.62	6.58
Mean							14.64	6.59
1	28	50.00	10.00	15.00		5000	15.37	6.92
2		50.00	10.00	10.00		5000	15.95	7.18
3		50.00	10.00	10.00		5000	15.75	7.09
Mean							15.69	7.06

Mix design-5 (100% CSS)

Required material property

No	material properties	C.A	F.A
1	unit weight	1556.56 kg/m^3	1609.78 kg/m^3
2	Fineness modulus		2.4
3	specific gravity	2.69	2.64
4	Absorption	0.23	0.40%
5	moisture content	0.29%	0.8%

Laboratory Adjusted weight for concrete mix

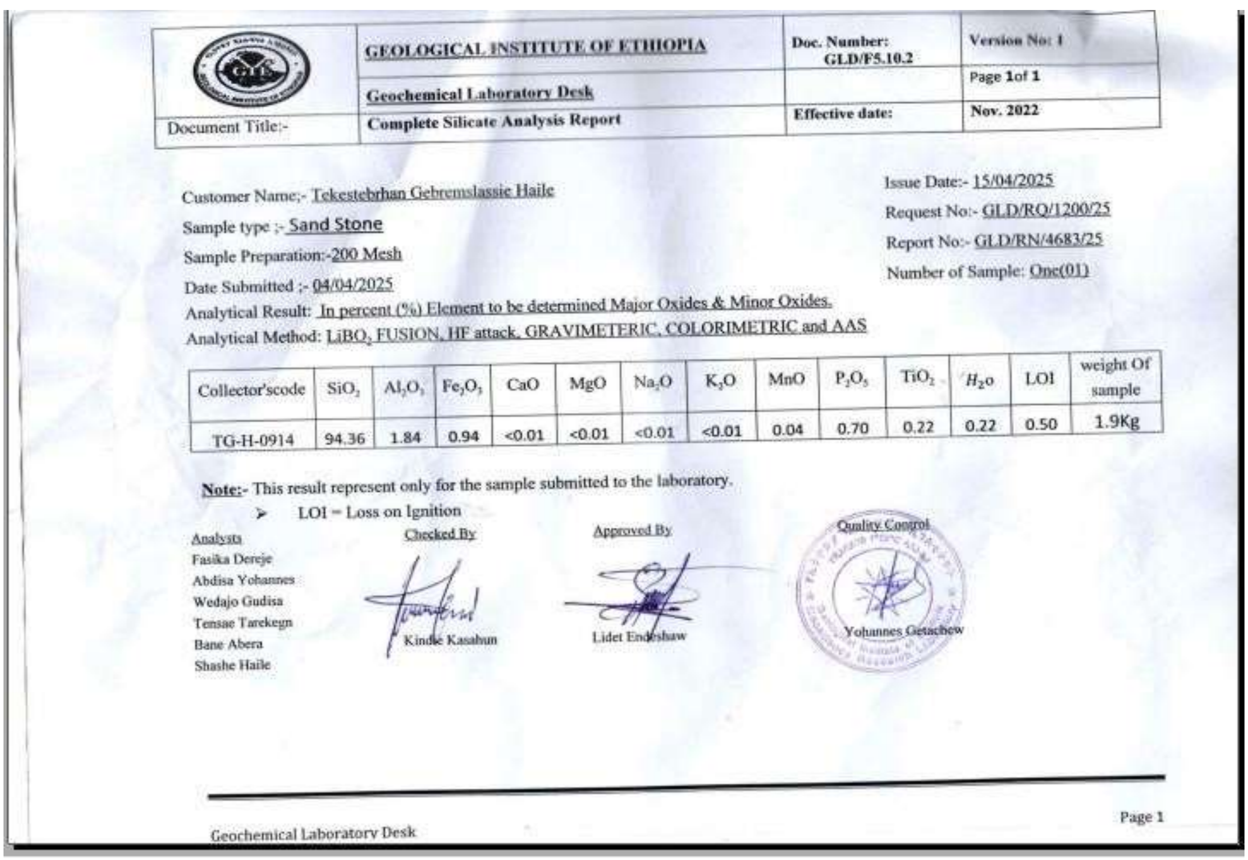
Material Type	Adjusted quantity(kg/m^3)	Weight(kg)
Water	201.63kg	14.51
Cement	418.37	30.12
Coarse Aggregate	1030.31	74.20
Fine Aggregate	691.89	49.82

Compressive and flexural strength test findings

No	test age (days)	dimensions (cm)			weight (gm)	volume (cm^3)	failure Load (kN)	comp. strength (MPa)	unite weight (gm/cm^3)
		L	W	H					
1	7	15.00	15.00	15.00	8900	3375	420.5	18.69	2.64
2		15.00	15.00	15.00	8330	3375	482.3	21.44	2.47
3		15.00	15.00	15.00	8530	3375	464.8	20.66	2.53
Mean							455.87	20.26	2.55
1	14	15.00	15.00	15.00	8560	3375	740.5	34.95	2.54
2		15.00	15.00	15.00	8530	3375	735.7	34.07	2.53
3		15.00	15.00	15.00	8700	3375	725.5	33.35	2.58
Mean							733.9	32.62	2.55
1	28	15.00	15.00	15.00	8652	3375	881.4	39.17	2.56
2		15.00	15.00	15.00	8494	3375	875.6	38.92	2.52
3		15.00	15.00	15.00	8183	3375	866.3	38.50	2.42
Mean							874.43	38.86	2.5

No	test ages (days)	dimensions (cm)			weight (gm)	volume (cm^3)	failure load (KN)	Flexural. strength (Mpa)
		B	B	D				
1	7	50.00	10.00	10.00		5000	14.38	6.47
2		50.00	10.00	10.00		5000	14.75	6.64
3		50.00	10.00	10.00		5000	15.01	6.75
						mean	14.71	6.62
1	28	50.00	10.00	10.00		5000	15.96	7.18
2		50.00	10.00	10.00		5000	16.01	7.20
3		50.00	10.00	10.00		5000	16.27	7.32
						mean	16.08	7.24

Appendix C. Complete Silicate Analysis of CHWSS According Ethiopian Geological Survey Report



	GEOLOGICAL INSTITUTE OF ETHIOPIA	Doc. Number: GLD/F5.10.2	Version No: 1
	Geochemical Laboratory Desk		Page 1of 1
Document Title:-	Complete Silicate Analysis Report	Effective date:	Nov. 2022

Customer Name;- Tekestebrhan Gebremslassie Haile

Sample type ;- Sand Stone

Sample Preparation:-200 Mesh

Date Submitted ;- 04/04/2025

Issue Date:- 15/04/2025

Request No:- GLD/RQ/1200/25

Report No:- GLD/RN/4683/25

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'scode	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2o	LOI	weight Of sample
TG-H-0914	94.36	1.84	0.94	<0.01	<0.01	<0.01	<0.01	0.04	0.70	0.22	0.22	0.50	1.9Kg

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

- LOI = Loss on Ignition

Analysts: Fasika Dereje, Abdisa Yohannes, Wedajo Gudisa, Tensae Tarekegn, Bane Abera, Shashe Haile

Checked By: Kindie Kasahun

Approved By: Lidet Endeshaw

Quality Control: Yohannes Getachew

Geochemical Laboratory Desk

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AppendixD. Experimental Pictures for specimen preparation

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