ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

ASSESSMENT OF PHYSICAL PROPERTIES OF AMBO AND JEMA SAND AND EVALUATION OF THEIR PERFORMANCE AS FINE AGGREGATE IN HIGH STRENGTH CONCRETE

BY

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Declaration

I hereby declare that this thesis entitled “Assessment of Physical Properties of Ambo and Jema Sand and Evaluation of their Performance as Fine Aggregate in High Strength Concrete” was composed by myself, with the guidance of my advisor, that the work contained herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted before, in whole or in part, for any other degree or professional qualification.

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Abstract

In Ethiopia, the construction of high-rise buildings, long span bridges and complex concrete structures which make use of high strength concrete is becoming common in recent times. In order to meet the ever increasing demand for fine aggregate in concrete construction, an alternative to the river sand is inevitable as river sand is quickly depleting and its quality from time to time is becoming questionable.

The use of sand stone as a replacement to the fine aggregate for the production of High strength concrete in Ethiopia is an important study area since sufficient research on detail engineering characteristics and performance is not yet fully investigated. In this research, the performance and rate of strength development of high strength concrete made from sand stone sampled from Ambo and Jema river basin is studied. In addition, a comparison of strength development of High Strength Concrete was made between the sandstone fine aggregates and river sand (control sand). The experimental concrete is prepared and mixed in two separate sizes of coarse aggregate, 19 mm and 12.5 mm nominal maximum. The corresponding water cement ratio for 19 mm coarse aggregate was 0.27 and for the 12.5 mm coarse aggregate it was 0.29. Chemical admixture was used for all the concrete mixes in proportion to the cement content.

The control concrete mix has attained the target strength for C70, C80 and C90 when 520 kg, 550 kg and 580 kg of cement per metric cube of concrete used and when 19 mm coarse aggregate used whereas it has not attained the C90 strength when 12.5 mm aggregate used. Concrete made with Ambo sand has attained the target strength of C70, C80 but failed for C90 for both types of coarse aggregate when used in the mix. Concrete made with Jema sands has not attained the target strength of C70, C80 and C90 for same amount of cement and coarse aggregate sizes that was used for the control mix.

For Ambo sand concrete, when 19 mm aggregate is used, the percent of the compressive strength against the control concrete is 96.4%, 96.6%, 96.1% for C70, C80, C90 and it is in order of 97.1%, 97.7%, 94.4% when 12.5 mm aggregate used. The percent of the compressive strength of Jema sand concrete against the control concrete when 19 mm aggregate is used is 90.8%, 87.6%, 85% for C70, C80, C90 and it is in order of 89.5%, 87.5%, 87.3% when 12.5 mm aggregate used.

The flexural test values, the modulus of elasticity values and mortar strength test results of concrete made from Ambo and Jema sands have met the requirement while Ambo sand produces a concrete with marginal increment than Jema sand. From the cost computation, to produce a unit volume of high strength concrete, the cost of concrete made from Ambo sand is 3.26% cheaper than Jema sand and it is 1.16% cheaper than the control sand.

Keywords: Ambo Sand, Compressive Strength, High Strength Concrete, Jema Sand, River sand

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List of Abbreviations

AAiT	Addis Ababa Institute of Technology
ACI	American Concrete Institute
ACV	Aggregate Crushing Value
AS	Ambo Sandstone
ASTM	American Society for Testing of Materials
BS	British Standard
CES	Compulsory Ethiopian standard
CTM	Concrete testing Machine
ECDSWC	Ethiopian Construction Design & Supervision Works Corporation
FM	Fineness Modulus of sand
HRWRA	High Range Water Reducer Admixture
HSC	High strength concrete
JS	Jema Sand stone
LA	Los Angeles Abrasion
OPC	Ordinary Portland cement
PPC	Portland Pozzolana Cement
SSD	Saturated surface dry
W/C	Water to cement ratio

CHAPTER 1: INTRODUCTION

1.1. Background

In Ethiopia, due to the rapidly increasing of the construction sector it is anticipated that sufficient quantity of fine aggregate for use in concrete will become scarce unless other options are sought other than the usual fine aggregate source. Fine aggregate source for concrete construction was highly dependent on the extraction from river banks. The exploitation of river sand for the construction of bulk construction has caused environmental degradation and disturbance of the ecosystem. River sand mining is carried out without consideration of its negative impacts on the environment and is considered as an alternative livelihood for the landless youth (Mingist and Gebremedhin, 2016). By removing sediment sand from the active channel bed, in-stream mines interrupt the continuity of sediment transport through the river system. Sand mining from rivers and lake banks can directly and indirectly damage the stream line of the river and the aquatic life by affecting the balance of the existing natural ecosystem (Chang et. al., 2012). In recent years, many construction sites intermittently stopped in Addis Ababa due to scarcity of river sand supply. River sands around Batu, Bulbula and Meki towns are exhausted due to prolonged extraction and by now it takes a longer time for the streams to recharge.

As the source of quality river sands depleted, the use of low quality or marginal river sands will be used in order to fill the demand for fine aggregate. The use of low quality of fine aggregate in concrete production is one of the main factors that causes of poor quality concrete. The use of low quality fine aggregate containing unwanted impurities can significantly contributed to reduction in the compressive strength of concrete strengths which may lead to poor quality of sand and ultimately causes early failure of concrete structures (BS 882, 1992).

It has been a long time since the concrete construction are undertaken by using rivers sand as a main constituent for the fine aggregate. River sand had been the primary choice for concrete construction because of its cheap price, easiness for extraction and shorter distances to major construction sites. The concrete construction was solely dependent upon the sediment river sand for long a time. Quite recently contractors and consultants who are involved in construction sector start to look for other options as a replacement of river sand. Among these replacement materials, crushed sand and sandstone are now emerging in the construction industry.

The physical properties of sandstone in Ethiopia should be studied to appropriately disseminate data about sandstone for use in concrete production. So far there is only limited research conducted on the suitability of sandstone as a concrete making material. Woyesa, Emer, and Abraham (2018) have studied on the suitability of Ambo sandstone fine aggregate as an alternative to river sand in normal-concrete production. The study has concluded the adequacy of Ambo sandstone as fine aggregate in normal-strength concrete production. The sand samples were extracted from Senkele and Aleltu quarry sites at Ambo Area.

The other piece of work that was conducted by (Ashenafi, 2018) which considered crushed Ambo sandstone as a partial or full replacement of river sand for normal-strength concrete. On the other hand (Anteneh, 2017) studied the suitability of crushed Jema sandstone for normal-strength concrete production as alternative to river sand. The results of the hardened properties of the mixes that were casted using different fine aggregate proportions of Jema crushed sandstone and river sand has shown satisfactory result.

In all of the researches mentioned above, the experiments were conducted by using sandstone as a replacement of fine aggregate in concrete mixes for normal strength concrete. The range of the concrete strength was limited within a range of C25 to C50 concretes. The performance of the Ambo and Jema sandstone in normal-strength concrete have proven satisfactory result but so far their performance in the development of HSC was not intensively researched and published.

Since the sandstone fine aggregate has quite satisfactorily fulfilled the strength requirement of normal-strength concrete as per the previous studies, its suitability for the production high strength concrete is studied assessed in this research work.

1.2. Statement of the Problem

From time and again, the development of concrete technology is increasing as complexity and performance of concrete structures stepping up to a next level. With the normal concrete strength, it is almost impossible to achieve the required concrete strength that can resist the ever increasing imposed loads in high rise buildings and complex structures. Over the past few years concrete technology has progressed and the associated target strength of concrete has increased.

In Ethiopia, building construction that makes use of concrete is increasing in its size and the required load bearing capacity. Due to the rising rapid urbanization, the height of a building is increasing in recent times. For example, the commercial bank of Ethiopia has built 209.3 m tall building having 48 floors and Nib Bank and United bank have built a similar tall building with height 137 m and 131 m respectively both having 35 floors. On the other hand, communal buildings like condominium houses that are being built by the Ethiopian government such that the maximum building height is increased from time to time as the number of occupants is increasing. Condominium building during the startup stage of the project in the year of 2005 had on average 4 to 5 floors per block. By now the number of floors on the newly constructed condominium buildings has increased to 13 because of the high demand for condominium houses and the scarcity of land. The construction of tall buildings by private builders is increasing from time to time. The construction of concrete structure for expressways, highway interchanges, and construction of sensitive structures like precast concrete electric poles, railway ballast, and bridges is increasing in the same fashion.

The first and foremost use of high strength concrete is in high rise buildings, where advantages like reduction in dead loads and reduced sizes of the columns can be attained which gives more usable area and rentable space. Furthermore, high strength concrete in high rise buildings has the advantage of reducing the dead loads and maintaining relatively lower cost and thereby increasing the net usable area.

High strength concrete (HSC) production should be adopted by using locally available materials through modification of the concrete mix design, selection of appropriate ingredients, utilization of effective admixtures and properly curing the hardened concrete. There is a uniform trend to use similar concrete constituents with regard to quality and quantity in normal-strength concrete in many construction sites in Ethiopia. When it comes to the specific purpose of a structure, the strength of concrete should be particularly designed based on the functionality of the structural under considerations.

The environmental degradation and destruction of biodiversity around streams was triggered and further intensified as more people seek river sand as their sole source of fine aggregate for construction purpose. In Ethiopia for example, the major sand supply for the construction of works in Addis Ababa and around the neighboring towns is the Awash Basin located 70-120 km southwest of the capital (Abebe, 2005).

The study of the quality adequacy of alternative source of fine aggregate for concrete production especially for HSC is the concern of this research. This research aimed in attaining high strength concrete requirements by using sandstone as a replacement of fine aggregate in the making of HSC.

1.3. Scope

This research uses the two sandstone sources as fine aggregate sources: Ambo sand and Jema sandstone. Previous experiments which have based their study on the sandstone from the same sources have been reviewed in the literature part of this paper.

In the evaluation of the sandstone source from Ambo town and Jema sandstone, it is proposed to check the development of the compressive strength of concrete or the production of high strength of concrete (HSC) because the dominant concrete character is its compressive strength. Flexural strength test conducted from the same concrete batch that is prepared for the compressive strength test and mortar strength of the sand samples is checked.

Other derivatives of the mechanical behavior of concrete like modulus of elasticity and tensile strength of the concrete specimens are to be indirectly evaluated.

1.4. Research questions

The under listed points are the main questions going to be answered in this research which is related to the evaluation of concrete specimens casted using sandstone from Ambo and Jema sources.

- Can sandstone be used for the production of HSC and if it is justified, can sandstone exhibit the same satisfactory performance like it does for the production of normal-strength concrete?
- By how much does the compressive strength and flexural strength of concrete produced from sandstone fine aggregate differs from a concrete made from river sand which is control sand?
- What is the optimal proportion of sandstone fine aggregate from the total volume of concrete for different grade of concrete?
- What will be the economic benefit of sandstone over river sand when using it in the production of high strength concrete by considering the main expenses?

1.5. Research Objectives

1.5.1. General Objectives

The general objective of this research is to check if high strength concrete (HSC) can be produced using sandstone as a replacement to the conventional river sand fine aggregate. The proposed sandstone sources are form Ambo and Jema sources. In order to produce a reliable and durable high strength concrete, the quality of sandstone should be properly assessed and evaluated as a replacement for the fine aggregate portion of a concrete. Therefore, in order to ensure maximum strength of concrete, the quality test of the sand samples from the proposed sandstone sources were conducted.

1.5.2. Specific Objectives

The specific objectives of this research are:

- To conduct a specific quality test on the fine aggregates (Jema and Ambo sand stones and river sand) and the selected basaltic coarse aggregate to make reliable HSC. The quality of the sands will be further checked using mortar strength tests.
- To determine the rate of compressive and flexural strength gain for the concrete made from rhe control River sand, Ambo and Jema sandstone as fine aggregate for a given cement contents.

- To identify the optimum cement content of HSC mix with different compressive strengths by using Ambo and Jema sandstone as fine aggregate.
- To compare the economic benefit of HSC made from sandstone versus river sand.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

2.1.1. High Strength Concrete

Concrete is a composite material consisting of aggregates enclosed in a matrix of pozzolanic cement material. Concrete has two major components which are cement paste and aggregates. The strength of concrete depends upon the strength and proportion of these components. The mechanical behavior of concrete like deformation properties, adhesion between the paste and aggregate surface are governed by the ingredients. With most natural aggregates, it is possible to make concretes up to 120 MPa of compressive strength by improving the strength of the cement paste, which can be controlled through the choice of water-content ratio and type and dosage of admixtures (Neville, 2011).

High strength concrete is concrete with strength above the normal concrete strength. The definition of the compressive strength of HSC has varied from time to time (ACI 363R-10). According to ACI 363R-10, there is no clear and distinct figure for specifying HSC to be used in all locations. The ACI committee recognized that the definition of HSC varies from one country to another. In a region where conventional concrete having strength 62 MPa is produced, the HSC is defined within the range of 83 MPa to 103 MPa.

In 2001, the ACI committee agreed in general that, a concrete with a compressive strength of 55 MPa (cylindrical) or greater is defined for HSC minimum strength requirement. In other words, the cubical strength of concrete with compressive strength above 70 Mpa is categorized under high strength concrete. In relation to the age of concrete, the compressive strength of the concrete specimens for high strength concrete is best evaluated at 7 days, 28 days and 56 days of age. The later ages, 28 day and 56 days strength, is considered because high strength concrete can gain considerable strength after 28 days (ACI 211R-08).

2.1.2. Application of high strength concrete

High-strength concrete is becoming popular in the fast developing world and its use continues to spread because of the demand for high strength concrete increases (ACI 363R-10). With the need for less space and more efficient structures, the use of HSC is highly important. Some of the use of HSC is in the construction of columns or shear walls of high-rise buildings, precast members like girder of long span bridges in highway construction, for the construction of aesthetically slim and important structures and for the construction of unusually big overhanging structures.

Since the modulus of elasticity of HSC is high, HSC has another advantage in relation to reduction in the structural deformation, control of deflection and creep which all takes the advantage of its modulus of elasticity. In addition due to its low permeability which is caused by a lower w/c ratio, HSC produces a more durable concrete irrespective of its compressive strength which makes it an adaptable structure material for environmentally severe conditions (Sidney et. al., 2003).

2.2. Important Ingredients of HSC

2.2.1. Admixtures and Additives

For the production of HSC, a conventional proportion of aggregate is not sufficient because with extremely low w/c and maximum cement content, the concrete mix will not be workable. According to Sidney et. al.(2003), the typical cement content of HSC ranges from 390 kg/m^3 to 560 kg/m^3. A concrete having cement content above 600 kg/m^3 for example represents an expensive and uneconomical mix design and the exothermic heat emission affects the concrete durability. On the other hand according to ACI 363R-10 reports on high strength concrete, section 4.5, the maximum and minimum cement content for HSC is specified to be with a range of 386 kg/m^3 to 593 kg/m^3.

In order to reduce the concrete w/c ratio to a minimum possible value and still maintaining its workability, chemical and mineral admixtures is desirable when preparing a mix of HSC. Admixtures or Additives in general are classified as mineral admixtures or chemical admixtures.

2.2.1.1. Mineral admixtures

The common mineral admixtures are natural pozzolana, silica fume, pulverized fly ash and ground granular blast furnace slag (ggbs). These admixtures increase the strength gain of concrete especially at later ages even at the same w/c ratio than concrete made without mineral admixtures (Neville, 2011).

2.2.1.2. Chemical Admixtures

ASTM C125 defines this admixture type as “a material other than water, hydraulic cement and fiber reinforced that is used as an ingredient of concrete or mortar and is added to the batch immediately before or during its mixing”.

The broad classification of Admixtures is

1) Air Entraining agents: - these type of admixtures are added to concrete to improve the resistance to freezing and thawing (ASTM C260).
2) Setting Controlling admixtures: - such type of admixtures is used when there is a need to control the setting time or to induce early hardening (ASTM C494).
3) Plasticizing admixtures: - these admixtures are water-soluble polymers designed to enhance workability by increasing slump or by reducing the water requirement for a desired workability (ASTM C494, C1017).

The Admixture classifications, property and the related ASTM specification are shown in *Table 2. 1*.

Table 2. 1: Types of Admixtures and their function (Sidney et. al.,2003)

Admixture Property	Admixtures Types	ASTM Specification
Workability	Water reducing admixtures	C494
	Plasticizers	C1017
	Air entraining Admixtures	C260
	Pumping Aid	
Set Control	Anti washout admixtures	
	Set accelerating admixtures	C494
	Set retarding admixtures	C494
	Extended set admixtures	
Strength inducing	Water reducing admixtures	C494
Durability	Air entraining admixtures	C260
	Water reducing admixtures	C494

To achieve the strength requirement of high strength of concrete, reducing the w/c ratio and improving the workability by using high range water-reducing admixtures or superplasticizer are the appropriate solution. In the following content, there is a short description of water reducing admixtures.

2.2.1.3. Water-reducing Admixtures (Plasticizers)

Water-reducing admixtures reduce the water required to attain a given slump which means that it tends to reduce the water required in a concrete mix. Achieving the desired slump with reduced water content can be obtained by reducing the w/c ratio and the utilization of water reducing admixtures with a subsequent improvement of the concrete strength in general. On the other hand, a decrease in w/c ratio produces concrete having lower permeability and higher durability character.

Very high compressive strength of concrete can be achieved when w/c ratio is lowered below 0.4 (ACI 211R-08, Table 6.4). A lower w/c ratio also improves the rate of strength gain at early ages. After 24 hours of normal curing, it is possible to obtain a compressive strength that would have taken 8 days to develop under the standard w/c ratio (Sidney et. al., 2003).

Superplasticizers can reduce the water content for a given workability by 25% to 35% and as compared to the conventional water-reducing admixtures, superplasticizers reduce the water demand by half (Neville, 2011). Therefore for HSC, the use of a high range water reducing admixture alone or in combination with other admixtures produces an appropriate concrete strength.

2.2.1.4. Coarse Aggregate

In HSC, the strength of the paste and the paste-aggregate bond are more important than the aggregate hardness alone. Different aggregate types have different purpose when used in concrete based on their physical characteristics. For example, an aggregate that contains more porous particles may not be suitable for concrete when the required strength is greater than 35 MPa but could satisfactorily be used for low-strength concrete that has the requirement of durability (Sidney et. al., 2003).

The type of coarse aggregate is one of the most important variables affecting the strength of HSC. It was generalized that not all aggregate types are suitable for HSC as they may restrict the overall strength potential of the concrete and on the application of loading on concrete a weaker coarse aggregate may break down before the cementitious matrix (Alaa and Hosam, 2014).

For an optimum compressive strength with a high cement content and low w/c ratio, the maximum aggregate size shall be preferably kept to a minimum of 9.5 mm (ACI Committee 363R-10). Further to the above recommendations, ACI 211.4r states that a coarse aggregate with a maximum size of 19 mm or 25 mm can be equally used for HSC.

Kozul and Darwin (1997) studied the effects of aggregate type, size, and content on concrete strength development. For high-strength concrete, test results to determine the effect of aggregate size on compressive strength showed that concrete with a 12 mm maximum size aggregate yields higher compressive strengths than concrete with a 19 mm maximum size aggregate, even though the difference is insignificant. Kozul and Darwin (1997) further experimented and concluded that High-strength concrete containing basaltic coarse aggregate yields higher compressive and flexural strengths than concrete made with similar compressive strength containing limestone or dolomite coarse aggregates.

The most commonly available local coarse aggregates for concrete production in Ethiopia are obtained from crushed basaltic rocks which is a member of the family of igneous rock (Abebe, 2005).

With regard to quality control of coarse aggregate, the coarse aggregates used in any series of tests of concrete shall come from single lots of well-graded, sound materials that conform to the requirements of Specification (ASTM C33).

2.2.2. Aggregate Size, Shape and Texture

The size of coarse aggregate depends on the type of work, class of concrete and arrangement of reinforcement provided in the concrete (Sanjeev and Rajiv, 2018). According to ACI 211.4R-08, an aggregate with a nominal maximum size of 9.5 mm, 12.5 mm, 19 mm and in some cases 25 mm can be used for HSC with minimum and sometimes with no difference in strength. For an optimum compressive strength with a high cement content and low w/c ratio, the maximum aggregate size should be kept as low as 9.5 mm (ACI 363R-10). In addition to the above recommendations, ACI 211.4R-08 states that a coarse aggregate with nominal maximum size of 19 mm or 25 mm can be used for concrete with compressive strength up to 60 MPa and aggregate with a maximum size of 9.5 mm or 12.5mm should be used for concrete with higher strength. ACI 363R-10 proposes that high strength can be attained with a nominal maximum of 19 mm or 25 mm of coarse aggregate as long as the aggregate fulfills the physical strength like shape and texture and when proper HRWRA is applied.

Aggregate shape and surface texture affect the bonding between the cement paste and the aggregates (Abebe, 2005). Highly irregular particles with entrant faces and sharp points will lead to greater-inter particle interactions during concrete mixing and handling. Aggregates that are flat and elongated should not be used for structural concrete because they increase inter-particle interaction and can easily break up. Concrete containing aggregates of this shape is more prone to segregation during handling of the concrete. Crushed stone from sound parent rock has a rough surface than natural sand and gravel. Crushed stone is abundantly angular and may have a rough surface texture which interferes more severely with the movement of adjacent particles (Neville, 2011).

2.2.3. Cement

Cement is a finely ground inorganic material with adhesive and cohesive properties which makes it capable of bonding together fragments or particles of solids matter into a compact whole. In civil engineering terms, cement is a material which form a paste when sets and hardens by means of hydration reactions, and which after hardening retains its strength and stability even under water and can be molded or deformed but later it sets and capable of carrying imposed loads (Neville, 2011).

2.2.3.1. Types of cement

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

A brief description of these two types of cements is discussed below.

A. Ordinary Portland Cement (Type-I)

This cement is general-purpose cement suitable for all uses where the special properties of other types are not required. Its use in concrete production includes in pavements, floors, reinforced concrete buildings, bridges, tanks, reservoirs, pipes, masonry units, and precast concrete products. The standard requires that it is made from 95 to 100 percent of Portland cement clinker and 0 to 5 percent of minor additional constituents. Minor additional constituents are one or more of the other cementitious materials or fillers. Filler is defined as any natural or inorganic mineral material other than a cementitious material (Neville, 2011)

B. Portland Pozzolana cement

Portland pozzolan cement is particularly suitable for use in mass concrete structures (such as in dams and bridge piers), where low heat of hydration is desired; hydraulic structures of all kinds where water tightness is important; structures subject to attack from ground water, sea water or diluted industrial wastes; and under water construction where concrete is deposited by bucket. A pozzolana may be used as a partial replacement of fine aggregate (sand) without a reduction of cement content, where high early strength is required (Taylor, 1977)

2.2.4. Water

Impure mixing water can cause problems by introducing impurities that have a detrimental effect on concrete quality therefore the mixing water for concrete shall be clear and apparently clean. According to ASTM C94, potable water can be used for HSC mixing without the need for further tests for quality compliance.

2.2.5. Fine Aggregate

Sand is loose, non-cohesive granular material, the grains or framework elements of which must by definition be sand-sized. Various attempts have been made to define sand more precisely. These attempts are largely directed toward expressing grain size in terms of grain diameter with respect to the percentage a specific grain size holds. Sands sediments, in general, differ from the igneous and other crystalline rocks in possessing a framework of grains. According to ASTM C125, the definition of sand with respect to its size is that portion of an aggregate passing the 4.75-mm (No. 4) sieve and retained on the 75-μm (No. 200) sieve.

Pettijohn, Potter and Siever (1972) defined sand as a product of a broken down of coarse-grained source rocks and the range of sizes (which is primarily of the quartz) is limited by the original texture of the source rock. Sand although restricted by definition to the 0.0625 to 2.00 mm range of diameters, actually encompasses a vast range in grain size. It is clear from the above discussion that "sand," both as a size term and as a deposit, is defined without referring to its composition or to its genesis. Sands could be made of quartz sand or carbonate sand. Sands could be originated from the indestructible residue of granite or basaltic (quartz sand) or the product of chemical precipitation so called oolitic sand (Pettijohn, Potter and Siever, 1972).

Sandstone is composed of those indurated sands of siliceous character. Sandstone is mixtures of mineral grains and rock fragments coming from naturally disaggregated products of erosion of rocks of all kinds. The total variety of rock types in any given eroding and sedimented sand can be represented in the overall sediment product. Therefore, the number of mineral species to be found in all sandstones is as large as the total number of mineral species known (Pettijohn, Potter and Siever, 1972).

2.2.5.1. Ambo sandstone Fine aggregate

Ambo sandstone is located at the central Ethiopia with the geology of Mesozoic sedimentary rock particularly sandstone which belongs to the sedimentary creation of central Ethiopia of Abay Basin. The main constituents of Ambo sedimentary rocks are mudstone, gypsum, shale and upper sandstone. The sandstone overlies the mudstone gypsum shale formation and it forms steep slope because of its resistance to erosion (Tamiru and Seifu, 2006).

Ambo sandstone is part of the major sandstone formation in Ethiopia. According to Haileyesus, Sintayehu and Tom (2000), the potential deposit of sandstone in Ethiopia is the Adigrat sandstone which extends along an axis from Ambo in the south, through the Abay valleys to Tigray in the north.

2.2.5.2. Jema sandstone

Jema sandstone is located at central Ethiopia North of the capital along the canyon of Jema river. Wondafresh, Haileyesus and Haily (1993) described Jema geology as one of the rich deposit of sandstone and limestone which occur in the bottoms of the valley of Abay River and its tributaries. The lower part of the limestone is having a thickness reaching more than one meter in depth. Jema sandstone is a sedimented deposit of red to pinkish and rounded grain sands with acceptable gradation without the need for re-crushing (Haileyesus, Sintayehu and Tom, 2000).

2.3. Previous studies on the application of Ambo and Jema sandstone as fine aggregate

Yerosan and Mikias (2020) have experimented on the compressive strength of normal-strength concrete (C25) using Ambo sandstone as a partial replacement of fine aggregate. The research used Ambo sandstone as fine aggregate (Sampled from Wodessa and Senkelle mountains). To maximize the concrete compressive strength, blending of Ambo Sandstone and River Sand extracted from Huluka River in Ambo was prepared with varying proportion and concrete casted with. After preparing of concrete specimen with different proportions of Ambo sand and River sand, the trend of the compressive strength of the concrete was studied. At the end of the research, it was concluded that 60% Ambo crushed sandstone and 40% river sand yielded higher compressive strength.

The limitations of the study are the number of trials was small and the natural river sand was selected from a local river in Ambo where its quality is questionable. This study indicated that concrete made from Ambo sandstone has recorded a better compressive strength of concrete than the concrete made from river sand alone.

Woyesa, Emer and Abraham (2018) studied the suitability of Ambo sandstone fine aggregate as an alternative to river sand replacement in normal-strength concrete production. In the research, the suitability of Ambo sandstone was examined by making concrete made from Ordinary Portland cement and crushed coarse aggregate. The fine aggregate was extracted from Aleltu and Senkele quarry site which located near to Ambo town. For concrete compressive strength with a mix ratio of 1:2:3 and w/c ratio of 0.50, the compressive strength of concrete made from Ambo sand has met the requirement for C25 concrete. The result of the study showed that with full replacement of Ambo sandstone fine aggregate, the concrete satisfied the minimum requirement for C25 concrete grade compressive strength.

Anteneh (2017) conducted a research on the suitability of crushed Jema sandstone for concrete production as an alternative to river sand. Ordinary Portland cement and normal river sand extracted from Alem Tena area were used to make control of mix for C25, C30 and C40. For the coarse aggregate, crushed basaltic rock for coarse aggregate from the local construction market was used. Based on the result, it is implied that the addition of crushed Jema sandstone brings about an increase in compressive strength of different concrete in making C25, C30 and C40. The use of unwashed sand in concrete reduces the strength of concrete as high by 20% from the washed sand as Ambo sand has clay content as high as 14% (Anteneh, 2017).

The results of the hardened properties of the mixes that were casted using different fine aggregate proportion of Jema crushed sandstone and river sand have shown that as the proportion of crushed Jema sandstone increased, the compressive strength of the concrete specimen increased accordingly. At full replacement of the Jema sandstone, the result of the compressive strength has shown the highest value than any of the other concrete mixes.

Ashenafi (2018) researched crushed Ambo sandstone as a partial and full replacement of river sand for C25 concrete. Different concrete mix was prepared by blending Ambo sandstone with natural river sand at different proportions. To get this result the researcher used ordinary Portland cement, crushed Ambo sandstone and river sand obtained from Legehar selling area in Addis Ababa. The coarse aggregate was obtained from Legehar market. The study concluded that an increase in strength of concrete cubes was observed as the proportion of crushed Ambo sandstone increased and the strongest concrete was obtained for full replacement of crushed Ambo sandstone proportion. The compressive strength of the concrete specimen made from Ambo sand has recorded the highest compressive strength than concrete specimen casted using river sand which is the control mix.

Shewaferaw (2006) has studied the production of normal and high strength concrete using manufactured sand and natural sand. Different proportion of crushed sand and natural river sand was prepared for normal strength, intermediate strength and high strength concrete using a water cement ratio and cement contents (OPC) of 0.54, 370 kg/m^3; 0.39, 460 kg/m^3; 0.30, 520 kg/m^3 respectively. The tests on the fresh concrete and the hardened concrete found that concrete made from an equal proportion of manufactured and natural sand yielded a higher strength with an economical dose of admixture than the concrete produced from different proportions of fine aggregates. The admixture used is super plasticizer SP-430 (Water- reducing admixture). The dose for the production of HSC was 12.62 lt/m^3. At 520 kg/m^3 of cement, the compressive strength was found to be in the range of 84 MPa to 91 MPa with different proportion of crushed and natural sand.

Nigus (2005) has conducted a study on the strength development of Messobo, Diradawa and Mughar cements. HSC was casted using Messobo OPC and Mughar OPC at a rate of 550 kg/m3 cement. A compressive strength of 85.39 MPa and 76.8 MPa respectively was obtained at 28th days with the application of w/c ratio at 0.27 and HRWRA dose of 16.5 lt/m^3.

2.4. Summary of literature review

High strength concrete has many definitions based on its compressive strength. According to ACI 360R-10, the minimum compressive strength of HSC is designated as 55 MPa (Equivalent to 70 MPa in cubical mold). HSC has many practical applications in civil engineering constructions and its popularity is increasing from time to time. The production of HSC concrete requires a careful selection of quality ingredients as the overall strength is governed by the strength of the individual ingredients of the concrete besides the adaptation of a lower w/c ratio and the inclusion of additives. With a lower w/c ratio, the use of HRWRA is vital in order to get a workable concrete and at the same time to obtain a maximum compressive strength based on the strength requirement of HSC.

The locally available sandstones (like Jema sand and Ambo sand) are important sources of fine aggregate for normal and high strength concrete. Jema sand and Ambo sand are not sufficiently researched on to use as fine aggregate in HSC.

2.5. Research gap identification

So far, there is limited number of researches conducted on the performance of Ambo and Jema sandstone to be used as fine aggregate of concrete as it has been described above. In most of the researches conducted, the target concrete is the normal-strength concrete strength which specifically is C25 concrete. Anteneh (2017) has increased the experimented strength of concrete up to 40 MPa which is still within the range of the normal-strength concrete. Regarding the cement content, Shewaferaw (2006) and Nigus (2005) have studied the strength development of high strength concrete using river sand and crushed sand as fine aggregate of concrete. The study has proven that a HSC can be achieved using a cement content at a rate of 520 kg/m^3 to obtain a compressive strength of 76 MPa and higher.

In all of the researches covered above, the target strength of the concretes was limited to normal-strength concrete while using sandstone as fine aggregate. The development of HSC using Jema or Ambo sandstone as fine aggregate of concrete has not been covered in any of the studies as discussed above which has left a research gap.

CHAPTER 3: METHODOLOGY AND MATERIAL

3.1 Methodology

3.1.1 Research Variables

The independent variables of this research are the predefined cement quantity and the target compressive strength of the concrete mix. The cement content and the target concrete strength are made to vary in the concrete mix design while using river sand and sandstone as fine aggregate of the concrete mix design are. Based on the concrete mix design, a related proportion of coarse aggregate, fine aggregate, water and chemical admixture content are produced to meet the design requirement of HSC.

The dependent variables in this research are the concrete compressive strength, flexural strength and other mechanical behavior of concrete specimens that are known after testing different batches of concrete. The dependent variables are the most important variables where the conclusion of the research shall base on. Individual and relative figures of the dependent variables are analyzed in order to produce sound conclusion.

Experimental research has some elements, so called moderating variables, which affect the strength of the relationship between a dependent and independent variables. The strength characteristic of concrete widely depends on the factors other than the predefined cement content or design ingredient proportions. For the purpose of this research, all other factors that cause variation in the strength of concrete are to be controlled and kept constant. Concrete mixing time, accuracy of measuring ingredients, compaction or vibration of concrete, curing method and time are maintained constant for the three types of sands.

3.1.2 Control mix

In all of the concrete mixes which are prepared using Jema and Ambo sand, river sand is the control in this experiment. The control mix is prepared in such a way that the material quality is maintained to meet all specification requirements in order to maximize the compressive strength of the specimens. Concerts made from Ambo and Jema sand are evaluated against the control mix to properly oversee the performance under the category of HSC.

3.1.3 Research Hypothesis

The application of sandstone as fine aggregate in concrete production is increasing from small scale private construction to vast construction projects like university expansion projects undertaken by the Ethiopian government. While concentrating on middle and small scale construction projects, the application of unwashed sandstone for concrete production is wide spread. However, the quality of the sandstone is not adequately investigated and studied.

The previous researcher conducted on the performance of Ambo and Jema sandstone in the production of normal concrete has shown satisfactory results. Therefore washed sandstone is assumed to give a similar result for HSC. For this research purpose, washed sandstone will be used for concrete casting in order to get optimum results.

3.1.4 Research design

The research is planned to be an experimental type of research where a designed and defined quantity of material ingredients will be used for concrete casting and the output on the final test result of the hardened concrete will be used as a basis to draw conclusions. In addition, based on the data obtained from the laboratory and the sandstone on-site inspection, a descriptive type of clarification is made.

The overall procedure of this study is categorized into three phases

Phase 1: Selection of suitable ingredients:-The target materials of this study which are Jema sand and Ambo sand are retrieved from the sources and are prepared to make it ready for the next laboratory tests. Ambo sand is sampled from Senkele Mountain near Ambo town and Jema sand is sampled from the valley of Jema river basin. The river sand is properly and adequately sampled from selling spot in Addis Ababa where the origin of the sand is from Langano. The sampled aggregates are washed before proceeding with quality tests.

The coarse aggregate for this research purpose is acquired from crusher site at Goro crushing site. To evaluate the strength of concrete when using the three types of sand under consideration, two types of coarse aggregate with nominal maximum size of 19 mm and 12.5 mm are selected and used throughout the experiment.

Phase 2: Laboratory activities: - In this phase, laboratory activities will be conducted on the samples to obtain the physical properties of the aggregates. Based on the quality test results, a concrete mix design (using ACI method) is prepared and different concrete having varying compressive strength is casted and tested in the fresh and hardened state. From the same mix of concrete, flexural specimens are casted in order to measure the flexural strength of each grade of concrete. In order to further check the suitability of the sands, mortar strength test is conducted.

Phase 3: Data analysis and interpretation: - the data obtained from the laboratory activities are recorded and a consistent data analysis is made. The whole conclusion of the study is based on the data analysis and interpretations.

3.1.5 Study Area

In this research, it is aimed to evaluation of Ambo and Jema sandstone as fine aggregate in the production of high strength concrete (HSC) while keeping the other concrete ingredients uniformly constant. The sources of the sandstones are from Ambo area and in the valley of Jema river basin. Therefore the study area is the sandstone source shown in the following map of Ethiopia particular to Ambo and Jema area sandstone. The geographical location of the source of Ambo and Jema sand stone which are located west and north of the capital city are shown in *Figure 3. 1*.

As shown in *Figure 3. 2*, Ambo sandstone is found at west and north-west of Ambo town and particularly at the Senkele and Faris mountainous land. Its accurate geographical location is $8^0$59’37.19’’N and $37^0$49’56.64’’E. The most excavated and utilized area is the Senkele Mountain.

Similarly Jema sandstone is found at the valley of Jema river Basin in the upper depression of the valley as shown in *Figure 3. 3*. It is mainly composed of sandstone deposit in the upper stratum and the area near the river stream is dominated by limestone. The highly exposed Jema sandstone is found in the north-east of Shewa Zone at Ensaro and Wayu Wereda Administration in Amhara Regional state with accurate geographical location $9^0$50’22.44’’N and $38^0$54’27.05’’E.

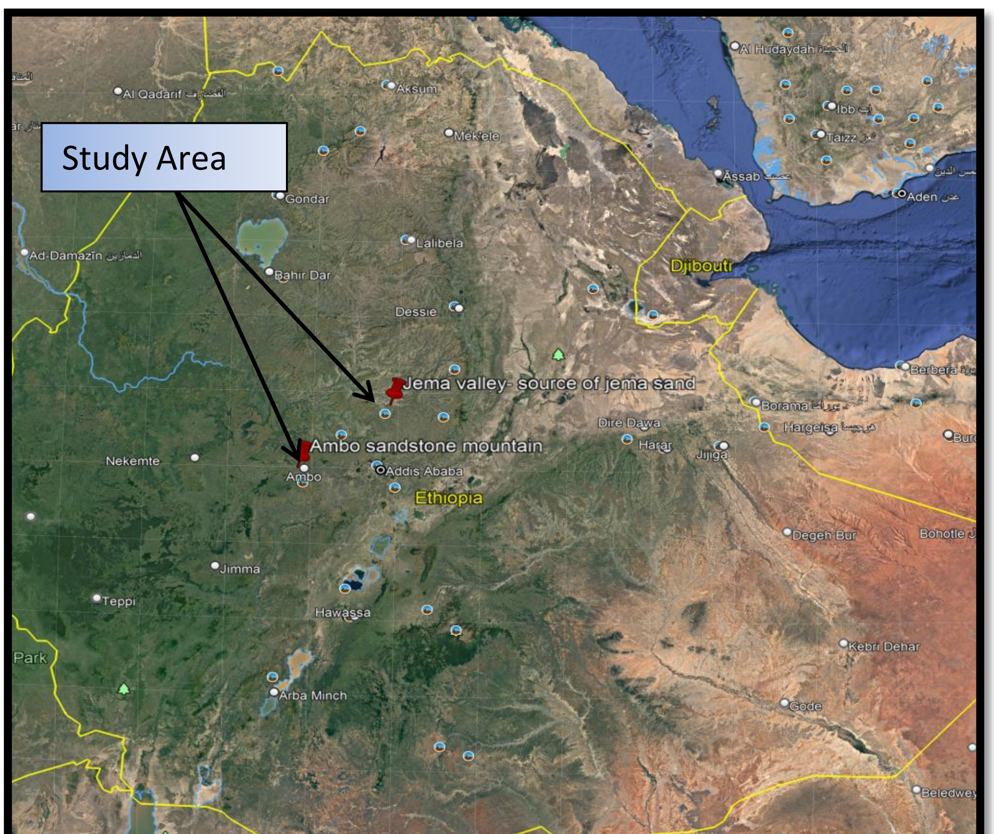


Figure 3. 1: Map of Ethiopia (Google Earth, 2023)

Figure 3. 2: Ambo sandstone source location (Google Earth, 2023)

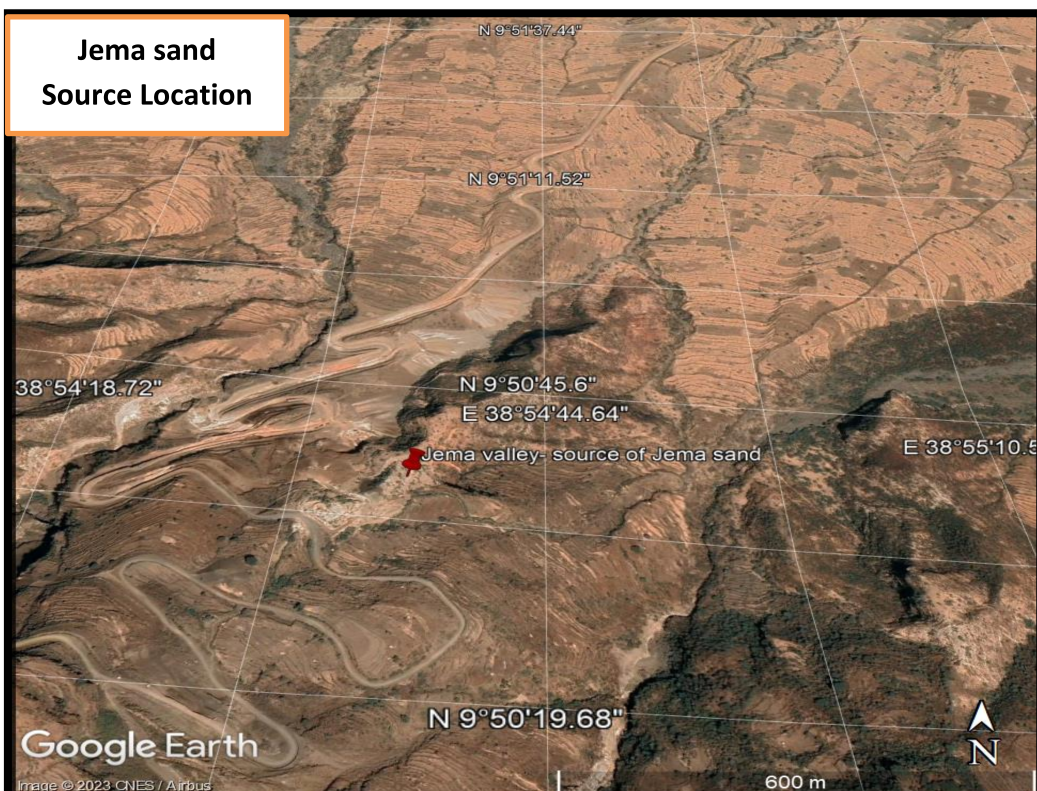


Figure 3. 3: Jema valley sandstone source location (Google Earth, 2023)

3.1.6 Expected outcomes

After the completion of this research study, several positive outcomes are expected including but not limited to:

- Provide a judgmental analysis based on the research experiment if Ambo or Jema sandstone produces concrete sufficiently better strength than a concrete made from conventional river sand
- Depending on the quality of sandstone, a remedial solution will be recommended to enhance the quality of sandstone that is intended to be used for concrete production.
- The estimated range of fine aggregate content, cement content and admixture content for a HSC mix
- Recommend a simple thumb rule in selection of fine aggregate type and source for HSC.

3.2 Properties of Concrete Ingredients

3.2.1 Fine aggregate

The fine aggregate to be used for this research is a naturally occurring fine rock particle from the sandstone Mountains of Jema and Ambo selected sites. The top surface of the sandstone mountain is covered with plenty of shrubs and a thin layer of top soil.

All the main quality standards for the fine aggregates are conducted and described in the forthcoming section. For HSC, the quality of individual ingredients affects strength development in general. Since Ambo and Jema sands are extracted from mountainous quarry. There is no considerable organic matter at greater depth however there is high possibility of unwanted silts and friable matter to be discovered with the sand. Therefore before proceeding to the quality tests, the three types of sands were washed thoroughly in order to reduce the silt content and any organic and clay impurities.

3.2.1.1 Ambo sand

Around Ambo area, there is a high scarcity of natural river sand because of limited number of streams and the geographic location of ambo area. There are two big rivers that cross the town of Ambo. The rivers cross Ambo town are Huluka River and Teltele River. Huluka River has a relatively bigger water discharge which flows over a basaltic river bed. The water is clean without having any significant sediment of sand particles. Teltele River has low volume of water discharge and in dry seasons, the water flow sometimes totally vanishes. It has no sediment of sand particles at either bank of the river.

The people in Ambo town and the surrounding area have no opportunity to get river sand for their consumption to make mortar or concrete. Ultimately the sand from the sandstone mountain is frequently used by the community for construction purpose.

Figure 3. 4: Ambo sandstone mountain (Left: Senkele Mountain, Right: Excavation of the sand)

3.2.1.2 Material description and physical property

The Ambo sand is extracted from Sandstone Mountains around Ambo town. It has a reddish color and with size predominantly fine-grained particles. The degree of consolidation of the sand varies with its depth. The sandstone at shallow depth and which is mixed with clay soil has loose cohesion and can be broken down by hand with no extra force. However, the sandstone at the lower depth is too strong to be broken by hand. At considerable depth, a hand tool or excavating equipment is required to excavate the sandstone and further to break down into the original particle size. Below a certain depth, approximately within a range of 5 m to 15 m, the sandstone ceases to exist and a hard conglomerate sedimentary rock is found.

The exact volume of this Ambo sandstone deposit is not studied based on the extent and the depth of the deposit. In order to identify an estimate quantity of the deposit, detailed ground exploration, geodetic measurement and geotechnical material classification is mandatory. From the Google Earth Map, 2023, the approximate land coverage of the sandstone is estimated to be 3 km^2 however the actual potential of the source shall be studied by geological experts.

The color which is reddish at the surface changes into yellowish hard rock as the stratification depth increases. After washing the Ambo sand, it was tested for different quality tests and the result is shown in *Table 3. 1.*

Table 3. 1: Physical properties of Ambo sand

Quality Parameters	Results	Test method
Bulk Specific gravity (Oven dry)	2.651	ASTM C127/C128
Bulk Specific gravity (SSD)	2.659	ASTM C127/C128
Apparent Specific gravity	2.673	ASTM C127/C128
Water Absorption (%)	0.32	ASTM C127/C128
Unit weight(kg/m^3)	1657	ASTM C29
Particle size distribution	Appendix B.1.1	ASTM C136
Fineness modulus	2.4	Gradation and FM as per ASTM C136, the sand is classified as fine sand.
Natural Moisture content (%)	0.17	ASTM C127/C128
Soundness (%)	15	ASTM C88 (Test conducted at ECDSWC)
Initial clay content before washing (%)	14	According to Ethiopian standard, maximum clay content is 6%.ASTM C33 maximum silt content to be 3%
Final clay content after washing (%)	0.7	

The clay content of Ambo sand was tested and found to be 14% which is more than the maximum designated values by ES and ASTM C33 standards. The sample was washed in six cycles until a significant proportion of the silt and clay is washed away. After that, the sample was sun-dried and the silt content was retested. The final clay content after washing was reduced to 0.7%.

The Ambo sandstone is widely used in the vicinity of its location in unwashed condition which creates poor concrete and mortar strength. As per the clay content tests conducted in the laboratory, the clay content of ambo sandstone is 14% which is much higher than the maximum requirement of Ethiopian Standards.

The chemical composition of Ambo sandstone is summarized as shown in *Table 3.2*. As per the chemical composition of the sand grains, the composition test depicts that Ambo sandstone is pure quartz arenite sandstone having 97.96% of silicate (SiO2) and the rest compositions are trace elements. The sand has no content of Cao, $NaCl_2$ and $MgCl_2$ which make it suitable for concrete production.

Table 3. 2: Chemical composition (%) of Ambo sand (Geological institute of Ethiopia, Appendix B.1.1)

SiO2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LoI
97.96	<0.01	0.6	<0.01	0.32	0.60	<0.01	<0.01	0.09	0.02	0.29	0.12

3.2.1.3 Jema Sandstone

As it has been described in the literature part, the Jema sandstone deposits in its natural form, is one of the uniformly arranged sands which occurs in the bottoms of the valleys of Abay River and its tributaries. Jema sand is located in the north east part of Addis Ababa which covers the deep valley of Jema river. Jema sand is loosely packed and readily erodible by water when it is exposed on the top surface of the mountain where it is found. Below a certain depth, the stratum gets firm and can stand at perfectly vertical slope as shown in *Figure 3. 6.*

Figure 3. 5: Jema sandstone (Left: vertical cliff of Jema sandstone, Right: Exposed by Erosion)

3.2.1.4 Material description and physical property

Since the source of Jema sandstone covers a considerable portion of the land in Jema Valley, its consideration as a substitute to the river sand for making concrete is important. Jema sand is a composition of fine-grained particles of rock. As per the gradation test which is shown in Appendix B.1.2, the Jema sand is categorized as fine sand with fineness modulus of 2.3.

The estimated land coverage of the Jema sandstone from Google Earth Map (2023) is approximately 860 sq. km however, the actual quantity of the source shall be meticulously studied by geological experts.

After washing Jema sand, it was tested for different quality tests and the result is shown in *Table 3.3*.

Table 3. 3: Physical properties of Jema sand

Quality Parameters	Results	Test method
Bulk Specific gravity(Oven dry)	2.648	ASTM C128
Bulk Specific gravity (SSD)	2.653	ASTM C128
Apparent Specific gravity	2.662	ASTM C128
Water Absorption (%)	0.2	ASTM C/C128
Unit weight(kg/m^3)	1656	ASTM C29
Particle size distribution	Refer Appendix B.1.2	ASTM C136
Fineness modulus	2.3	Gradation and FM as per ASTM C136, the sand is fine sand.
Natural Moisture content (%)	0.18	ASTM C128
Soundness (%)	17	ASTM C88 (Test conducted at ECDSWC)
Initial clay content(%), before washing	3.1	According to Ethiopian standard, maximum silt content is 6% ASTM C33 maximum clay content is 3%
Final clay content (%), after washing	0.3	

The initial clay content of Jema sand was tested and found to be 3.1% which is not within the acceptable range as per the designated in ASTM C33 standard. The sample is washed in two cycles before proceeding to the next quality tests and as a result significant proportion of the clay part is removed. After the sample was dried, the clay content was checked again. The clay content is reduced to 0.3%. The sampling of Jema sand from the source is shown in *Figure 3. 7*.

The chemical composition of Jema sandstone is summarized as shown in *Table 3.4*. As per the chemical composition of the sand grains, the composition test depicts that Jema sanstone is pure quartz arenite sandstone having 98.62% of silicate (SiO_2) and the rest compositions are trace elements. The sand has no content of CaO, $NaCl_2$ and $MgCl_2$ which make it suitable for concrete production.

Table 3. 4: Chemical composition (%) of Jema sand (Geological institute of Ethiopia, Appendix B.1.2)

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LoI
98.62	<0.01	0.56	<0.01	0.02	<0.01	<0.01	<0.01	0.11	<0.01	0.2	0.5

Figure 3. 6: Sampling from pure Jema sandstone

3.2.1.5 River sand

The river sand in this research is a fine aggregate used in the control concrete mix. Proper attention was given in searching a high quality natural river sand that satisfies the requirements in ASTM C33.

3.2.1.5.1 Material description and physical property

The source of sand for the control mix is from Langano area. The natural river sand was sampled and prepared in sufficient quantity as per the requirement of the concrete mix design. The sand was first screened by 4.75 mm sieve to remove any oversized particles and then washed. The clay content of the unwashed sand was 4.5%. The clay content when tested after washing of the sand became 0.7% which its quality improved. The summary of quality parameters of the river sand is shown in *Table 3. 3*.

Table 3. 5: Physical property of the selected River sand

Quality Parameters	Results	Test method, Acceptable range
Bulk specific gravity(Oven dry)	2.624	ASTM C127/C128
Bulk specific gravity (SSD)	2.658	ASTM C127/C128
Apparent specific gravity	2.717	ASTM C127/C128
Water Absorption (%)	1.3	ASTM C127/C128
Unit weight(kg/m^3)	1582	ASTM C29
Particle size distribution	Refer Appendix B.1.3	ASTM C136
Fineness modulus	2.9	Sieving to determine the gradation and FM as per ASTM C136
Natural Moisture content (%)	0.52	ASTM C127/C128

Soundness (%)	8.8	ASTM C88 (Test conducted at ECDSWC)
Initial clay content(%), before washing	4.5	According to Ethiopian standard, maximum clay content is 6%
Final clay content(%), after washing	0.7	ASTM C33 maximum clay content is 3%

3.2.2 Coarse aggregate

The coarse aggregate for this research has been thoroughly assessed at different crushing sites and selling spots. Crusher sites at Kality, Bole Bulbula CMC and Filidoro sites were assessed to check their quality. In addition, coarse aggregate selling spots at CMC Mickael, kara, Laghar have been also visited. Most of the aggregates in the assessed sites have a higher nominal size of above 37 mm with gap gradation. Some of the aggregates are flaky and elongated which will not be suitable for HSC.

Aggregates found around Goro crushing site (on the right side of the road from Goro to Bole Lemi Industrial Park) are preferable aggregates with respect to size, gradation, hardness and texture. The aggregate fulfills the shape and texture requirement of a standard aggregate. A sample from a crusher site called Dereje Belete Crushing Plant was retrieved for this research purpose. The selected coarse aggregate is found to be free from fissures or weak planes, clean, and free of surface dust coatings.

The original sample of the 19 mm aggregate contains a larger aggregate size where it is screened and the oversized particles are removed. Therefore the original sample was sieved on a 19 mm sieve to discard any aggregate particles larger than 19 mm size. The 12.5 mm size aggregate in its existing state has no larger than 12.5 mm particles so the sample is not screened for oversize particles.

Table 3. 6: Aggregate physical property for nominal maximum size of 19 mm

Quality Parameters	Results	Test method
Nominal maximum size	19mm	ASTM C136
Particle side distribution	Refer appendix B.2.1	ASTM C136, According to ASTM C33
Bulk Sp. gr.(Oven dry)	2.739	ASTM C127
Bulk Sp. gr.(SSD)	2.754	ASTM C127
Apparent Sp. gr.	2.781	ASTM C127
Water Absorption	0.55%	ASTM C127
Oven dry-Roded Unit weight(kg/m^3)	625	ASTM C29
Natural Moisture content	0.3%	ASTM C127

Los Angeles Abrasion value	6%	ASTM C131, According to ES, the maximum value of LA shall not exceed 30%.
ACV	11%	BS 812 part 110 (Tested at ECDSWC), Maximum permissible value is 30% (ASTM D5821)

Table 3. 7: Aggregate physical property for nominal maximum size of 12.5 mm

Quality Parameters	Results	Test method
Nominal maximum size	12.5mm	ASTM C136
Particle side distribution	Refer appendix B.2.2	ASTM C136, According to ASTM C33, the gradation falls within the upper and lower limit.
Bulk Sp. gr.(Oven dry)	2.738	ASTM C127
Bulk Sp. gr.(SSD)	2.753	ASTM C127
Apparent Sp. gr.	2.781	ASTM C127
Water Absorption	0.57%	ASTM C127
Oven dry-Roded Unit weight (kg/m^3)	1602	ASTM C29
Natural Moisture content	0.45%	ASTM C127
Los Angeles Abrasion value	8%	ASTM C131, According to ES, the maximum value of LA shall not exceed 30%.
ACV	11%	BS 812 part 110 (Tested at ECDSWC), Maximum permissible value is 30% (ASTM D5821)

3.2.3 Cement, Admixture and water

For this research purpose, Ordinary Portland cement (CEM-I-42.5 grade) manufactured by Dangote Cement Enterprise was selected for its availability in the market and for its proven quality as justified by Bekele (2016). The cement content for HSC is normally at the upper limit of the recommended range per meter cube of concrete. The use of Ordinary Portland cement has the advantage of attaining high early strength especially when used at a lower w/c ratio (Neville, 2011). In using OPC at high content, the concrete produces thermal cracking and high shrinkage as the heat of hydration becomes higher.

3.2.3.1 Admixture

The admixture used for this research is superplasticizer SP60 for high-performance concrete. SASplast SP60 is manufactured by SAS Construction Chemicals Ltd established and operated in Gelan town. The use of SP60 gives high workability and good slump retention without changing the target initial or final strength (SASplast SP60 material catalog).

As per the material catalog of SASplast, SP60 is naphthalene sulphonate based liquid plasticizer intended for use in high strength concrete. It conforms to the requirement of type F and G of ASTM C494-08 classification and it can be used to considerably reduce mixing water resulting in high strength concrete. Since the admixture has a retarding effect, the dose is carefully checked to attain a workable concrete at the same time reducing the retarding effect. The concrete produced using HRWRA (typically SP 60) results in low permeable concrete and more durable concrete (Sidney et. al., 2003).

The normal dosage of SP60 as depicted by the manufacturer is within a range of 0.5-2.5% of the cement weight however it is recommended that the actual dose, which can be justified by trial mix, can vary from the recommended dose based on the material properties of the concrete ingredients.

3.2.3.2 Water

Tap water from AAWSA supply is used for mixing the concrete and curing of the specimens.

3.3 Mortar strength

3.3.1 Ingredient preparation and proportioning for mortar strength test

The effect of cement on sand bondage can be clearly shown by casting mortar and testing it for compressive strength. Mortar as it is commonly understood is a mixture of cement, sand and water. Mortar has a different purpose in everyday construction. It is used as plastering material as well as bonding agents in masonry construction. Besides mortar by itself is part of concrete.

Mortar strength is influenced by different characteristics of the ingredient material properties and the w/c ratio. The cement-sand bondage is best determined by mortar strength. The mortar mixes are prepared using Dangote OPC cement (the same cement brand for the main experiment).

The mortar strength test was prepared in accordance to ASTM C109 and ASTM C270.

In accordance to ASTM C109 Section 10, the ingredient proportion is as shown below:-

Cement to sand ratio=2.75 (one part cement to 2.75 part sand in weight proportion).

Water to cement ratio =0.485

In order to prepare a mortar for one mold with size 7 cm*7 cm*7 cm, volume = 343 cm^3

Cement= (1/3.75)*343= 91.47 cm^3

Sand= (2.75/3.75)*343= 251.54 cm^3

Cement weight=1.44kg/m3*91.47=131.72 gm

Sand weight (Jema sand) =1.656*251.53=416.53 gm

Water (Jema sand) =0.485*131.72gm=43.88 gm

Sand weight (Ambo sand) =1.657*251.53=416.79gm

Water (Ambo sand) =0.485*131.72gm=43.88 gm

Sand weight (River sand) =1.582*251.53=397.92 gm

Water (River sand) =0.485*131.72gm=43.88 gm

As per the proportion computation shown above, the final proportion of the mortar mixes is shown in *Table 3. 8*.

Table 3. 8: Material Proportion for mortar

Main Ingredient	Mix code	Cement-Sand Ratio	w/c	Sand (kg)	Cement (kg)	Water (lt)
River sand	MRR	2.75	0.485	4118.5	1363.3	43.88
Ambo sand	MRA	2.75	0.485	4313.8	1363.3	43.88
Jema sand	MRJ	2.75	0.485	4311	1363.3	43.88

3.3.2 Procedure for Mixing and casting

The cement sand and the water was separately weighed as classified as Jema, Ambo and River sand mortar. The ingredients are mixed manually in a wide bowl using a mason trowel. Before adding water the cement and the sand were thoroughly mixed together in dry condition and the water was added in two separate batches.

The ingredients are mixed to obtain a uniformly mixed mortar before adding in the molds. The mold for the mortar test is a plastic cubical mold having 70 mm side dimension. After adding the mortar in the molds, the mold was tamped with a rubber mallet in three layers to obtain a proper compaction without causing bleeding.

3.3.3 Curing and Testing

After 24 hours from casting of the mortar, the specimens were carefully removed from the mold and stored in water-filled tank until the specimens are tested. The compressive strength test and the dry mortar unit weight measurement are conducted on the cured samples of the mortar. The compressive machine was set at a rate of loading of 0.28 MPa/s which is run uniformly during testing of the mortar cubes. The outcome of the experiment is discussed in Chapter 4.

3.4 Concrete

3.4.1 Mix Proportions

Because much of the interest in high-strength structural concrete is specified in terms of compressive strength, compressive strength of concrete is the primary concern of this research. In addition, the strength of concrete can be evaluated in a number of ways including the modulus of elasticity and flexural or fracture strength. In this experiment, the concrete mix proportions of the constituent materials, measuring and mixing of the concrete, curing condition, rate of loading and method of testing are carefully controlled in order to avoid deviation from the standard.

Since high strength concrete can gain considerable strength after the specified 28-day age, the 56 days strength was considered besides the 7th and 28th compressive strength.

3.4.2 Material quality tests

All the quality tests of coarse aggregate, fine aggregates and admixtures were tested and identified in order to produce a concrete with highest compressive strength and acceptable workability.

The quality of river sand was checked and confirmed that its value falls within the required specifications of ASTM as it is in the control mix. The other two types of sand under the subject of this experiment were washed properly and tested for the required quality criteria. There is no modification done on the fine aggregate because the objective of this experiment is to evaluate the performance of the sands in their natural form.

3.4.3 Cement content

The quantity of cement material proportioned in a HSC mixture is best determined by making trial batches or making adaptations to previous studies. The required content of cement material in a HSC mixture is usually governed by the required w/c ratio. According to ACI 363R-10, section 4.5, the typical cement materials contents in HSC test programs have ranged from 386 kg/m^3 to 593 kg/m^3. The upper limit of cement in concrete is placed with respect to the economical production of concrete and limiting the excess heat released during the hydration process of the cement.

In evaluating optimum cement materials contents, trial mixtures usually are proportioned to get a uniform consistency. This can be achieved either by allowing the admixture dosage to vary and keeping the water content fixed, or by allowing the water content to vary and keeping the admixture dosage fixed.

In this research, the w/c ratio was kept constant and the admixture dosage was varied to observe its effect on the consistency of the concrete. With the given w/c ratio and admixture content, the cement content is varied for the different grades of concrete.

3.4.4 Tests on fresh concrete

In order to check the workability and the practical water demand of the concrete mix, a slump test is done on the fresh concrete. For high strength concrete water reducing admixture is added to concrete in order to lower the w/c ratio and increase the strength of the concrete. According to ACI 211.4R-08 manual for the design of high strength concrete mix design, the slump should be checked before and after adding the HRWRA. Before the addition of the admixture, the slump should be within a range of 30 mm to 50 mm and after the addition of the HRWRA, the slump s recommended to exceed 180 mm in order to have a workable concrete (ACI 211.4-08).

3.5 Concrete Trial mix

3.5.1 Trial concrete mix 1- checking and fixing w/c

In order to maximize the compressive strength of the different grades of concrete, the w/c ratio shall be reduced as much as possible given that the slump is within the acceptable range. In ACI 211.4R-08 Table 6.5, the recommended maximum w/c ratio for high-strength concrete for different concrete target strengths is shown. The w/c figures are the maximum values that should not be exceeded.

The given values in Table 6.5 of ACI 211.4R-08 for 10,000 psi, 11,000psi and 12,000 psi cylindrical compressive strength corresponds to the w/c ratio of C70, C80 and C90 cubical compressive strength respectively. The value of the w/c ratio according to ACI manual for the 19 mm and 12 mm coarse aggregate sizes and the proposed w/c ratio for this experiment purpose are listed in *Table 3.10* and *Table 3.11*. To maximize the concrete strength in all classes, the proposed w/c ratio for the C90 concrete was adopted for the other concrete grades.

Table 3. 9: Proposed w/c ratio for different concrete strength when 12.5 mm aggregate size used

Sand Type	Concrete strength (Mpa)	Size of aggregate (mm)	w/c	Cement (kg)	Sand (kg)	Aggregate (kg)	Water (lt)	Measured slump (mm)
River sand	C70	12.5	0.29	520	786.	1094.9	147.67	40
		19	0.27	520	696.2	1173.5	148.84	45
Ambo	C70	12.5	0.29	520	771.1	1094.9	142.41	35
		19	0.27	520	696.2	1173.5	143.94	35
Jema	C70	12.5	0.29	520	751.35	1094.9	141.86	50
		19	0.27	520	693.37	1173.5	143.47	35

Table 3. 10: Proposed w/c ratio value for different concrete strength when19 mm aggregate size used

Target Concrete strength (MPa)		Cement content (kg/m^3)	Recommended w/c ratio for 12.5 mm C.A.	Proposed w/c ratio
River sand (Control	C70	520	0.36	0.29
	C80	550	0.32	
	C90	580	0.29	
Ambo sand	C70	520	0.36	0.29
	C80	550	0.32	
	C90	580	0.29	
Jema	C70	520	0.36	0.29
	C80	550	0.32	
	C90	580	0.29	

Table 3. 11: Summary of concrete ingredient proportion for the trial mix-1

Target Concrete strength(Mpa)		Cement (kg/m3)	Recommended w/c ratio for 19mm C.A.	Proposed w/c ratio
River sand (Control mix)	C70	520	0.35	0.27
	C80	550	0.31	
	C90	580	0.27	
Ambo sand	C70	520	0.35	
	C80	550	0.31	

	C90	580	0.27	0.27
Jema sand	C70	520	0.35	0.27
	C80	550	0.31	
	C90	580	0.27	

3.5.1.1 Finding of the trial mix 1

For evaluation of concrete slump based on the proposed w/c ratio, concrete with strength 70 MPa is selected. A trial mix design was prepared for a cement content of 520 kg and w/c ratio of 0.27 for 19 mm nominal aggregate size and 0.29 for 12.5 mm nominal coarse aggregate. With the same parameter, the mix design of concrete containing Jema, Ambo and River Sand was prepared. During mixing of the trial concrete, the measured slump of the different mix is shown in *Table 3. 9*. Accordingly to the measured slump, the proposed w/c ratio is acceptable to be used in all other grades of the concrete.

3.5.2 Trial concrete mix 2- determination of admixture dose

From the material catalog produced by the admixture manufacturer, the recommended range of the admixture (SP60 HRWRA) is 0.5-2.5% of the cement amount in weight proportion. In order to determine the optimum dose of the admixture three trial mixes were conducted at admixture dosage of 2.5%, 2% and 1.6%. For the trial concrete mix, C70 grade of concrete made for the control mix which is the River sand was selected. The selected coarse aggregate for these mixes are 19 mm and 12 mm size coarse aggregate and the target concrete strength for the trial mix was selected to be C70. Totally six(6) trial mixes were prepared for C70 concrete with two categories of coarse aggregate which produced a total of 18 cubes.

The admixture dose and its effect on the fresh concrete mix and the result of the tests conducted on the hardened concrete specimens are shown in *Table 3. 12*.

Table 3. 12: Trial mix to evaluate the admixture usage and the corresponding findings

Coarse aggregate used	Cement content (kg/m^3)	proposed Admixture rate	Admixture amount (lt/m^3)	Admixture amount for trial mix (0.015m^3)	Effect of admixture (Observation and slump)	Avg. Compress. strength (7 days)
19 mm	520 (w/c=2.7)	2.5%	15.86	0.195	-Zero slump -Free flowing concrete -Difficult to remove from the mold after 24 hours from casting -Curing started after 48 hours from casting because of prolonged setting time -Retarded setting	38.9 MPa
12.5 mm	520 (w/c=2.9)		15.86	0.195		30 MPa
19 mm	520 (w/c=2.9)	2.0%	12.68	0.156	-Zero slump -Free flowing concrete -Difficult to remove from the mold after 24 hours from casting -Curing started after 48 hours from casting -Retarded setting	40.4 MPa
12.5 mm	520 (w/c=2.7)		12.68	0.156		44.6 MPa
19 mm	520 (w/c=2.7)	1.6%	10.15	0.125	-A slump ranging at 180mm obtained -Better workability -Readily removed from the mold after 24 hours from casting -Curing started after 24 hours from casting	60.2 MPa
12.5 mm	520 (w/c=2.7)		10.15	0.125		57.8 MPa

3.5.2.1 Finding of the trial mix 2

From the findings which is shown in *Table 3.12*, the optimum dose of the HRWRA is fixed at 1.6% since the measured slump is in accordance to the recommendation by ACI 211R. The trial mix depicted that as the content of the admixture increases, the setting time increases and its 7 day compressive strength decreases. The trial mix has indicated that the optimum dosage of SP60 HRWRA is obtained at 1.6% for Dangote OPC cement.

3.6 Concrete mix design and proportions

The design High strength Concrete mix design is made using ACI method for HSC design manual (ACI 211.4R-08). For high-strength concrete mixtures specially selected cement materials and chemical admixtures are used, and achieving a low w/c ratio is considered essential.

To enhance the quality of the mix design prescribed cement content was used for the different grades of concrete. In addition data from the trial concrete mix and previous studies has been incorporated to produce a more practical proportion of the ingredients.

The designation and description is made to clearly clarify the type of the concrete mix. The first alphabet detects the initial letter of the fine aggregate used, the second figure before fore slash indicates the characteristics strength of the concrete and the last two digit figure indicates the nominal size of the coarse aggregate used in the mix. 02 aggregate stands for the 19mm aggregate and 01 stands for the 12mm aggregate.

- → J70/02, J80/02, J90/02 and J70/01, J80/01, J90/01:- The concretes in this batch uses Jema sand for fine aggregate part, with 01 and 02 coarse aggregate and characteristics strength of 70 MPa, 80 MPa, 90 MPa.
- → A70/02, A80/02, A90/02 and A70/01, A80/01, A90/01:- The concretes in this batch uses Ambo sand for fine aggregate part with 01 and 02 coarse aggregate and characteristics strength of 70 MPa, 80 MPa, 90 MPa.
- → R70/02, R80/02, R90/02 and R70/01, R80/01, R90/01:- The concretes in this batch uses River sand for fine aggregate part with 01 and 02 coarse aggregate and characteristics strength of 70 MPa, 80 MPa, 90 MPa.

As shown in *Table 3.13* to *Table 3.18*, the ingredient proportions for the three types of sand that are the subject of this study are indicated.

Table 3. 13: Concrete ingredients made from River sand with 01 aggregate

Mix type	Mix	Target strength (MPa)	Cement content (kg/m^3)	w/c	Aggregate (kg/m^3)	Sand (kg/m^3)	Water (lt/m^3)	Admixture (lt/m^3)
River sand	R01/70	70	520	0.29	1094.9	786.5	147.67	10.15
River sand	R01/80	80	550	0.29	1094.9	737.4	155.34	10.74
River sand	R01/90	90	580	0.29	1094.9	691	163	11.32

Table 3. 14: Concrete ingredients made from Jema sandstone with 01 aggregate

Mix type	Mix code	Target strength (MPa)	Cement content (kg/m^3)	w/c	Aggregate (kg/m^3)	Sand (kg/m3)	Water (lt/m^3)	Admixture (lt/m^3)
Jema sandstone	J01/70	70	520	0.29	1094.9	751.35	141.86	10.15
Jema sandstone	J01/80	80	550	0.29	1094.9	720	149.91	10.74
Jema sandstone	J01/90	90	580	0.29	1094.9	674.65	158.11	11.32

Table 3. 15: Concrete ingredients made from Ambo sandstone with 01 aggregate

Mix type	Mix code	Target strength (MPa)	Cement content (kg/m^3)	w/c	Aggregate (kg/m^3)	Sand (kg/m^3)	Water (lt/m^3)	Admixture (lt/m^3)
Ambo sand	A01/70	70	520	0.29	1094.9	771.1	142.41	10.15
Ambo sand	A01/80	80	550	0.29	1094.9	722.9	152.1	10.74
Ambo sand	A01/90	90	580	0.29	1094.9	674.72	158.94	11.32

Table 3. 16: Concrete ingredients made from River sand with 02 aggregate

Mix type	Mix code	Target strength (MPa)	Cement content (kg/m^3)	w/c	Aggregate (kg/m^3)	Sand (kg/m^3)	Water (lt/m^3)	Admixture (lt/m^3)
River sand	R01/70	70	520	0.27	1173.5	710.09	148.84	10.15
River sand	R01/80	80	550	0.27	1173.5	655.4	156.53	10.74
River sand	R01/90	90	580	0.27	1173.5	609.15	164.28	11.32

Table 3. 17: Concrete ingredients made from Jema sandstone with 02 aggregate

Target Ingredient	Mix code	Target strength (MPa)	Cement content (kg/m^3)	w/c	Aggregate (kg/m^3)	Sand (kg/m^3)	Water (lt/m^3)	Admixture (lt/m^3)
Jema sand	J02/70	C70	520	0.27	1173.5	693.37	143.47	10.15
Jema sand	J02/80	C80	550	0.27	1173.5	640.05	151.57	10.74
Jema sand	J02/90	C90	580	0.27	1173.5	594.6	159.72	11.32

Table 3. 18: Concrete ingredients made from Ambo sandstone with 02 aggregate

Mix type	Mix code	Target strength (MPa)	Cement content (kg/m^3)	w/c	Aggregate (kg/m^3)	Sand (kg/m^3)	Water (lt/m^3)	Admixture (lt/m^3)
Ambo sand	A02/70	70	520	0.27	1173.5	696.2	143.94	10.15
Ambo sand	A02/80	80	550	0.27	1173.5	642.6	152.38	10.74
Ambo sand	A02/90	90	580	0.27	1173.5	597.09	160.41	11.32

3.6.1 Procedure

3.6.1.1 Measuring Batching and mixing

The ingredients were separately weighed. The aggregate cement and then sand are mixed by a horizontally rotating mixer. Next, half of the required water is added while the mixer is still mixing. The pre measured admixture is then added. Finally the remaining water less the admixture volume is added and mixed. At the end of the mixing, the slump of the concrete is measured according to ASTM C143.

The concrete is added into the molds and vibrated with a mechanical vibrator to obtain a proper compaction without causing bleeding and segregation. The total wet mixing time of the concrete was controlled to be 3 minutes. For compressive strength test, cubical molds of 150 mm dimension made from steel were used. For flexural test, the size of the mold used is 100 mm*100 mm*500 mm molds made from steel and plastic.

3.6.1.2 Curing

Curing of the concrete is one of the most crucial processes in the production of HSC. The w/c ratio of HSC is normally below 0.4 and as low as 0.25 in some instances. A low w/c ratio implies low water content for a given volume of concrete. In order to preserve the original mixing water of the concrete, a continuous supply of water should be provided during the curing stage so that the expected strength development was maintained. Water curing of high-strength concrete is highly recommended because of the low water-cement materials ratios it employs. Concretes with low w/c ratios benefited more from the application of additional surface water than concretes with high w/c ratios

According to ACI 363R-10, the most effective method of water-curing for HSC consists of total immersion of the finished concrete in water. A concrete immersed in water absorbs water through capillary pores and there will be more water for the hydration of the concrete which will compensate the lower amount of the initial mixing water.

The concrete specimens that are casted for this research purpose are cured by complete immersed in water for as long as 28 days. In the case of the 7 days testing, the concrete was cured in water until the time the specimens were tested. During the curing process, the temperature of the water is the same as the environmental temperature and there is no application of heating mechanism.

3.6.1.3 Properties of hardened concrete

On cured specimens of concrete, the compressive strength test, flexural strength test, weight and density of specimens were tested and recorded. The concrete compressive machine where the tests conducted is ‘controls’ brand. For testing of the concrete cubes, the rate of loading was set at rate of 0.28 MPa/s. The test result and outcomes of the experimental concretes are discussed in Chapter 4.

CHAPTER 4: RESULTS AND DISCUSSION

4.1. General

In this section, the experimental findings of tests conducted on the control mix, Jema sand and Ambo sand are discussed. The test results of Jema and Ambo concretes are compared with the control mix as well as the common concrete standards in order to adequately evaluate the suitability of the sands for high strength concrete.

Most of the necessary input data are based on laboratory testing and findings. As per the formal procedure of concrete mix design, the mix design for each category of concrete was done after the quality and identification of the ingredient materials are tested and known. The target strength in HSC formation can be obtained by properly selecting and washing aggregates, limiting the maximum size of coarse aggregates, using high amount of cement than the required for normal concrete, reducing the w/c ratio and utilizing proper HRWR admixtures. This study embraces the quality of the concrete ingredients and concrete strength test results to meet the governing minimum lower limit of the strength for HSC.

4.2. Characteristics and strength behavior of the experimental concretes

4.2.1. Properties of fresh concrete mix

The high strength concrete is a blend of coarse and fine aggregate, cement, water and plasticizer. There were eighteen (18) concrete mixes other than the trial concrete mixes. The result of the trial mix was reported in Chapter 3.

One of the most important aspects of a high strength concrete is its workability. With less w/c ratio, the concrete becomes stiff and unworkable. In general, unworkable concrete is not advisable to work with.

The stiffness of the HSC is improved by adding proper amount of superplasticizer. The dose for the entire concrete mix is 1.6% of the weight of the cement used. In a very controlled mixing the workability of the concrete mixes was improved. The measured slumps are shown in *Table 4. 1* and the values are in the range of 180 mm to 235 mm which is acceptable.

As per the standard specification for concrete structure, produced by the Japan Society of Civil Engineers (JSCE, 2007), the recommended slump for HSC at the time of placing should be between 180 mm and 210 mm (section 6.4.2 p.319).

Table 4. 1: Measured Slump of concrete mix after adding of admixture

Mix designation	Measured slump	Average of the slump
Concrete made from River sand		
R70/01	185	185
R80/01	190	
R90/01	180	
R70/02	210	193
R80/02	170	
R90/02	200	
Concrete made from Jema sand		
J70/01	235	225
J80/01	210	
J90/01	230	
J70/02	200	195
J80/02	185	
J90/02	200	
Concrete made from Ambo sand		
A70/01	235	223
A80/01	220	
A90/01	215	
A70/02	195	202
A80/02	200	
A90/02	210	

According to the result of the slump measurement, the slump of concrete made from the river sand is stiffer than that of the other concretes made from Jema and Ambo sands. The percentage of concrete mixes that have slumps which that fall within the recommended slump range is 78%. All the slump of the control mix falls within the required range. Concrete made from 12.5 mm aggregate in the case of Ambo and Jema sand have a little higher slump than the concrete mixed using 19 mm coarse aggregate. This may attribute to the higher w/c ratio of the 12.5 mm coarse aggregate and the aggregate's own smaller size as compared to the 19 mm coarse aggregate. Since Jema sand and

Ambo sands do have finer grain size than the control sand, the concrete made from Jema or Ambo sand have recorded a higher slump than the concrete made from the control sand.

4.2.2. Properties of hardened concrete

Much of the interest in high-strength structural concrete is limited to compressive strength and these compressive strength and related measurements are of primary concern. The strength and variability of the concrete can be established only by specimens made, cured, and tested under standard conditions.

In order to test the concrete cubes for compressive strength concrete cubes with dimention15 cm and for flexural test, bar of concretes with dimension 10 cm x10 cm x 50 cm were casted and cured in a soaking tank for 28 days. The concrete specimen was carefully leveled and made smooth to avoid uneven surfaces and irregular faces so that trustable results were found. Curing of the concrete specimens was conducted in accordance to Chapter 3 of this report.

4.2.2.1. Compressive strength of concrete

As it has been stated above, the concrete compressive test is the direct test method to determine how strong the concrete is. All the concrete was tested in AAiT material laboratory. The compressive machine has a capacity to apply 3000 KN which is equivalent to 133 MPa for testing concrete cubes. The rate of loading was set at 0.28 MPa/s to comply with ASTM C39. The mean value of the compressive test result of the concrete made from Jema sand, Ambo sand and river sand is summarized in six distinct Tables as shown below (*Table 4. 2 to Table 4. 7*).

Table 4. 2: Summary of mean compressive strength of River sand with 01 Aggregate

River Sand	mix designation	Cement (kg/m^3)	Target Strength (MPa)	Compressive strength (MPa)		
				7 days	28 days	56 days
Coarse Aggregate size, 12 mm	R70/01	520	C70	61.36	72.10	74.65
	R80/01	550	C80	69.62	81.78	83.59
	R90/01	580	C90	79.93	88.74	91.42

Table 4. 3: Summary of mean compressive strength of River sand with 02 Aggregate

River Sand	Concrete mix designation	Cement Content (kg/m^3)	Target Strength (MPa)	Compressive strength (MPa)		
				7 days	28 days	56 days
Coarse Aggregate size, 20 mm	R70/02	520	C70	68.67	75.01	76.03
	R80/02	550	C80	74.30	82.92	84.45
	R90/02	580	C90	82.18	91.35	92.58

Table 4. 4: Summary of mean compressive strength of Jema sand with 01 Aggregate

Jema Sand	Concrete mix designation	Cement Content (kg/m^3)	Target Strength (MPa)	Compressive strength (MPa)		
				7 days	28 days	56 days
Coarse Aggregate size, 12 mm	J70/01	520	C70	57.57	64.52	67.33
	J80/01	550	C80	63.37	71.56	76.23
	J90/01	580	C90	69.52	77.45	79.46

Table 4. 5: Summary of mean compressive strength of Jema sand with 02 Aggregate

Jema Sand	Concrete mix designation	Cement Content (kg/m^3)	Target Strength (MPa)	Compressive strength (MPa)		
				7 days	28 days	56 days
Coarse Aggregate size, 20 mm	J70/02	520	C70	60.63	68.11	68.97
	J80/02	550	C80	64.73	72.67	73.67
	J90/02	580	C90	70.97	77.60	78.34

Table 4. 6: Summary of mean compressive strength of Ambo sand with 01 Aggregate

Ambo Sand	Concrete mix designation	Cement Content (kg/m^3)	Target Strength (MPa)	Percentage attainment against the control mix		
				7 days	28 days	56 days
Coarse Aggregate size, 12 mm	A70/01	520	C70	62.71	69.99	72.25
	A80/01	550	C80	68.25	79.90	81.35
	A90/01	580	C90	72.10	83.73	84.32

Table 4. 7: Summary of mean compressive strength of Ambo sand with 02 Aggregate

Ambo Sand	Concrete mix designation	Cement Content (kg/m^3)	Target Strength (MPa)	Percentage attainment against the control mix		
				7 days	28 days	56 days
Coarse Aggregate size, 20 mm	A70/02	520	C70	61.53	72.28	73.49
	A80/02	550	C80	72.34	80.12	82.25
	A90/02	580	C90	78.79	87.77	89.44

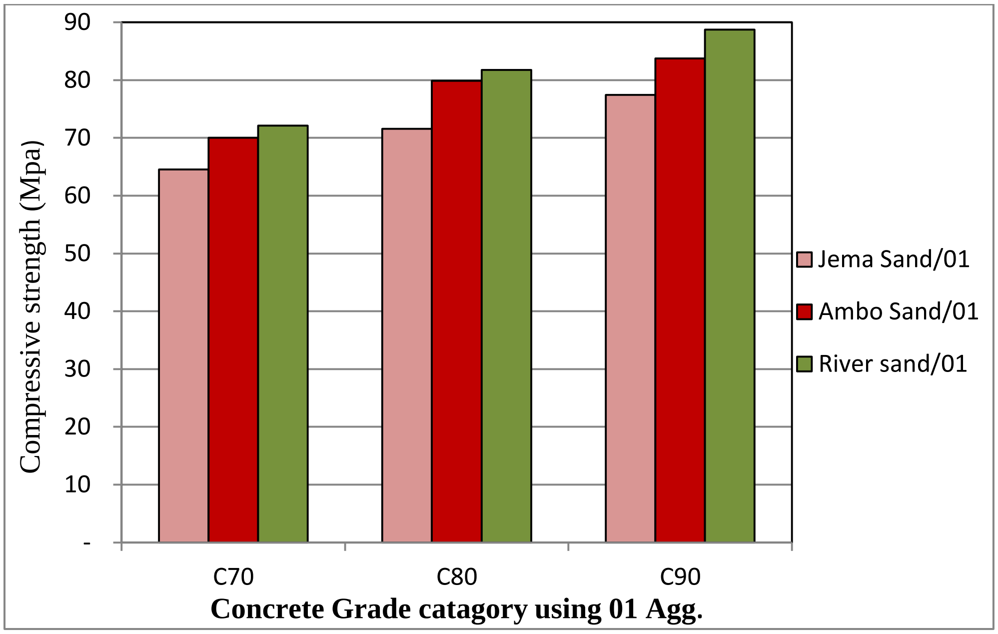
4.2.2.2. Graphical representation of the test results

The chart in *Graph 4. 1* and *Graph 4. 2* show the mean value of the compressive strength tests of the three types of concretes (made from Jema, Ambo and River sands). In utilizing the two types of coarse aggregate, the control mix (made from river sand) has a record of the highest value in the three categories of the target strength followed by Ambo concrete and Jema concrete.

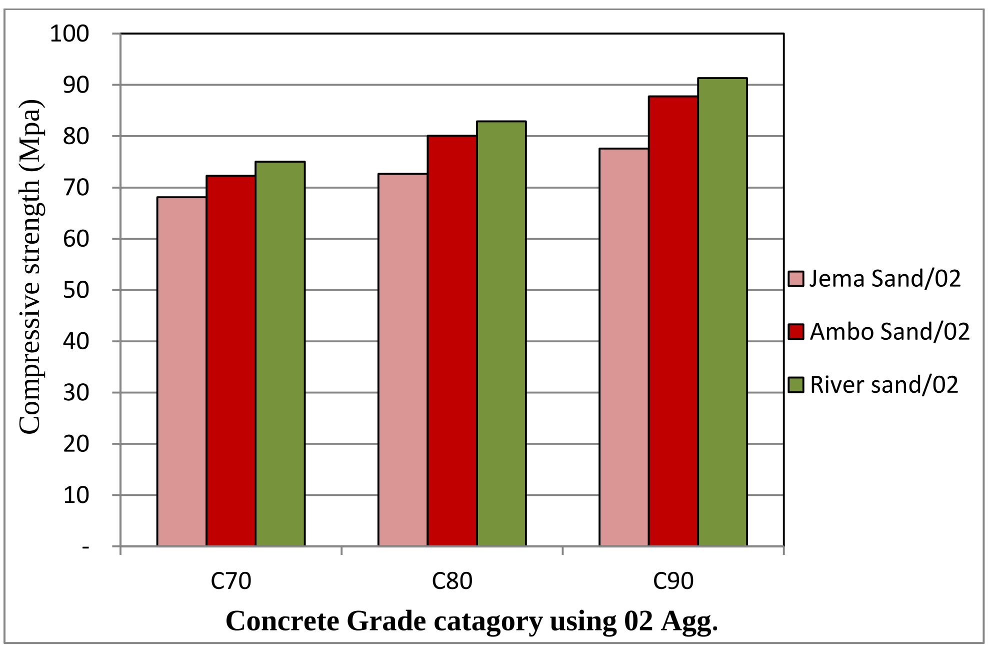
The control mix which is made from selected and treated river sand could achieve the desired compressive strength in all categories of target concrete strength and with the two types of coarse aggregates used except that the concrete made from the control mix for C90 (12.5 mm coarse aggregate and 580 kg of cement used) has failed to attain target strength. In general, the concrete mix used 19 mm coarse aggregate has recorded higher strength than the 12.5 mm coarse aggregate mix as a different w/c ratio used in each case.

Ambo concrete has attained the target strength at C70 and C80 with a cement content of 520 kg/m^3 and 550 kg/m^3 used however it failed to attain the target strength of C90 where its cement content is 580 kg/m^3. This is true for 19 mm and 12.5 mm coarse aggregate mixes. In the same trend of the control mix, the concrete mix used 19 mm coarse aggregate has recorded higher strength than the 12.5 mm coarse aggregate mix as there is a difference in w/c ratio. The difference from the control mix when 19mm coarse aggregate was used is 2.73 MPa, 2.8 MPa, 3.57 MPa and for 12 mm coarse aggregate the difference is 2.11 MPa, 1.88 MPa, 5.01 MPa for concrete category C70, C80, C90 respectively.

Jema concrete has failed to attain the target compressive strength at the three categories of target strength where the control mix has achieved under the same standard and process of mixing. The recorded laboratory compressive strength of Jema sand is in order of 6.9 MPa, 10.25 MPa and 13.75 MPa below the control mix for C70, C80, C90 and when 19 mm aggregate was used. When 12.5 mm coarse aggregate was used, the difference became 7.58 MPa, 10.22 MPa, 11.29 MPa below the control mix for concrete category C70, C80, C90 respectively. While considering the coarse aggregate nominal size, concrete casted using 19 mm coarse aggregate has recorded a higher strength than the concrete casted using 12.5 mm coarse aggregate.



Graph 4. 1: 28th day compressive strength of the three types of concrete using 01 aggregate

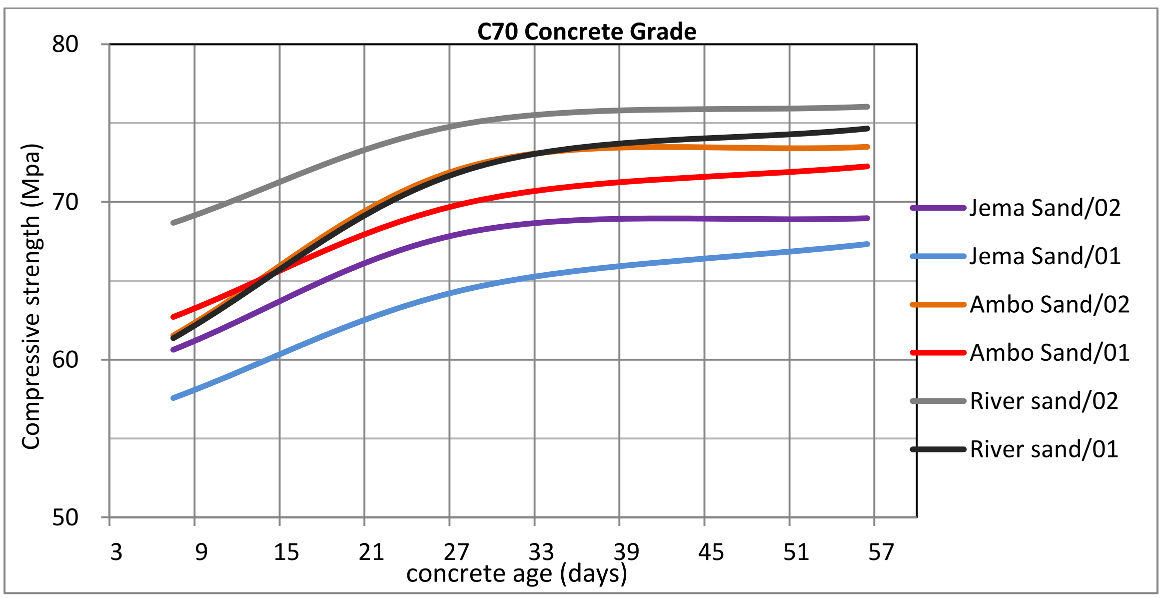


Graph 4. 2: 28th day compressive strength of the three types of concrete using 02 aggregate

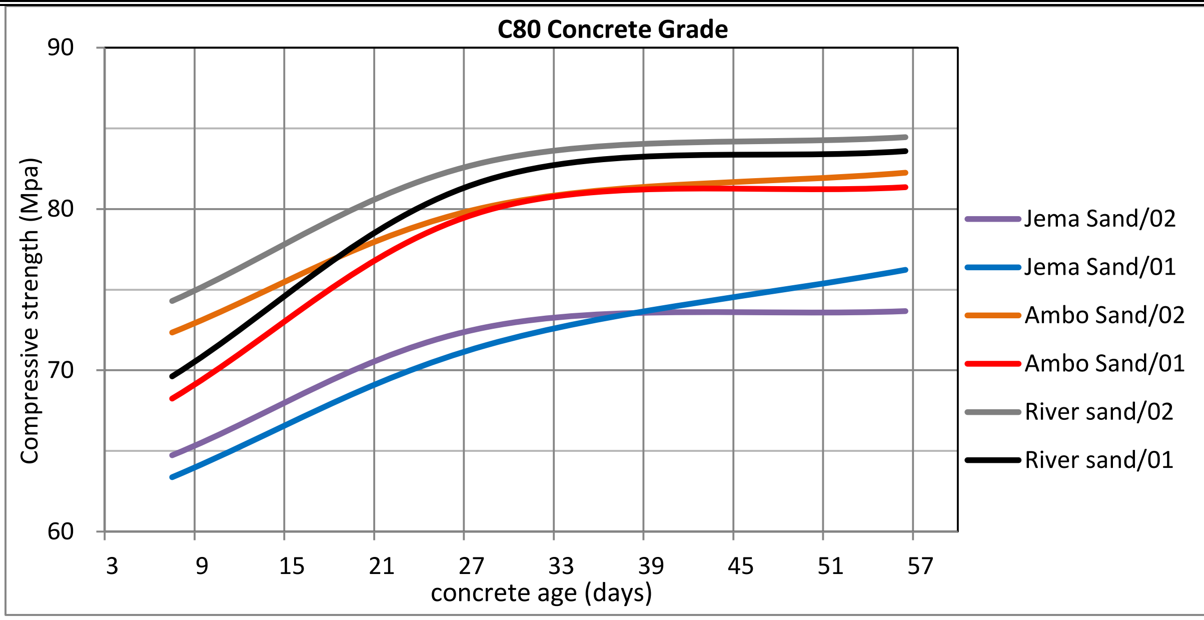
4.2.2.3. Rate of strength development

The rate of strength development of the individual concrete mix from the 7^{th} day to the 56^{th} days for C70, C80 and C90 concrete strength was graphed and shown in *Graph 4. 3, Graph 4. 4 and Graph 4. 5*. The rate of strength development at 7^{th} day is very high. On the average of the overall concrete mixes, the 7^{th} day compressive strength against the 28^{th} day strength is 89.5%, 87.7% and 88.6% for concretes made from Jema, Ambo and River sands. The result is in compliance with other scholars. Parrott (1969) has conducted a research on the rate of strength development for HSC and his report showed that the 7 to 28-day strengths of typical HSC are within a range of 0.8 to 0.9. Aside from the control mix, Ambo concrete cubes have shown higher early strength than Jema concrete cubes. The control mix has surpassed both the Jema and Ambo concretes at early strength and later age strength.

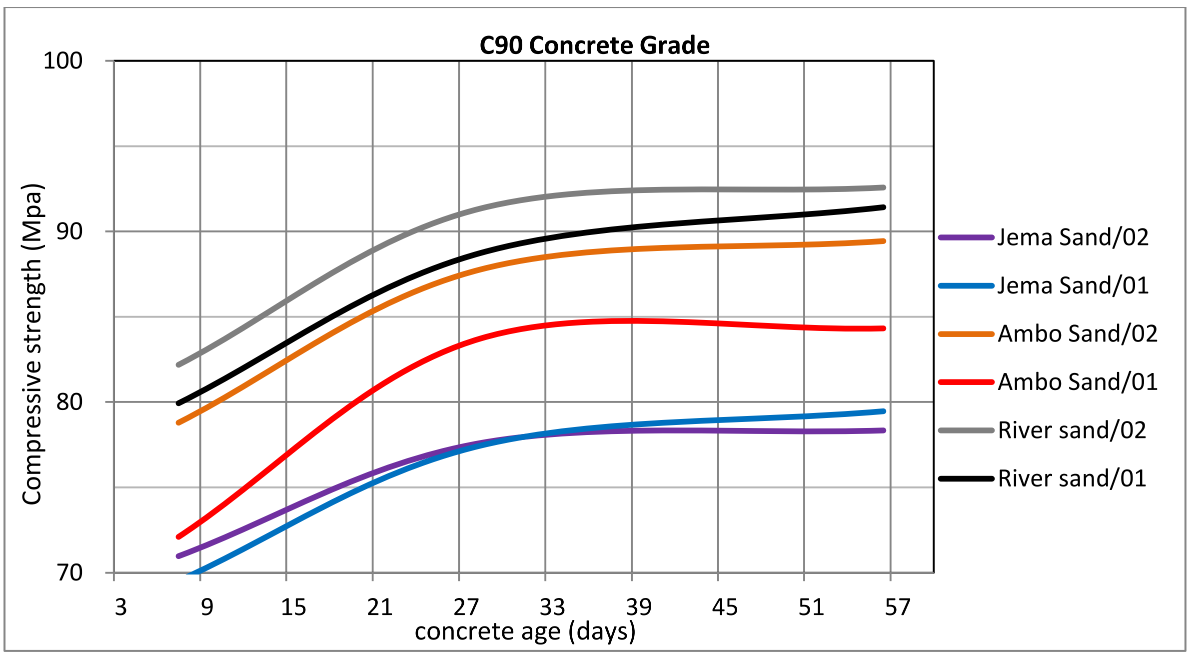
The higher rate of strength development of HSC at early ages is caused first by the increase in the internal curing temperature in the concrete cubes due to a higher heat of hydration and secondly shorter distance between hydrated particles in the concrete due to a low w/c ratio.



Graph 4. 3: Rate of strength development of the three types of concrete for C70



Graph 4. 4: Rate of strength development of the three types of concrete for C80



Graph 4. 5: Rate of strength development of the three types of concrete for C90

4.2.2.4. Comparison of Jema and Ambo Concretes with the control concrete mix

As shown in the four Tables below (*Table 4. 8* to *Table 4. 11),* the percentage of the strength of Jema and Ambo concrete was computed against the control mix for each strength and age of the concrete.

For Jema sand, the 28th day compressive strength is within the range of 85% - 91% of the compressive strength of the control mix when 19 mm and 12.5 mm coarse aggregate are used.

For Ambo concrete, the 28th day compressive strength is within the range of 94% - 98% of the compressive strength of the control mix when 19 mm and 12.5 mm coarse aggregate are used.

Table 4. 8: Percentage attainment of Jema Concrete against the control mix-02 Aggregate

Jema Sand	Concrete mix designation	Cement Content (kg/m^3)	Target Strength (MPa)	Percentage attainment against the control mix		
				7 days	28 days	56 days
Coarse Aggregate size, 20mm	J70/02	520	C70	88.3%	90.8%	90.7%
	J80/02	550	C80	87.1%	87.6%	87.2%
	J90/02	580	C90	86.4%	85.0%	84.6%

Table 4. 9: Percentage attainment of Jema Concrete against the control mix-01 Aggregate

Jema Sand	Concrete mix designation	Cement Content (kg/m^3)	Target Strength (MPa)	Percentage attainment against the control mix		
				7 days	28 days	56 days
Coarse Aggregate size, 12mm	J70/01	520	C70	93.8%	89.5%	90.2%
	J80/01	550	C80	91.0%	87.5%	91.2%
	J90/01	580	C90	87.0%	87.3%	86.9%

Table 4. 10: Percentage attainment of Ambo Concrete against the control mix-02 Aggregate

Ambo Sand	Concrete mix designation	Cement Content (kg/m^3)	Target Strength (MPa)	Percentage attainment against the control mix		
				7 days	28 days	56 days
Coarse Aggregate size, 20mm	A70/02	520	C70	89.6%	96.4%	96.7%
	A80/02	550	C80	97.4%	96.6%	97.4%
	A90/02	580	C90	95.9%	96.1%	96.6%

Table 4. 11: Percentage attainment of Ambo Concrete against the control mix-01 Aggregate

Ambo Sand	Concrete mix designation	Cement Content (kg/m^3)	Target Strength (MPa)	Percentage attainment against the control mix		
				7 days	28 days	56 days
Coarse Aggregate size, 12mm	A70/01	520	C70	102.2%	97.1%	96.8%
	A80/01	550	C80	98.0%	97.7%	97.3%
	A90/01	580	C90	90.2%	94.4%	92.2%

4.2.2.5. Modulus of Elasticity

Modulus of elasticity (Ec) is defined as the ratio of the applied stress to the corresponding deflection or strain. It is one of the measurements of hardened concrete behavior. Modulus of elasticity has more beneficial in the design of structures where even the slightest deflection is the concern of the design element. For HSC, the consideration of Modulus of elasticity has more advantageous to avoid excessive deflection in ultimate and service limit design methods.

Modulus of elasticity depends on a number of concrete characters including aggregate type, concrete constituents, mix design and proportions, bond between cement paste and aggregate and age of the concrete. Modulus of elasticity can be directly measured in the laboratory using a concrete compression testing machine and compressometer to measure the strain. Measuring Ec in the laboratory using this method is beyond the scope of this research work.

To calculate the modulus of elasticity of concrete, many countries have developed their own empirical formulas and included in their national standards. For example, ACI 318 developed a formula to compute the Ec of concrete which considers the weight of the sample and the characteristics strength (Fck).

$Ec=wc^{1.5}0.043\sqrt{fc'}$, where fc' is the 28 day characteristics strength – ACI 318-19 (19.2.2.1a)

wc:- unit weigh of concrete

The Ethiopian standard (CES 149, 2015) has specified the Ec using the empirical formula as shown below.

$Ecm = 22[(f_{cm})/10]^{0.3}$, where fcm = fck + 8 ($f_{cm}$ is the mean compressive strength at 28 days)

The value is recommended to be increased by 20% for basaltic aggregate (CES 149, section 3.1.3).

As shown above, ACI standard considers the weight of the concrete to calculate the Ec whereas ES uses only the mean strength at 28 days and is further increased by 20% for basaltic aggregate.

The value of the Ec for the three type of sand for the different concrete grade is shown in *Table 4. 12 and Table 4. 13.*

Table 4. 12: Modulus of elasticity of concrete specimen for 01 coarse aggregate

Target strength→	C70		C80		C90	
Concrete made from	ACI (GPa)	CES (GPa)	ACI (GPa)	CES (GPa)	ACI (GPa)	CES (GPa)
River sand	45.70	49.28	49.67	50.99	51.79	52.15
Jema Sand	42.81	47.83	45.87	49.18	48.38	50.25
Ambo Sand	45.82	48.87	48.02	50.67	50.18	51.31

Table 4. 13: Modulus of elasticity of concrete specimen for 02 coarse aggregate

Target strength→	C70		C80		C90	
Concrete made from	ACI (GPa)	CES (GPa)	ACI (GPa)	CES (GPa)	ACI (GPa)	CES (GPa)
River sand	47.28	49.81	49.76	51.18	52.28	52.57
Jema Sand	44.84	48.53	46.38	49.38	47.65	50.27
Ambo Sand	46.43	49.31	48.90	50.71	51.51	51.99

The modulus of elasticity refers to the amount of stress a concrete absorbs for an amount of elastic strain which implies that the higher the modulus of Elasticity, the more resistance is the material to deformation within the elastic range. While considering the ACI values of the Ec, except for the Jema specimen made with aggregate 01 size, the modulus of elasticity of the entire concrete specimen have a result of Ec within the range of 45 to 52 GPa.

4.2.2.6. Flexural strength of concrete

Flexural strength (modulus of rupture) of concrete is its ability to resist tensile of shear load. The flexural strength has a key application in the design of concrete pavement. Concrete is strong in compression but its tensile strength is not as good as its compressive strength. In general consideration, as the compressive strength of concrete increases, its flexural strength increases accordingly. As a simple- thumb rule, ACI 363R-10 recommends that the flexural strength of normal concrete is approximately 10% of the compressive strength for normal strength concrete however many researchers have commented that for HSC this percentage estimate is misleading. The flexural strength may be below this percentage ratio because the increase in compressive strength has lower effect on the flexural strength.

According to ASTM C78-08, when the third point loading method is used to apply the load on the specimen, the formula to compute the flexural strength of the simple beam becomes

$R = PL/bd^2$, where P is the breaking load, L is the length of the specimen, b and d are

Cross-sectional dimension of the beam

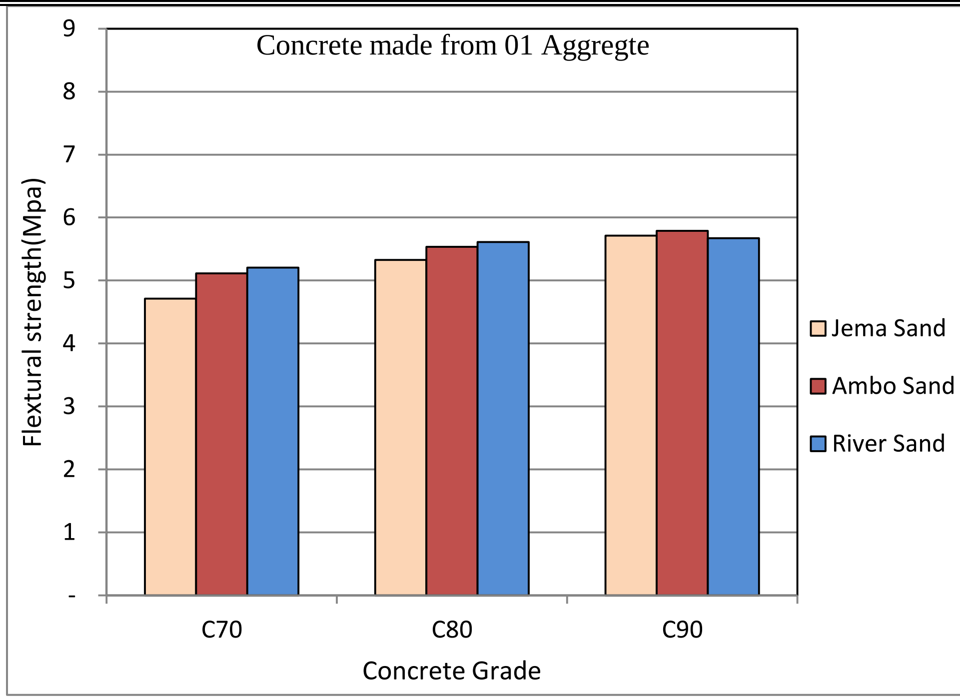
In CES 149, 2015, table 3.1, the standard has put a recommended values of the flexural based on the mean compressive strength of the concretes.

The flexural test is conducted as per ASTM C78 using third point loading. The rate of loading is 0.017 MPa/s which is kept constant until the specimens are fractured. The values corresponding to cubical strength of C70, C80 and C90 was recorded and included in *Table 4. 14*.

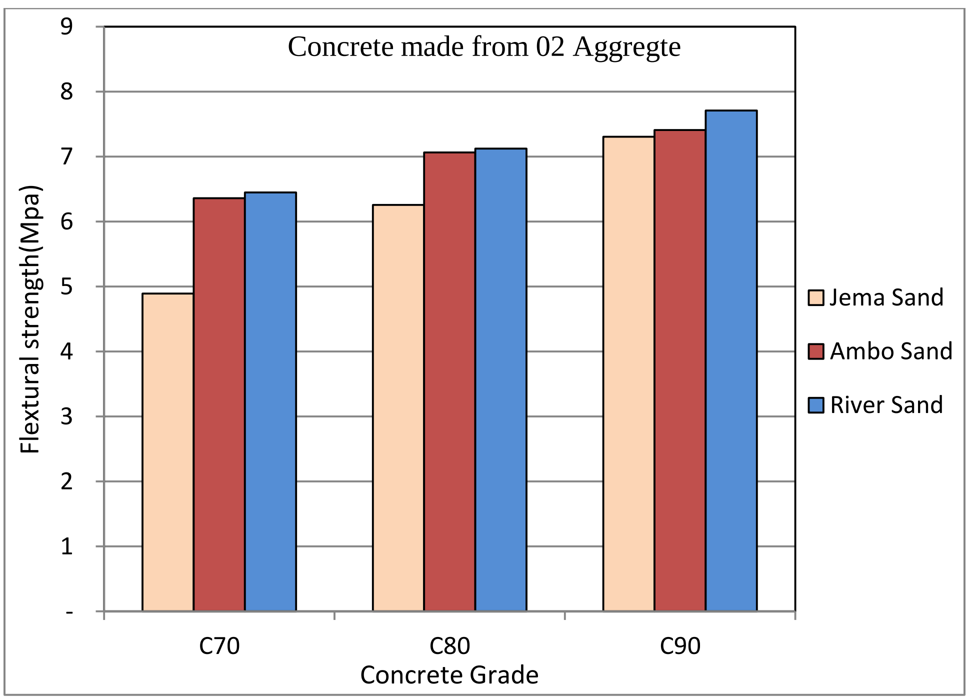
Table 4. 14: Mean flexural strength of test cubes made from Jema, Ambo and River sand

Target compressive strength→	**Mean Flexural strength(MPa) at 28 days**					
	C70	C80	C90	C70	C80	C90
Recommended flexural strength(MPa) (CES 149)	4.2	4.5	4.6	4.2	4.5	4.6
Concrete type (Fine aggregate in concrete)	with 20 mm Coarse aggregate			with12.5 mm Coarse aggregate		
Jema Sand	4.89	6.26	7.31	4.71	5.33	5.72
Ambo Sand	6.36	7.07	7.41	5.12	5.54	5.79
River Sand	6.45	7.13	7.71	5.21	5.61	5.67

From the above table Ambo concrete has recorded higher flexural strength than Jema sand for 19 mm coarse aggregate whereas, for 12.5 mm aggregate, the three concrete mixes have close to equal flexural strength. The graphical representation of the mean flexural strengths made from 19 mm and 12.5 mm coarse aggregates for target strength of C70, C80 and C90 concrete strength is shown in *Graph 4. 6 and Graph 4. 7*.



Graph 4. 6: Graphical representation of flexural strength using 01 aggregate



Graph 4. 7: Graphical representation of flexural strength using 02 aggregate

4.2.2.7. Tensile strength

The tensile strength of concrete is not direct strength criterion of HSC however its strength has a practical function to evaluate cracking and control of deflection under service load. The tensile strength of concrete can be measured directly by the application of an axial tensile load over a given cross-sectional area of the concrete specimen. Since measuring the tensile strength of concrete is not the scope of this research, its measurement in the laboratory is not conducted.

Different codes have produced an empirical formula to determine the tensile strength of concrete based on the compressive strength.

The Ethiopian standard (CES, 2015) has formulated the following formula to determine the tensile strength of concrete (f_t).

$f_t = 2.12\ln(1+f_{cm}/10)$ where f_{cm} is the mean compressive strength

Therefore the tensile strength of each concrete mix can be readily evaluated according to the given code.

4.2.2.8. Mortar Strength

The selected three types of sand were used to cast mortar and test for compressive strength. The casting mold is cubical with size 7 cm for all types of sand mortars.

The mortars were prepared and casted in accordance to the outline procedures in Section 3.3.

The mortar specimens were tested by a compressive testing machine in accordance to ASTM C109 where the rate of loading of the machine was adjusted at 1350 N/s. *Table 4. 15* shows the mean compressive strength of the mortars at the 3rd, 7th and 28th days of age. In order of strength gain, Ambo Mortar supersedes Jema Mortar in all of the strengths and Ambo mortar has more close results with the control mix which is made from river sand. In ASTM or other international standards, there is no minimum specified mortar strength to determine the sand quality.

Mortar strength test is one of the criteria to check the presence of impurities in sand. Impure sand containing organic matter or other undesirable materials exhibits lower strength because these unwanted matters coat the sand particles and affect the formation of strong bond between the cement and the sand.

The relative mortar strength measures the ratio of mortar made from the sand in subject to the mortar made from the standard sand or the control mix. The relative mortar strength of Jema sand is 0.88 and Ambo sand is 1.

Table 4. 15: Summary of average mortar strength for ambo and Jema sandstone

Mortar made from	Mortar age			Average weight @ 28 days (gm)	Difference change from the control mix @ 28 days (MPa)	Percentage change from the control mix@ 28 days
	3 days	7 days	28 days			
Jema sand	14.82	21.22	28.88	2218	-3.79	88.4%
Ambo sand	16.48	25.39	32.97	2253	+0.3	100.93%
River sand	17.58	26.14	32.67	2257	±0.0	100%

The graphical representation of the mortar strength at different age is shown in *Graph 4. 8.*

Graph 4. 8: Graphical representation of the mortar strength at different age

The ratio of the mortar strength at the 3rd day when compared with its own 28th day is maximum for the control mix (53.8%) and sand followed by Jema (51.32%) and Ambo mortar (49.98%). The strength development of individual mortars is graphically shown in *Graph 4. 9.*

The rate of strength gain from the 3rd days to 28th day for Jema, Ambo and River sand is 0.49%. 0.5% and 0.46% respectively. This indicates that Ambo sand has the minimum 3 days of strength and the maximum 28 days strength. At the 28 days strength of Ambo sand and the control mix River sand are almost equal in strength. The strength of Jema sand at the 28 days is lower than the control mix by 3.8 MPa whereas the mortar strength at 28th day of Ambo sand has almost equal strength with the control sand.

Graph 4. 9: Rate of mortar strength development

4.2.2.9. Profile of concrete specimen at failure under load

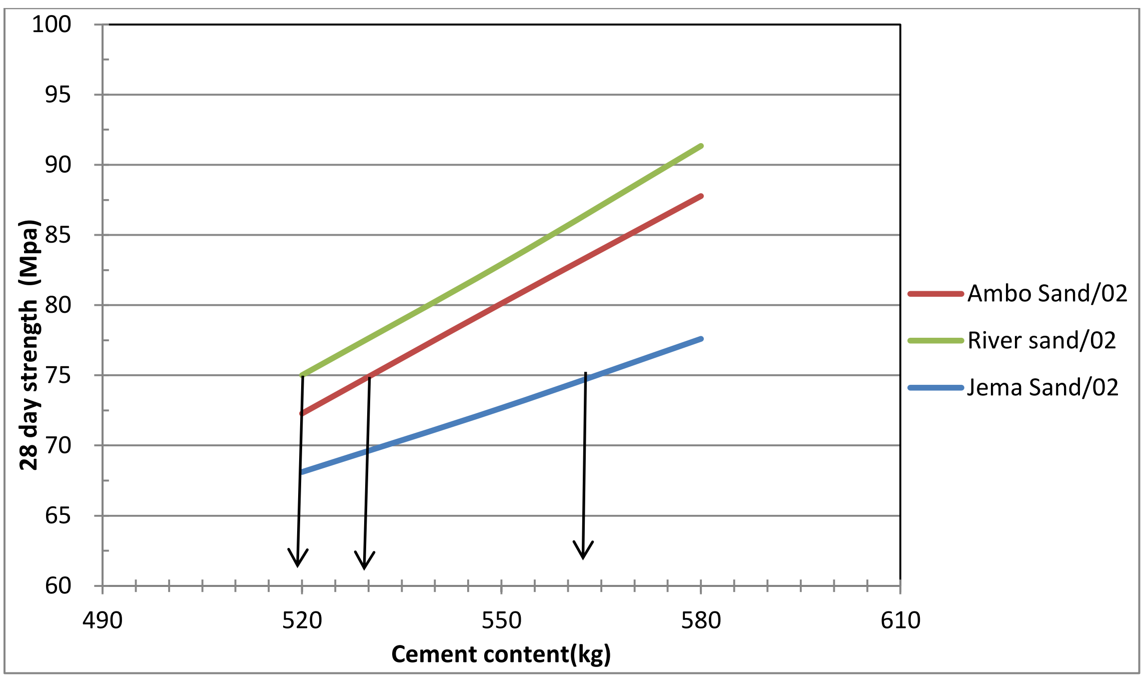
After the concrete was tested for compression and fracture load, the specimen was observed to study the failure mode. In compression, the specimens were crushed in a similar pattern that the failure was within the internal concrete matrix. The internal failure face of the concrete specimen shows that the concrete failed after individual coarse aggregates are cracked. The same observation was depicted in the flexural concrete specimen where the failure plane cracked all the interfering coarse aggregates. High strength concrete exhibits a lower cumulative length of micro cracks and shows a lower deformation (probably due to a higher modulus of elasticity). Typical failure mode in compression and flexure is shown in *Figure 4. 1*.

Figure 4. 1: Failure mode of samples (Left: under axial load, Right: under flexure load)

4.3. Economic analysis and Cost difference

Concrete is one of the widely used construction materials. Its cost has a direct impact on the sustainability of the construction industry. The cost of HSC when compared with the normal strength concrete is high because of the higher cement content, the use of high quality aggregates, the cost of chemical or mineral admixtures and the need to conduct a repetitive trial test.

In this research three types of concrete casted using Jema, Ambo and River sand. In section *4.2.2.4*, it is indicated that the general strength of Ambo Concrete is better than Jema Concrete. A graph was drawn by considering the cement content in the concrete against the attained strength at 28 days for the three types of sand. A horizontal line is drawn at 75 MPa strength (*Graph 4.10*) in order to cross all the graphs and the corresponding cement content was recorded for cost calculation. Therefore the cost comparison was made to produce a single cubic meter of concrete which can produce 75 MPa.



Graph 4. 10: 28^{th} day compressive strength of concretes for different cement content

The cost calculation for each sand type was performed considering the cost of the individual sand and other related costs (*Table 4. 16*). Mixing of the concrete and transportation cost is not included in the cost calculation as it is considered constant for the every concrete types. The cost calculation is assumed at base location of Addis Ababa and accordingly all related costs are considered at the base location.

The main difference between the cost calculation of River sand, Jema and Ambo sand lies on:-

- The distance from the extraction site to Addis Ababa.
- Cement content to produce a unit volume of concrete
- Admixture quantity as it depends on the cement content
- Sand washing cost. From the observation during laboratory activity, Ambo sand requires washing in 6 cycles and Jema requires washing in 2 cycles in order to remove the silt and clay content.

Table 4. 16: Material cost analysis for the three sand types

Material cost types	**Concrete made from Jema sand**			**Concrete made from Ambo sand**			**Concrete made from River sand**		
	Unit price (Br.)	Qty.	Material cost (Br.)	Unit price (Br.)	Qty.	Material cost (Br.)	Unit price (Br.)	Qty.	Material cost (Br.)
Cement OPC(Qt.)	2000	5.62	11,240	2000	5.30	10,600	2000	5.20	10,400
Coarse aggregate (m^3)	2300	0.72	1,661.66	2300	0.72	1,661.66	2300	0.72	1,661.66
Fine aggregate (m^3)	715.2	0.40	288.05	647.1	0.40	261.65	2,200	0.40	889.56
water(lt)	0.5	200	100.00	0.5	200	100.00	0.5	200	100.00
Admixture (lt)	117	7.37	862.35	117	6.95	813.25	117	6.82	797.90
Sand washing cost (washing cycle)	62.5	2.00	125.00	62.5	6.00	375.00	62.5	2.00	125.00
Total material cost			**14,277.06**			**13,811.56**			**13,974.12**

Notes: 1) Unit cost of materials at the time of preparing the cost calculation is the material cost is April 2023

2) Labour cost is excluded since it is not variable cost that depends on the sand type.

The result in the cost calculation includes material cost only. The material cost to produce a unit volume of concrete having strength of 75 MPa with Jema sand is 14,277.06 Br., for Ambo sand is 13,811.56 Br. and for the river sand is 13,974.12 Br. There is a cost difference of 465.5 Br/m^3 between the Jema and Ambo concretes while Ambo concrete is cheaper. The material cost for the concrete made from river sand is higher by an amount of 162.56 Br. than the Ambo concrete while in all cases, Ambo concrete is cheapest sand to make HSC. In other words, utilizing Ambo sand for HSC is 3.26% cheaper than Jema sand and 1.16% cheaper than the river sand given that the strength in the subject is 75 MPa.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The research focused on the suitability of sandstone as fine aggregate for the production of high strength concrete. The fine aggregates were retrieved from the source locations at Jema Valley and Ambo Mountains. In order to properly evaluate the strength development and achievement of the two sand sources, a control mix was prepared from selected site and parallel comparisons were made. All the three sands were properly washed and quality tests were conducted before concrete mixes. Using the three sands, concrete specimens were casted and tested. From the overall research conducted, the following important points were concluded.

- Ambo and Jema sands when used as fine aggregate have achieved considerable strength to meet the requirements of High strength concrete. However, the cement demand to produce a specific compressive strength is different for the two sands. The compressive strength of Ambo sandstone concrete is higher than Jema sand in the three grades of concrete (C70, C80 and C90) when concrete is casted with an equal amount of cement content. The modulus elasticity of all the concrete specimens have higher values than stipulated by different scholars. Even though the strength that have attained for a specific target strength are different when using Jema and Ambo sandstone, it is in general concluded that sand source from Ambo and Jema sources can be used for the production of HSC.
- The flexural strengths of the three types of sands have achieved a higher flexural strength than what is recommended by CES. Even though Ambo concrete has recorded higher flexural strength than Jema sand for 19 mm coarse aggregate, the difference in strength is slight. Concrete casted using 12 mm aggregate, the three concrete mixes (made from Jema, Ambo and river sand) have close to equal flexural strength.
- High strength concrete has shown a higher rate of strength gain at early ages as compared to the normal strength concrete. On the average of the overall concrete mixes, the 7^{th} day compressive strength against the 28^{th} day strength is 89.5%, 87.7% and 88.6% for concretes made from Jema, Ambo and River sands.
- By making the destination place at Addis Ababa, the unit cost of high strength concrete made from Ambo sand is cheaper when made from river sand or Jema sand. The cost of concrete made using Ambo sand is 3.26% cheaper than Jema sand and it is 1.16% cheaper than the control sand.

5.2. Recommendations

In Ethiopia, most of the sand for construction comes from river beds and the use of sand for construction from mountainous quarries is uncommon. Sandstone is the other potentially untapped option to quench the fine aggregate demand in the current rapidly developing construction sector. Below, there are recommendations forwarded on the sandstone utilizations based on the outcome of this research.

- In general it is recommended that Ambo sand and Jema sand can be used to produce HSC after properly washed until the silt and clay content is vanished. The initial clay content of Ambo and Jema sand is 14% and 3.1%. Without washing, either of the two sands should not be used for any construction activity because of the high silt and clay amount.
- Ambo sand exhibits a strong bond with OPC cement during mortar preparation hence Ambo sand is recommended to be used for plastering purpose than Jema sand. However, the unusual reddish color can be treated by painting when with appropriate paint or treat with cement wash.
- Since the source of Ambo and Jema sand is from the excavation of Sandstone Mountain, proper scientific extraction practices shall be in put place. In order to minimize environmental degradation and reduce the negative impacts of the residential or agricultural land downhill across the extraction site, flood control and silt trapping structure shall be planned.
- The Federal or Regional bureaus can promote the benefit of the two of sand extracted from Sandstone Mountain to be used as an alternative to the fine aggregate for HSC concrete production. They can further promote more researches to be conducted on the two sandstone sources.

5.3. Area of further studies

Apart from what is listed and studied in this research, HSC using natural sandstone material has not been studied in depth. A few of the possible research area on the production of HSC using natural sand stone is listed below.

- As a direct extension of this work, the production of high-performance concrete using Ambo and Jema sand can be investigated. In addition, since the cement content of HSC is more significant in determining the key behavior of the concrete, chemical shrinkage which results in the development of internal voids in the paste structure without causing pronounced volume change and autogenous shrinkage which results in overall volume external volume change in concrete have pronounced effect on concrete. These key elements are amongst the most important factors that future research could focus on.
- High-strength concrete is more sensitive to cement brands than normal-strength concrete hence the effect of different cement brands on the strength development and durability of concrete shall be studied when sandstone is used as a replacement to the fine aggregate.
- Blending of Jema and Ambo sand with river sand or with crushed sand in the production of HSC is another study area targeting the production of HSC. Its effect on the economy and quality of HSC can be studied.
- Coarse aggregate may have a more pronounced effect in high-strength concrete than in conventional concrete therefore repeating the HSC design using a different aggregate other than basaltic aggregates(like granite aggregate) is another study area in the development of HSC.

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Appendix 1 - Material Laboratory Test Results

A.1 Concrete compressive strength test result of individual samples

A.1.1	Mix code:	J70/02			Target concrete strength =			70 MPa
Coarse Aggregate Nominal Size=				20 mm	Fine Aggregate Type:-		Jema sand	
Concrete Age (days)	Sample no	Dimention(cm)			Weight(gm)	Unit Weight (kg/m^3)	Failure load(KN)	Compressive Strength (MPa)
		L	W	D				
	1	15	15	15	8499	2,518.22	1293.3	57.45
7	2	15	15	15	8332	2,468.74	1414.5	62.86
	3	15	15	15	8505	2,520.00	1385.9	61.58
Average						2,502.32		60.63
	1	15	15	15	8505	2,520.00	1565.1	69.56
28	2	15	15	15	8418	2,494.22	1564.4	69.53
	3	15	15	15	8575	2,540.74	1468.8	65.24
Average						2,518.32		68.11
	1	15	15	15	8555	2,534.81	1587.4	70.5
56	2	15	15	15	8498	2,517.93	1583.1	70.36
	3	15	15	15	8516	2,523.26	1486.1	66.04
Average						2,525.33		68.97

A.1.2	Mix code:	J70/01			Target concrete strength =			70 MPa
Coarse Aggregate Nominal Size=				12.5 mm	Fine Aggregate Type:-		Jema sand	
Concrete Age (days)	Sample no	Dimention(cm)			Weight(gm)	Unit Weight (kg/m^3)	Failure load(KN)	Compressive Strength (MPa)
		L	W	D				
	1	15	15	15	8606	2549.93	1274.5	56.64
7	2	15	15	15	8579	2541.93	1316.4	58.51
	3	15	15	15	8458	2506.07	1295.1	57.56
Average						2532.64		57.57
	1	15	15	15	8374	2481.19	1421.3	63.17
28	2	15	15	15	8390	2485.93	1501.4	66.73
	3	15	15	15	8407	2490.96	1432.8	63.67
Average						2486.02		64.52
	1	15	15	15	8330	2468.15	1442.6	64.07
56	2	15	15	15	8324	2466.37	1624.8	72.21
	3	15	15	15	8339	2470.81	1479	65.7
Average						2468.44		67.33

A.1.3	Mix code: J80/02				Target concrete strength =			80 MPa
Coarse Aggregate Nominal Size=			20 mm		Fine Aggregate Type:- Jema sand			
Concrete Age (days)	Sample no	Dimention(cm) L	W	D	Weight(gm)	Unit Weight (kg/m^3)	Failure load(KN)	Compressive Strength (MPa)
	1	15	15	15	8418	2494.22	1545	68.67
7	2	15	15	15	8643	2560.89	1200.1	62.12
	3	15	15	15	8667	2568.00	1426.7	63.41
Average						2,541.04		64.73
	1	15	15	15	8496	2517.33	1540.5	68.47
28	2	15	15	15	8535	2528.89	1644.9	73.11
	3	15	15	15	8491	2515.85	1719.8	76.44
Average						2,520.69		72.67
	1	15	15	15	8524	2525.63	1562.5	69.44
56	2	15	15	15	8520	2524.44	1671.2	74.27
	3	15	15	15	8532	2528.00	1741.2	77.3
Average						2,526.02		73.67

A.1.4	Mix code: J80/01				Target concrete strength =			80 MPa
Coarse Aggregate Nominal Size=			12.5 mm		Fine Aggregate Type:- Jema sand			
Concrete Age (days)	Sample no	Dimention(cm) L	W	D	Weight(gm)	Unit Weight (kg/m^3)	Failure load(KN)	Compressive Strength (MPa)
	1	15	15	15	8553	2534.22	1392.3	61.88
7	2	15	15	15	8692	2575.41	1410.3	62.68
	3	15	15	15	8603	2549.04	1465.3	65.56
Average						2,552.89		63.37
	1	15	15	15	8626	2555.85	1631.9	72.49
28	2	15	15	15	8516	2523.26	1550.9	68.93
	3	15	15	15	8320	2465.19	1468.3	73.26
Average						2,514.77		71.56
	1	15	15	15	8445	2502.22	1655.2	73.52
56	2	15	15	15	8447	2502.81	1823	81
	3	15	15	15	8320	2465.19	1668	74.16
Average						2,490.07		76.23

A.1.5	Mix code: J90/02				Target concrete strength =			90 MPa
Coarse Aggregate Nominal Size=			20 mm		Fine Aggregate Type:-		Jema sand	
Concrete Age (days)	Sample no	Dimention(cm)			Weight(gm)	Unit Weight (kg/m^3)	Failure load(KN)	Compressive Strength (MPa)
		L	W	D				
	1	15	15	15	8655	2564.44	1708.8	74.95
7	2	15	15	15	8333	2469.04	1504.6	66.85
	3	15	15	15	8494	2516.74	1599.7	71.1
Average						2,516.74		70.97
	1	15	15	15	8513	2522.37	1833.7	81.5
28	2	15	15	15	8402	2489.48	1724.6	76.65
	3	15	15	15	8507	2520.59	1679.6	74.65
Average						2,510.81		77.60
	1	15	15	15	8526	2526.22	1862.2	82.76
56	2	15	15	15	8456	2505.48	1725.4	76.68
	3	15	15	15	8592	2545.78	1700.4	75.57
Average						2,525.83		78.34

A.1.6	Mix code: J90/01				Target concrete strength =			90 MPa
Coarse Aggregate Nominal Size=			12.5 mm		Fine Aggregate Type:-		Jema sand	
Concrete Age (days)	Sample no	Dimention(cm)			Weight(gm)	Unit Weight (kg/m^3)	Failure load(KN)	Compressive Strength (MPa)
		L	W	D				
	1	15	15	15	8539	2530.07	1592.7	70.79
7	2	15	15	15	8511	2521.78	1505.4	66.66
	3	15	15	15	8678	2571.26	1600.2	71.12
Average						2,541.04		69.52
	1	15	15	15	8632	2557.63	1753.9	78.13
28	2	15	15	15	8476	2511.41	1703.4	75.71
	3	15	15	15	8585	2543.70	1766.5	78.51
Average						2,537.58		77.45
	1	15	15	15	8640	2560.00	1782.1	79.25
56	2	15	15	15	8405	2490.37	1704	75.74
	3	15	15	15	8502	2519.11	1875.7	83.4
Average						2,523.16		79.46

A.1.7	Mix code: A70/02				Target concrete strength =			70 MPa
Coarse Aggregate Nominal Size=			20 mm		Fine Aggregate Type:-		Ambo sand	
Concrete Age (days)	Sample no	Dimention(cm) L	W	D	Weight(gm)	Unit Weight (kg/m^3)	Failure load(KN)	Compressive Strength (MPa)
	1	15	15	15	8580	2542.22	1610.5	71.58
7	2	15	15	15	8810	2610.37	1241.5	55.17
	3	15	15	15	8527	2526.52	1302.4	57.85
Average						2,559.70		61.53
	1	15	15	15	8469	2509.33	1578.6	70.16
28	2	15	15	15	8423	2495.70	1579.2	70.19
	3	15	15	15	8686	2573.63	1721.2	76.48
Average						2,526.22		72.28
	1	15	15	15	8487	2514.67	1601.1	71.16
56	2	15	15	15	8443	2501.63	1748.5	77.71
	3	15	15	15	8473	2510.52	1612.2	71.6
Average						2,508.94		73.49

A.1.8	Mix code: A70/01				Target concrete strength =			70 MPa
Coarse Aggregate Nominal Size=			12.5 mm		Fine Aggregate Type:-		Ambo sand	
Concrete Age (days)	Sample no	Dimention(cm) L	W	D	Weight(gm)	Unit Weight (kg/m^3)	Failure load(KN)	Compressive Strength (MPa)
	1	15	15	15	8287	2455.41	1320	58.67
7	2	15	15	15	8258	2446.81	1422.2	63.21
	3	15	15	15	8272	2450.96	1490.4	66.24
Average						2,451.06		62.71
	1	15	15	15	8317	2464.30	1520.8	67.59
28	2	15	15	15	8451	2504.00	1483.6	65.94
	3	15	15	15	8847	2621.33	1720.4	76.45
Average						2,529.88		69.99
	1	15	15	15	8345	2472.59	1542.4	68.55
56	2	15	15	15	8420	2494.81	1558	69.31
	3	15	15	15	8627	2556.15	1775.8	78.9
Average						2,507.85		72.25

A.1.9	Mix code: A80/02				Target concrete strength =			80 MPa
Coarse Aggregate Nominal Size=				20 mm	Fine Aggregate Type:-		Ambo sand	
Concrete Age (days)	Sample no	Dimention(cm)			Weight(gm)	Unit Weight (kg/m^3)	Failure load(KN)	Compressive Strength (MPa)
		L	W	D				
	1	15	15	15	8692	2575.41	1709.1	75.96
7	2	15	15	15	8604	2549.33	1744.2	77.52
	3	15	15	15	8551	2533.63	1430.5	63.55
Average						2,552.79		72.34
	1	15	15	15	8559	2536.00	1804.7	80.21
28	2	15	15	15	8472	2510.22	1823.6	81.05
	3	15	15	15	8559	2536.00	1780.2	79.1
Average						2,527.41		80.12
	1	15	15	15	8377	2482.07	1814.5	80.64
56	2	15	15	15	8503	2519.41	1846.5	82.02
	3	15	15	15	8525	2525.93	1891.8	84.08
Average						2,509.14		82.25

A.1.10	Mix code: A80/01				Target concrete strength =			80 MPa
Coarse Aggregate Nominal Size=				12.5 mm	Fine Aggregate Type:-		Ambo sand	
Concrete Age (days)	Sample no	Dimention(cm)			Weight(gm)	Unit Weight (kg/m^3)	Failure load(KN)	Compressive Strength (MPa)
		L	W	D				
	1	15	15	15	8265	2448.89	1664.1	73.96
7	2	15	15	15	8378	2482.37	1487.1	66.09
	3	15	15	15	8321	2465.48	1455.5	64.69
Average						2,465.58		68.25
	1	15	15	15	8649	2562.67	1799.7	79.99
28	2	15	15	15	8258	2446.81	1788.9	79.51
	3	15	15	15	8559	2536.00	1804.7	80.21
Average						2,515.16		79.90
	1	15	15	15	8637	2559.11	1862.4	82.73
56	2	15	15	15	8586	2544.00	1872.6	83.22
	3	15	15	15	8439	2500.44	1757.25	78.1
Average						2,534.52		81.35

A.1.11	Mix code: A90/02				Target concrete strength =			90 MPa
Coarse Aggregate Nominal Size=			20 mm		Fine Aggregate Type:-		Ambo sand	
Concrete Age (days)	Sample no	Dimention(cm)			Weight(gm)	Unit Weight (kg/m^3)	Failure load(KN)	Compressive Strength (MPa)
		L	W	D				
	1	15	15	15	8515	2522.96	1820.9	80.91
7	2	15	15	15	8692	2575.41	1800.8	80.02
	3	15	15	15	8603	2549.04	1697.4	75.44
Average						2,549.14		78.79
	1	15	15	15	8469	2509.33	1873	83.21
28	2	15	15	15	8514	2522.67	1994.1	88.63
	3	15	15	15	8712	2581.33	2058.3	91.48
Average						2,537.78		87.77
	1	15	15	15	8491	2515.85	1800.8	85.62
56	2	15	15	15	8458	2506.07	2054.9	91.33
	3	15	15	15	8609	2550.81	2055.6	91.36
Average						2,524.25		89.44

A.1.12	Mix code: A90/01				Target concrete strength =			90 MPa
Coarse Aggregate Nominal Size=			12.5mm		Fine Aggregate Type:-		Ambo sand	
Concrete Age (days)	Sample no	Dimention(cm)			Weight(gm)	Unit Weight (kg/m^3)	Failure load(KN)	Compressive Strength (MPa)
		L	W	D				
	1	15	15	15	8649	2562.67	1659.3	73.75
7	2	15	15	15	8335	2469.63	1683.9	74.84
	3	15	15	15	8419	2494.52	1523.5	67.7
Average						2,508.94		72.10
	1	15	15	15	8608	2550.52	1974.8	87.77
28	2	15	15	15	8499	2518.22	1934.4	85.97
	3	15	15	15	8553	2534.22	1742.4	77.44
Average						2,534.32		83.73
	1	15	15	15	8620	2554.07	1991.5	88.55
56	2	15	15	15	8487	2514.67	1935.2	86.01
	3	15	15	15	8569	2538.96	1765	78.4
Average						2,535.90		84.32

A.1.13	Mix code: R70/02				Target concrete strength =			70 MPa
Coarse Aggregate Nominal Size=			20 mm		Fine Aggregate Type:-		River sand	
Concrete Age (days)	Sample no	Dimention(cm) L	W	D	Weight(gm)	Unit Weight (kg/m^3)	Failure load(KN)	Compressive Strength (MPa)
	1	15	15	15	8628	2556.44	1611.9	71.62
7	2	15	15	15	8664	2567.11	1424.6	63.31
	3	15	15	15	8625	2555.56	1599	71.09
Average						2,559.70		68.67
	1	15	15	15	8529	2527.11	1721	76.49
28	2	15	15	15	8538	2529.78	1612.5	71.62
	3	15	15	15	8510	2521.48	1708.2	76.92
Average						2,526.12		75.01
	1	15	15	15	8506	2520.30	1594.4	73.82
56	2	15	15	15	8690	2574.81	1742.1	77.42
	3	15	15	15	8628	2556.44	1728.4	76.86
Average						2,550.52		76.03

A.1.14	Mix code: R70/01				Target concrete strength =			70 MPa
Coarse Aggregate Nominal Size=			12 mm		Fine Aggregate Type:-		River sand	
Concrete Age (days)	Sample no	Dimention(cm) L	W	D	Weight(gm)	Unit Weight (kg/m^3)	Failure load(KN)	Compressive Strength (MPa)
	1	15	15	15	8437	2499.85	1564.2	69.52
7	2	15	15	15	8370	2480.00	1224.2	54.42
	3	15	15	15	8597	2547.26	1353.6	60.14
Average						2,509.04		61.36
	1	15	15	15	8297	2458.37	1543.5	68.54
28	2	15	15	15	8591	2545.48	1564.4	72.53
	3	15	15	15	8444	2501.93	1692.9	75.24
Average						2,501.93		72.10
	1	15	15	15	8337	2470.22	1634.1	72.58
56	2	15	15	15	8551	2533.63	1659.3	73.7
	3	15	15	15	8675	2570.37	1748.7	77.67
Average						2,524.74		74.65

A.1.15	Mix code:	R80/02			Target concrete strength =			80 MPa
Coarse Aggregate Nominal Size=				20 mm	Fine Aggregate Type:-		River sand	
Concrete Age (days)	Sample no	Dimention(cm) L	W	D	Weight(gm)	Unit Weight (kg/m^3)	Failure load(KN)	Compressive Strength (MPa)
	1	15	15	15	8370	2480.00	1810.1	80.45
7	2	15	15	15	8497	2517.63	1704.6	75.76
	3	15	15	15	8724	2584.89	1507.5	66.68
Average						2,527.51		74.30
	1	15	15	15	8524	2525.63	1894.9	84.22
28	2	15	15	15	8533	2528.30	1944	86.4
	3	15	15	15	8540	2530.37	1758.1	78.14
Average						2,528.10		82.92
	1	15	15	15	8421	2495.11	1921.9	85.42
56	2	15	15	15	8532	2528.00	1977.3	87.83
	3	15	15	15	8579	2541.93	1779.9	80.1
Average						2,521.68		84.45

A.1.16	Mix code:	R80/01			Target concrete strength =			80 MPa
Coarse Aggregate Nominal Size=				12 mm	Fine Aggregate Type:-		River sand	
Concrete Age (days)	Sample no	Dimention(cm) L	W	D	Weight(gm)	Unit Weight (kg/m^3)	Failure load(KN)	Compressive Strength (MPa)
	1	15	15	15	8483	2513.48	1615.9	71.82
7	2	15	15	15	8540	2530.37	1665.9	74.04
	3	15	15	15	8313	2463.11	1417.6	63.01
Average						2,502.32		69.62
	1	15	15	15	8517	2523.56	1832.8	82.46
28	2	15	15	15	8347	2473.19	1878.7	84.5
	3	15	15	15	8824	2614.52	1763.9	78.39
Average						2,537.09		81.78
	1	15	15	15	8613	2552.00	1859	82.6
56	2	15	15	15	8532	2528.00	1911	84.8
	3	15	15	15	8721	2584.00	1785.6	83.36
Average						2,554.67		83.59

A.1.17	Mix code: R90/02				Target concrete strength =			90 MPa
Coarse Aggregate Nominal Size=			20 mm		Fine Aggregate Type:- River sand			
Concrete Age (days)	Sample no	Dimention(cm)			Weight(gm)	Unit Weight (kg/m^3)	Failure load(KN)	Compressive Strength (MPa)
		L	W	D				
	1	15	15	15	8694	2576.00	1863.6	82.83
7	2	15	15	15	8752	2593.19	1817.1	80.76
	3	15	15	15	8823	2614.22	1866.6	82.96
Average						2,594.47		82.18
	1	15	15	15	8536	2529.19	2031	90.3
28	2	15	15	15	8752	2593.19	2012.6	89.45
	3	15	15	15	8325	2466.67	2121	94.29
Average						2,529.68		91.35
	1	15	15	15	8532	2528.00	2061.7	91.58
56	2	15	15	15	8663	2566.81	2038.7	90.61
	3	15	15	15	8548	2532.74	2149.8	95.54
Average						2,542.52		92.58

A.1.18	Mix code: R90/01				Target concrete strength =			90 MPa
Coarse Aggregate Nominal Size=			12 mm		Fine Aggregate Type:- River sand			
Concrete Age (days)	Sample no	Dimention(cm)			Weight(gm)	Unit Weight (kg/m^3)	Failure load(KN)	Compressive Strength (MPa)
		L	W	D				
	1	15	15	15	8552	2533.93	1842.6	81.89
7	2	15	15	15	8432	2498.37	1800.6	80.03
	3	15	15	15	8492	2516.15	1752	77.87
Average						2516.15		79.93
	1	15	15	15	8585	2543.70	1991.2	88.5
28	2	15	15	15	8614	2552.30	1986.3	88.28
	3	15	15	15	8499	2518.22	2012.4	89.44
Average						2538.07		88.74
	1	15	15	15	8626	2555.85	2019.6	89.76
56	2	15	15	15	8586	2544.00	2113	93.87
	3	15	15	15	8556	2535.11	2039.2	90.63
Average						2544.99		91.42

A.2 Flexural test result of individual samples

A.2.1

Jema sand Flexural strength test Result using 20 mm coarse aggregate (28th days)

Target strength	Sample no	Dimention(m)			Failure Load(KN)	Modulus of rupture= *Pl/bd2* (MPa)
		L	b	d		
	1	0.45	0.1	0.1	10.40	4.68
C70	2	0.45	0.1	0.1	10.30	4.64
	3	0.45	0.1	0.1	11.90	5.36
Average						**4.89**
	1	0.45	0.1	0.1	12.7	5.72
C80	2	0.45	0.1	0.1	15.1	6.80
	3	0.45	0.1	0.1	13.9	6.26
Average						**6.26**
	1	0.45	0.1	0.1	16.7	7.52
C90	2	0.45	0.1	0.1	15.8	7.11
	3	0.45	0.1	0.1	16.2	7.29
Average						**7.31**

A.2.2

Jema sand Flextural strength test Result using 12.5 mm coarse aggregate (28th days)

Target strength	sample no	Dimention(m)			Failure Load(KN)	Modulus of rupture= *Pl/bd2* (MPa)
		L	b	d		
	1	0.45	0.1	0.1	8.80	3.96
C70	2	0.45	0.1	0.1	10.90	4.91
	3	0.45	0.1	0.1	11.70	5.27
Average						**4.71**
	1	0.45	0.1	0.1	12	5.40
C80	2	0.45	0.1	0.1	11.8	5.31
	3	0.45	0.1	0.1	11.7	5.27
Average						**5.33**
	1	0.45	0.1	0.1	12.1	5.45
C90	2	0.45	0.1	0.1	13.7	6.17
	3	0.45	0.1	0.1	12.3	5.54
Average						**5.72**

A.2.3

Ambo sand Flexural strength test Result using 20 mm coarse aggregate (28th days)

Target strength	sample no	Dimention(m)			Failure Load(KN)	Modulus of rupture= *Pl/bd2* (MPa)
		L	b	d		
	1	0.45	0.1	0.1	13.8	6.21
C70	2	0.45	0.1	0.1	14.4	6.48
	3	0.45	0.1	0.1	14.2	6.39
Average						**6.36**
	1	0.45	0.1	0.1	16.3	7.34
C80	2	0.45	0.1	0.1	15.1	6.80
	3	0.45	0.1	0.1	15.7	7.07
Average						**7.07**
	1	0.45	0.1	0.1	16.2	7.29
C90	2	0.45	0.1	0.1	16.5	7.43
	3	0.45	0.1	0.1	16.7	7.52
Average						**7.41**

A.2.4

Ambo sand Flexural strength test Result using 12.5 mm coarse aggregate (28th days)

Target strength	Sample no	Dimention(m)			Failure Load(KN)	Modulus of rupture= *Pl/bd2* (MPa)
		L	b	d		
	1	0.45	0.1	0.1	11.1	5.00
C70	2	0.45	0.1	0.1	10.7	4.82
	3	0.45	0.1	0.1	12.3	5.54
Average						**5.12**
	1	0.45	0.1	0.1	12.2	5.49
C80	2	0.45	0.1	0.1	12.4	5.58
	3	0.45	0.1	0.1	12.3	5.54
Average						**5.54**
	1	0.45	0.1	0.1	12.4	5.58
C90	2	0.45	0.1	0.1	12.5	5.63
	3	0.45	0.1	0.1	13.7	6.17
Average						**5.79**

A.2.5

River sand Flexural strength test Result using 20 mm coarse aggregate (28th days)

Target strength	sample no	Dimention(m) L	b	d	Failure Load(KN)	Modulus of rupture= *Pl/bd2* (MPa)
	1	0.45	0.1	0.1	14	6.30
C70	2	0.45	0.1	0.1	14.6	6.57
	3	0.45	0.1	0.1	14.4	6.48
Average						**6.45**
	1	0.45	0.1	0.1	16.7	7.52
C80	2	0.45	0.1	0.1	14.9	6.71
	3	0.45	0.1	0.1	15.9	7.16
Average						**7.13**
	1	0.45	0.1	0.1	16.8	7.56
C90	2	0.45	0.1	0.1	17.1	7.70
	3	0.45	0.1	0.1	17.5	7.88
Average						**7.71**

A.2.6

River sand Flexural strength test Result using 20 mm coarse aggregate (28th days)

Target strength	sample no	Dimention(m) L	b	d	Failure Load(KN)	Modulus of rupture= *Pl/bd2* (MPa)
	1	0.45	0.1	0.1	12.5	5.63
C70	2	0.45	0.1	0.1	12.8	5.76
	3	0.45	0.1	0.1	9.4	4.23
Average						**5.21**
	1	0.45	0.1	0.1	12.6	5.67
C80	2	0.45	0.1	0.1	12.4	5.58
	3	0.45	0.1	0.1	12.4	5.58
Average						**5.61**
	1	0.45	0.1	0.1	12.6	5.67
C90	2	0.45	0.1	0.1	12.9	5.81
	3	0.45	0.1	0.1	12.3	5.54
Average						**5.67**

A.3 Mortar compressive strength test result of individual samples

A.3.1		Mortar strength test: Jema Sandstone						
Mortar Age	Sample no	Dimention(cm) L	W	D	Weight(gm)	Unit Weight (kg/m^3)	Failure load(KN)	Compressive strength (MPa)
3	1	7	7	7	754	2,198.3	70.2	14.33
	2	7	7	7	717.5	2,091.8	73.8	15.06
	3	7	7	7	756	2,204.1	73.8	15.07
	Average					2,164.72		14.82
7	1	7	7	7	761.5	2,220.1	96.4	19.68
	2	7	7	7	755.7	2,203.2	103.8	21.19
	3	7	7	7	756	2,204.1	111.6	22.78
	Average					2,209.14		21.22
28	1	7	7	7	766.2	2,233.8	156.2	31.87
	2	7	7	7	756.6	2,205.8	139.7	28.52
	3	7	7	7	759.8	2,215.2	128.6	26.25
	Average					2,218.27		28.88

A.3.2		Mortar strength test: Ambo Sand						
Mortar Age	Sample no	Dimention(cm) L	W	D	Weight(gm)	Unit Weight (kg/m^3)	Failure load(KN)	Compressive strength (MPa)
3	1	7	7	7	751.3	2,190.38	75.80	15.46
	2	7	7	7	757	2,207.00	85.20	17.40
	3	7	7	7	758.2	2,210.50	81.30	16.58
	Average					2,202.62		16.48
7	1	7	7	7	740.4	2,158.60	133.5	27.29
	2	7	7	7	748.2	2,181.34	123.1	23.07
	3	7	7	7	743.1	2,166.47	126.5	25.81
	Average					2,168.80		25.39
28	1	7	7	7	772.5	2,252.19	168.1	34.31
	2	7	7	7	773.4	2,254.81	152.6	31.14
	3	7	7	7	772.7	2,252.77	164.003	33.47
	Average					2,253.26		32.97

A.3.3		Mortar strength test: River Sand						
Mortar Age	Sample no	Dimention(cm)			Weight(gm)	Unit Weight (kg/m^3)	Failure load(KN)	Compressive strength (MPa)
		L	W	D				
3	1	7	7	7	762.6	2,223.32	80	16.33
	2	7	7	7	750.7	2,188.63	91.6	18.73
	3	7	7	7	774	2,256.56	86.6	17.67
	Average					2,222.84		17.58
7	1	7	7	7	760	2,215.74	119.4	24.37
	2	7	7	7	761.9	2,221.28	135.8	27.73
	3	7	7	7	759.5	2,214.29	128.3	26.32
	Average					2,217.10		26.14
28	1	7	7	7	774.3	2,257.43	165.9	33.86
	2	7	7	7	766.2	2,233.82	156.2	31.87
	3	7	7	7	782	2,279.88	168.1	32.28
	Average					2,257.05		32.67

B.1- Fine Aggregate laboratory test results

B.1.1 –Ambo sand

Ambo Sand

SPECIFIC GRAVITY AND ABSORPTION OF FINE AGGREGATES

Description					unit	Trial A	Trial B	Average
B. Mass of pycnometer + water					gm	706.9	706.9	
S. Mass of SSD sample					gm	500	500	
C.Mass of pycnometer + water + sample					gm	1018.5	1019.3	
A. Mass of oven dry sample					gm	498.9	497.9	
Water Temperature						25 °c	25 °c	
°C	18	20	21	22	23	24	25	26
k	1.0016	1.0012	1.0009	1.007	1.0005	1.0003	1.0000	0.9997
Bulk sp. gravity (oven dry) Sd = A*k/(B+S-C)						2.648	2.653	2.651
Bulk sp. gravity (SSD) Ss = S*k/(B+S-C)						2.654	2.664	2.659
Apparent specific gravity Sr = A*k/(A+B-C)						2.664	2.683	2.673
Water absorption Aw = (S-A)*100/A						0.22	0.42	0.32

Ambo Sand

DETERMINATION OF UNIT WEIGHT

Description	Loose		
	1	**2**	**3**
A Weight of Agg. + Weight of Container(g)	28075	27973	28207
B Weight of Container(g)	4860	4860	4860
C Weight of Aggregate(g) (A - B)	23215	23113	23347
D Volume of Container(cm3)	14020	14.02	14.02
Unit Weight of Aggregate(kg/m3) (C/D)	1656	1649	1665
Average Unit Weight of Aggregate(kg/m3)	1657		

Ambo Sand

Clay and Silt Content

Clay and silt content After washing

Description	unit	Trial A	Trial B
A. Level of Sand	ml	130	128
A. Level of silt and clay	ml	148	146
silt and clay content=(B-A)/A		13.85%	14.06%
Average		14.0%	

Clay and silt content After washing

Description	unit	Trial A	Trial B
A. Level of Sand	ml	147	145
A. Level of silt and clay	ml	148	146
silt and clay content=(B-A)/A		0.68%	0.69%
Average		0.7%	

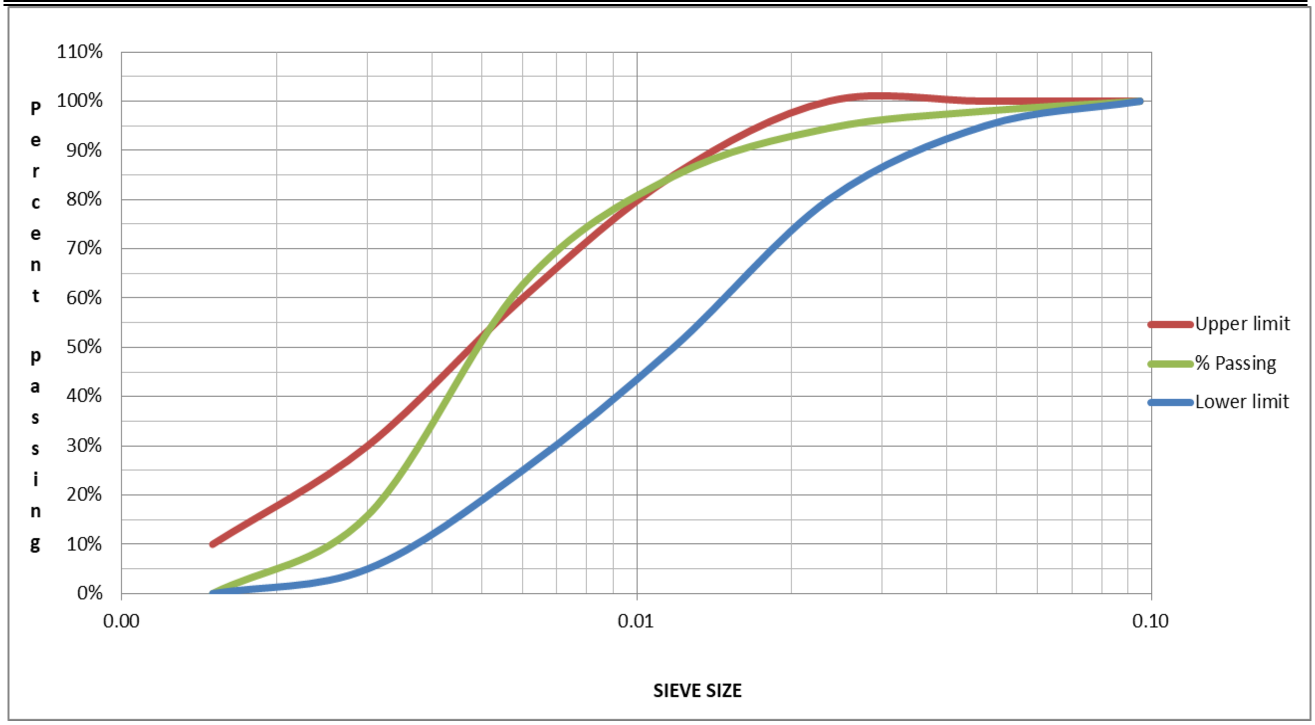
Ambo Sand

SIEVE ANALYSIS

Before wash: **500gm**

Sieve Sizes		9.5	4.75	2.36	1.18	0.600	0.300	0.150	Total
Weight Retained(gm)		0.0	9.7	16.8	47.2	106.7	226.5	76.7	**483.6**
Cumulative Weight Retained(gm)		0.00	9.70	26.50	73.70	180.40	406.90	483.60	
% Retained		**0.00%**	**2.01%**	**5.48%**	**15.24%**	**37.30%**	**84.14%**	**100.00%**	
% Passing		**100.00%**	**97.99%**	**94.52%**	**84.76%**	**62.70%**	**15.86%**	**0.00%**	
Specification Limits ASTM C33	**Lower limit**	**100.00%**	**95.00%**	**80.00%**	**50.00%**	**25.00%**	**5.00%**	**0.00%**	
	Upper limit	**100.00%**	**100.00%**	**100.00%**	**85.00%**	**60.00%**	**30.00%**	**10.00%**	

F.M.= 2.4



- Ambo Sand Chemical Composition test result

	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:- Shimels Gemechu

Sample type :-Sand(Ambo)

Sample Preparation: -200 Mesh

Date Submitted:- 27/04/2023

Issue Date:-26/05/2023

Request No:- GLD/RQ/1201/23

Report No:- GLD/RN/1858/23

Number of Sample:-One (01)

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

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

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI	Weight of Sample
Ambo	97.96	<0.01	0.60	<0.01	0.32	0.60	<0.01	<0.01	0.09	0.02	0.29	0.12	2.00Kg

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

Analysts	Checked By	Approved By	Quality Control
Haimanot Bayeh Gadisa Wakuma Nigist Fikadu	Lidet Endeshaw	Yohannes Getachew	Negash Worku

Geological Survey of Ethiopia Central Geological Laboratory

B.1.2 –Jema sand

Jema Sand

SPECIFIC GRAVITY AND ABSORPTION OF FINE AGGREGATES

Description					unit	Trial A	Trial B	Average
B. Mass of pycnometer + water					gm	706.9	706.9	
S. Mass of SSD sample					gm	500	500	
C.Mass of pycnometer + water + sample					gm	1018.2	1018.7	
A. Mass of oven dry sample					gm	499.1	498.9	
Water Temperature						25 °c	25 °c	
^{o}C	18	20	21	22	23	24	25	26
k	1.0016	1.0012	1.0009	1.007	1.0005	1.0003	1.0000	0.9997
Bulk sp. gravity (oven dry) Sd = A*k/(B+S-C)						2.645	2.650	2.648
Bulk sp. gravity (SSD) Ss = S*k/(B+S-C)						2.650	2.656	2.653
Apparent specific gravity Sr = A*k/(A+B-C)						2.658	2.666	2.662
Water absorption Aw = (S-A)*100/A						0.18	0.22	0.20

Jema Sand

DETERMINATION OF UNIT WEIGHT

Description	Loose		
	1	**2**	**3**
A Weight of Agg. + Weight of Container(g)	28047	28073	28105
B Weight of Container(g)	4860	4860	4860
C Weight of Aggregate(g) A - B	23187	23213	23245
D Volume of Container(cm3)	14020	14.02	14.02
Unit Weight of Aggregate(kg/m3) C/D	1654	1656	1658
Average Unit Weight of Aggregate(kg/m3)	1656		

Jema Sand

Clay and Silt Content

Clay and silt content Before washing

Description	unit	Trial A	Trial B
A. Level of Sand	ml	143	145
A. Level of silt and clay	ml	148	149
silt and clay content=(B-A)/A		3.50%	2.76%
Average		3.1%	

Clay and silt content After washing

		Trial A	Trial B
A. Level of Sand	ml	147	148
A. Level of silt and clay	ml	148	148
silt and clay content=(B-A)/A		0.68%	0.00%
Average		0.3%	

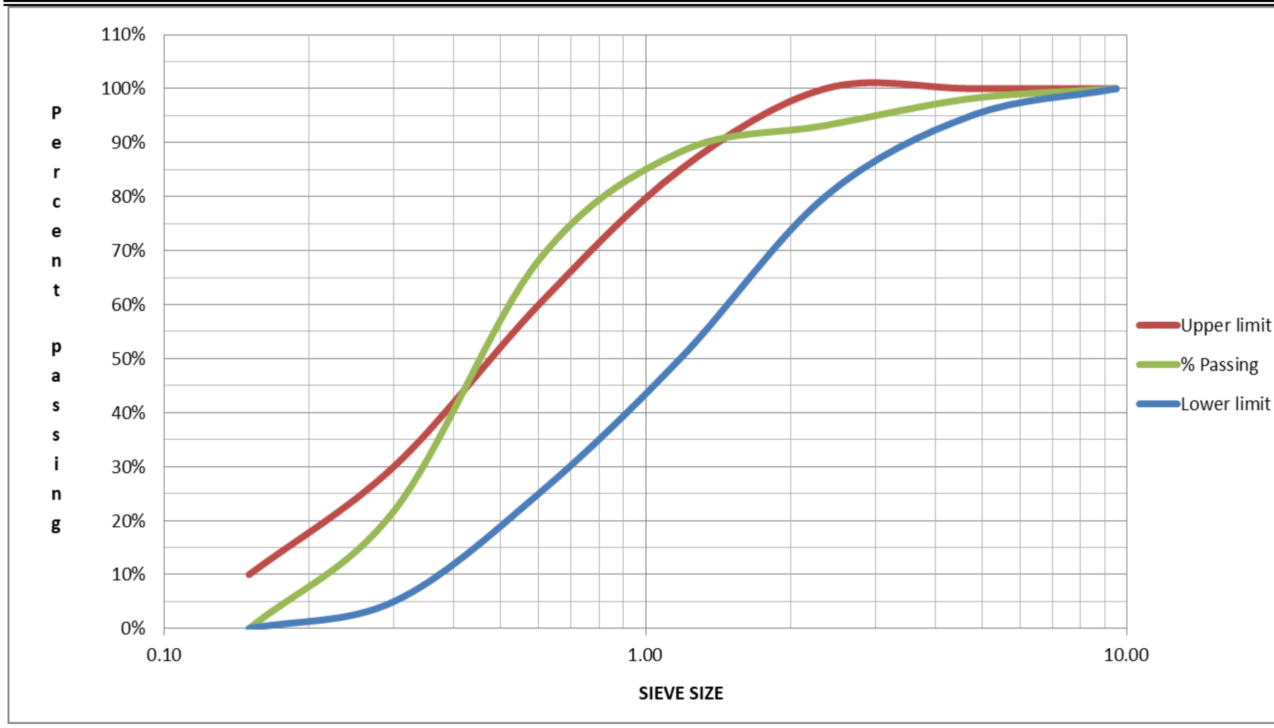
Jema Sand

SIEVE ANALYSIS

Before wash: 500gm

Sieve Sizes		9.5	4.75	2.36	1.18	0.600	0.300	0.150	Total
Weight Retained(gm)		0.0	9.1	25.0	24.3	99.9	231.8	108.5	**498.6**
Cumulative Weight Retained(gm)		0.00	9.10	34.10	58.40	158.30	390.10	498.60	
% Retained		**0.00%**	**1.83%**	**6.84%**	**11.71%**	**31.75%**	**78.24%**	**100.00%**	
% Passing		**100.00%**	**98.17%**	**93.16%**	**88.29%**	**68.25%**	**21.76%**	**0.00%**	
Specification Limits ASTM C33 Table 1	**Lower limit**	**100.00%**	**95.00%**	**80.00%**	**50.00%**	**25.00%**	**5.00%**	**0.00%**	
	Upper limit	**100.00%**	**100.00%**	**100.00%**	**85.00%**	**60.00%**	**30.00%**	**10.00%**	

F.M.= 2.3



- Ambo Sand Chemical Composition test result

	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:- Shimels Gemechu
Sample type :-Sand(Jema)
Sample Preparation: -200 Mesh
Date Submitted:- 27/04/2023
Analytical Result: In percent (%) Element to be determined Major Oxides & Minor Oxides.
Analytical Method: $LiBO_2$ FUSION, HF attack, GRAVIMETERIC, COLORIMETRIC and AAS

Issue Date:-26/05/2023
Request No:- GLD/RQ/1200/23
Report No:- GLD/RN/1857/23
Number of Sample:-One (01)

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI	Weight of Sample
Jema	98.62	<0.01	0.56	<0.01	0.02	<0.01	<0.01	<0.01	0.11	<0.01	0.20	0.50	2.30Kg

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

Analysts
Haimanot Bayeh
Gadisa Wakuma
Nigist Fikadu

Checked By
Lidet Endeshaw

Approved By
Yohannes Getachew

Quality Control
Negash Worku

B.1.3 –River sand

River Sand

SPECIFIC GRAVITY AND ABSORPTION OF FINE AGGREGATES

Description					unit	Trial A	Trial B	Average
B. Mass of pycnometer + water					gm	706.9	706.9	
S. Mass of SSD sample					gm	500	500	
C.Mass of pycnometer + water + sample					gm	1018.2	1019.5	
A. Mass of oven dry sample					gm	493.2	494	
Water Temperature						25 °c	25 °c	
°C	18	20	21	22	23	24	25	26
k	1.0016	1.0012	1.0009	1.007	1.0005	1.0003	1.0000	0.9997
Bulk sp. gravity (oven dry) Sd = A*k/(B+S-C)						2.614	2.635	2.624
Bulk sp. gravity (SSD) Ss = S*k/(B+S-C)						2.650	2.667	2.658
Apparent specific gravity Sr = A*k/(A+B-C)						2.711	2.722	2.717
Water absorption Aw = (S-A)*100/A						1.38	1.21	1.30

River Sand

DETERMINATION OF UNIT WEIGHT

Description	Loose		
	1	2	3
A Weight of Agg. + Weight of Container(g)	27013	27372	26743
B Weight of Container(g)	4860	4860	4860
C Weight of Aggregate(g) A - B	22153	22512	21883
D Volume of Container(cm3)	14020	14.02	14.02
Unit Weight of Aggregate(kg/m3) C/D	1580	1606	1561
Average Unit Weight of Aggregate(kg/m3)	1582		

River Sand

Clay and Silt Content

Clay and silt content Before washing

Description	unit	Trial A	Trial B
A. Level of Sand	ml	142	145
A. Level of silt and clay	ml	150	150
silt and clay content=(B-A)/A		5.63%	3.45%
Average		4.5%	

Clay and silt content After washing

		Trial A	Trial B
A. Level of Sand	ml	148	149
A. Level of silt and clay	ml	149	150
silt and clay content=(B-A)/A		0.68%	0.67%
Average		0.7%	

Jema Sand

SIEVE ANALYSIS

Before wash: 500gm

Sieve Sizes		9.5	4.75	2.36	1.18	0.600	0.300	0.150	Total
Weight Retained(gm)		0.0	14.6	74.0	85.6	97.5	120.7	104.4	**496.8**
Cumulative Weight Retained(gm)		0.00	14.60	88.60	174.20	271.70	392.40	496.80	
% Retained		**0.00%**	**2.94%**	**17.83%**	**35.06%**	**54.69%**	**78.99%**	**100.00%**	
% Passing		**100.00%**	**97.06%**	**82.17%**	**64.94%**	**45.31%**	**21.01%**	**0.00%**	
Specification Limits ASTM C33	**Lower limit**	**100.00%**	**95.00%**	**80.00%**	**50.00%**	**25.00%**	**5.00%**	**0.00%**	
	Upper limit	**100.00%**	**100.00%**	**100.00%**	**85.00%**	**60.00%**	**30.00%**	**10.00%**	

F.M.= 2.90

Company Name:
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Title:

Geotechnical Laboratory Testing Report

Document No	Issue No.	Page No.
OF/ECDSWC/0996	1	1 of 1

Client Ref.:-	GL/175/2023
Date Received:-	07/04/2023
Reported on:-	26/04/2023

Lab No. :- 1898/15-1900/15
Submitted by :- Shimelis Gemechu
Project :- AAU MSC Thesis
Station :- As Stated Below
Test Requested :- As Stated Below
Reported to :- Shimelis Gemechu
Client Contact Person:- Shimels G.

No.	Test Date	Test Type	Standard Test Methods	Sand Sample Test Result		
				Lab No.:- 1898/15	Lab No.:- 1899/15	Lab No.:- 1900/15
				Sample Id.:-	Sample Id.:-	Sample Id.:-
				Jema Sand	Ambo Sand	River Sand
				Location:-		
				Jema	Ambo	Figa
1	18/04/2023-26/04/2023	Soundness by Sodium Sulphate (%)	ASTM C88	17.01	15.03	8.78

REMARK:- The samples were collected & submitted to the laboratory by Client.
:- Sample results relate only to items tested.

Processed by :- Getu M.
Geotechnical Engineer

Checked By :- Biruk A.
Senior Geotechnical Engineer

Approved By :- Bethelhem B.
Geotechnical Lab S/P Manager

Ethiopian Construction Design & Supervision Works Corporation

Among the major services rendered by the Geotechnical and Material Laboratory Testing s/processes of Ethiopian Construction Design & Supervision Works Corporation are:
•In Geotechnical Laboratory:-Testing the engineering properties of Soil Mechanics and Rock Mechanics.
•In Material Testing Laboratory:- Testing the engineering properties of various Construction materials, such as Aggregates, Asphalts/Bitumen/, Cements, Rocks, Water, Reinforcement steel bars, Hollow Blocks, Bricks, Ceramics, Tiles,Asphalt & Concrete Core Tests, Concrete Mix Designs, Asphalt Mix Designs, Sampling of the soil and construction materials, and so on

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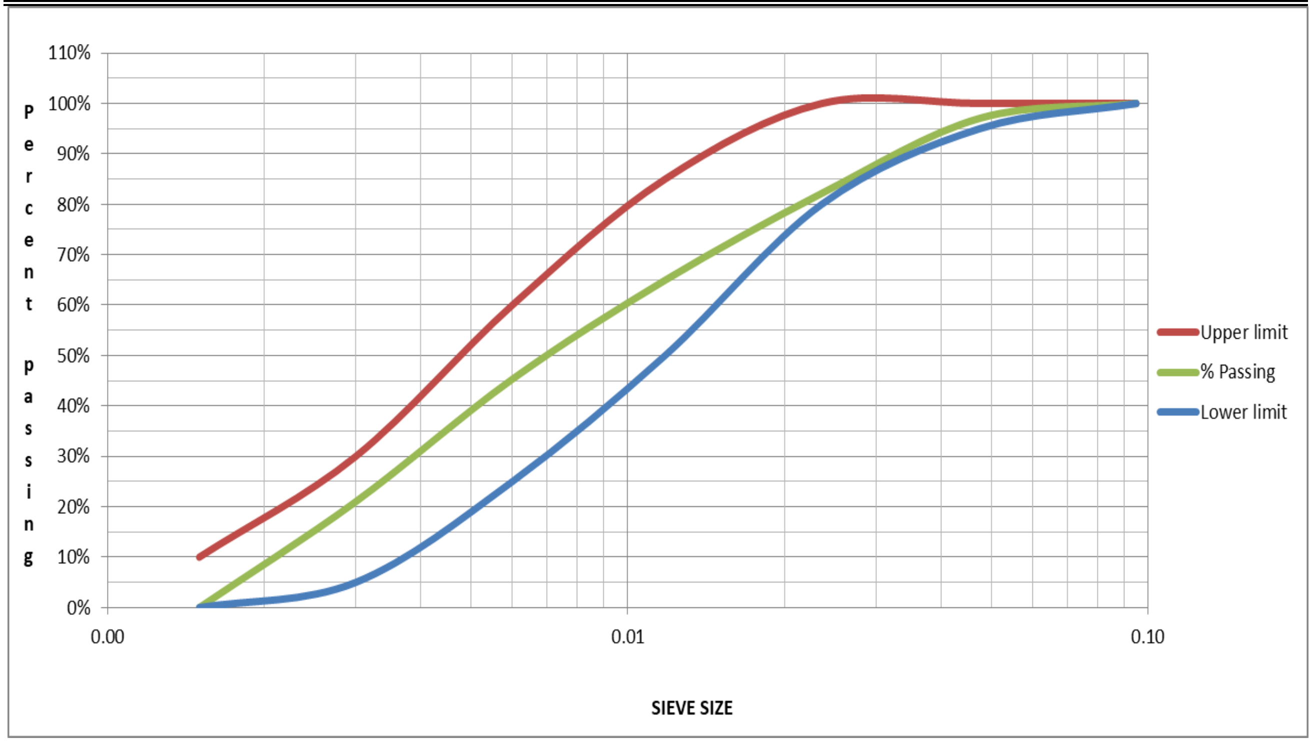


B.2 – Coarse Aggregate laboratory test results

B.2.1 – Coarse Aggregate nominal maximum size 19 mm

Coarse Aggregate Size 19mm

SPECIFIC GRAVITY AND ABSORPTION OF FINE AGGREGATES

Description				unit	A		B				Avg.
Aggregate Size (mm)					20.0 - 5.0		20.0 - 5.0				
B. Mass of SSD sample in air				gm	5013		5030				5021.5
C. Mass of saturated sample in water				gm	3193		3204				3198.5
A. Mass of oven dry sample				gm	4997		4991				4994
Water Temperature					25 °c		25 °c				
°C	18	19	20	21	22	23	24	25	26	27	
k	1.0016	1.0014	1.0012	1.0009	1.007	1.0005	1.0003	1.000	0.9997	0.9995	
Bulk sp. gravity (oven dry) A*k/(B-C)					2.746		2.732				2.739
Bulk sp. gravity (SSD) B*k/(B-C)					2.754		2.753				2.754
Apparent specific gravity A*k/(A-C)					2.770		2.792				2.781
Water absorption Aw = [(B-A)*100/A					0.32		0.78				0.55

Coarse Aggregate Size 19mm

DETERMINATION OF UNIT WEIGHT

Description	Loose			Oven dry Dry rodded unit weight		
	1	**2**	**3**	**1**	**2**	**3**
A Weight of Agg. + Weight of Container(g)	27328	27460	27502	27678	27557	27700
B Weight of Container(g)	4860	4860	4860	4860	4860	4860
C Weight of Aggregate(g) A - B	22468	22600	22642	22818	22697	22840
D Volume of Container(cm3)	14020	14020	14020	14020	14020	14020
Unit Weight of Aggregate(kg/m3) C/D	1603	1612	1615	1628	1619	1629
Average Unit Weight of Aggregate(kg/m3)	1610			1625		

Coarse Aggregate Size 19mm

LOS ANGELES ABRASION

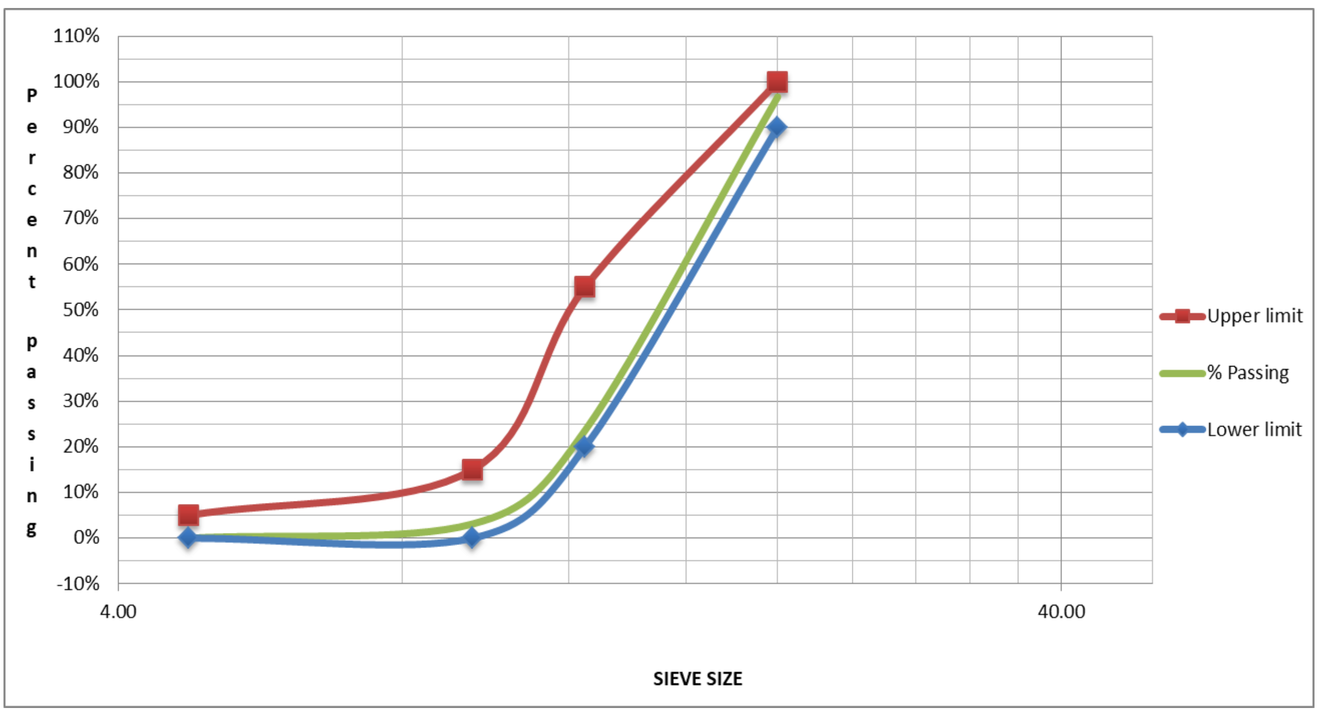
Sieve Size				Mass of Indicated Sizes (gm), Grading & Type				
Passing		**Retained on**		**A**	**B**		**C**	**D**
mm	Inch	mm	Inch				-	-
75	(3")	63.5	(2 1/2")	-	-		-	-
63.5	(2 1/2")	50.8	(2")	-	-		-	-
50	(2")	37.5	(1 1/2")	-	-		-	-
37.5	(1 1/2")	25	(1")	1250±25	-		-	-
25	(1")	19	(3/4")	1250±25	-		-	-
19	(3/4")	12.5	(1/2")	1250±10	2500±10		-	-
12.5	(1/2")	9.5	(3/8")	1250±10	2500±10		-	-
9.5	(3/8")	6.3	(1/4")	-	-		2500±10	-
6.3	(1/4")	4.75	(No 4)	-	-		2500±10	-
4.75	(No4)	2.36	(No 8)	-	-		-	5000±10
Total				5000±10	5000±10		5000±10	5000±10
Number of Spheres					11			
Number of Revolutions					500			
Rate of rotation					30RPM			
GRADING TYPE					**Trial - 1**	**Trial - 2**		
Initial Weight= w1			gm		5000	5001		
Weight retained On 1.70mm sieve after Test =w2			gm		4659	4712.9		
% Passing 1.70mm Sieve (w1-w2)/w1*100			%		6.82	5.76		
AVERAGE			**%**		6			

Coarse Aggregate Size 19mm

SIEVE ANALYSIS

Before wash: 4815.00

Sieve Sizes		25	20	12.5	9.5	4.75	PAN	Total
Weight Retained(gm)		0	154	3367	946	143	0	**4610**
Cumulative Weight Retained(g		0	154	3521	4467	4610	4610	
% Retained		0.00%	3.34%	76.38%	96.90%	100.00%	100.00%	
% Passing		**100.00%**	**96.66%**	**23.62%**	**3.10%**	**0.00%**	**0.00%**	
Specification Limits ASTM C33	**Lower limit**	**100.00%**	**90.00%**	**20.00%**	**0.00%**	**0.00%**		
	Upper limit	**100.00%**	**100.00%**	**55.00%**	**15.00%**	**5.00%**		



Company Name:

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Ethiopian Construction Design & Supervision Works Corporation

Tel: + 251-11-872-2285 / + 251-11-872-3628 / + 251-11-872-3698 Fax + 251-11-661-53-71 P.O.Box 2561 E-mail info@ecdswc.com

Title:	Document No:	Issue No.	Page No.
Material Laboratory Test Result Summary	OF/ECDSWC/837	2	1 of 1

Client Ref.:- ==========

Code : - 5158/15
Client Name : - Shimelis Gemechu
Project : - AAU MSC Thesis
Sample Type : - Coarse Aggregate (02)
Station : - ============
Sampling Date : - ============
Reported to : - Shimelis Gemechu
Performance Date : - 07/04/2023-10/04/2023

Date of Receipt: - 04/04/2023
Reported on: - 13/04/2023

No.	Tests Type and (Standard Methods)	Coarse Aggregate (02) Test Result
1	Aggregate Crushing Value (BS 812 Part 110) (%)	11

REMARK: - The samples were collected and submitted to the laboratory by the client.
This laboratory test result relates only to the items tested under the speified code.

Tested by ______ **Reported by** ______ **Checked by** ______ **Approved by** ______

Date 13/4/23 Date 13/04/2023 Date 17/04/2023 Date 17/4/23

Testing Expert **Material Engineer** **Senior Material Engineer** **Material Lab S/P Manager**

Among the major services rendered by the Geotechnical and Material Laboratory Testing s/processes of Ethiopian Construction Design & Supervision Works Corporation are:

□ **In Geotechnical Laboratory**:- Testing the engineering properties of Soil Mechanics and Rock Mechanics.

□ **In Material Testing Laboratory**:- Testing the engineering properties of various Construction materials, such as Aggregates, Asphalts/ Bitumen/, Cements, Rocks, Water, Reinforcement steel bars, Hollow blocks, Bricks, Ceramics, Tiles, Asphalt and Concrete Core Tests, Concrete Mix Designs, Asphalt Mix Designs, Sampling of the soil and construction materials, and so on.

Please make sure that this document is the correct version before use

B.2.2 – Coarse Aggregate nominal maximum size 12.5 mm

Coarse Aggregate Size 12.5mm

SPECIFIC GRAVITY AND ABSORPTION OF FINE AGGREGATES

Description				unit	A		B				Avg.
Aggregate Size (mm)					20.0 - 5.0		20.0 - 5.0				
B. Mass of SSD sample in air				gm	5008		5011				5009.5
C. Mass of saturated sample in water				gm	3190		3191				3190.5
A. Mass of oven dry sample				gm	4981		4981				4981
Water Temperature					25 °c		25 °c				
°C	18	19	20	21	22	23	24	25	26	27	
k	1.0016	1.0014	1.0012	1.0009	1.007	1.0005	1.0003	1.000	0.9997	0.9995	
Bulk sp. gravity (oven dry) A*k/(B-C)					2.740		2.735				2.738
Bulk sp. gravity (SSD) B*k/(B-C)					2.755		2.752				2.753
Apparent specific gravity A*k/(A-C)					2.781		2.781				2.781
Water absorption Aw = [(B-A)*100/A					0.54		0.60				0.57

Coarse Aggregate Size 12.5mm

DETERMINATION OF UNIT WEIGHT

Description	Loose			Oven dry Dry rodded unit weight		
	1	**2**	**3**	**1**	**2**	**3**
A Weight of Agg. + Weight of Container(g)	27195	27248	27285	27280	27315	27385
B Weight of Container(g)	4860	4860	4860	4860	4860	4860
C Weight of Aggregate(g) A - B	22335	22388	22425	22420	22455	22525
D Volume of Container(cm3)	14020	14020	14020	14020	14020	14020
Unit Weight of Aggregate(kg/m3) C/D	1593	1597	1600	1599	1602	1607
Average Unit Weight of Aggregate(kg/m3)	1596			1602		

Coarse Aggregate Size 12.5mm

LOS ANGELES ABRASION

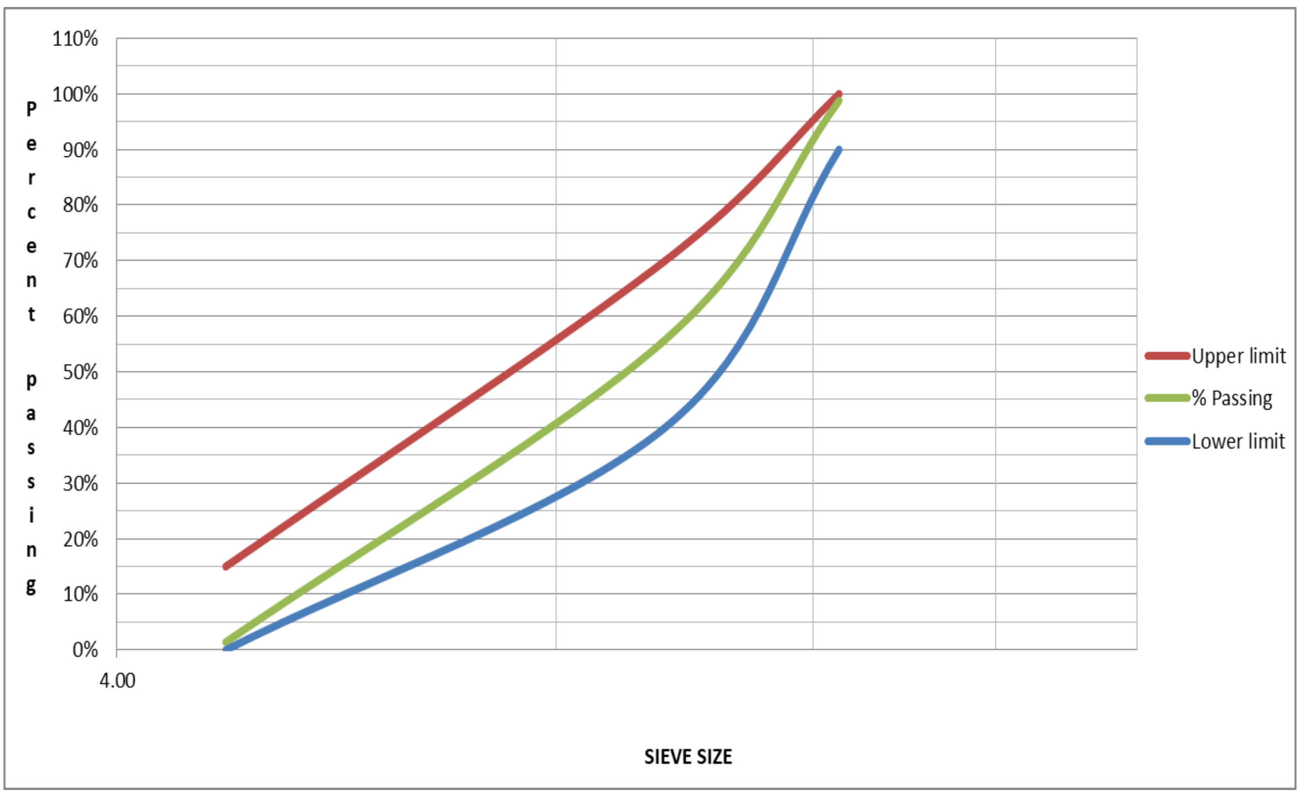
Sieve Size				Mass of Indicated Sizes (gm), Grading & Type				
Passing		Retained on		A	B	C		D
mm	Inch	mm	Inch			-		-
75	(3")	63.5	(2 1/2")	-	-	-		-
63.5	(2 1/2")	50.8	(2")	-	-	-		-
50	(2")	37.5	(1 1/2")	-	-	-		-
37.5	(1 1/2")	25	(1")	1250±25	-	-		-
25	(1")	19	(3/4")	1250±25	-	-		-
19	(3/4")	12.5	(1/2")	1250±10	2500±10	-		-
12.5	(1/2")	9.5	(3/8")	1250±10	2500±10	-		-
9.5	(3/8")	6.3	(1/4")	-	-	2500±10		-
6.3	(1/4")	4.75	(No 4)	-	-	2500±10		-
4.75	(No4)	2.36	(No 8)	-	-	-		5000±10
Total				5000±10	5000±10	5000±10		5000±10
Number of Spheres						8		
Number of Revolutions						500		
Rate of rotation						30RPM		
GRADING TYPE						**Trial - 1**	**Trial - 2**	
Initial Weight= w1			gm			5000	5001	
Weight retained On 1.70mm sieve after Test =w2			gm			4604	4627.5	
% Passing 1.70mm Sieve (w1-w2)/w1*100			%			7.92	7.47	
AVERAGE			**%**			8		

Coarse Aggregate Size 12.5mm

SIEVE ANALYSIS

Before wash: **4815.00**

Sieve Sizes		**19**	**12.5**	**9.5**	**4.75**	**PAN**	Total
Weight Retained(gm)		0	60	2135	2700	70	**4965**
Cumulative Weight Retained(gm)		0	60	2195	4895	4965	
% Retained		0.00%	1.21%	44.21%	98.59%	100.00%	
% Passing		**100.00%**	**98.79%**	**55.79%**	**1.41%**	**0.00%**	
Specification Limits ASTM C33 Table 3	**Lower limit**	**100.00%**	**90.00%**	**40.00%**	**0.00%**		
	Upper limit	**100.00%**	**100.00%**	**70.00%**	**15.00%**		



Appendix 2-Photographic Images

Fig. 1: Ambo sand After washed and dried

Fig. 2: Jema sand after washed and dried

Fig. 3: Laboratory testing on Ambo sand

Fig. 4: Laboratory testing on Jema sand

Fig. 5: Concrete mixing in horizontally roating mixer

Fig. 6: Quartering of sand before seive analysis

Fig. 7: Concrete cube specimmen before testing

Fig. 8: Flexural bars after test (failure is at the middle third)

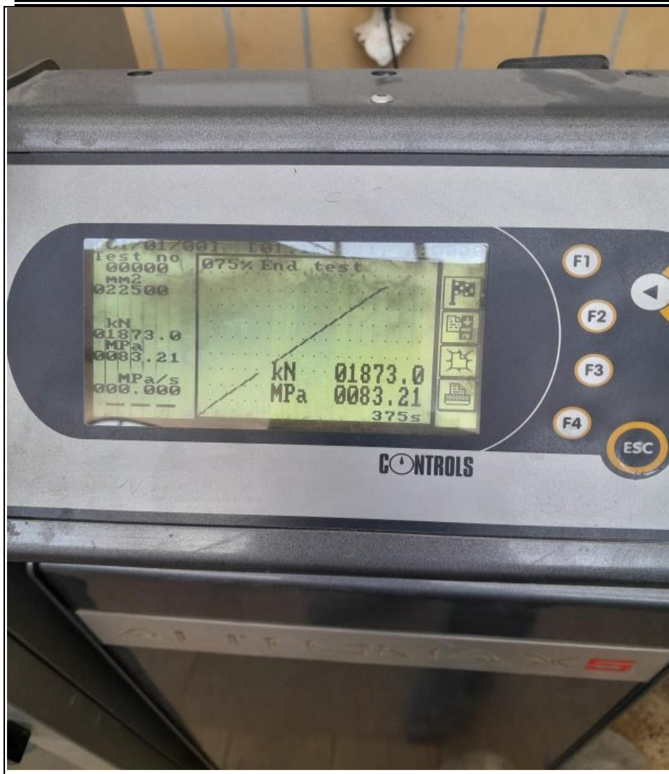


Fig. 9: Typical compressive test reading on the CTM

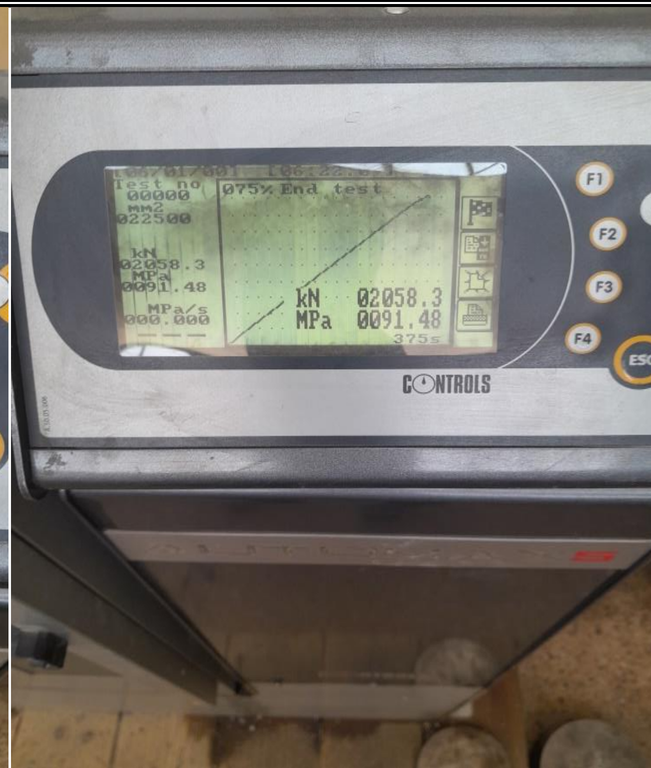


Fig. 10: Typical compressive test reading on the CTM

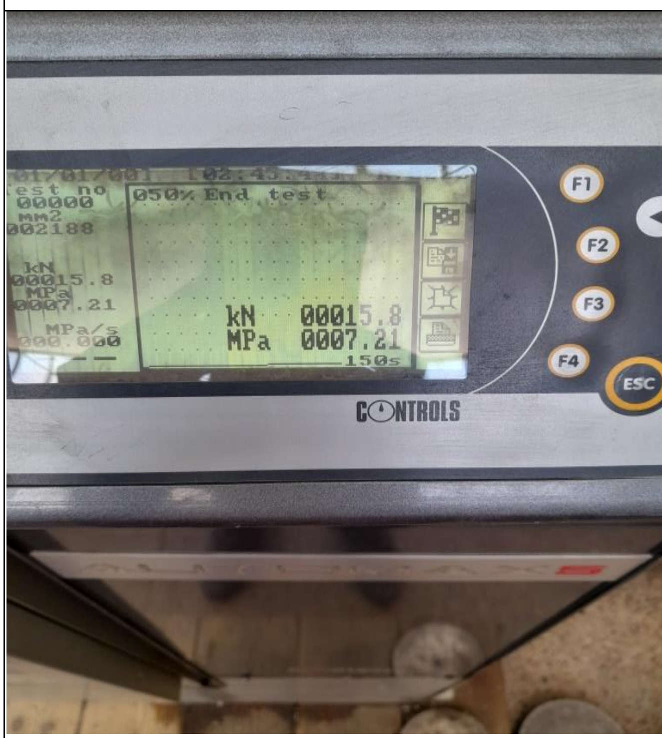


Fig. 11: Typical Flexural test reading on the CTM

Fig. 12: Typical mortar test reading on the CTM