**ADDIS ABABA UNIVERSITY**

**SCHOOL OF GRADUATE STUDIES**

**ADDIS ABABA INSTITUTE OF TECHNOLOGY**

**SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING**

# SUITABILITY OF CRUSHED JEMA SANDSTONE FOR CONCRETE PRODUCTION AS ALTERNATIVE TO RIVER SAND

A thesis submitted to the School of Graduate Studies of the Addis Ababa University in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering

(Construction Technology and Management)

**By**

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# ABSTRACT

The current booming construction industries demand large reserves of construction materials and skilled workmanship. Having the luxury of abundant construction materials is one of the manifestations of a great construction industry. So far several attempts have been made to partially or fully replace river sand by other relevant fine aggregates. One of these materials were crushed Jema sandstone and this research studies its suitability as a fine aggregate.

Initially, river and crushed Jema sandstone samples to be used in the concrete mixes were collected and their physical properties were studied. Twenty four different concrete mixes having eight mix proportions for both river and crushed Jema sandstone were prepared for 25, 30 and 40 MPa concrete strengths using a water cement ratio and cement contents of 0.58, 330kg/$m^3$; 0.53, 370kg/$m^3$; 0.45, 450kg/$m^3$ respectively. The properties of these mixes have then been assessed both at the fresh and hardened state. In addition, chemical composition of crushed Jema sandstone was investigated. The result of silicate analysis test shows that it has a silica content greater than 94% which is desirable in sand.

The results of the hardened properties of the mixes have shown that, the addition of crushed Jema sandstone resulted in increased compressive strengths. This suggests that using crushed Jema sandstone can achieve better strength of concrete. The test results showed that for all grades of concrete mix proportion, concrete with 100% crushed Jema sandstone was capable of achieving a higher compressive strength than the river sand control mix. However, as the concrete grade increased from C-25 to C-40, the relative strength gain decreased.

**Keywords:** Crushed Jema sandstone, compressive strength, chemical composition, concrete

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# ACRONYMS

| | |
|---|---|
| CA | Coarse Aggregate |
| CJS | Crushed Jema Sandstone |
| CRS | Crushed Rock Sand |
| DoE | Department of the Environment |
| ES | Ethiopian Standard |
| FA | Fine Aggregate |
| FM | Fineness Modulus |
| HSC | High Strength Concrete |
| ISC | Intermediate Strength Concrete |
| NSC | Normal Strength Concrete |
| OPC | Ordinary Portland cement |
| PPC | Portland Pozzolana Cement |
| RS | River Sand |
| SSD | Saturated Surface Dry |
| W/C | Water to cement ratio |

# CHAPTER ONE

# INTRODUCTION

## 1.1 General

Aggregates, both fine and coarse, take about 65-75% by volume of concrete and are important ingredients in concrete production. The parent materials of aggregates are derived mainly from volcanic activity. The majority of sand is collected from riverbeds [1].

Sand is a naturally produced material resulting from the mechanical and chemical breakdown of rocks. Sand is the most common and loosely packed mineral on the earth's surface. It is smaller than gravel and larger than silt and clay, sand particles mostly range from 0.02 mm to 2.00 mm in diameter. Sand accumulates in areas where sediments are transported and deposited, in areas such as desert, beach, and river environments [2].

The main natural and cheapest sources of sand are riverbeds and these natural resources are depleting very fast and increasing in cost rapidly due to transportation. Transportation is a major factor in the delivered price of construction sand [3]. The major sand supply for the construction works in and around Addis Ababa is the Awash basin located about 70-120 km southeast of the city. The method of quarrying sand is generally very old and the producers do not attempt to clean and grade the sand right from the source [2].

Sand may require a significant dredging industry, raising environmental concerns over depletion of natural river sand and landslides. Also depletion of the resources leads to the production and supply of poor quality sand that will in turn cause structural defects in concrete production application. In addition there is a day to day incremental rate in the consumption of natural sand due to the increasing construction activities in the country.

Although the sources of sand are widespread and inadequate supply, there is a local shortage. Land use conflicts and environmental problems associated with rapid urban expansion are major factors contributing to these shortages.

Demand pressures, land use regulations, and the cost of meeting environmental and reclamation requirements are factors that will cause a rising price trend. Larger operations with more efficient equipment, more automation, and better planning and design will be the trend of the industry in the future [2].

So far several attempts were made to find a suitable replacement for natural sand. Among these attempts, the use of crushed aggregate has shown a great deal of promise as a replacement [4]. Another potential substitution is the Jema and Guder river basin Sandstone deposit. Even though no research studies have been carried out to assess its suitability, Yotek Construction Company is using sandstone as fine aggregate in Ambo area.

Sandstone is a sedimentary rock composed mainly of sand sized mineral or rock grains. Most sandstone is composed of quartz and or feldspar because these are the most common minerals in earth's crest. Like sand, sandstone could have any color, but the most common colors are yellow, red, gray and white.

## 1.2 Statement of the Problem

The current booming construction industries demand large reserves of construction materials and skilled workmanship. Having the luxury of abundant construction materials is one of the manifestations of a great construction industry. Sand is one of the main construction materials. Rapid and constant usage of river sand is leading to environmental problems associated with its depletion.

Moreover the sources of this river sand are located several hundreds of kilometer away from the capital where the majority of the construction industry sector is located. When we look at the current availability and condition of river sand in Ethiopia, one can easily see that it is an alarming issue. Therefore, it is mandatory to identify alternative sources of sand and study whether it can be as effectively used as a replacement for natural sand.

To this regard, one possible alternative material that can be used as a replacement for natural sand is the use of sandstone. Due to the forecast shortfall in the supply of natural sands and the increased activity in the construction sector, it is apparent that time will come, when sandstone may play a significant role as an ingredient in concrete production.

In addition to these, studies show that natural sand, which is available today, is deficient in many aspects to be used directly for concrete production.

Some of the factors include:

- ✓ It doesn't contain fine particles, in the required proportion.
- ✓ Contains an organic and soluble compound that affects the setting time and properties of cement.
- ✓ The presence of impurities such as clay, dust and silt coatings, increase water requirement and impair bond between cement paste and aggregate [3].

To this effect, this research is carried out to study the suitability of crushed Jema river sandstone as partial or full replacement of river sand.

## 1.3 Objective of the Research

The general objective of this research work is to study the impact of crushed Jema sandstone on the general properties of concrete in both the fresh and hardened state and compare the result with that of concrete produced using river sand.

The specific objectives of this research are:

- ➢ To investigate mineralogical composition of Jema sandstone.
- ➢ To determine the rate of strength gain for the concrete with and without crushed Jema sandstone.

## 1.4 Research Significance

The successful completion of this research will have significance for the production of concrete by:

- ✓ Assisting the current fast growing construction industry by providing an alternative to the widely used river sand.
- ✓ Studying the chemical and physical properties of sandstone and its effect in fresh and hardened concrete property.
- ✓ Attaining a comparative cost advantage since per meter cube cost of sandstone is cheaper than that of river sand.

## 1.5 STRUCTURE OF THE RESARCH

This thesis is structured with six chapters and further break down in to different sections and sub sections. An introduction is provided with statement of the objectives and methodology of the study in the first chapter.

The second chapter consists of the fundamentals of concrete and its constituents and requirement of fine aggregate by referring and reviewing different literatures. Designing property of concrete mixtures and its manufacturing process, the properties of the fresh and hardened concrete and its control tests are the main highlight of this chapter. It will also address river sand replacement materials which have been practical in previously conducted researches and sandstone as fine aggregate in Ethiopia will be presented here.

Chapter three deals with the methodology followed to conduct this research.

Chapter four will be focusing on the materials properties and mix proportion of the research. It will discuss the properties of materials used for the production of concrete, mix proportions selected, specimen preparation, and testing procedures.

Chapter five deals with test results obtained from the experimental study and gives discussion based on the findings. It will illustrate and explain in detail the significance and meaning of each result. This will be followed by the last chapter, chapter six, which states the conclusions and recommendations derived from the research. Finally a list of reference material used to assist this research will be listed together with annexes showing detailed test procedures and results. A photographic presentation is also attached in the annex.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Introduction

The proposed topic of this thesis has been addressed previously by different researchers in the field. Hence this section provides an overview of studies and literatures that investigate concrete constituents, fine aggregate, requirements of river sand for concrete production, environmental and technical defect of river sand, mix design selection, properties of concrete both in fresh and hardened state and finally river sand replacement material we will discussed.

## 2.2 Constituent of Concrete

Concrete, the oldest and the most widely used construction material in the construction of civil engineering structures, is a composite material that consists of essentially cements, aggregate and water. Besides, chemical admixtures are essential when special properties are desired [1].

Concrete is made to possess different properties by adjusting the proportions and varying the properties of the concrete making materials.

Aggregates, both fine and coarse, take about 65-75% by volume of concrete and are important ingredients in concrete production, its properties affects the properties of concretes the most [2].

### 2.2.1 Cement

Cements, are finely ground inorganic materials with adhesive and cohesive properties which make them capable of uniting or bonding together fragments or particles of solids matter into a compact whole. In engineering purpose cements are materials which form a paste which sets and harden by means of hydration reactions, and which after hardening retain its strength and stability even under water and can be molded or deformed but later it sets and hardens to a rigid mass [3].

#### 2.2.1.1 Chemical composition of Portland cement

Portland cement is made by grinding together its principal raw materials, which are [1]:

1. Argillaceous, for example silicates of alumina in the form of clays and shale's ,and
2. Calcareous, for example calcium carbonate in the form of limestone, chalk, and marl which is a mixture of clay and calcium carbonate.

The mixture is then burned in a rotary kiln at a temperature between 1300 and 15000c. The material partially fuses in to a clinker which is taken from the kilns, cooled and then passed on to ball mills where gypsum is added and it is ground to the required fineness.

The resulting cement is allowed to contain small strictly limited percentages of materials not required, some disadvantageous for some uses, such as iron oxide and sulpher trioxide. Table 2.1 shows oxide composition ranges for Portland cements indicate a general idea of the composition of cement [1].

Table 2.1 Oxide content of Portland cement row materials

| Oxides | Ranges |
|---|---|
| Lime ($CaO$) | 60-70% |
| Silica ($SiO_2$) | 17-25% |
| Alumina ($Al_2O_3$) | 3-8% |
| Iron Oxide ($Fe_2O_3$) | 0.5-6% |
| Sulphur trioxide ($SO_3$) | 1.0- 3% |
| Magnesia ($MgO$) | 0.1- 4% |
| Soda ($Na_2O$) and Potash ($K_2O$) | 0.5-1.3% |

The above constituents forming the raw materials used in the manufacturer of Portland cement combine to form compounds in the finished product. The following four compounds are regarded as the major constituents of cement: tricalcium silicate ($3CaO.SiO_2$ or $C_3S$), dicalcium silicate ($2CaO.SiO_2$ or $C_2S$), tricalcium aluminate ($3CaO.Al_2O_3$ or $C_3A$), and tricalcium aluminoferrite ($4CaO.Al_2O_3.Fe_2O_3$ or $C_4AF$).These compounds are different in rate of reaction, heat liberation and cementing value [1].

#### 2.2.1.2 Types of cement

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

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

**A. Oridnary Portland Cement**

Ordinary Portland (Type-I) cement is a general-purpose cement suitable for all uses where the special properties of other types are not required. Its uses in concrete include pavements, floors, reinforced concrete buildings, bridges, tanks, reservoirs, pipe, masonry units, and precast concrete products. The standard requires that it is made from 95 to 100 percent of Portland cement clinker and 0 to 5 percent of minor additional constituents. Minor additional constituents are one or more of the other cementitious materials or filler. Filler is defined as any natural or inorganic mineral material other than a cementitious material [1].

Variations in its composition may produce a difference of up to ±20 % in the compressive strength of concrete that is made with it, but uniform results are obtainable by drawing cement from one source of supply [5].

**B. Portland pozzolana cement**

Portland Pozzolana cement is manufactured by blending 10-30 percent by weight of pozzolanic material with Portland cement; either by simple mixing or by inters grinding with cement clinker. The calcium hydroxide liberated during the process of hydration of the cement combines slowly with the pozzolana to give it cementitious properties, thereby contributing to water tightness and long, continued gain in strength of the concrete.

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 pozzolan may be used as a partial replacement of the fines of sand, without a reduction of cement content, where high early strength is required [5].

#### 2.2.1.3 Hydration of cement

Hydration is the term given to the reaction between cement and water. It is because of hydration process that cement, when in contact with water, forms a paste and then hardens to a stone like mass. However, unlike the reaction of the other calcareous cements, hydration of

Portland cement is a far more complex phenomenon. This is so because Portland cement is a heterogeneous mixture of several chemical compounds, which are complex in themselves [3].

The most important components of Portland cement from the strength development point of view are $C_2S$ and $C_3S$ which, on hydration, form the same compounds in differing proportions. $C_3S_2H_3$ is the final product of hydration of both $C_2S$ and $C_3S$, the reactions of hydration can be written for $C_3S$ and $C_2S$ respectively, as follows [1].

$$2(3CaO.SiO_2) + 6H_2O \longrightarrow 3CaO.2SiO_2.3H_2O + 3Ca(OH)_2$$

$$2(2CaO.SiO_2) + 4H_2O \longrightarrow 3CaO.2SiO_2.3H_2O + Ca(OH)_2$$

#### 2.2.1.4 Factors affecting rate and heat of hydration

Heat of hydration is the heat generated when cement and water react. The rate of hydration of Portland cement, and hence the heat evolution, are affected by a number of factors and is briefly discussed as follows [3].

**a) Cement Composition**

The reaction of cement with water is, in the first instance, a reaction of individual compounds. It follow that, at an early age, the rate of hydration of the constituents in the cement is the same as the rate of hydration of the separate compounds.

The speed with which the chemical reactions proceed depends on the affirmation of the individual compounds to water. The first to react are the aluminates. The rate of hydration of the aluminates can be possibly retarded by varying the percentage of gypsum ($CaSO_4.2H_2O$). The amount of gypsum to properly retard the setting varies mainly with the content of $C_3A$ and the fineness of the cement. In very hot countries, cements that are used for making concrete should have reduced proportions of the constituents that hydrate rapidly ($C_3A$ and $C_3S$) with accompanying high rate of heat liberation. Unchecked rate of hydration accompanied by hot climatic conditions will lead to excessive expansion of the fresh concrete. At later ages, contraction takes place with resulting cracks that will seriously affect the structure. The high heat liberation of the rapid hardening constituents can be put to advantage in very cold regions where freezing and thawing might adversely affect a freshly cast concrete.

**b) Fineness of cement**

The finer the grinding of the cement, the faster should be the hydration process and vice versa. However, the ultimate degree of hydration is not affected by the fineness of the cement. A finer cement will require not only more water to cover the higher surface area, but also relatively more gypsum to retard the speedy hydration of the decreased number of aluminates particles.

**c) Water cement ratio**

Both the rate of hydration and the heat evolution are affected by the water/cement ratio. The water/cement ratio has practically no influence on the rate of hydration in the first 24 hours after mixing. Later on, the rate of hydration decreases with a decrease in a water/cement ratio.

**d) Age of paste**

It has been understood that the rate of hydration of cements, and hence the heat evolution, is highest at early age. Depending on the grain size distribution in the cement and the pressure of water, hydration may continue for several years after mixing but at a much-reduced rate.

**e) Ambient condition**

The rate of hydration of Portland cement is influenced by the ambient temperature, and identical results cannot be expected from specimens that are subjected to different thermal histories. The rate of hydration increases with temperature and this is true only at earlier ages. Ultimately, however, the same degree of hydration is reached irrespective of the curing temperature.

### 2.2.2 Aggregate

#### 2.2.2.1 General

Aggregates are defined as inert, granular, and inorganic materials that normally consist of stone or stone-like solids.

Aggregates can be used alone (in road bases and various types of fill) or can be used with cementing materials (such as Portland cement or asphalt cement) to form composite materials or concrete. The most popular use of aggregates is to form Portland cement concrete. Approximately three-fourths of the volume of Portland cement concrete is occupied by aggregate. It is inevitable that a constituent occupying such a large percentage of the mass should have an important effect on the properties of both the fresh and hardened products [2].

#### 2.2.2.2 Classification of Aggregates

Aggregates can be divided into several categories according to different criteria. [1]

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

ii. In accordance with unit weight
   - Light weight aggregate: The unit weight of aggregate is less than 1120 $kg/m^3$. The corresponding concrete has a bulk density less than 1800 $kg/m^3$.
   - Normal weight aggregate: The aggregate has unit weight of 1520-1680 $kg/m^3$. The concrete made with this type of aggregate has a bulk density of 2300-2400 $kg/m^3$.

- Heavy weight aggregate: The unit weight is greater than 2100 kg/m$^3$. The bulk density of the corresponding concrete is greater than 3200 kg/m$^3$.

iii. In accordance with sources:

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

#### 2.2.2.3 Physical Properties of Aggregates

Since at least three-quarters of the volume of concrete is occupied by aggregate, the physical properties of the aggregate greatly affect the strength, durability and structural performance of concrete. Therefore the physical properties of aggregates should be well tested and known to produce the right quality of concrete. Important properties of aggregate that affect the performance of concrete are discussed as follows:-

**A. Sampling**

Samples shall be representative and certain precautions in sampling have to be made. No detailed procedures can be laid down as the conditions and situations involved in taking samples in the field can vary widely from case to case. Nevertheless, a practitioner can obtain reliable results bearing in mind that the sample taken is to be representative of the bulk of the material.

The main sample shall be made up of portions drawn from different parts of the whole. The minimum number of these portions is described in BS 812; part 105; 1990 [6].

The main sample may be rather large, and so the sample has to be reduced before testing. To maintain the representative sample, quartering or riffling reduction techniques are used. [1]

**B. Particle shape and surface texture**

Roundness measures the relative sharpness or angularity of the edges and corners of a particle. Roundness is controlled largely by the strength and abrasion resistance of the parent rock and by the amount of wear to which the particle has been subjected. In the case of crushed aggregate, the particle shape depends not only on the nature of the parent rock but also on the type of crusher and its reduction ratio, i.e. the ratio of the size of material fed into the crusher to the size of the finished product. Particles with a high ratio of surface area to volume are also of particular interest for a given workability of the control mix.

The flakiness and elongation tests are useful for general assessment of aggregate but they do not adequately describe the particle shape. The presence of elongated particles in excess of 10 to 15% of the mass of coarse aggregate is generally undesirable, but no recognized limits are laid down [1].

Surface texture of the aggregate affects its bond to the cement paste and also influences the water demand of the mix, especially in the case of fine aggregate. The shape and surface texture of aggregate influence considerably the strength of concrete. The effects of shape and texture are particularly significant in the case of high strength concrete.

The full role of shape and texture of aggregate in the development of concrete strength is not known, but possibly a rougher texture results in a larger adhesive force between the particles and the cement matrix.

The shape and texture of fine aggregate have a significant effect on the water requirement of a mix made with the given aggregate. Flakiness and shape of coarse aggregates have an appreciable effect on the workability of concrete [1].

**C. Grading of fine and coarse aggregate**

The grading determine the paste requirement for a workable concrete since the amount of void requires needs to be filled by the same amount of cement paste in a concrete mixture. To obtain a grading curve for aggregate, sieve analysis will be conduct.

**D. Bond of aggregate**

Bond between aggregate and cement paste is an important factor in the strength of concrete, but the nature of bond is not fully understood. A rougher surface, such as that of crushed particles, results in a better bond due to mechanical interlocking.

In addition, bond is affected by other physical and chemical properties of aggregate, related to its mineralogical and chemical composition, and to the electrostatic condition of the particle surface. In any case, for good development of bond, it is necessary that the aggregate surface be clean and free from adhering clay particles [1].

The determination of the quality of bond of aggregate is difficult and no accepted tests exist. Generally, when bond is good, a crushed specimen of normal strength concrete should contain some aggregate particles broken right through, in addition to the more numerous ones pulled out from their sockets. An excess of fractured particles, might suggest that the aggregate is too weak [1].

**E. Strength of aggregate**

The compressive strength of concrete cannot significantly exceed that of the major part of the aggregate contained. If the aggregate under test leads to a lower compressive strength of concrete, and in particular if numerous individual aggregate particles appear fractured after the concrete specimen has been crushed, then the strength of the aggregate is lower than the nominal compressive strength of the concrete mix. Such aggregate can be used only in a concrete of lower strength.

Thus a low strength may be due to the weakness of constituent grains or the grains may be strong but not cemented together [1].

**F. Deleterious Substance of aggregate**

For satisfactory performance, concrete aggregates should be free of deleterious materials. There are three categories of deleterious substances that may be found in aggregates: impurities, coatings and weak or unsound particles.

Table 2.2: Deleterious substances in aggregates [7]

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

### 2.2.2.4 Coarse Aggregate

The maximum size of coarse aggregate is typically 19 mm or 25 mm. An intermediate-sized aggregate, around 9.5 mm, is sometimes added to improve the overall aggregate gradation. [7]
The most commonly available local coarse aggregates are obtained from normal weight crushed basaltic rocks and lightweight volcanic ash, which are a member of a family of igneous rock (scoria or pumice). [2]

#### 2.2.2.5 Fine Aggregate

Aggregate passing through 4.75 mm sieve are defined as fine. They may be natural sand deposited by rivers and crushed stone obtained by crushing stones [1].

## 2.3 Types of Fine Aggregate

### 2.3.1 Crushed/Manufactured Sand

Crushed sand is used for aggregate materials having dimensions less than 5.0mm that are processed from crushed rock or gravel and intended for construction use. The use of crushed sand in concrete has been known since the Roman time. In modern technology, natural aggregates have proved to be significantly economical in use, for which reason extensive use of crushed sand has been concentrated to regions or projects where the availability of natural aggregates has been limited. [4]

The growing problem of surplus fines from hard rock quarries has, however, in recent times encouraged a development towards more use of manufactured aggregates in many populated areas, and for several concrete applications [8].

Crushed /manufactured sand has rough surface texture and the particle size distribution curve can be adjusted in the manufacturing of the material.

Manufactured sands are made by crushing aggregate to size appropriate for use as a fine aggregate (< 5.0mm). The crushing process caused the manufactured sand to have an irregular particle shape. These fine particles and irregular shape of the aggregate have detrimental effects on the workability and finish of the concrete. These negative effects have given manufactured sands a poor reputation in the construction industry.

### 2.3.2 Natural River Sand

Rivers sand is a naturally occurring granular material composed of finely divided rock and mineral particles. The composition of sand is highly variable, depending on the local rock sources and conditions, most common constituent of sand in inland continental settings and non-tropical coastal settings is silica (silicon dioxide, or $SiO_2$), usually in the form of quartz. An individual particle in this range size is termed a sand grain. Sand grains are between gravel and silt [1].

The construction industry in Ethiopia mainly uses sand from streambeds, which are commonly derived from quartzo-feldspathic basement rock, sandy marine sediments and alluvial deposits. The major sand supply for the construction works in and around Addis Ababa is the Awash basin located about 70-120 km southeast of the city [2].

The typically sand is produced by manual labor and transported by animal to trucks and then the sand is transported to Addis Ababa.

#### 2.3.2.1 Requirement of Sand for concrete

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

##### 2.3.2.1.1 Grading of fine aggregate

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

To obtain a grading curve for aggregate, sieve analysis will be conduct. According to ES C.D3.201, BS882 and ASTM the grading requirement of fine aggregate, are summarized as shown in Table 2.3 [9].

Table 2.3 BS and ASTM grading requirements of fine aggregate

<table>
<tr><th rowspan="3">Sieve Size</th><th colspan="5">Percentage of passing %</th></tr>
<tr><th colspan="4">BS882:1973</th><th rowspan="2">ASTM standards (C33-78)</th></tr>
<tr><th>Grading Zone 1</th><th>Grading Zone 2</th><th>Grading Zone 3</th><th>Grading Zone 4</th></tr>
<tr><td>9.5mm</td><td>100</td><td>100</td><td>100</td><td>100</td><td>100</td></tr>
<tr><td>4.75mm</td><td>90-100</td><td>90-100</td><td>95-100</td><td>95-100</td><td>95-100</td></tr>
<tr><td>2.36mm</td><td>60-95</td><td>75-100</td><td>85-100</td><td>95-100</td><td>80-100</td></tr>
<tr><td>1.18mm</td><td>30-70</td><td>55-90</td><td>75-100</td><td>90-100</td><td>50-85</td></tr>
<tr><td>600μm</td><td>15-34</td><td>35-59</td><td>60-79</td><td>80-100</td><td>25-60</td></tr>
<tr><td>300μm</td><td>5-20</td><td>8-30</td><td>12-40</td><td>15-50</td><td>10-30</td></tr>
<tr><td>150μm</td><td>0-10</td><td>0-10</td><td>0-10</td><td>0-15</td><td>2-10</td></tr>
</table>

##### 2.3.2.1.2 Fineness Modulus

Using the sieve analysis results, a numerical index called the fineness modulus (FM) is often computed. The FM is the sum of the total percentages coarser than each of a specified series of sieves, divided by 100.

The specified sieves are 9.5 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600μm, 300 μm, and 150 μm (No. 4, 8, 16, 30, 50, and 100). Note that the lower limit of the specified series of sieves is the 150 μm (No. 100) sieve and that the actual size of the openings in each larger sieve is twice that of the sieve below. The coarser the aggregate size, the higher the FM. For fine aggregate used in concrete, the FM generally ranges from 2.3 to 3.1 as called for in ASTM C 33[10].

It is used as an index to the fineness or coarseness and uniformity of aggregate supplied, but it is not an indication of grading since there could be an infinite number of grading which will produce a given fineness modulus. The following limits may be taken as guidance [11]:

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

Sand having a fineness modulus more than 3.2 will be unsuitable for making satisfactory concrete [11]. However, it is clear that one parameter, the average, cannot be representative of a distribution: thus the same fineness modulus can represent an infinite number of totally different size distributions or grading curves.

The fineness modulus cannot, therefore, be used as a description of a grading of an aggregate but it is valuable for measuring slight variations in the aggregate from the same source. [1].

#### 2.3.2.1.3 Silt Content

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

A simple test which can be made on site to give a guide to the amount of silt in natural sand is the 'field settling' test. This test should not be used for crushed rock sands.

According to the Ethiopian Standard it is recommended to wash the sand or reject if the silt content exceeds a value of 6%. [12]

#### 2.3.2.1.4 Deleterious Substance of aggregate

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

The amount of deleterious substances shall not exceed the following limits [13]:

Maximum PermissibleLimits, By Weight

1. Clay Lumps…………………………………………………………..0.5%
2. Coal and Lignite……………………………………………………...0.5%
3. Material Passing the No. 200 Sieve ……………………………………3.0%
4. Other Deleterious Substances (such…………………………………….3.0%
   as Shale, Alkali, Mica, Coated Grains, Soft and Flaky Particles)

#### 2.3.2.2 Environmental and Technical Effect of River Sand

##### 2.3.2.2.1 Environmental Effect

River basins have long been exploited as source of fine aggregates for building constructions. Depending up on the geomorphic/ geologic setting, river sand mining can impose serious environmental consequences in the long run. The cumulative effects of uncontrolled sand mining have substantially altered the physical as well as social environment

The environmental effects of natural river sand mining can be broadly classified into three categories [14]:

A. **Physical Effect**

   The large-scale extraction of streambed materials, mining and dredging below the existing streambed, and the alteration of channel-bed form and shape leads to several impacts such as erosion of channel bed and banks, increase in channel slope, and change in channel morphology. These impacts may cause: (1) the undercutting and collapse of river banks, (2) the loss of adjacent land and/or structures, (3) upstream erosion as a result of an increase in channel slope and changes in flow velocity, and (4) downstream erosion due to increased carrying capacity of the stream, downstream changes in patterns of deposition, and changes in channel bed and habitat type.

B. **Water Quality Effect**

   Mining and dredging activities, poorly planned stockpiling and uncontrolled dumping of overburden, and chemical/fuel spills will cause reduced water quality for downstream users, increased cost for downstream water treatment plants and poisoning of aquatic life.

C. **Ecological Effect**

   Mining which leads to the removal of channel substrate, re-suspension of streambed sediment, clearance of vegetation, and stockpiling on the streambed, will have ecological impacts. These impacts may have an effect on the direct loss of stream reserve habitat, disturbances of species attached to streambed deposits, reduced light penetration, reduced primary production, and reduced feeding opportunities.

#### 2.3.2.2.2 Technical Defect

It is agreed that natural sand, which is available today, is deficient in many aspects to be used directly for concrete production. Some of the factors include: [3]

- ✓ It doesn't contain fine particles, in the required proportion.
- ✓ Contains an organic and soluble compound that affects the setting time and properties of cement.
- ✓ The presence of impurities such as clay, dust and silt coatings, increase water requirement and impair bond between cement paste and aggregate.
- ✓ The presence of organic materials affects durability of the concrete therefore it shortens the life of the concrete product [7].

## 2.4 Mix Design Selection

### 2.4.1 General

The process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing a concrete of the required, strength, durability, and workability as economically as possible, is termed the concrete mix design. The proportioning of ingredient of concrete is governed by the required performance of concrete in 2 states, namely the plastic and the hardened states. If the plastic concrete is not workable, it cannot be properly placed and compacted. The property of workability, therefore, becomes of vital importance.

The compressive strength of hardened concrete which is generally considered to be an index of its other properties, depends upon many factors, e.g. quality and quantity of cement, water and aggregates; batching and mixing; placing, compaction and curing [15].

There are different factor that needs to be considered while preparing the mix design. Some of the factors are strength margin, measurement of workability, free water and W/C ratio, aggregate type and grading, cement content and aggregate size.

### 2.4.2 Method of Specifying Concrete Mixes

There are four methods to specify concrete mixes namely designed mix, prescribed mix, standard mix and designated mix [1].

1. **Designed mix: -** is specified by the designer in terms of strength, cement content, and water to cement ratio. Compliance relies on strength testing.
2. **Prescribed mix: -** is specified by the designer in terms of the nature and proportions of mix ingredients. The use of prescribed mixes is advantageous when particular properties of concrete are required.
3. **Standard mix: -** is based on ingredients and proportions fully listed in codes and standards. In Ethiopian context, mix proportions for grade C-5 to C- 30 is specified in EBCS 2-1995 of section 8.2[16].
4. **Designated mix: -** the concrete producer selects the water cement ratio and the minimum cement content. This approach can be used only if the concrete producer holds a special certificate of product conformity based on product testing and surveillance, coupled with certification of quality assurance.

## 2.5. Properties of Concrete

### 2.5.1 Properties of Fresh Concrete

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

#### 2.5.1.1. Workability

Workability is a general term to describe the properties of fresh concrete. Workability is often defined as the amount of mechanical work required for full compaction of the concrete without segregation [13].

This is a useful definition because the final strength of the concrete is largely influenced by the degree of compaction. A small increase in void content due to insufficient compaction could lead to a large decease in strength.

The primary characteristics of workability are consistency (or fluidity) and cohesiveness. Consistency is used to measure the ease of flow of fresh concrete.

#### 2.5.1.1.1 Factors affecting workability

The workability of concrete is affected by a number of factors, which include the following [1]:

**A. Water content:**

Except for the absorption by particle surfaces, water must fill the spaces among particles. Additional water "lubricates" the particles by separating them with a water film. Increasing the amount of water will increase the fluidity and make concrete easy to be compacted. Indeed, the total water content is the most important parameter governing consistency. But, too much water reduces cohesiveness, leading to segregation and bleeding. With increasing water content, concrete strength is also reduced.

**B. Aggregate properties:**

The shape and texture of aggregate particles can also affect the workability. As a general rule the more nearly spherical and smoother the particles, the more workable concrete.

In addition to this for a fixed w/c ratio, an increase in the aggregate/cement ratio will decrease the fluidity. Generally speaking, a higher fine aggregate/coarse aggregate ratio leads to a higher cohesiveness.

**C. Maximum aggregate size:**

For a given w/c ratio, as the maximum size of aggregate increases, the fluidity increases. This is generally due to the overall reduction in surface area of the aggregates. For this research the maximum aggregate size is 19mm diameter.

**D. Cement:**

Increased fineness will reduce fluidity at a given w/c ratio, but increase cohesiveness. Under the same w/c ratio, the higher the cement content, the better the workability (as the total water content increases).

**E. Admixtures:**

Air entraining agent and super plasticizers can improve the workability.

**F. Temperature and time:**

As temperature increases, the workability decreases. Also, workability decreases with time. These effects are related to the progression of chemical reaction.

#### 2.5.1.2 Setting of concrete

Setting is defined as the onset of rigidity in fresh concrete. It can also be defined as the transition process of changing of concrete from plastic state to hardened state. It is different from hardening, which describes the development of useful and measurable strength. Setting precedes hardening although both are controlled by the continuing hydration of the cement. [1]

#### 2.5.1.3 Hydration

Concrete derives its strength by the hydration of cement particles. The hydration of cement is not a momentary action but a process continuing for long time. Of course, the rate of hydration is fast to start with, but continues over a very long time at a decreasing rate In the field and in actual work, even a higher water/cement ratio is used, since the concrete is open to atmosphere, the water used in the concrete evaporates and the water available in the concrete will not be sufficient for effective hydration to take place particularly in the top layer.

If the hydration is to continue, extra water must be added to refill the loss of water on account of absorption and evaporation. Therefore, the curing can be considered as creation of a favorable environment during the early period for uninterrupted hydration. The desirable conditions are a suitable temperature and ample moisture.

### 2.5.2. Properties of Hardened Concrete

The major properties of hardened concrete are: strength, modulus of elasticity, durability, creep and shrinkage. Some of them will be discussed as follows:-

A. **Strength of concrete**

   Strength of concrete is commonly considered its most valuable property, although in many practical cases other characteristics such as durability and impermeability may in fact be more important. Nevertheless, strength usually gives an overall picture of the quality of concrete because strength is directly related to the structure of the hardened cement paste [1].

   Of all, compressive strength of concrete is the most important one because the best quality of concrete is in its compression resistance or capacity. More over other strengths like flexural and tensile can be correlated to this property. The 3, 7 and 28-day compressive strength of concrete will be determined by a standard uniaxial compression test is accepted universally as a general index of concrete strength.

**B. Durability**

The durability of concrete may be defined as the ability of concrete to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties. Different concretes require different degrees of durability depending on the exposure environment and the properties desired. The concrete ingredients, proportioning of those ingredients, interactions between the ingredients, and placing and curing practices determine the ultimate durability and life of the concrete. [7]

## 2.6 River Sand Replacement Materials

### 2.6.1. General

Cement, sand and aggregate are essential needs for any construction industry. Sand is a major material used for preparation of mortar and concrete and plays a most important role in mix design. In general consumption of natural sand is high, due to the large use of concrete and mortar. Hence the demand of natural sand is very high in developing countries to satisfy the rapid infrastructure growth. Natural sand deposits are being used up and causing serious threat to environment as well as the society. Rapid extraction of sand from river bed causing so many problems like losing water retaining soil strata, deepening of the river beds and causing bank slides, loss of vegetation on the bank of rivers, disturbs the aquatic life as well as disturbs agriculture due to lowering the water table in the well etc are some of the examples [17].

Options for various river sand alternatives, such as offshore sand, quarry dust and filtered sand have also been made [18]. Physical as well as chemical properties of fine aggregate affect the durability, workability and also strength of concrete, so fine aggregate is a most important constituent of concrete and cement mortar. Generally river sand or pit sand is used as fine aggregate in mortar and concrete. Together fine and coarse aggregate make about 65- 70 % of total volume of concrete and hence it is very important to fine suitable type and good quality aggregate nearby site [2]. Recently natural sand is becoming a very costly material because of its demand in the construction industry due to this condition research began for cheap and easily available alternative material to natural sand. Some alternatives materials have already been used as a replacement of natural sand such as fly-ash, quarry dust or limestone and siliceous stone powder, filtered sand, copper slag are used in concrete and mortar mixtures as a partial or full replacement of natural sand [19].

Even though offshore sand is actually used in many countries such as the UK, Sri Lanka, Continental Europe, India and Singapore, most of the records regarding use of this alternative found mainly as a lesser extent of practice in the construction field [20].

When we look at the current availability and condition of river sand in Ethiopia, one can easily see that it is an alarming issue. The major problems regarding rivers sand faced in this country is that it is being depleted. Due to this, the cost of river sand is increasing as its transportation cost is increasing. The facts like in Ethiopia is also almost same in others countries. So the need to find an alternative aggregate material to river sand in construction works has assumed greater importance now a days.

Researcher and Engineers have come out with their own ideas to decrease or fully replace the use of river sand and use recent innovations such as M-Sand (manufactured sand), robot sand, stone crusher dust, filtered sand, treated and sieved silt removed from reservoirs as well as dams besides sand from other water bodies. Some of the research outcomes will be discussed as follows below:

### 2.6.2 Manufactured Sand

Manufactured sand is a term used for aggregate materials less than 4.75mm and which are processed from crushed rock or gravel. The possibility of manufactured sand replacing river sand was studied by different scholars and Engineering students all over the world. So far the results from these researches have indicated that it could be a suitable replacement for river sand.

In Ethiopia a research conducted by Shewaferaw Dinku, on the use of manufactured sand in concrete production, the following findings were established [4]:-

1. The results of the hardened properties of the mix have shown that the concrete mix for ISC and HSC with proportion of manufactured and natural sand achieved a higher compressive strength almost at all tested age of concrete.
2. A mean compressive strength of 93MPa, which is about C-75 concrete were produced using a 50% proportion of both natural and manufactured sand whereas with the same proportion of constituent material, a mean compressive strength of 88MPa was achieved on 100%NS and 100%MS indicating that the suitable proportion of NS and MS would result in improved compressive strength.
3. Manufactured sands are made by crushing aggregate to sizes appropriate for use as a fine aggregate. During the crushing process the manufactured sand have irregular shapes

and more fine particles contributing to improved compressive strength, compared to natural sand control mix.

4. Due to the irregular particle shape of the manufactured sand, in addition to the reduced amount of water cement ratio, manufactured sand is more important for high strength concrete mixes.
5. Analysis made on the influence of manufactured sand in the cost of the concrete revealed that no significant cost variation is observed for mixes with fully or partial replacement of the manufactured sand with natural one.
6. Manufactured sand offers important economic advantages in regions where the availability of natural sand is scarce or in cities where transportation cost is high as in the case of Addis Ababa and Jimma.
7. The use of manufactured sand in the construction industry helps to prevent unnecessary damages to the environment and provide optimum exploitation of the resources.
8. Manufactured sand offers a viable alternative to the natural sand if the problems associated with the workability of the concrete mix can be resolved by using super plasticizer. The addition of super plasticizer to a concrete mix with manufactured sand allows the mix to have a better workability.

In Kenya also a research conducted on crushed rock sand as partial replacement of natural sand. From the study Manguriu et.al, 2013 conclude [21]:-

1. The mechanical properties of crushed rock sand depend on the source of its raw material hence selection of quarry is very important for obtaining quality fine aggregate. The crushed rock that was tested satisfied most of the mechanical and physical properties required for concrete. However it required blending to meet the desired gradation because of excessive fines.
2. Crushed rock sand improved most of the concrete properties. While the average compressive Strength of the control mix was 22.5 N/mm2, peak compressive strength of 23.6 N/mm2 was obtained with 20 % replacement of natural river sand (RS). The indirect tensile strength of the concrete increased from 1.28 to 1.42 N/mm2 with 20 % RS replacement, a 10.1 % increase in strength justifying the importance of crushed rock sand as fine aggregates. The flexural strength increased by 16.7 % with 20 % crushed rock sand. The beam deflection reduced by 50 % with 20 % crushed rock sand.
3. From the general behavior of concrete made with partially replaced natural river sand and the properties of the rock sand conclusion is herein drawn that CRS is a suitable partial replacement of natural sand.

4. The 0 to 60 % CRS resulted in strength values above that of the design (20 N/mm2). However the best results were achieved with 20 % CRS. The replacement of natural river sand can therefore made up to 60%.

### 2.6.3 Other Types of Material Used as a Replacement

Even though most of the researches done for replacement of river sand focuses on the use of manufactured sand, there are some other materials investigated. These materials include: Sandstone, Quarry dust, Robot sand, used foundry sand, Stone dust and Ceramic scarp, and Laterite with combination of Quarry dust. Some of the research paper is presented below.

**A. Quarry Dust**

The quarry dust is the by-product which is formed in the processing of the granite stones which broken downs into the coarse aggregates of different sizes. Quarry dust has been used for different activities in the construction industry such as road construction and manufacture of building materials such as light weight aggregates, bricks, and tiles.

The following conclusions were made from the research conducted by Chandana Sukesh et al. 2013 [19].

1. The Replacement of the sand with quarry dust shows an improved in the compressive strength of the concrete.
2. The specific gravity is almost same both for the natural river sand and quarry dust. The variation of the physical properties like particle size distribution and bulking is much varying parameter that which effect the mix design of the concrete.
3. The results show the decrease in the workability of concrete when the percentage of the replacement is increasing. The workability is very less at the standard water-cement ratio and the water that is required for making the concrete to form a zero slump with a partial replacement requires more water. The test conducted at 50% replacement showed that the water-cement ratio increased to 1.6 at which the slump cone failed completely.
4. The ideal percentage of the replacement of sand with the quarry dust is 55% to 75% in case of compressive strength.

**B. Used Foundry Sand**

Used Foundry sand (UFS) is a discarded material coming from ferrous and nonferrous metal casting industry. It’s a mixture of high quality size-specific silica sand, few amount of impurity of ferrous and nonferrous by-products from the metal casting process itself and a variety of binders.

According to the obtained test results, it can be concluded that structural mortar and concrete can be manufactured with UFS as a partial replacement of river sand.

A suitable recycling of the discarded foundry sand as building construction material could be suggested.

### C. Blast Furnace Slag

Blast furnace slag as by–product, which is a non–biodegradable waste material from that only a small percentage of it is used by cement industries to manufacture cement. In present study alternatives of natural sand, blast furnace slag were evaluated for their suitability of replacing natural sand for making mortar and concrete. Mortar with proportions (1:4) for 0%, 25%, 50%, 75% and 100% replacement and concrete of M-20 and M-30 grades for 0%, 25%, 50%, 75% and 100% replacement cube were also prepared respectively. From this study the following conclusion was drawn [22]:

1. Using of blast furnace slag as a replacement of fine aggregate will might prove an economical and environmentally friendly solution.
2. Chemical Composition with respect to Silica, Aluminium, Oxygen, Calcium and magnesium are nearest to normal sand in Blast furnace slag.
3. At 100% replacement of natural sand, compressive strength decreases when compared with the cubes prepared with 100% natural sand only.
4. Blast furnace slag can be used as alternative of fine aggregates in making mortar up to 60% replacement, which reduces the consumption of natural sand.
5. When blast furnace slag was examined as replacement of natural sand for making concrete, compressive strength of cubes (28 days) is comparable with that of the cubes prepared with natural sand up to 75% replacement. Beyond this, compressive strength decreases with increase in the replacement.

## 2.7 Sandstone

### 2.7.1. General

Sandstone is a sedimentary rock composed mainly of sand sized mineral or rock grains. Most sandstone is composed quartz and or feldspar because these are the most common minerals in earth's crest. Like sand sandstone may be any color, but the most common colors are tan, brown, yellow, red, gray and white.

Since sandstone beds often form highly visible cliffs and other topographic features, certain colors of sandstone may be strongly identified with certain regions. Sandstones are clastic in origin (as opposed to organic, like chalk or coal). They are formed from the cemented grains that may be fragments of a pre-existing rock, or else just mono–minerallic crystals. The cements binding these grains together are typically calcite, clays and silica.

Grain size of sandstone is within the sand size range of 0.2 to 0.06 mm. Sandstone is also classified using the amount of quartz concentration is a measure of maturity. Accordingly rich sandstone, called orthoquartize, is the well sorted variety cemented mainly with secondary silica. Such quartzite sandstone, plentiful in Ethiopia, is utilized to manufacture glass and is currently in use for small scale Glass and Bottle factory in Addis Ababa [23].

### 2.7.2 Previous Work Related to Sandstone

In western shewa part of the country there are no detailed research activity conducted like main Ethiopian rift valley though the area is interesting from hydrogeological and geological point of view for there are indicative of resource potential which may need proper attention.
Some reviews of existing pervious work include [24]:

The earliest known exploration of sandstone deposit in the Ethiopia was first conducted at the request of Measjsrsh. Shah and Ranade of Sunderji Kalidas Co., the investigation was made to locate outcrops of sandstone with silica purity >97 %, suitable for the chemical industry, near to Addis Ababa, and in economic situation.  All the recent investigations were made in order to find minerals with high silica content which is useful for a raw material for glass factories.

In 1962, Bogale Biazen was the first geologist to visit the Senkele area in ambo and concluded that the sandstone there could be used for making low quality glass but could be difficult to exploit [24].

In 1963 the US Department of the Interior-Land and water resources of the Blue Nile Basin conducted a detailed survey of the ambo area for five years and determined the geology of sandstone deposit in the ambo area.

In 1964, W.S Atkins and Partners expanded the glass industry in Ethiopia and concluded that the sandstone deposit of the ambo area is good for making clear class and other chemical industries that use silica after a detailed site investigation and laboratory analysis involving crashing of the sand manually, and in the ceramic mortar; with no iron tool touching any sample. The samples were analyzed by The Ethiopian Geological Survey Laboratory for $A1_2O_3$ (titration method) and for Fe (by Atomic Absorption), hence calculating the Silica Purity.

Despite the fact that all of the investigations mentioned above are for the glass and chemical factory application the Ambo sand stone is mainly known in the construction industry as a dimension stone as Regarding building stone, the best potential of sandstone lies within the thick, red bed series of the ambo Sandstone along an axis from Ambo in the south, through the Abay valley including Senkele area also in Tigray, Harar Regions and in the Abay River gorge etc.

Exploitation mainly occurs in the deposits near the town of Ambo, the cross-bedded, red and white sandstone is worked to ashlars, split bricks and slabs mainly with the help of simple tools such as sledge hammers, wedges and crow.

The dimension stone products are distributed throughout most of Ethiopia, even though a major part of the production is used in the capital. Sandstone reveals a pronounced development of cross bedding on both a small and large scales, and displays a pronounced lamination. Accordingly, in the form of thin sheets and slabs sandstone has very attractive colors of green, purple and reddish brown sometimes in concentric forms. The silica cemented variety of sandstone, in particular, is suitable for dimension stone. The colorings are not superficial but penetrate to depths of several meters. However, superficial dendritic pattern of different colors are also very much in evidence.

Generally considerable deposits of sandstone appear to be present in Ethiopia. Sandstone is supplied for Addis Ababa from the Ambo Town about 125 km west of Addis Ababa, hence named the carved rock after the Town “Ambo Dingay”.

### 2.7.3 Sandstone as Fine Aggregate

Commercial sandstone is a sedimentary rock composed of minerals and rock fragments within the sand size range of 0.2 to 0.06 mm.

> "The possibility of sandstone replacing river sand was studied by Paramasivam Suresh Kumar, in Malaysia, Thesis; on "A study on high performance concrete using sandstone aggregate". From his research he concludes that locally available sandstone aggregate can be used in concrete production'' [25].

Even though no study yet done in Ethiopia, Ambo sandstone used as replacement of river sand in the construction industry. Yotek Construction Company uses this material in ambo site.
In addition to Ambo sandstone; Jema sandstone also used for masonry construction for diversion of river. This shows that sandstone will be one of natural sand replacement material.

### 2.7.4 Use of Sandstone sand in the Ethiopian construction industry

#### 2.7.4.1 Concrete Production

It was observed that the concrete production using ambo sandstone in Ambo University Technology campus of expansion project. The river sand is becoming scares and very expensive since it has to be imported from the Awash basin through Addis. This scarcity will intern raise the cost of the concrete production by using river sand.

In Ambo University Technology Campus there are more than 23 contractors engaged in the construction of administration, laboratory and dormitory buildings. In this site rectangular sand washing pits are built in order to wash away the reddish pink color of the Ambo sandstone sand and to remove the silt content.

According to Ambo University project manager, the use of Ambo sandstone sand is enforced by the local authority construction department without further study on the nature and behavior of the sand and documented prior trial mix design which is tailor made for Ambo sandstone sand in specific.

All construction in this campus adopting the customary mix proportion used in concrete while using river sand the 1:2:3 (1 batch of cement two boxes of Ambo sand stone sand and three boxes of aggregate) used for the production of C-25 structural concrete.

Concrete workability slump tests as well as cube tests are not conducted at every concrete casting regardless of the technical specification which dictates taking of concrete cube samples and sent to the laboratory for the analysis of compressive strength every 30 $m^3$ and on site concrete slump tests should be taken at every concrete cast, rather at these site representative sample for grade beam, slab and top tie beams are only taken once at the respective casting.

Some laboratory compressive strength test results of concrete specimens made at AAU college of commerce and Ambo university phase III building project using a water cement ratio of 0.50, 360kg/$m^3$ of PPC cement, 763 kg/$m^3$ of fine aggregate and 1073kg/$m^3$ coarse aggregate. The respective compressive strength for concrete mix is shown in Tables 2.4 and 2.5, respectively.

Table 2.4 Concrete cube test result of AAU College of commerce project

| Class of concrete | Cement type & quantity | Age | Compressive Strength (MPa) |
|---|---|---|---|
| C-25 | **OPC - 390kg/m3** | 7 | 21.8 |
| | | 7 | 22.5 |
| | | 7 | 23.1 |
| | | **Average** | **22.5** |
| | | 28 | 29.7 |
| | | 28 | 29.1 |
| | | 28 | 31.0 |
| | | **Average** | **29.9** |

Table 2.5 Concrete cube test result of Ambo University project

| Class of Concrete | Observed slump (mm) | Cement type & quantity | Age | Compressive Strength (MPa) |
|---|---|---|---|---|
| C-25 | 67 | **PPC - 360kg/m3** | 7 | 16.9 |
| | | | 7 | 15.6 |
| | | | 7 | 16.9 |
| | | | **Average** | **16.5** |
| | | | 28 | 24.4 |
| | | | 28 | 24.4 |
| | | | 28 | 24.9 |
| | | | **Average** | **24.6** |

As can be seen from the results of the laboratory and information from the project personnel, the use of ambo sandstone sands in concrete causes the concrete to have poor workability. The water required for a given degree of workability (slump) is directly related to the void space in the aggregate. When the void space is high, the water requirement necessary for given workability will also be high. And the strength of the concrete will also be low unless additional cement is added.

In addition, the higher fines content of manufactured sand has significant effects on the workability and strength of concrete. Producing concrete with the above situation leads to uneconomical concretes because of the larger surface area of the finer particles.

#### 2.7.4.2. Plastering

The main factor of the Ambo sandstone sand is the color effect due to its physical property in plastering; the reddish yellow color of the Ambo sandstone sand outshines the grayish color of the mortar paste and will give the final finish a muddy color. This muddy color will affect the gypsum coating and the final paint, due to this effect washing of the Ambo sandstone sand is conducted, while some contractors prefer mixing of the Ambo sandstone with river sand imported from Awash basin for the final coat plastering.

#### 2.7.4.3 Hollow Concrete Block (HCB) Production

The other important aspect of Ambo sandstone sand in ambo area is, its use for the production of hollow concrete blocks, the local authority encourages small and micro associations to be engaged in the production of the HCB blocks using Ambo sandstone sand as a replacement for river sand.

In the construction site of the ambo university, these micro and small associations are the ones who provide the Hollow concrete blocks needed for the construction. In the production of HCB blocks, red ash, Ambo sandstone sand and cement are mixed with water and dried after being compressed in the HCB compressor machine.

According to project manager of Yotek construction company in Ambo University construction project, Ambo sandstone sand used for total construction of Ambo University Agricultural Campus at Guder. The use of Ambo sandstone sand is being introduced in to the capital and neighboring cities step by step we have observed construction of building undertaken by Ambo sandstone sand replacement around Legetafo.

### 2.7.5 Characterization of Sandstone

The characterization and identification of minerals is fundamental in the development and operation of mining and minerals processing systems. Worldwide, sandstones have been used as construction material for centuries and are still being used for this purpose.

Although, sandstones show similar appearances and properties; a geological background may cause differences in colour, mineral composition, granulometric properties, pressure strength and weathering behavior [26].

On the other hand, mineralogical properties of sandstones could predict their mechanical properties such as the uniaxial compressive strength. The inherent parameters of sandstones can be characterized by their petro graphical properties [27].

Even though no study yet conducted on Jema sandstone deposit, there is one study, studied by Bogale Bizen on Ambo sandstone in 1963. From his research chemically sandstone is very resistant Mono-Mineralic rock, with silica as the principal. The percentage of each constituent is as follows in table 2.6 [24]:

Table 2.6 chemical constituents of Ambo sandstone

| Constituent | Oxide composition | % of chemical composition |
|---|---|---|
| Silica | $SiO_2$ | 97.6% |
| Iron | $Fe_2O_3$ | 0.9% |
| Alumina | $Al_2O_3$ | 1% |
| Magnesia | $MgO$ | 0.15% |
| Traces | | 0.35% |

# Chapter 3

# Methods and Materials Methodology

## 3.1 Crushed Jema Sandstone

Sandstone of Mesozoic age occurs in several places in Ethiopia. In the Central part of the country deposits are found in Ambo, Jema, Guder, Muger and Abay. Similar deposits also found in the eastern and northern part of the country. Jema river basin is one the major deposit of sandstone. Jema sand commonly known as Red sand, which is extracted from Jema river basin sandstone deposit area which is found in Amhara region about 140km from Addis Ababa, Jema river is one of the Blue Nile river basin tributary located between Lemi and Alem Dogol town.

At present, exploitation of sandstones for building purposes occurs mainly in the Ambo quarries. The Ambo sandstone is yellow to red. Whereas the Jema sandstone is generally white, yellow and red in color, predominantly micaceous, with intercalations of green shale [28]. This paper mainly focuses on the suitability of Jema sandstone deposit. Physical and chemical test results of crushed Jema sandstone were discussed in chapter five.

Location of Jima river basin sandstone deposit is presented in the fig 3.1 of the geological map of Ethiopia.

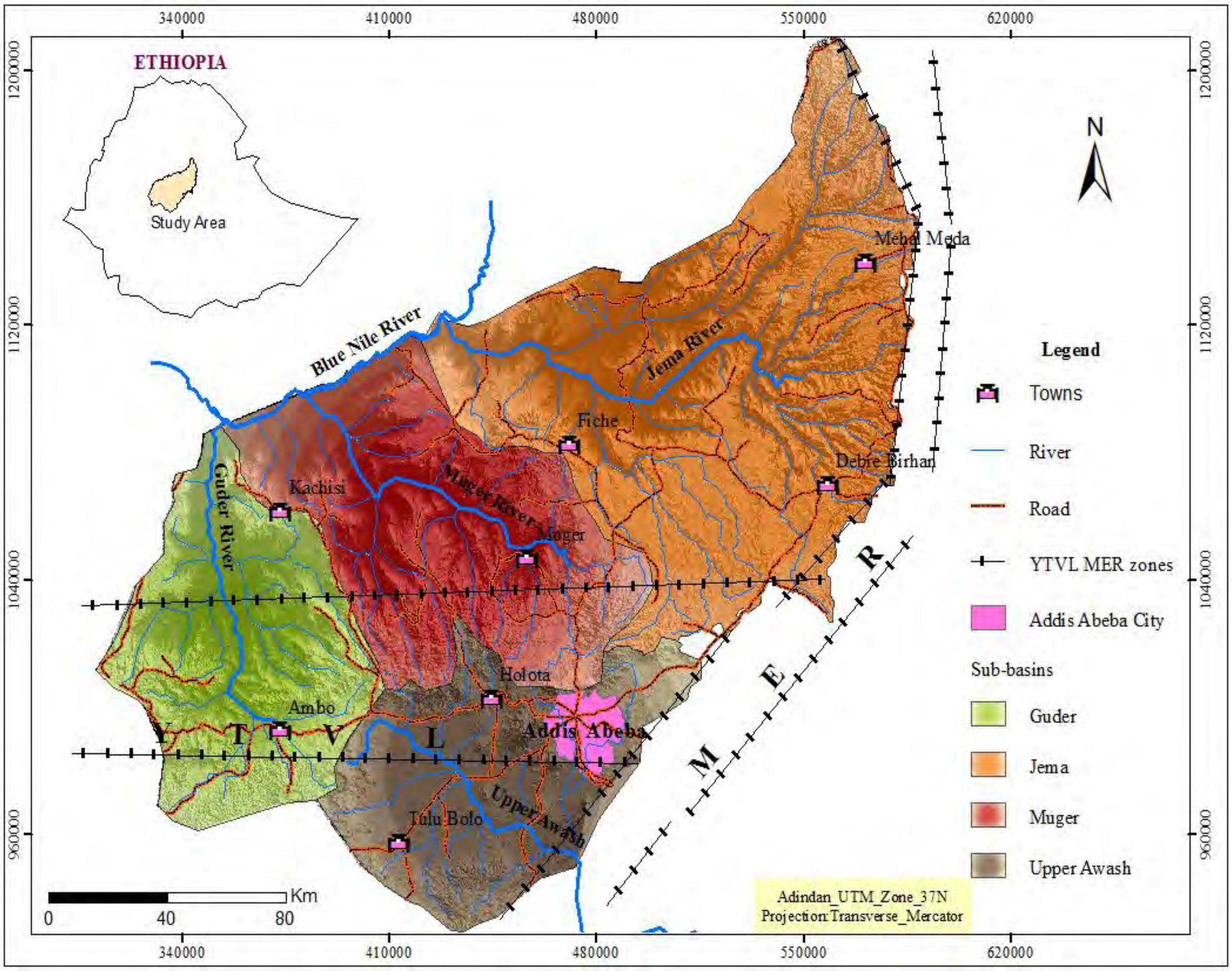


Fig 3.1 Location of Jema sandstone deposit

## 3.2 Methodology

The following methodology have been employed to achieve the objectives of this research

Stage 1: Literature review

A comprehensive literature review were made to understand the previous efforts and the laboratory testing procedures, which include the review of textbooks, periodicals and academic journals, seminar, conference and research papers.

Stage 2: Experimental study

1. Characterization of sandstone: - Conducting absorption capacity, moisture content, specific gravity, gradation and silt content and silicate analysis was conducted.

2. Different mixes targeting at characteristics compressive strength of 25 MPa and higher were also made.

    - ✓ Each grade of concrete were prepared with eight different mix proportions: the first with 100% river sand used as a control mix, the second with 100% crushed Jema sandstone, the third with 100% washed Jema sandstone and the rest with the partial replacement of river sand with 10%, 15%, 25%, 50% and 75% of washed Jema sandstone.
    - ✓ The other constituent material was constant.
    - ✓ For compressive strength test nine 150*150*150mm cubes were casted for $7^{th}$, $28^{th}$, and $56^{th}$ days.
    - ✓ For flexural strength test of concrete two 100x100x500mm prisms with 100% river sand, 75% and 100% Jema sandstone sand was casted for $7^{th}$ and $28^{th}$ days from each mix.

3. Based on the findings, conclusions and recommendations are given.

# CHAPTER 4

# MATERIALS PROPERTIES AND MIX PROPORTIONS

## 4.1 General

As the major objective of the research work is to study suitability of crushed Jema sandstone on the properties of mortar and concrete, different mixes targeting at characteristics compressive strength of 25 MPa and higher were made.

Each grade of concrete were prepared with eight different mix proportions: one with 100% river sand used as a control mix, one with 100% unwashed Jema sandstone,  one with 100% washed Jema sandstone and the rest with the partial replacement of river sand with 10%, 15%, 25%, 50% and 75% of washed Jema sandstone.

Physical tests of the materials and compressive strength tests were carried out in the Addis Ababa institute of technology construction materials laboratory. In addition to this chemical test like silicate analysis test were carried out in Geological Survey of Ethiopia, Geochemical Laboratory.

## 4.2 Cement

Ordinary Portland cement (OPC) produced as per CEM-I-42.5 grade contains 95% clinker and 5% gypsum produced by Dangote Cement PLC was used throughout the experiment. The reason to select only one cement type is due to financial and time limitation to perform experiments. OPC, were used for the preparation of all grades of concrete samples and PPC was used for mortar samples.

## 4.3 Aggregate

### 4.3.1 Properties of Fine Aggregate

To make control of mix for C-25, C-30 and C-40 normal river sand which is extracted from Alemtena area, was used to prepare the concrete samples. The Jema sandstone sand commonly known as Red sand, which is extracted from Jema river basin area which is found in Amhara region about 140km from Addis Ababa, Jema River is one of the Blue Nile river basin located between Lemi and Alem Dogol town.

The fine aggregate is full of dust film on its surface. For this reason, the fine aggregate were washed thoroughly and dried to saturated surface dry (SSD) state before doing any test.

In addition to this, all fine aggregates retained on 9.5mm sieve size were no longer relevant, and all the passing fine aggregate were used for experimentation.

In order to design and make a concrete mix, a number of tests were carried out on the above materials. The test performed includes: sieve analysis, bulk and dry density, moisture content, absorption capacity, unit weight, chemical test like silicate analysis etc. All aggregates tests were done in accordance with the Ethiopian standards and conforms to the ASTM requirements. The physical properties of fine aggregates obtained from the tests are summarized in Table 4.1 below.

Table 4.1 Physical properties of fine aggregate

| Item no. | Description | | Test result |
|---|---|---|---|
| 1 | Silt content | River sand | 1.57% |
| | | Unwashed Jema sandstone | 13.8% |
| | | Washed Jema sandstone | 0.69% |
| 2 | Fineness modulus | River sand | 2.79 |
| | | Jema sandstone | 2.64 |
| 3 | Moisture content | River sand | 2.36% |
| | | Jema sandstone | 0% |
| 4 | Absorption Capacity | River sand | 3.57% |
| | | Jema sandstone | 7.11% |
| 5 | Specific gravity | Bulk | 2.30 |
| | | SSD | 2.47 |
| | | Apparent | 2.67 |

According to ES C.D3.201, the gradation result of the original sample sand is out of range on sieves 300μm and 150μm size. So, it is blended with finer sand to make it within the range. The grading requirements for fine aggregates according to ES C.D3.201 and, the particle size distribution of original and blended aggregate used for the experiment is shown in Fig 4.1 and 4.2, respectively.

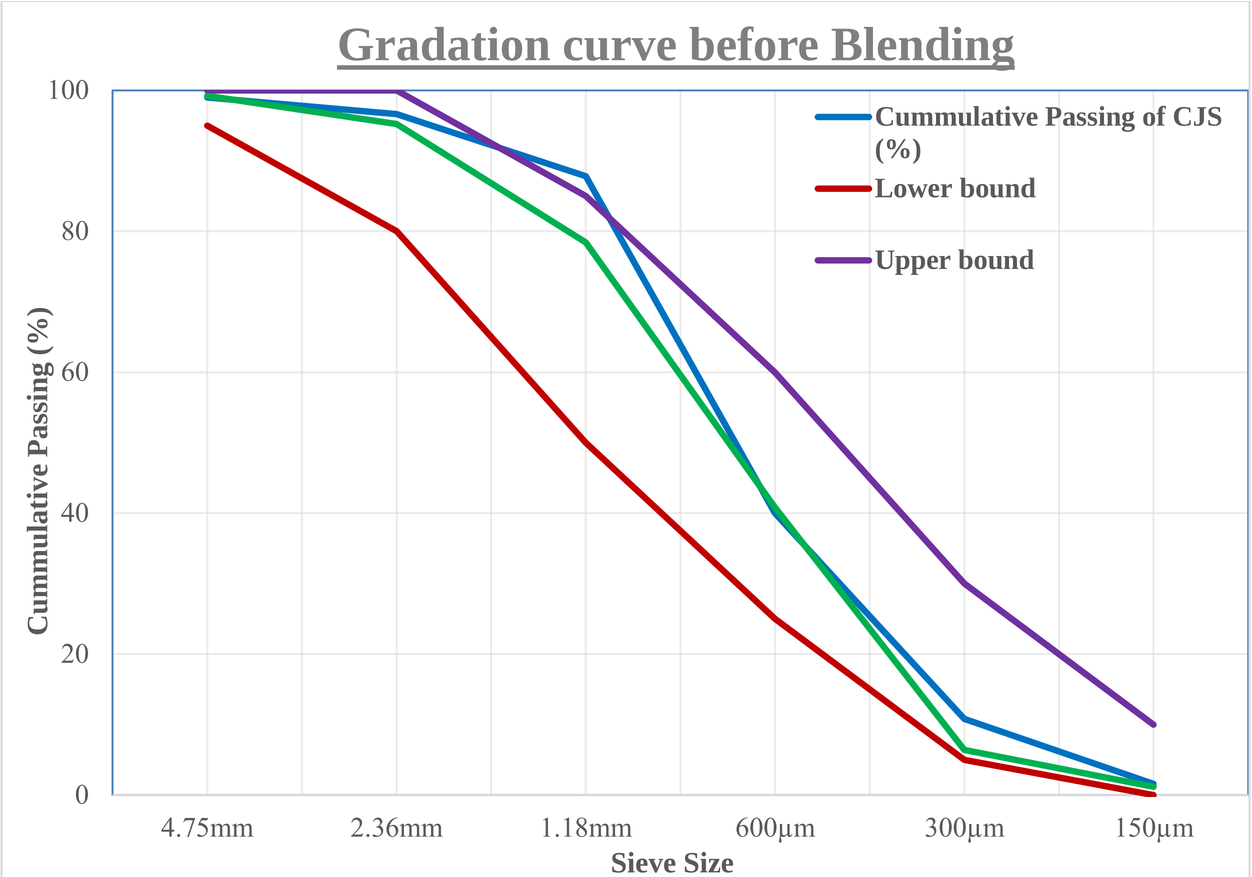


Fig. 4.1 Gradation curve for RS and CJS before blending

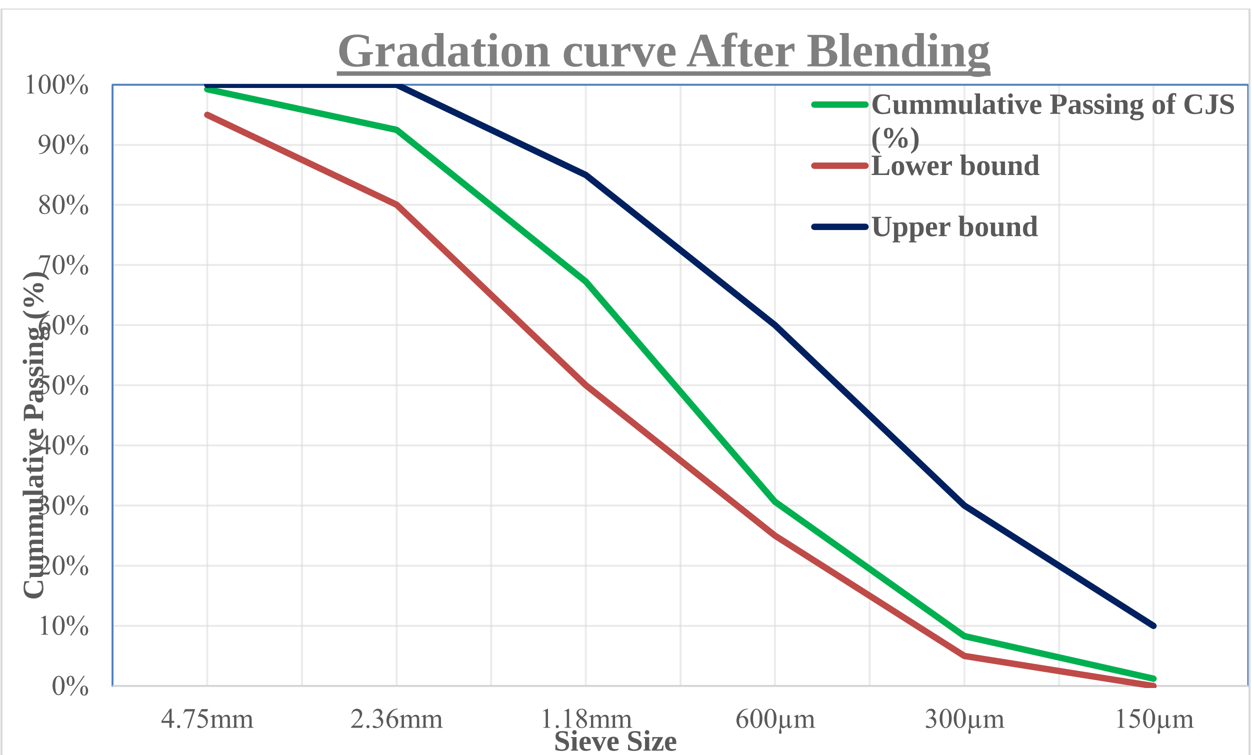


Fig. 4.2 Gradation curve for CJS after blending

### 4.3.2 Properties of Coarse Aggregate

The coarse aggregate used for this research was crushed basaltic rock, was brought from site under construction which is located around Bole sub-city. The aggregate coming from the construction site was washed thoroughly and dried in air inside the laboratory room. The size of coarse aggregate used for experimental investigation was a mixture of 20mm and 10mm diameter aggregate sizes and it was sieved and stored in different grades for blending. In this study a maximum size of 19 mm diameter aggregate was used in all the concrete mix design.

The physical properties of coarse aggregate test results are shown in the Table 4.2 below.

Table 4.2 Physical properties of coarse aggregate

| Item no. | Description | | Test result |
|---|---|---|---|
| 1 | Nominal maximum aggregate size | | 19mm |
| 2 | Moisture content | | 1.52 |
| 3 | Dry unit weight | | 1.6 |
| 4 | Absorption capacity | | 1.0 |
| 5 | Specific gravity | Bulk | 2.74 |
| | | Bulk(SSD) | 2.77 |
| | | Apparent | 2.82 |

## 4.4 Water

Potable water which is supplied from the Addis Ababa water supply and sewerage Authority is used for all mortar and concrete mixes.

## 4.5 Mix Proportions

### 4.5.1 Concrete

In order to analyze the effects of sandstone, river sand and/or the combined effect of both have on the properties of concrete, different mixes with a characteristic strength of normal strength (C-25) to high strength (C-40) were prepared.

Department of Environment (DOE) mix design method was adopted to proportion the mixes. The mix was prepared for characteristic strength of 25, 30 and 40 MPa.

Altogether a total of 24 mixes, for each water cement ratio eight mix were prepared. For each mix nine 150*150*150mm cubes for compressive strength test for 7$^{th}$, 28$^{th}$ and 56$^{th}$ day was casted.

The table below shows the mix proportions used to produce the different concretes. The letters **RS** and **CJS** designates river sand and crushed Jema sandstone respectively.

**Mix series I.** The mixes were prepared using Dangote ordinary Portland cement (OPC) for normal concrete strength using a water cement ratio of 0.58 and cement content of 330kg/m$^3$. Mix proportions with the amount of coarse and fine aggregates are shown in Table 4.3.

Table 4.3 Mix proportion summary for C-25 Concrete Strength

| Mix Proportion | Mix Code | Cement type | Cement quantity (kg/m$^3$) | W/C | Water (kg/m$^3$) | CA (kg/m$^3$) | FA (kg/m$^3$) |
|---|---|---|---|---|---|---|---|
| 100%RS | $MT_{11}$ | Danagote OPC | 330 | 0.58 | 190 | 1205 | 650 |
| 90%RS & 10% CJS | $MT_{12}$ | Danagote OPC | 330 | 0.58 | 190 | 1205 | 650 |
| 85%RS & 15% CJS | $MT_{13}$ | Danagote OPC | 330 | 0.58 | 190 | 1205 | 650 |
| 75%RS & 25% CJS | $MT_{14}$ | Danagote OPC | 330 | 0.58 | 190 | 1205 | 650 |
| 50%RS & 50% CJS | $MT_{15}$ | Danagote OPC | 330 | 0.58 | 190 | 1205 | 650 |
| 25%RS & 75% CJS | $MT_{16}$ | Danagote OPC | 330 | 0.58 | 190 | 1205 | 650 |
| 100% CJS | $MT_{17}$ | Danagote OPC | 330 | 0.58 | 190 | 1205 | 650 |
| 100% unwashed CJS | $MT_{18}$ | Danagote OPC | 330 | 0.58 | 190 | 1205 | 650 |

**Mix series II.** The mixes were prepared using Dangote ordinary Portland cement (OPC) for concrete strength of C-30 MPa using a water cement ratio of 0.53 and cement content of 370kg/m$^3$. Mix proportions with the amount of coarse and fine aggregates are shown in Table 4.4.

Table 4.4 Mix proportion summary for C-30 Concrete Strength

| Mix Proportion | Mix Code | Cement type | Cement quantity (kg/m$^3$) | W/C | Water (kg/m$^3$) | CA (kg/m$^3$) | FA (kg/m$^3$) |
|---|---|---|---|---|---|---|---|
| 100%RS | $MT_{21}$ | Danagote OPC | 370 | 0.53 | 190 | 1295 | 560 |
| 90%RS & 10% CJS | $MT_{22}$ | Danagote OPC | 370 | 0.53 | 190 | 1295 | 560 |
| 85%RS & 15% CJS | $MT_{23}$ | Danagote OPC | 370 | 0.53 | 190 | 1295 | 560 |
| 75%RS & 25% CJS | $MT_{24}$ | Danagote OPC | 370 | 0.53 | 190 | 1295 | 560 |
| 50%RS & 50% CJS | $MT_{25}$ | Danagote OPC | 370 | 0.53 | 190 | 1295 | 560 |
| 25%RS & 75% CJS | $MT_{26}$ | Danagote OPC | 370 | 0.53 | 190 | 1295 | 560 |
| 100% CJS | $MT_{27}$ | Danagote OPC | 370 | 0.53 | 190 | 1295 | 560 |
| 100% unwashed CJS | $MT_{28}$ | Danagote OPC | 370 | 0.53 | 190 | 1295 | 560 |

**Mix series III.** The third mixes were prepared using Dangote ordinary Portland cement (OPC) for C-40 concrete strength using a water cement ratio of 0.45 and cement content of 450kg/m$^3$. Mix proportions with the amount of coarse and fine aggregates are shown in Table 4.5.

Table 4.5 Mix proportion summary for C-40 Concrete Strength

| Mix Proportion | Mix Code | Cement type | Cement quantity (kg/m$^3$) | W/C | Water (kg/m$^3$) | CA (kg/m$^3$) | FA (kg/m$^3$) |
|---|---|---|---|---|---|---|---|
| 100%RS | $MT_{31}$ | Danagote OPC | 450 | 0.45 | 190 | 1360 | 505 |
| 90%RS & 10% CJS | $MT_{32}$ | Danagote OPC | 450 | 0.45 | 190 | 1360 | 505 |
| 85%RS & 15% CJS | $MT_{33}$ | Danagote OPC | 450 | 0.45 | 190 | 1360 | 505 |
| 75%RS & 25% CJS | $MT_{34}$ | Danagote OPC | 450 | 0.45 | 190 | 1360 | 505 |
| 50%RS & 50% CJS | $MT_{35}$ | Danagote OPC | 450 | 0.45 | 190 | 1360 | 505 |
| 25%RS & 75% CJS | $MT_{36}$ | Danagote OPC | 450 | 0.45 | 190 | 1360 | 505 |
| 100% CJS | $MT_{37}$ | Danagote OPC | 450 | 0.45 | 190 | 1360 | 505 |
| 100% unwashed CJS | $MT_{38}$ | Danagote OPC | 450 | 0.45 | 190 | 1360 | 505 |

### 4.5.3 Mortar

To better understand the impact of crushed Jema sandstone, mortar tests was also conducted. Compressive strength of mortar was carried out using both crushed Jema sandstone and river sands. In case of Jema sandstone both washed and unwashed state was used.

This was seen necessary because, to closely analyze the sand, the other variable which is the coarse aggregate must be avoided. For this research, water to cement ratio of 0.50 was used to investigate the corresponding compressive strength of the mortar. Mix proportions with the amount of water and fine aggregates are shown in Table 4.6.

Table 4.6 Mix proportion summary for Mortar with water to cement ratio of 0.5

| Mix Code | Mix Proportion | Cement type | Cement quantity (gm) | W/C | Water (gm) | FA (gm) |
|---|---|---|---|---|---|---|
| MS 1-1 | 100%RS | Danagote PPC | 660 | 0.50 | 330 | 1685 |
| MS 1-2 | 100% washed CJS | Danagote PPC | 660 | 0.50 | 330 | 1685 |
| MS 1-3 | 100% unwashed CJS | Danagote PPC | 660 | 0.50 | 330 | 1685 |

## 4.6 Preparation of Specimens and Mixing Procedure of concrete

The concrete moulds and mixer were cleaned from all dust and coated with releasing agent (oil) to smooth the surface and to prevent sticking of mixed concrete with the mold and mixer. The ingredients, such as; cement, fine aggregate (river sand and Jema sandstone), coarse aggregate and water were measured by weight balance. After that the weighted coarse aggregate was first added to the mixer and the cement was added after the coarse aggregate and then the fine aggregate is added next to cement and dry mixed for a minute. Then, water was added to the dry mixed concrete ingredients mixture and thoroughly mixed for two more minute. The mixed concrete was checked for workability by filling the standard slump cone with three layers by rodding each layer with 25 times. Then, after the slump is checked, the mixed concrete was placed in the mould and well compacted in two layers with the help of a table vibrator for 45 seconds. After vibration the top surface is finished using a trowel. The concrete moulds are kept for 24 hours and then the casted concrete cubes were removed from the mould. All concrete specimens were cured for seven days and exposed to room temperature of the laboratory until the day of testing.

Out of many test applied to the concrete, compressive strength test is the utmost important which gives an idea about all the characteristics of concrete. Test for compressive strength is carried out either on cube or cylinder. Various standard codes recommend concrete cylinder or concrete cube as the standard specimen for the test. American Society for Testing Materials ASTM C39/C39M provides Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens, for cube test two types of specimens either cubes of 15cm X 15cm X 15cm or 10cm X 10cm x 10cm depending upon the size of aggregate are used. In this specific research cube of 15cm X 15cm x 15cm sizes were preferred. These specimens are tested at the age of $7^{th}$, $28^{th}$ and $56^{th}$ days of concrete. Load should be applied gradually at the rate of 140 $kg/cm^2$ per minute till the Specimens fails.

## 4.7 Mix Proportion for Mortar

As it was mentioned earlier, the main target of this research is to study the suitability of Jema sandstone sand for mortar and concrete production in comparison with river sand.

For mortar mix preparation, specifications and guidelines from ASTM C 270- 10 and ASTM C 109-07 were used.

A mix ratio of 1 part cement to 3 parts of mortar was adopted according to ASTM C 270 – 10. Then this volumetric ratio was converted to weight ratio by using a batch factor

Another variation from the standards was the mixing procedure adapted and the compaction method used. According; to both ASTM C 270 – 10 and ASTM C 109-07, mechanical mix shall be used and compaction shall be done by using hand tamping. However in this research hand mixing and compaction by column vibrator was used.

Once mixing was done, the mortar was placed in 5mm cubic steel mold and compaction was done, as mentioned above, by applying a column vibrator to the base of the mold for several seconds.

The samples were let to harden for 24 hours before they were demolded and put in a container with water for curing purpose until the day of testing.

# CHAPTER 5

# TEST RESULTS AND DISCUSSIONS

## 5.1 General

It was stated above that the main objectives of the laboratory test specimens were to:

- Study the suitability of crushed Jema sandstone on the general properties of concrete in both the fresh and hardened state and compare the result with that of concrete produced using river sand.
- Check if the properties of crushed Jema sandstone is compatible with different standard
- Investigate the effect of percentage replacement of river sand by crushed Jema sandstone on different properties concrete.
- Determine the rate of strength gain for the concrete with and without crushed Jema sandstone.

In the following sections, the test results are presented and evaluated in light of the requirements of concrete strength and workability.

## 5.2 Test Result

### 5.2.1 Jema Sandstone Sand

#### 5.2.1.1 Sieve Analysis

The results of sieve analysis, as expected, have shown that crushed Jema sandstone contains larger amount of fine materials than the natural sand. The grading of the natural and Jema sandstone sand is different requiring variable aggregate blending. ASTM C33 provides guide lines for gradation and fineness modulus for fine aggregate that can be used in concrete. From the sieve analysis result except sieve no 1.18mm and 600μm all satisfy the grading requirement of ES.C.D3.201 in conformation with ASTM C33. But the fineness modulus is outside the range provided in ASTM. So, the material is standardized for the mix in this research. The results of all sieve analysis for all aggregate samples used in the concrete mix are attached in the annex A.

#### 5.2.1.2 Silt Content

The silt content of the original sample was found to be 13.8% which was above the allowable limit. According to the Ethiopian standard it is recommended to wash sand or reject if the silt content exceeds a value of 6%. Therefore it was necessary to wash it to reduce the silt content. On the other to keep the original material property one mix was prepared with unwashed Jema sandstone.

However, for the mortar test part of this research, washed Jema sandstone with silt content of 0.69% was used so as to compare it with the river sand. The results of silt content are attached in the annex A.

#### 5.2.1.3 Mineralogical Composition

As mentioned above, it was necessary to conduct complete silicate analysis test on both sand types used in this research. Sample of crushed Jema sandstone was submitted to Ethiopian Survey of Ethiopia; Geoscience Laboratory Center and the mineral composition of river sand were referred from different literature [29]. Table 5.1 shows summarized findings from Ethiopian Survey of Ethiopia; Geoscience Laboratory Center and literatures.

**Table 5.1**: Complete silicate analysis of crushed Jema sandstone and different river sand

| **Constituent** | **% of Chemical Composition** | | | |
|---|---|---|---|---|
| | Jema Sand | Ambo Sand | Northern shewa river sand | Dire dawa Sand |
| $SiO_2$ | 94.46 | 94.18 | 75.89 | 72.64 |
| $Fe_2O_3$ | 1.58 | 0.84 | 3.34 | 4.40 |
| $Al_2O_3$ | 1.81 | 2.14 | 5.34 | 10.40 |
| MgO | 0.22 | 0.24 | 0.04 | < 0.01 |
| CaO | 0.42 | 0.28 | 0.01 | 0.81 |
| $Na_2O$ | 1.08 | 1.06 | 0.01 | 3.21 |
| $K_2O$ | 0.38 | 0.12 | 2.01 | 4.56 |
| MnO | <0.01 | 0.04 | 0.02 | 0.20 |
| $P_2O_5$ | 0.07 | 0.03 | 0.01 | 0.04 |
| $TiO_2$ | 0.58 | 0.12 | 0.05 | 0.42 |
| $H_2O$ | 0.05 | 0.16 | 0.02 | 0.47 |
| LOI | 0.85 | 1.46 | 0.99 | 1.40 |

As it can clearly be seen from the table, there is a significant silica content difference between river sand and Jema sandstone. More over this difference is enhanced even more for the washed sandstone sand and river. This indicates that the washing of the sandstone remove impurities like $Fe_2O_3$ and $Al_2O_3$ and gave more silica contents.

As the content $Fe_2O_3$ and $Al_2O_3$ is reduced, the color of sandstone sand changes from darker to lighter, it was chemically accompanied by increasing in silica content. This shows that the color of reddish and light brownish color is due to the content of iron and aluminum.
However the chemical composition of river sand has high aluminum, iron and potassium content when compared to Jema sandstone and Ambo sand restricting its uses in other areas than concrete making. As discussed in chapter 2, high silica content is very desirable in glass making, sand blasting, sand paper production and other areas. Even making of construction materials like asbestos cement pipe, asphalt roof tile and sand-lime brick require very high silica content.

One specification given by ASTM is for the use of Ottawa Standard Sand for testing compressive strength of hydraulic cement mortars and concrete. According to Xenaki and Athanasopoulos, 2002; and ASTM C 778-02, 2002, Ottawa sand consists of rounded grains of clear, colorless quartz. It contains about 98.7% of silica (by mass) which is free from clay, loam, iron compounds, or other foreign substances. It is also considered to non-reactive due to its round shape. Coincidently Jema sandstone sand and Ambo sand is very close to meeting this specification with regards to silica content. But its roundness and reactivity requires further investigation.

### 5.2.2 Concrete Test

#### 5.2.2.1 Fresh Property of Concrete

The results of the slump tests carried out on the fresh concrete gave an indication of the workability of the concrete. As shown in Table 5.2, for concrete strength of 25, 30 and 40 MPa with water to cement ratio of 0.58, 0.53 and 0.45, respectively, a minimum slump of 28mm is observed.

Table 5.2 Fresh concrete property

| Expected Slump | Mix Code | Observed Slump (mm) | | |
|---|---|---|---|---|
| | | C-25 | C-30 | C-40 |
| 30-60 | 100% RS | 49 | 45 | 38 |
| | 90% RS + 10 CJS | 47 | 40 | 35 |
| | 85% RS + 15 CJS | 47 | 42 | 35 |
| | 75% RS + 25 CJS | 44 | 40 | 32 |
| | 50% RS + 50 CJS | 41 | 38 | 33 |
| | 25% RS + 75 CJS | 40 | 28 | 35 |
| | 100% CJS | 39 | 36 | 32 |
| | 100% unwashed CJS | 37 | 34 | 29 |

The concrete mix which contains Jema sandstone are relatively harsher than the other mixes in all the mix series this is mainly because of: (1) because it is finer it has larger surface area to volume ratio in turn it needs more water and more paste to fill the spaces thoroughly; (2) it will decrease the mobility of the mass due to varying combination of sizes.

#### 5.2.2.2 Hardened property of concrete

##### 5.2.2.2.1 Discussion on compressive strength of concrete

The most common tests carried out on concrete specimens is compressive strength test due to the fact that: structural design codes are based mainly on compressive strength of concrete; it is assumed that most of the important properties of concrete are directly related to compressive strength, and the test is easy and relatively inexpensive to carry out.

The compressive strength of the concrete specimens was determined by testing concrete cubes of size 150mm. All specimens were weighed and measured to determine the area of the cube and density of the concrete. The hardened properties of the concrete have been determined at the ages of 7, 28 and 56 days. At each age a minimum of three specimens were tested to ensure the accuracy of test results. The use of Jema sandstone sand by replacing fully or partially of river sand had an effect on the compressive strength of concrete.

The values of compressive strength development test for 25, 30 and 40 MPa with different percent of crushed Jema sandstone replacements are shown as a graph in Fig. 5.1, Fig 5.2 and Fig. 5.3 respectively.

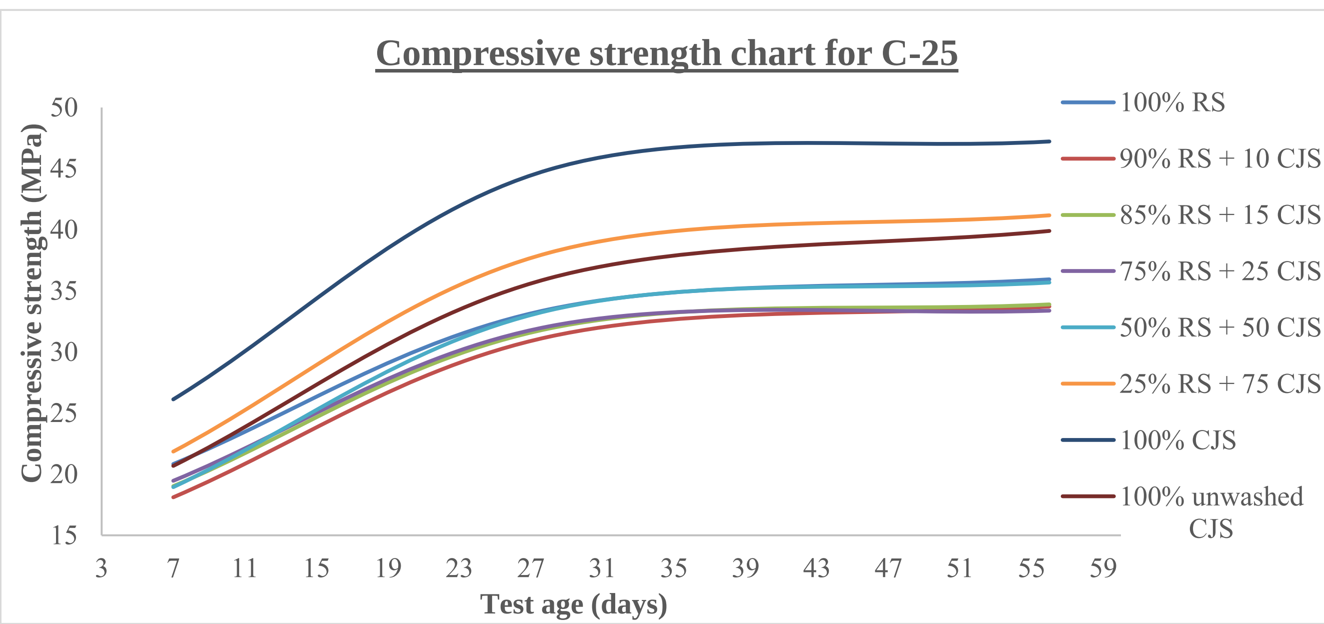


**Fig. 5.1** Compressive strength comparison for C-25 Concrete

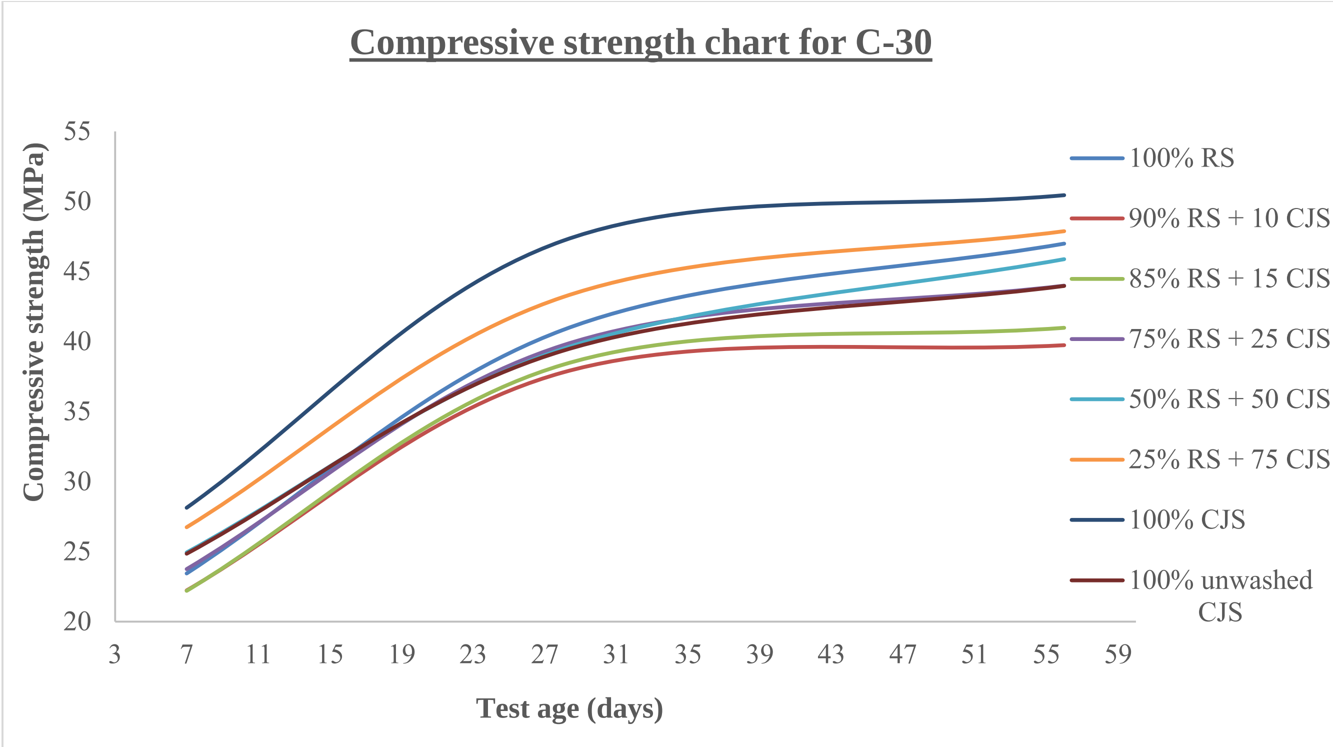


**Fig. 5.2** Compressive strength comparison for C-30 Concrete

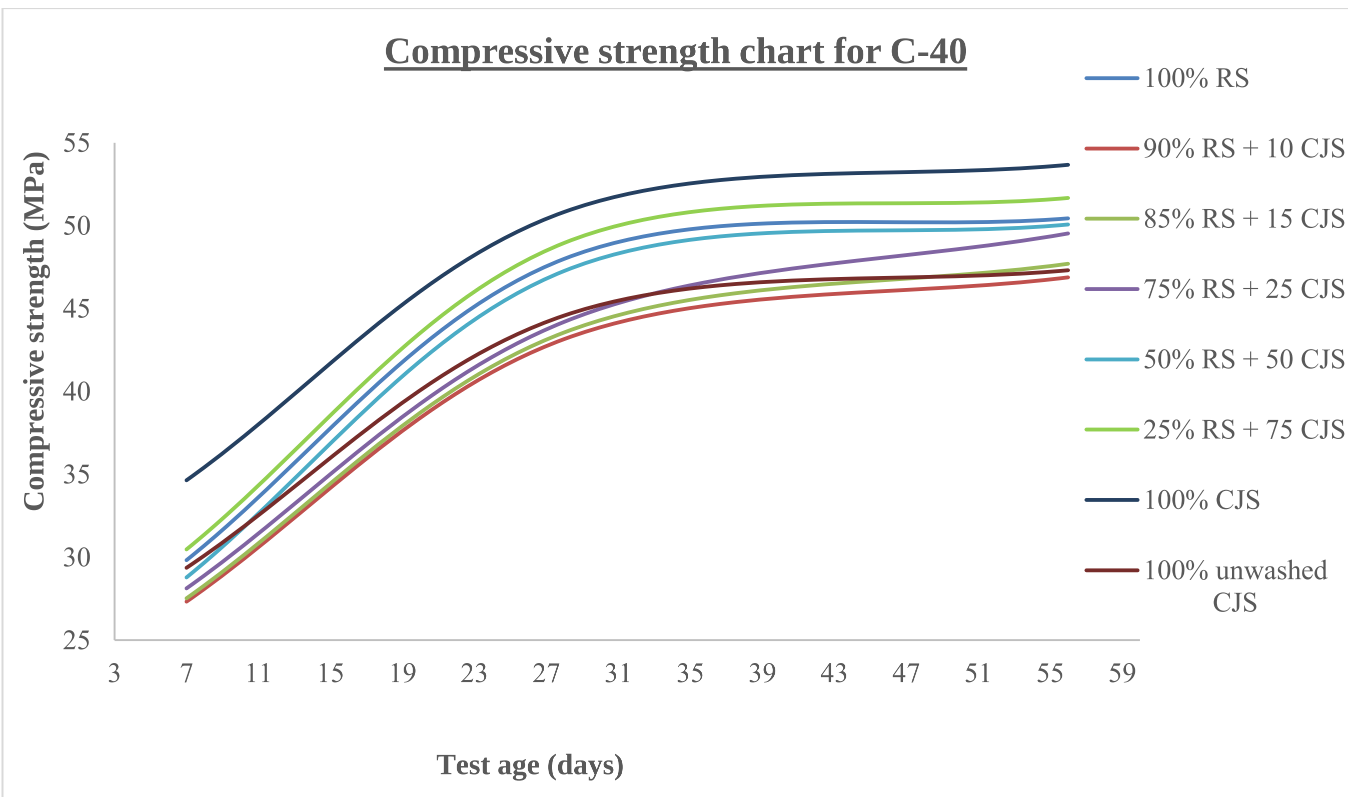


**Fig. 5.3** Compressive strength comparison for C-40 Concrete

The compressive strength test result for C-25 of 10%, 15%, 25%, 50%,75% and 100% crushed Jema sandstone replaced concrete at the 28day have been shown 2.15%, 4.72%, 6.68%, 15.31% and 34.15% from the reference concrete (90%RS+10%JSS). Similarly, for C-30 of 10%, 15% , 25%, 50%,75% and 100% Jema sandstone sand replaced concrete at the 28day have been shown 1.45%, 5.13%, 4.44%, 14.23% and 24.87% from the reference concrete(90%RS+10%), while for C-40 of 10%, 15% , 25%, 50%,75% and 100% Jema sandstone sand replaced concrete at the 28day have been shown 0.93%, 2.42%, 11.11%, 13.43% and 17.77% from the reference concrete (90%RS+10%).

Table 5.3 Effect of percentage increment on compressive strength

| Mix Code | Percentage increment on compressive strength | | |
|---|---|---|---|
| | C-25 | C-30 | C-40 |
| 85% RS + 15% CJS | 2.15% | 1.45% | 0.93% |
| 75% RS + 25% CJS | 4.72% | 5.13% | 2.42% |
| 50% RS + 50 %CJS | 6.68% | 4.44% | 11.11% |
| 25% RS + 75% CJS | 15.31% | 14.23% | 13.43% |
| 100% CJS | 34.15% | 24.87% | 17.77% |

Therefore, the test result shows as the percent of replacement increased from 0% to 100% the compressive strength has been well improved.

This research have been also shown that the compressive strength development of C-25 , C-30 and C-40 concrete with 100% Jema sandstone at the 28day have been shown 34.15%, 15.60% and 5.89% from the reference concrete (100% river sand). Therefore, based on the test results as concrete grade increased from C-25 to C-40, the relative strength gain decreased.

The concrete test results for C-25 at the 7$^{th}$ day showed about 70.38% of the 28$^{th}$ day compressive strength. Similarly, for C-30 at the 7$^{th}$ day showed about 66.30% of the 28$^{th}$ day compressive strength; while C-40 at the 7$^{th}$ day showed about 57.22% of the 28$^{th}$ day compressive strength.

In general, the addition of crushed Jema sandstone resulted in increased compressive strengths. This suggests that using crushed Jema sandstone can achieve a better strength in concrete.

The test results showed that for all grade of concrete mix proportion, concrete with 100% crushed Jema sandstone was capable of achieving a higher compressive strength than concrete with river sand control mix. However, as the concrete grade increased from C-25 to C-40, the relative strength gain decreased. This shows that the use of crushed Jema sandstone for normal strength concrete production is more useful and special cares have to be taken to ensure that the concrete mix achieves a suitable finish.

Table 5.4, 5.5 and 5.6 shows the summary of mean compressive strength of concrete made using Dangote OPC for C-25, C-30 and C-40 respectively and tested at the age of 7$^{th}$, 28$^{th}$ and 56$^{th}$ days of age. The raw data for the compressive strength values are shown in annex B.

Table 5.4: Mean compressive strength of C-25 concrete test result at 7$^{th}$, 28$^{th}$ and 56$^{th}$ days.

| Concrete Grade | Sand proportion | Mean Compressive strength (MPa) | | |
|---|---|---|---|---|
| | | 7$^{th}$ Day | 28$^{th}$ Day | 56$^{th}$ Day |
| **C-25** | 100% RS | 20.82 | 33.47 | 35.93 |
| | 90% RS + 10 JSS | 18.10 | 31.23 | 33.71 |
| | 85% RS + 15 JSS | 19.01 | 31.90 | 33.88 |
| | 75% RS + 25 JSS | 19.45 | 32.08 | 33.37 |
| | 50% RS + 50 JSS | 18.93 | 33.38 | 35.67 |
| | 25% RS + 75 JSS | 21.84 | 38.10 | 41.17 |
| | 100% JSS | 26.11 | 44.96 | 47.21 |
| | 100% unwashed JSS | 20.97 | 36.01 | 39.89 |

Table 5.5: Mean compressive strength of C-30 concrete test result at 7$^{th}$, 28$^{th}$ and 56$^{th}$ days.

| Concrete Grade | Sand proportion | Mean Compressive strength (MPa) | | |
|---|---|---|---|---|
| | | 7$^{th}$ Day | 28$^{th}$ Day | 56$^{th}$ Day |
| **C-30** | 100% RS | 23.44 | 40.82 | 46.99 |
| | 90% RS + 10 JSS | 22.23 | 37.79 | 39.74 |
| | 85% RS + 15 JSS | 22.20 | 38.34 | 40.98 |
| | 75% RS + 25 JSS | 23.75 | 39.73 | 43.99 |
| | 50% RS + 50 JSS | 24.94 | 39.47 | 45.88 |
| | 25% RS + 75 JSS | 26.74 | 43.17 | 47.88 |
| | 100% JSS | 28.13 | 47.19 | 50.45 |
| | 100% unwashed JSS | 24.85 | 39.34 | 43.97 |

Table 5.6: Mean compressive strength of C-40 concrete test result at 7th, 28th and 56th days.

| Concrete Grade | Sand proportion | Mean Compressive strength (MPa) | | |
|---|---|---|---|---|
| | | 7th Day | 28th Day | 56th Day |
| **C-40** | 100% RS | 29.83 | 48.01 | 50.45 |
| | 90% RS + 10 JSS | 27.33 | 43.17 | 46.89 |
| | 85% RS + 15 JSS | 27.53 | 43.57 | 47.71 |
| | 75% RS + 25 JSS | 28.13 | 44.21 | 49.54 |
| | 50% RS + 50 JSS | 28.79 | 47.28 | 50.08 |
| | 25% RS + 75 JSS | 30.48 | 48.97 | 51.68 |
| | 100% JSS | 34.65 | 50.84 | 53.68 |
| | 100% unwashed JSS | 29.37 | 44.59 | 47.32 |

**5.2.2.2.1 Discussion on flexural strength of concrete**

The flexural strength test is also used to determine the tensile strength of the concrete. When point load is applied at the center of the sample concrete, the member is subjected to bending moment.

This test was performed for seven and twenty eight days for 0%, 75 % and 100% crushed Jema sandstone added concrete. The values of rate of flexural strength development test for C-25, C-30 and C-40 with 0%, 75% and 100% of crushed Jema sandstone replacement are shown as a graph in Fig. 5.4, Fig 5.5 and Fig. 5.6 respectively.

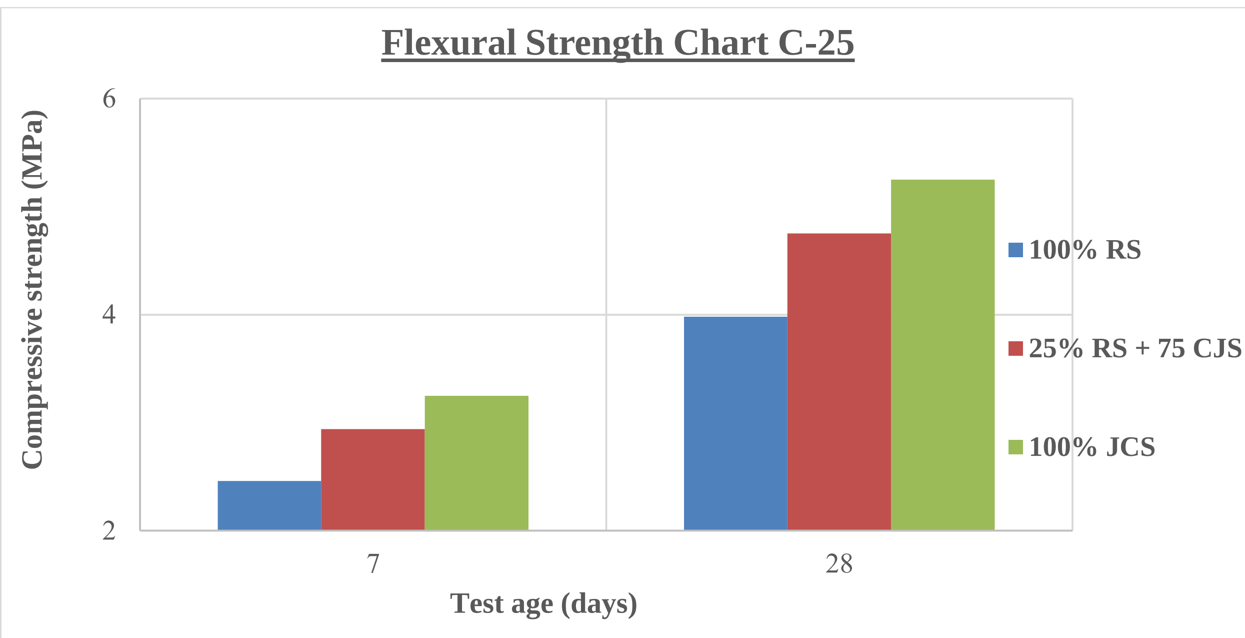


**Fig. 5.4** Flexural strength comparison for C-25 Concrete

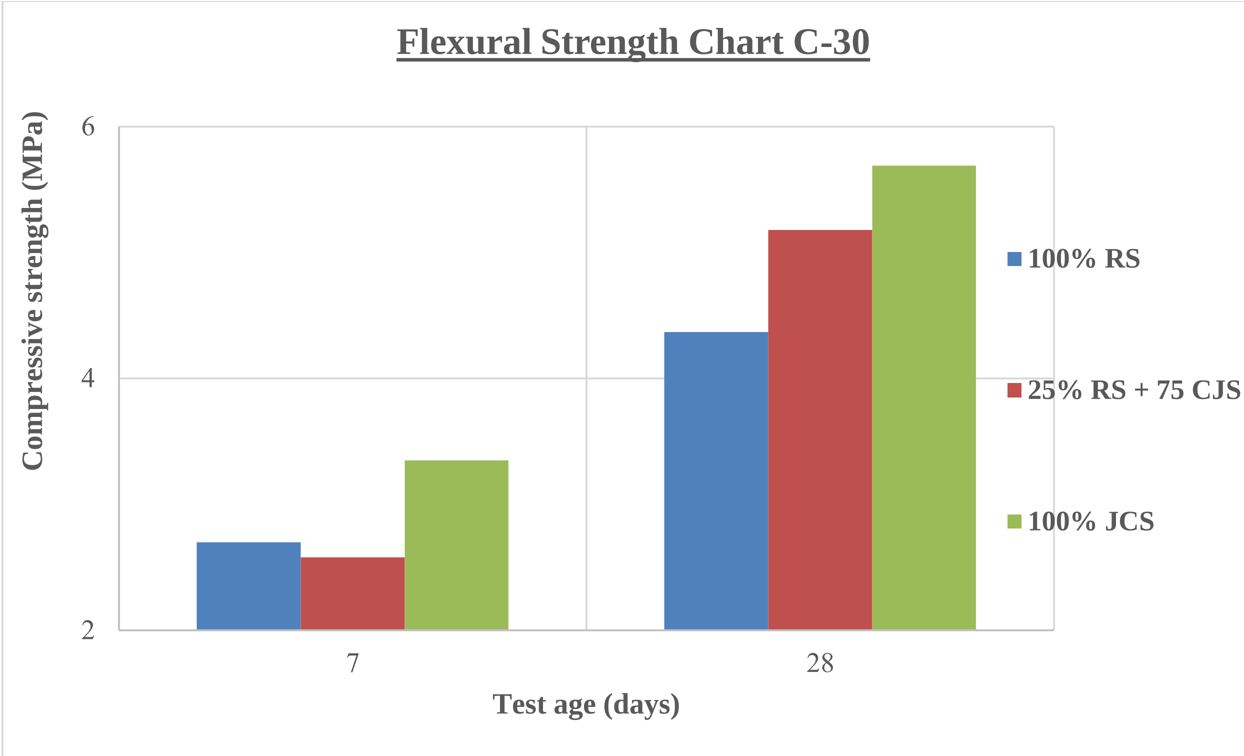


**Fig. 5.5** Flexural strength comparison for C-30 Concrete

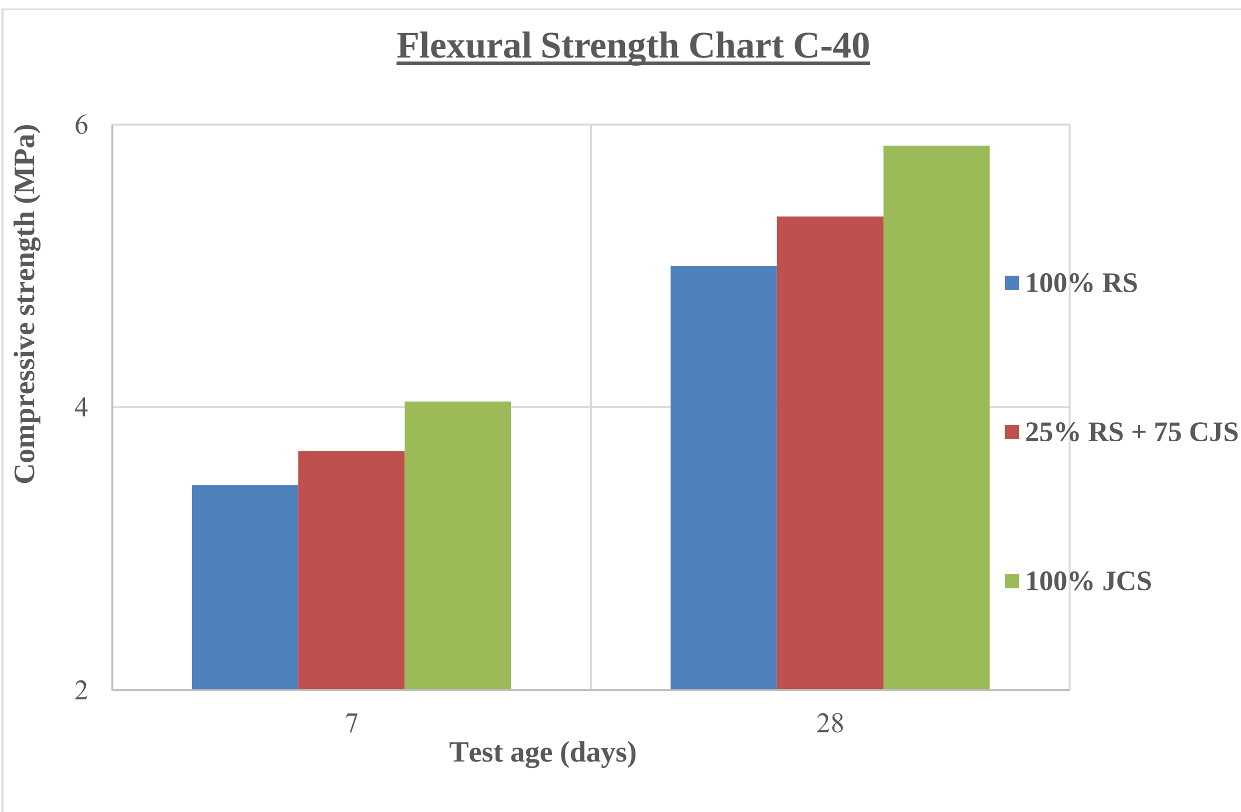


**Fig. 5.6** Flexural strength comparison for C-40 Concrete

In C-25 concrete grade at the twenty eight days, the flexural strength development of 0%, 75% and 100% replacement of river sand the concrete was 3.98MPa, 4.75MPa and 5.25MPa respectively. This indicates the rate of flexural strength development of 75% Jema sandstone concrete was improved by 0.77MPa or 19.3% from 0% of Jema sandstone replacement. For 100% Jema sandstone the rate of flexural strength development was improved by 1.27MPa or 24.2% and 0.5 MPa or 10.52% from 0% and 75% of Jema sandstone replacement.

In C-30 concrete grade at the twenty eight days, the flexural strength development of 0%, 75% and 100% replacement of river sand the concrete was 4.37MPa, 5.18MPa and 5.69MPa respectively. This indicates the rate of flexural strength development of 75% Jema sandstone concrete was improved by 0.81MPa or 18.5% from 0% of Jema sandstone replacement. For 100% Jema sandstone the rate of flexural strength development was improved by 1.32MPa or 20.2% and 0.51 MPa or 9.84% from 0% and 75% of Jema sandstone replacement.

In C-40 concrete grade at the twenty eight days, the flexural strength development of 0%, 75% and 100% replacement of river sand the concrete was 5.00MPa, 5.35MPa and 5.85MPa respectively. This indicates the rate of flexural strength development of 75% Jema sandstone concrete was improved by 0.35MPa or 7.0% from 0% of Jema sandstone replacement. For 100% Jema sandstone the rate of flexural strength development was improved by 0.85MPa or 17% and 0.50 MPa or 9.34% from 0% and 75% of Jema sandstone replacement.

This research have been also shown that the flexural strength development of C-25 , C-30 and C-40 concrete with 100% crushed Jema sandstone at the 28day have been shown 24.2%, 23.2% and 17% from the reference concrete. Therefore, based on the test results as concrete grade increased from C-25 to C-40, the relative strength gain decreased. It can be concluded that the use of crushed Jema sandstone for normal strength concrete production is more useful.

However, as the percent of replacement increased the flexural strength has been well improved. Therefore, the Jema sandstone sand with 100% was capable of achieving a higher flexural strength than the river sand control mix.

Table 5.7 shows the summary of mean flexural strength of concrete made using Dangote OPC for C-25, C-30 and C-40 and tested at the age of 7$^{th}$ and 28$^{th}$ days of age. The raw data for the flexural strength values are shown in annex B.

Table 5.7: Mean flexural strength test results

| Concrete Grade | Sand proportion | Mean Compressive strength (MPa) | |
|---|---|---|---|
| | | 7th Day | 28th Day |
| **C-25** | 100% RS | 2.46 | 3.98 |
| | 25% RS + 75 JSS | 2.94 | 4.75 |
| | 100% JSS | 3.25 | 5.25 |
| **C-30** | 100% RS | 2.58 | 4.37 |
| | 25% RS + 75 JSS | 2.98 | 5.18 |
| | 100% JSS | 3.35 | 5.69 |
| **C-40** | 100% RS | 3.45 | 5.00 |
| | 25% RS + 75 JSS | 3.69 | 5.35 |
| | 100% JSS | 4.04 | 5.85 |

### 5.2.3 Mortar Test Result

The compressive strength of the mortar specimens was determined by testing mortar cubes of size 50mm. All specimens were weighed and measured to determine the area of the cube and density of the mortar. The hardened properties of the mortar have been determined at the ages of 3, 7, 28 and 56 days. At each age a minimum of three specimens were tested to ensure the accuracy of test results.

The compressive strength of the mortar mixes, are shown in Fig. 5.7. The figures confirm that the increase in the compressive strength is achieved through the use of Jema sandstone sand.

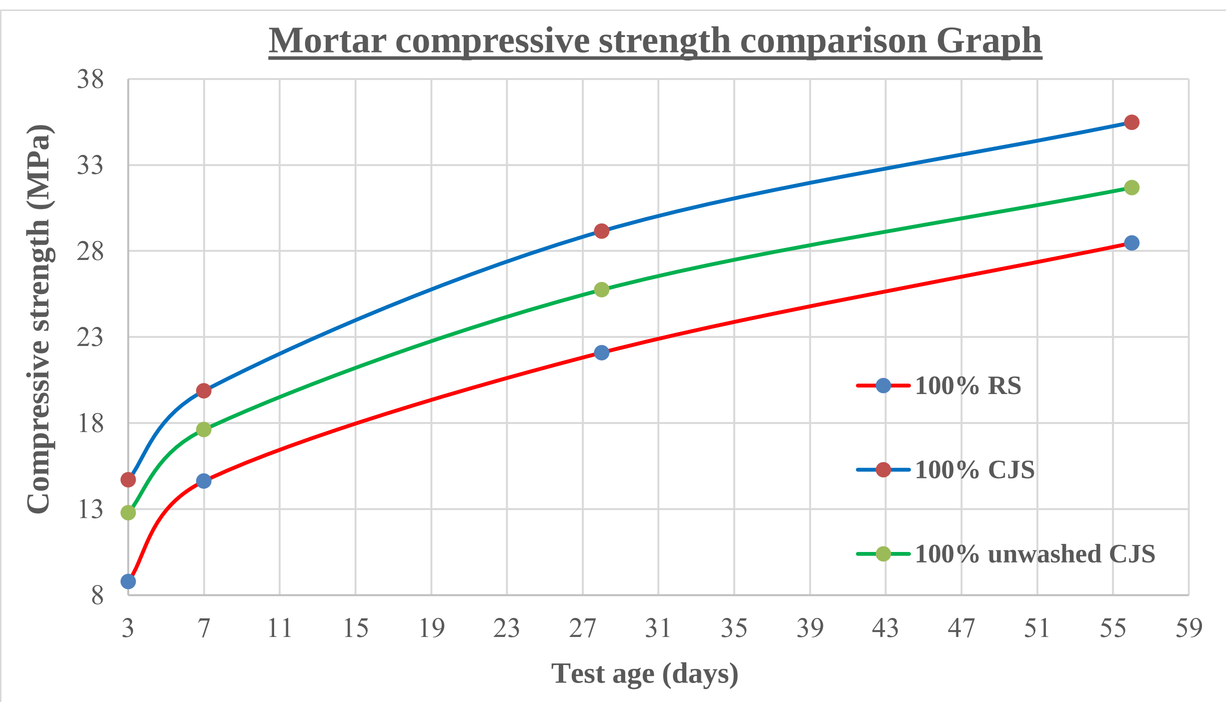


Fig. 5.7 Mortar compressive strength comparison

It can be clearly seen that the mortar prepared using washed Jema sandstone and normal Jema sandstone have shown considerable strength gain. The washed Jema sandstone has shown much more strength gain over both river sand and the washed Jema sandstone.

The fact that the sand to be used for mortar testing should contain high silica content is that the sand grains must remain intact while the bond between the cement paste and the grains broke during testing. From the results of compression test, it can be concluded that the effect of silicon dioxide content has little effect on compressive strength of mortar cube.

Table 5.8 shows the summary of mean compressive strength of mortar made using Dangote PPC for 0.5% water cement ratio and tested at the age of $3^{rd}$,$7^{th}$, $28^{th}$ and $56^{th}$ days of age. The raw data for the compressive strength values are shown in annex B.

Table 5.8 Summary of Compressive Strength Test Result of mortar at $3^{rd}$, $7^{th}$, $28^{th}$ and $56^{th}$ days

| Water/Cement ratio | Sand type | Mean Compressive strength (MPa) | | | |
|---|---|---|---|---|---|
| | | $3^{rd}$ Day | $7^{th}$ Day | $28^{th}$ Day | $56^{th}$ Day |
| 0.5 | 100% RS | 8.78 | 14.62 | 22.09 | 28.46 |
| | 100% JSS | 14.69 | 19.87 | 29.15 | 35.48 |
| | 100% unwashed JSS | 12.78 | 17.61 | 25.74 | 31.68 |

## 5.3 Qualitative Economic Analysis

The aggregate production in Ethiopia has been and will continue to be a local business based on easily accessible natural deposits. Most of the aggregate quarries are owned by the farmers on a private land and they sell their product or lease the quarry to contractors for different works.
Almost all aggregates used for construction in Ethiopia are natural in origin. The major sand supply for the construction works in and around Addis Ababa is the Awash basin located about 70-120 km southeast of the city. The method of quarrying sand is generally very old and the producers do not attempt to clean and grade the sand right from the source [2].

The true cost of aggregate material is influenced by various factor, hence production and transportation costs play the major role. But the economic impact of Jema sandstone sand has not been deeply investigated and it was difficult to get the exact figure about its production cost.

Based on the information average production cost of the natural fine aggregate at Jema basin is 125 birr per meter cube including vat while Jema sandstone sand is 71.875 birr per meter cube including vat.

Information regarding the method of transportation of construction sand from the quarry to the first point of use is not easily available. As all producers don't keep records of cost per $m^3$ per km, the cost of transport for $1m^3$ of aggregate to a km distance is difficult to estimate or it will take a long process of data collection.

Construction aggregate prices are expected to increase in the future due to the rising cost of fuel used in the production and transporting processes. The rise in fuel cost is expected to affect the delivery prices of construction sand and gravel.

However the price from different transporting companies and independent truck owners is approximately 25 birr per kilometer including vat and excluding other expenses.

In Addis Ababa the purchase price of natural sand is increasing, by simply comparing the production cost of river sand and Jema sand it's advisable to use Jema sandstone sand as alternative sand. Whereas a significant cost reduction for construction in Fechi, Lemi and Alem Dogolo area since the quarry site exist 20-40 km outside the city which will bring down the transportation cost to the minimum, however detail review of all other implications should be consider when taking alternative material for concrete production.

# CHAPTER 6

# CONCLUSIONS AND RECOMMENDATIONS

## 6.1 CONCLUSIONS

Suitability of crushed Jema sandstone in producing concrete for normal strength, intermediate strength and high strength in full and partial replacement were studied and after the research work is done, the following conclusions are made and recommendations are forwarded.

1. In general, is observed an increase in strength as the proportion of crushed Jema sandstone is increased. From all grade of concrete mixes, concrete with 100% crushed Jema sandstone proportion was capable of achieving higher compressive strength than concrete with river sand control mix.
2. The relative strength gain decreased as the concrete grade increased from C-25 to C-40. This shows that the use of crushed Jema sandstone is more useful for normal strength concrete production.
3. Crushed Jema sandstone is made by crushing sandstone rock to sizes appropriate for use as a fine aggregate. During the crushing process the Jema sandstone have more fine particles that may contribut to improved compressive strength, compared to river sand.
4. Crushed Jema sandstone offers a viable alternative to the river sand if the problems associated with the workability of the concrete mix can be resolved by using admixture.
5. The crushed Jema sandstone must be first washed and graded to meet the standard requirement of ASTM.

## 6.2 RECOMMENDATIONS

Based on the investigation made the following recommendations are forwarded;

1. Concerned bodies should do more work regarding advertising this sand to create awareness. Because it has tremendous economic benefit for the zone in particular and makes construction works faster in the lack of river sand around center of the country.
2. For plastering purpose it's better to add river sand in crushed Jema sandstone mortar to reduce the color effect.
3. Designers, contractors and material suppliers need to understand the effects of crushed Jema sandstone fines content on concrete water demand and concrete durability.
4. The silica in crushed Jema sandstone needs detail investigation to determine whether it's reactive or not. If it is found to be reactive, further studies are required with regards to potential alkali silica reactivity problems in concrete.

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## ANNEX A

## MATERIALS TEST RESULTS

### A.1. Properties of cement

#### A.1.1. Normal consistency of Dangote OPC cement

| Test No. | Sample weight [gm] | Water added [gm] | % of Water | Penetration [mm] | Water cement ratio at 10±1mm penetration |
|---|---|---|---|---|---|
| 1 | 300 | 87 | 29 | 33 | From the calculation the w/c ratio for normal consistency is approximately 27% |
| 2 | 300 | 84 | 28 | 18 | |
| 3 | 300 | 81 | 27 | 10 | |

#### A.1.2. Normal consistency of Dangote PPC

| Test No. | Sample weight [gm] | Water added [gm] | % of Water | Penetration [mm] | Water cement ratio at 10±1mm penetration |
|---|---|---|---|---|---|
| 1 | 300 | 90 | 30 | 25 | From the calculation the w/c ration for normal consistency is approximately 29% |
| 2 | 300 | 84 | 28 | 15 | |
| 3 | 300 | 82.5 | 27.5 | 9 | |

### A.2. Properties of Fine Aggregate

#### A.2.1. Silt content

| **Silt content Before washing** | | | |
|---|---|---|---|
| Sand type | Amount of Silt deposit | Amount of clear | Silt content % |
| River sand | 20 | 280 | 7.14 |
| Jema Sandstone sand | 35 | 255 | 13.8 |
| **Silt content after washing** | | | |
| | Amount of Silt deposit | Amount of clear | Silt content % |
| River sand | 5 | 298 | 1.57 |
| Jema Sandstone sand | 2 | 290 | 0.69 |

#### A.2.2. Sieve analysis

#### A.2.2.1. Sieve analysis fine aggregate

| | Crushed Jema sandstone | | | | | |
|---|---|---|---|---|---|---|
| Sieve size | Weight of Sieve (gm) | Weight of Sieve and retained (gm) | Weight Retained (gm) | Percentage retained (%) | Cummulative Coarser (%) | Cummulative Passing (%)CJS |
| 4.75 mm | 426 | 431 | 5 | 1.00 | 1.00 | 99.00 |
| 2.36 mm | 388 | 400 | 12 | 2.40 | 3.40 | 96.60 |
| 1.18 mm | 354 | 398 | 44 | 8.80 | 12.20 | 87.80 |
| 600 µm | 325 | 564 | 239 | 47.80 | 60.00 | 40.00 |
| 300 µm | 302 | 448 | 146 | 29.20 | 89.20 | 10.80 |
| 150µm | 277 | 323 | 46 | 9.20 | 98.40 | 1.60 |
| Pan | 243 | 251 | 8 | 1.60 | - | - |
| Total | | | 500 | 100.00 | 264.20 | - |
| Fineness Modulus | | | | | 2.64 | |

| | River Sand | | | | | |
|---|---|---|---|---|---|---|
| Sieve size | Weight of Sieve (gm) | Weight of Sieve and retained (gm) | Weight Retained (gm) | Percentage retained (%) | Cummulative Coarser (%) | Cummulative Passing (%) |
| 4.75 mm | 426 | 430 | 4 | 0.80 | 0.80 | 99.20 |
| 2.36 mm | 388 | 408 | 20 | 4.00 | 4.80 | 95.20 |
| 1.18 mm | 354 | 438 | 84 | 16.80 | 21.60 | 78.40 |
| 600 µm | 325 | 513 | 188 | 37.60 | 59.20 | 40.80 |
| 300 µm | 302 | 474 | 172 | 34.40 | 93.60 | 6.40 |
| 150µm | 277 | 303 | 26 | 5.20 | 98.80 | 1.20 |
| Pan | 243 | 249 | 6 | 1.20 | - | - |
| Total | | | 500 | 100.00 | 278.80 | - |
| Fineness Modulus | | | | | 2.79 | |

**A.2.2. Specific gravity of Jema Sandstone**

Weight of pycnometer = 320g

Weight of sand = 500 g

Va = Volume of water added to pycnometer = 797cm$^3$

V = Volume of pycnometer = 1000 cm$^3$

A = weight of oven-dry sample in air, [g] = 466.8g

**Formula**

**C = 0.9976Va + 500 + W**

Where:

C = weight of pycnometer filled with sample plus, water, [g]

Va = volume of water added to pycnometer, [cm$^3$]

W = weight of the pycnometer, [g]

C = 0.9976Va + 500 + W

C = 0.9976*797 + 500 + 320

**C = 1615.09gm**

**B=0.9976V + W**

Where:

B = weight of flask filled with water, [g]

V = volume of flask, [cm$^3$]

W = weight of flask empty, [g]

**B=0.9976V + W**

B = 0.9976 *1000 + 320

**B = 1317.6 g**

**Bulk specific gravity**

$$Bulk\ sp\ gr = \frac{A}{B + 500 - C} = \frac{466.8}{1317.6 + 500 - 1615.09} = 2.30$$

**Bulk specific gravity (saturated- surface dry)**

$$Bulk\ sp\ gr(SSD) = \frac{B}{B + 500 - C}$$

$$Bulk\ sp\ gr(SSD) = \frac{500}{1317.6+500-1622.07} = 2.47$$

**Apparent specific gravity**

$$Apparent\ sp\ gr(SSD) = \frac{A}{B + A - C}$$

$$= \frac{466.8}{1317.6+466.8-1622.07} = 2.77$$

**Absorption capacity**

$$Absorption\ (\%) = \frac{500 - A}{A} x100 = \frac{500 - 466.8}{466.8} x100 = 7.11$$

## A.2.3. Moisture content

A = weight of original sample = 500g

B= weight of oven dry sample = 500g

W= moisture content (%)

$$w\ (\%) = \frac{A-B}{B} * 100 = \frac{500-500}{500} * 100 = 0\%$$

## A.3. Properties Coarse aggregate

### A.3.1. Sieve analysis

| Sieve size (mm) | Weight of Sieve (gm) | Wt. Of sieve and retained (gm) | Weight Retained (gm) | Percentage Retained (%) | Cumulative Coarser (%) | **Cumulative Passing (%)** |
|---|---|---|---|---|---|---|
| 37.5 | 440.5 | 0 | 0 | 0 | 0 | **100** |
| 19 | 715 | 813 | 98 | 4.9 | 4.9 | **95.1** |
| 12.5 | 447.5 | 1621 | 1173.5 | 58.67 | 63.57 | **36.43** |
| 9.5 | 445.5 | 663 | 217.5 | 10.87 | 74.44 | **25.56** |
| 4.75 | 426.5 | 909.5 | 483 | 24.16 | 98.6 | **1.4** |
| Pan | 254 | 282 | 28 | 1.4 | 100 | **0.0** |
| Total | | | | | **241.51** | |

### A.3.2. Compacted Unit weight

| Wt of cylindrical metal(kg) | Wt of container + aggregate (kg) | Height of cylinder (m) | Dia. of cylinder (m) | Wt of aggregate (kg) | Volume of container ($m^3$) | Compacted unit eight ($kg/m^3$) |
|---|---|---|---|---|---|---|
| 4.835 | 27.650 | 0.28 | 0.255 | 22.815 | 0.01429975 | 1595.48 |

### A.3.3. Specific gravity

Weight of oven dry sample in air (mass A) = 4906g

Weight of saturated surface dry sample in air (mass B) = 4951g

Weight of saturated sample in water (mass C) = 3166 g

**Bulk specific gravity:** $Bulk\ sp\ gr = \frac{A}{B-C}$

$$Bulk\ sp\ gr = \frac{4906}{4951-3166} = 2.74$$

**Bulk specific gravity (saturated surface dry basis) :** $Bulk\ sp\ gr\ (SSD\ basis) = \frac{B}{B-C}$

$$BAlk\ sp\ gr\ (SSD\ basis) = \frac{4951}{4951-3166} = \ 2.77$$

**Apparent specific gravity :** $Apparent\ sp\ gr = \frac{A}{A-C}$

$$Apparent\ sp\ gr = \frac{4906}{4906-3166} = 2.82$$

**Absorption capacity:** $Absorption\ Capacity\ (\%) = \frac{B-A}{A} * 100$

$$Absorption\ Capacity = \frac{4951-4906}{4906} x100 = 1.0\%$$

### A.3.4. Moisture content

A = weight of original sample = 2000g

B= weight of oven dry sample = 1970g

W= moisture content (%)

$$w\ (\%) = \frac{A-B}{B} * 100$$

$w\ (\%) = \frac{2000-1970}{1970} * 100$= 1.52%

## ANNEX B

## Test Results

### B: 1 Cube Compressive Strength Test Result of Concrete

**Mix Series 1-1** **Concrete grade:- C-25** **Ratio:- 100%RS:0%CJS**

| No | Test age (days) | Dimension (cm) | | | Weight (gm) | Volume ($cm^3$) | Failure Load (kN) | Compressive Strength (MPa) | Unit Weight ($gm/cm^3$) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| 1 | 7 | 14.80 | 15.00 | 15.00 | 8198.00 | 3330.00 | 446.90 | 20.13 | 2.46 |
| 2 | | 15.00 | 14.90 | 14.90 | 8118.00 | 3330.15 | 452.70 | 20.26 | 2.44 |
| 3 | | 14.90 | 15.00 | 15.00 | 8129.00 | 3352.50 | 493.23 | 22.07 | 2.42 |
| **Mean** | | | | | | | **464.28** | **20.82** | **2.44** |
| 1 | 28 | 14.90 | 15.10 | 15.00 | 8390.00 | 3374.85 | 749.20 | 33.30 | 2.49 |
| 2 | | 15.00 | 15.10 | 15.10 | 8320.00 | 3420.15 | 719.67 | 31.77 | 2.43 |
| 3 | | 15.00 | 15.00 | 15.00 | 8115.00 | 3375.00 | 659.90 | 29.33 | 2.40 |
| **Mean** | | | | | | | **709.59** | **31.47** | **2.44** |
| 1 | 56 | 15.00 | 15.10 | 15.00 | 8385.00 | 3397.50 | 755.06 | 33.34 | 2.47 |
| 2 | | 15.10 | 14.90 | 15.00 | 8514.00 | 3374.85 | 811.20 | 36.05 | 2.52 |
| 3 | | 15.00 | 15.00 | 15.00 | 8245.00 | 3375.00 | 729.20 | 32.41 | 2.44 |
| **Mean** | | | | | | | **765.15** | **33.93** | **2.48** |

**Mix Series 1-2** **Concrete grade:- C-25** **Ratio:- 90%RS:10%CJS**

| No | Test age (days) | Dimension (cm) | | | Weight (gm) | Volume ($cm^3$) | Failure Load (kN) | Compressive Strength (MPa) | Unit Weight ($gm/cm^3$) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| 1 | 7 | 15.00 | 14.90 | 15.00 | 8090.00 | 3352.50 | 409.43 | 18.32 | 2.41 |
| 2 | | 14.90 | 15.00 | 14.90 | 8032.00 | 3330.15 | 400.40 | 17.91 | 2.41 |
| 3 | | 14.90 | 15.00 | 15.00 | 8089.00 | 3352.50 | 403.90 | 18.07 | 2.41 |
| **Mean** | | | | | | | **404.58** | **18.10** | **2.41** |
| 1 | 28 | 15.00 | 15.00 | 15.00 | 8267.00 | 3375.00 | 749.20 | 33.30 | 2.45 |
| 2 | | 15.00 | 15.00 | 15.00 | 8350.00 | 3375.00 | 695.04 | 30.89 | 2.47 |
| 3 | | 15.00 | 14.90 | 15.00 | 8220.00 | 3352.50 | 659.50 | 29.51 | 2.45 |
| **Mean** | | | | | | | **701.25** | **31.23** | **2.46** |
| 1 | 56 | 15.00 | 15.00 | 15.00 | 8385.00 | 3375.00 | 747.90 | 33.24 | 2.48 |
| 2 | | 15.00 | 15.00 | 14.90 | 8314.00 | 3352.50 | 745.90 | 33.15 | 2.48 |
| 3 | | 14.90 | 15.00 | 15.00 | 8245.00 | 3352.50 | 776.48 | 34.74 | 2.46 |
| **Mean** | | | | | | | **756.76** | **33.71** | **2.47** |

**Mix Series 1-3** **Concrete grade:- C-25** **Ratio:- 85%RS:15%CJS**

| No | Test age (days) | Dimension (cm) | | | Weight (gm) | Volume ($cm^3$) | Failure Load (kN) | Compressive Strength (MPa) | Unit Weight ($gm/cm^3$) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| 1 | 7 | 14.90 | 15.00 | 15.00 | 8272.00 | 3352.50 | 454.70 | 20.34 | 2.47 |
| 2 | | 15.00 | 14.90 | 15.00 | 8156.00 | 3352.50 | 391.90 | 17.53 | 2.43 |
| 3 | | 14.90 | 15.00 | 15.00 | 8118.00 | 3352.50 | 427.90 | 19.15 | 2.42 |
| **Mean** | | | | | | | **424.83** | **19.01** | **2.44** |
| 1 | 28 | 15.00 | 15.00 | 14.90 | 8219.00 | 3352.50 | 685.90 | 30.48 | 2.45 |
| 2 | | 15.00 | 15.00 | 15.00 | 8193.00 | 3375.00 | 721.70 | 32.08 | 2.43 |
| 3 | | 15.00 | 15.00 | 15.00 | 8136.00 | 3375.00 | 745.60 | 33.14 | 2.41 |
| **Mean** | | | | | | | **717.73** | **31.90** | **2.43** |
| 1 | 56 | 15.00 | 15.00 | 14.90 | 8250.00 | 3352.50 | 791.00 | 35.16 | 2.46 |
| 2 | | 15.00 | 15.00 | 14.90 | 8350.00 | 3352.50 | 732.80 | 32.57 | 2.49 |
| 3 | | 14.90 | 15.00 | 14.90 | 8330.00 | 3330.15 | 757.80 | 33.91 | 2.50 |
| **Mean** | | | | | | | **760.53** | **33.88** | **2.48** |

**Mix Series 1-4** **Concrete grade:- C-25** **Ratio:- 75%RS:25%CJS**

| No | Test age (days) | Dimension (cm) | | | Weight (gm) | Volume ($cm^3$) | Failure Load (kN) | Compressive Strength (MPa) | Unit Weight ($gm/cm^3$) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| 1 | 7 | 15.00 | 14.90 | 15.00 | 8206.00 | 3352.50 | 449.43 | 20.11 | 2.45 |
| 2 | | 15.00 | 15.00 | 14.90 | 8171.00 | 3352.50 | 432.40 | 19.22 | 2.44 |
| 3 | | 14.90 | 15.00 | 15.00 | 8100.00 | 3352.50 | 425.23 | 19.03 | 2.42 |
| **Mean** | | | | | | | **435.69** | **19.45** | **2.43** |
| 1 | 28 | 15.10 | 15.00 | 15.00 | 8267.00 | 3397.50 | 749.20 | 33.08 | 2.43 |
| 2 | | 15.00 | 15.10 | 15.00 | 8100.00 | 3397.50 | 693.04 | 30.60 | 2.38 |
| 3 | | 15.00 | 14.90 | 15.00 | 8220.00 | 3352.50 | 727.90 | 32.57 | 2.45 |
| **Mean** | | | | | | | **723.38** | **32.08** | **2.42** |
| 1 | 56 | 14.80 | 15.00 | 15.00 | 8385.00 | 3330.00 | 747.90 | 33.69 | 2.52 |
| 2 | | 15.00 | 14.90 | 14.90 | 8514.00 | 3330.15 | 775.90 | 34.72 | 2.56 |
| 3 | | 14.90 | 15.00 | 15.00 | 8245.00 | 3352.50 | 708.48 | 31.70 | 2.46 |
| **Mean** | | | | | | | **744.09** | **33.37** | **2.45** |

**Mix Series 1-5 Concrete grade:- C-25 Ratio:- 50%RS:50%CJS**

| No | Test age (days) | Dimension (cm) | | | Weight (gm) | Volume ($cm^3$) | Failure Load (kN) | Compressive Strength (MPa) | Unit Weight ($gm/cm^3$) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| 1 | 7 | 14.90 | 15.00 | 15.00 | 8108.00 | 3352.50 | 388.00 | 17.36 | 2.42 |
| 2 | | 15.00 | 15.00 | 15.00 | 8117.00 | 3375.00 | 417.00 | 18.53 | 2.41 |
| 3 | | 14.90 | 15.00 | 15.00 | 8241.00 | 3352.50 | 467.00 | 20.89 | 2.46 |
| **Mean** | | | | | | | **424.00** | **18.93** | **2.43** |
| 1 | 28 | 14.90 | 15.10 | 15.00 | 8187.00 | 3374.85 | 722.10 | 32.09 | 2.43 |
| 2 | | 15.00 | 15.10 | 15.10 | 8213.00 | 3420.15 | 750.90 | 33.15 | 2.40 |
| 3 | | 15.00 | 15.00 | 15.00 | 8376.00 | 3375.00 | 784.78 | 34.88 | 2.48 |
| **Mean** | | | | | | | **752.59** | **33.38** | **2.44** |
| 1 | 56 | 15.00 | 15.10 | 15.00 | 8350.00 | 3397.50 | 811.20 | 35.81 | 2.46 |
| 2 | | 15.10 | 14.90 | 15.00 | 8190.00 | 3374.85 | 763.89 | 33.95 | 2.43 |
| 3 | | 15.00 | 15.00 | 15.00 | 8473.00 | 3375.00 | 837.89 | 37.24 | 2.51 |
| **Mean** | | | | | | | **804.33** | **35.67** | **2.46** |

**Mix Series 1-6 Concrete grade:- C-25 Ratio:- 25%RS:75%CJS**

| No | Test age (days) | Dimension (cm) | | | Weight (gm) | Volume ($cm^3$) | Failure Load (kN) | Compressive Strength (MPa) | Unit Weight ($gm/cm^3$) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| 1 | 7 | 14.90 | 15.00 | 15.00 | 8272.00 | 3352.50 | 524.70 | 23.48 | 2.47 |
| 2 | | 15.00 | 14.90 | 15.00 | 8056.00 | 3352.50 | 491.90 | 22.01 | 2.40 |
| 3 | | 14.90 | 15.00 | 15.00 | 8118.00 | 3352.50 | 447.60 | 20.03 | 2.42 |
| **Mean** | | | | | | | **488.07** | **21.84** | **2.43** |
| 1 | 28 | 15.00 | 15.00 | 14.90 | 8219.00 | 3352.50 | 785.10 | 34.89 | 2.45 |
| 2 | | 15.00 | 15.00 | 15.00 | 8093.00 | 3375.00 | 871.40 | 38.73 | 2.40 |
| 3 | | 15.00 | 15.00 | 15.00 | 8136.00 | 3375.00 | 915.30 | 40.68 | 2.41 |
| **Mean** | | | | | | | **857.27** | **38.10** | **2.42** |
| 1 | 56 | 15.00 | 15.00 | 14.90 | 8450.00 | 3352.50 | 971.20 | 43.16 | 2.52 |
| 2 | | 15.00 | 15.00 | 14.90 | 8350.00 | 3352.50 | 863.89 | 38.40 | 2.49 |
| 3 | | 14.90 | 15.00 | 14.90 | 8530.00 | 3330.15 | 937.89 | 41.96 | 2.56 |
| **Mean** | | | | | | | **924.33** | **41.17** | **2.52** |

**Mix Series 1-7 Concrete grade:- C-25 Ratio:- 0%RS:100%CJS**

| No | Test age (days) | Dimension (cm) | | | Weight (gm) | Volume ($cm^3$) | Failure Load (kN) | Compressive Strength (MPa) | Unit Weight ($gm/cm^3$) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| 1 | 7 | 15.00 | 15.00 | 14.90 | 8422.00 | 3352.50 | 578.70 | 25.72 | 2.51 |
| 2 | | 15.00 | 14.80 | 15.00 | 8488.00 | 3330.00 | 659.90 | 29.73 | 2.55 |
| 3 | | 15.60 | 15.20 | 15.00 | 8414.00 | 3556.80 | 542.60 | 22.88 | 2.37 |
| **Mean** | | | | | | | **593.73** | **26.11** | **2.48** |
| 1 | 28 | 15.00 | 15.00 | 14.90 | 8183.00 | 3352.50 | 955.70 | 42.48 | 2.44 |
| 2 | | 14.90 | 15.10 | 15.00 | 8537.00 | 3374.85 | 1085.60 | 48.25 | 2.53 |
| 3 | | 14.90 | 15.00 | 15.00 | 8409.00 | 3352.50 | 982.90 | 43.98 | 2.51 |
| **Mean** | | | | | | | **1008.07** | **44.90** | **2.49** |
| 1 | 56 | 14.90 | 15.00 | 14.90 | 8450.00 | 3330.15 | 1071.20 | 47.93 | 2.54 |
| 2 | | 15.00 | 15.50 | 15.00 | 8350.00 | 3487.50 | 1042.90 | 44.86 | 2.39 |
| 3 | | 15.00 | 15.00 | 15.00 | 8530.00 | 3375.00 | 1099.00 | 48.84 | 2.53 |
| **Mean** | | | | | | | **1071.03** | **47.21** | **2.49** |

**Mix Series 1-8 Concrete grade:- C-25 Ratio:- 0%RS:100%CJS(unwashed)**

| No | Test age (days) | Dimension (cm) | | | Weight (gm) | Volume ($cm^3$) | Failure Load (kN) | Compressive Strength (MPa) | Unit Weight ($gm/cm^3$) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| 1 | 7 | 14.90 | 15.00 | 14.90 | 8165.00 | 3330.15 | 489.80 | 21.91 | 2.45 |
| 2 | | 15.00 | 15.00 | 15.00 | 8332.00 | 3375.00 | 442.10 | 19.65 | 2.47 |
| 3 | | 15.00 | 15.00 | 15.00 | 8453.00 | 3375.00 | 459.90 | 20.44 | 2.50 |
| **Mean** | | | | | | | **463.93** | **20.67** | **2.48** |
| 1 | 28 | 15.00 | 15.00 | 15.00 | 8306.50 | 3375.00 | 834.90 | 37.11 | 2.46 |
| 2 | | 15.00 | 15.00 | 14.90 | 8211.00 | 3352.50 | 783.90 | 34.84 | 2.45 |
| 3 | | 15.00 | 14.90 | 15.10 | 8228.00 | 3374.85 | 806.50 | 36.09 | 2.44 |
| **Mean** | | | | | | | **808.43** | **36.01** | **2.45** |
| 1 | 56 | 15.00 | 15.00 | 15.00 | 8400.00 | 3375.00 | 961.20 | 42.72 | 2.49 |
| 2 | | 15.00 | 15.50 | 15.00 | 8280.00 | 3487.50 | 897.00 | 38.58 | 2.37 |
| 3 | | 15.00 | 15.00 | 15.00 | 8226.70 | 3375.00 | 863.01 | 38.36 | 2.44 |
| **Mean** | | | | | | | **907.07** | **39.89** | **2.43** |

**Mix Series 2-1 Concrete grade:- C-30 Ratio:- 100%RS:0%CJS**

| No | Test age (days) | Dimension (cm) | | | Weight (gm) | Volume ($cm^3$) | Failure Load (kN) | Compressive Strength (MPa) | Unit Weight ($gm/cm^3$) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| 1 | 7 | 14.90 | 15.00 | 15.00 | 8460.00 | 3352.50 | 570.91 | 25.54 | 2.52 |
| 2 | | 14.90 | 15.40 | 14.90 | 8390.00 | 3418.95 | 489.76 | 21.34 | 2.45 |
| 3 | | 14.90 | 14.90 | 15.00 | 8380.00 | 3330.15 | 453.34 | 20.42 | 2.52 |
| **Mean** | | | | | | | **504.67** | **22.44** | **2.50** |
| 1 | 28 | 14.90 | 15.10 | 15.20 | 8430.00 | 3419.85 | 831.30 | 36.95 | 2.47 |
| 2 | | 15.10 | 15.00 | 15.00 | 8560.00 | 3397.50 | 879.50 | 38.83 | 2.52 |
| 3 | | 14.80 | 14.90 | 14.90 | 8400.00 | 3285.75 | 830.80 | 37.67 | 2.56 |
| **Mean** | | | | | | | **847.20** | **37.82** | **2.51** |
| 1 | 56 | 14.90 | 15.00 | 14.90 | 8440.00 | 3330.15 | 948.30 | 42.43 | 2.53 |
| 2 | | 14.90 | 15.00 | 14.90 | 8432.00 | 3330.15 | 897.10 | 40.14 | 2.53 |
| 3 | | 14.90 | 14.90 | 15.00 | 8432.00 | 3330.15 | 897.10 | 40.41 | 2.53 |
| **Mean** | | | | | | | **914.17** | **40.99** | **2.53** |

**Mix Series 2-2 Concrete grade:- C-30 Ratio:- 90%RS:10%CJS**

| No | Test age (days) | Dimension (cm) | | | Weight (gm) | Volume (cm3) | Failure Load (KN) | Compressive Strength (Mpa) | Unit Weight (gm/cm3) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| 1 | 7 | 14.90 | 15.00 | 15.00 | 8272.00 | 3352.50 | 483.70 | 21.64 | 2.47 |
| 2 | | 15.00 | 14.90 | 15.00 | 8156.00 | 3352.50 | 498.90 | 22.32 | 2.43 |
| 3 | | 14.90 | 15.00 | 15.00 | 8118.00 | 3352.50 | 507.60 | 22.71 | 2.42 |
| **Mean** | | | | | | | **496.73** | **22.23** | **2.44** |
| 1 | 28 | 15.00 | 15.00 | 14.90 | 8219.00 | 3352.50 | 795.10 | 35.34 | 2.45 |
| 2 | | 15.00 | 15.00 | 15.00 | 8193.00 | 3375.00 | 860.40 | 38.24 | 2.43 |
| 3 | | 15.00 | 15.00 | 15.00 | 8136.00 | 3375.00 | 895.30 | 39.79 | 2.41 |
| **Mean** | | | | | | | **850.27** | **37.79** | **2.43** |
| 1 | 56 | 15.00 | 15.00 | 14.90 | 8250.00 | 3352.50 | 863.20 | 38.36 | 2.46 |
| 2 | | 15.00 | 15.00 | 14.90 | 8250.00 | 3352.50 | 863.00 | 38.36 | 2.46 |
| 3 | | 14.90 | 15.00 | 14.90 | 8130.00 | 3330.15 | 949.89 | 42.50 | 2.44 |
| **Mean** | | | | | | | **892.03** | **39.74** | **2.45** |

**Mix Series 2-3 Concrete grade:- C-30 Ratio:- 85%RS:15%CJS**

| No | Test age (days) | Dimension (cm) | | | Weight (gm) | Volume ($cm^3$) | Failure Load (kN) | Compressive Strength (MPa) | Unit Weight ($gm/cm^3$) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| 1 | 7 | 15.00 | 14.90 | 15.00 | 8186.00 | 3352.50 | 485.10 | 21.70 | 2.44 |
| 2 | | 14.90 | 15.10 | 15.00 | 8133.00 | 3374.85 | 496.10 | 22.05 | 2.41 |
| 3 | | 14.90 | 15.10 | 15.00 | 8235.00 | 3374.85 | 514.20 | 22.85 | 2.44 |
| **Mean** | | | | | | | **498.47** | **22.20** | **2.43** |
| 1 | 28 | 15.00 | 15.00 | 14.90 | 8160.00 | 3352.50 | 848.10 | 37.69 | 2.43 |
| 2 | | 14.90 | 15.00 | 15.00 | 8253.50 | 3352.50 | 915.00 | 40.94 | 2.46 |
| 3 | | 14.90 | 15.00 | 15.00 | 8189.00 | 3352.50 | 880.00 | 39.37 | 2.44 |
| **Mean** | | | | | | | **881.03** | **39.34** | **2.45** |
| 1 | 56 | 14.90 | 15.10 | 14.90 | 8229.00 | 3352.35 | 896.90 | 39.86 | 2.45 |
| 2 | | 14.90 | 15.10 | 14.90 | 8199.00 | 3352.35 | 946.30 | 42.06 | 2.45 |
| 3 | | 15.00 | 15.00 | 15.00 | 8199.00 | 3375.00 | 922.70 | 41.01 | 2.43 |
| **Mean** | | | | | | | **921.97** | **40.98** | **2.44** |

**Mix Series 2-4 Concrete grade:- C-30 Ratio:- 75%RS:25%CJS**

| No | Test age (days) | Dimension (cm) | | | Weight (gm) | Volume ($cm^3$) | Failure Load (kN) | Compressive Strength (MPa) | Unit Weight ($gm/cm^3$) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| 1 | 7 | 14.90 | 15.00 | 14.90 | 8220.00 | 3330.15 | 509.90 | 22.81 | 2.47 |
| 2 | | 15.00 | 14.90 | 15.00 | 8290.00 | 3352.50 | 558.87 | 25.01 | 2.47 |
| 3 | | 14.90 | 15.00 | 15.00 | 8270.00 | 3352.50 | 523.78 | 23.44 | 2.47 |
| **Mean** | | | | | | | **530.85** | **23.75** | **2.47** |
| 1 | 28 | 14.90 | 15.00 | 15.00 | 8227.00 | 3352.50 | 862.70 | 38.60 | 2.45 |
| 2 | | 14.90 | 14.90 | 15.00 | 8286.00 | 3330.15 | 895.20 | 40.32 | 2.49 |
| 3 | | 14.90 | 14.90 | 15.00 | 8313.00 | 3330.15 | 899.97 | 40.27 | 2.50 |
| **Mean** | | | | | | | **885.95 6667** | **39.73** | **2.48** |
| 1 | 56 | 14.90 | 14.90 | 14.90 | 8315.00 | 3307.95 | 958.90 | 43.19 | 2.51 |
| 2 | | 15.00 | 14.90 | 15.00 | 8315.00 | 3352.50 | 992.18 | 44.39 | 2.48 |
| | | 14.90 | 15.00 | 14.90 | 8315.00 | 3330.15 | 992.15 | 44.39 | 2.50 |
| **Mean** | | | | | | | **981.07 6667** | **43.99** | **2.50** |

**Mix Series 2-5 Concrete grade:- C-30 Ratio:- 50%RS:50%CJS**

| No | Test age (days) | Dimension (cm) | | | Weight (gm) | Volume ($cm^3$) | Failure Load (kN) | Compressive Strength (MPa) | Unit Weight ($gm/cm^3$) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| 1 | 7 | 14.90 | 15.00 | 14.90 | 8210.00 | 3330.15 | 535.89 | 23.98 | 2.47 |
| 2 | | 14.90 | 15.00 | 15.00 | 8290.00 | 3352.50 | 553.08 | 24.75 | 2.47 |
| 3 | | 14.90 | 15.20 | 14.90 | 8343.00 | 3374.55 | 590.78 | 26.09 | 2.47 |
| **Mean** | | | | | | | **559.92** | **24.94** | **2.47** |
| 1 | 28 | 15.00 | 15.00 | 14.90 | 8310.00 | 3352.50 | 907.60 | 40.34 | 2.48 |
| 2 | | 14.90 | 15.10 | 15.00 | 8490.00 | 3374.85 | 994.40 | 44.20 | 2.52 |
| 3 | | 15.00 | 15.20 | 14.90 | 8343.00 | 3397.20 | 909.40 | 39.89 | 2.46 |
| **Mean** | | | | | | | **937.13** | **41.47** | **2.48** |
| 1 | 56 | 15.20 | 15.00 | 14.90 | 8487.00 | 3397.20 | 1079.40 | 47.34 | 2.50 |
| 2 | | 15.00 | 15.10 | 15.00 | 8329.00 | 3397.50 | 979.60 | 43.25 | 2.45 |
| | | 15.00 | 15.00 | 15.00 | 8453.00 | 3375.00 | 1058.90 | 47.06 | 2.50 |
| **Mean** | | | | | | | **1039.30** | **45.88** | **2.48** |

**Mix Series 2-6 Concrete grade:- C-30 Ratio:- 75%RS:25%CJS**

| No | Test age (days) | Dimension (cm) | | | Weight (gm) | Volume ($cm^3$) | Failure Load (kN) | Compressive Strength (MPa) | Unit Weight ($gm/cm^3$) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| 1 | 7 | 14.90 | 15.20 | 14.90 | 8330.00 | 3374.55 | 592.90 | 26.18 | 2.47 |
| 2 | | 14.90 | 15.30 | 14.90 | 8270.00 | 3396.75 | 548.08 | 24.04 | 2.43 |
| 3 | | 15.00 | 15.30 | 14.90 | 8280.00 | 3419.55 | 550.78 | 24.00 | 2.42 |
| **Mean** | | | | | | | **563.92** | **24.74** | **2.44** |
| 1 | 28 | 14.90 | 15.20 | 14.90 | 8350.00 | 3374.55 | 957.00 | 42.26 | 2.47 |
| 2 | | 14.90 | 15.10 | 15.00 | 8260.00 | 3374.85 | 908.50 | 40.38 | 2.45 |
| 3 | | 14.90 | 15.30 | 15.00 | 8330.00 | 3419.55 | 932.00 | 40.88 | 2.44 |
| **Mean** | | | | | | | **932.50** | **41.17** | **2.45** |
| 1 | 56 | 15.00 | 14.90 | 15.00 | 8487.00 | 3352.50 | 1093.70 | 48.94 | 2.53 |
| 2 | | 14.90 | 15.00 | 14.90 | 8329.00 | 3330.15 | 1043.90 | 46.71 | 2.50 |
| 3 | | 15.00 | 15.00 | 15.00 | 8453.00 | 3375.00 | 1079.80 | 47.99 | 2.50 |
| **Mean** | | | | | | | **1072.47** | **47.88** | **2.51** |

**Mix Series 2-7 Concrete grade:- C-30 Ratio:- 0%RS:100%CJS**

| No | Test age (days) | Dimension (cm) | | | Weight (gm) | Volume ($cm^3$) | Failure Load (kN) | Compressive Strength (MPa) | Unit Weight ($gm/cm^3$) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| 1 | 7 | 14.90 | 15.10 | 15.00 | 8540.00 | 3374.85 | 664.90 | 29.55 | 2.53 |
| 2 | | 14.90 | 15.10 | 14.90 | 8400.00 | 3352.35 | 620.50 | 27.58 | 2.51 |
| 3 | | 14.90 | 15.00 | 14.80 | 8390.00 | 3307.80 | 609.00 | 27.25 | 2.54 |
| **Mean** | | | | | | | **631.47** | **28.13** | **2.52** |
| 1 | 28 | 15.00 | 15.00 | 15.00 | 8450.00 | 3375.00 | 1094.20 | 48.63 | 2.50 |
| 2 | | 15.00 | 15.00 | 15.00 | 8420.00 | 3375.00 | 1032.90 | 45.91 | 2.49 |
| 3 | | 15.00 | 15.00 | 15.00 | 8380.00 | 3375.00 | 1057.90 | 47.02 | 2.48 |
| **Mean** | | | | | | | **1061.67** | **47.19** | **2.49** |
| 1 | 56 | 15.00 | 14.90 | 15.00 | 8305.00 | 3352.50 | 1060.90 | 47.47 | 2.48 |
| 2 | | 14.90 | 15.00 | 15.00 | 8414.00 | 3352.50 | 1194.90 | 53.46 | 2.51 |
| 3 | | 15.00 | 14.90 | 15.00 | 8350.00 | 3352.50 | 1126.70 | 50.41 | 2.49 |
| **Mean** | | | | | | | **1127.50** | **50.45** | **2.49** |

**Mix Series 2-8 Concrete grade:- C-30 Ratio:- 0%RS:100%CJS(unwashed)**

| No | Test age (days) | Dimension (cm) | | | Weight (gm) | Volume ($cm^3$) | Failure Load (kN) | Compressive Strength (MPa) | Unit Weight ($gm/cm^3$) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| 1 | 7 | 15.00 | 15.00 | 15.00 | 8530.00 | 3375.00 | 592.90 | 26.35 | 2.53 |
| 2 | | 15.00 | 15.00 | 15.00 | 8470.00 | 3375.00 | 535.00 | 23.78 | 2.51 |
| 3 | | 15.00 | 15.00 | 14.90 | 8480.00 | 3352.50 | 549.70 | 24.43 | 2.53 |
| **Mean** | | | | | | | **559.20** | **24.85** | **2.52** |
| 1 | 28 | 14.90 | 15.20 | 14.90 | 8380.00 | 3374.55 | 887.00 | 39.16 | 2.48 |
| 2 | | 14.90 | 15.10 | 15.00 | 8460.00 | 3374.85 | 916.50 | 40.74 | 2.51 |
| 3 | | 14.90 | 15.00 | 15.00 | 8230.00 | 3352.50 | 852.00 | 38.12 | 2.45 |
| **Mean** | | | | | | | **885.17** | **39.34** | **2.48** |
| 1 | 56 | 15.00 | 14.90 | 15.00 | 8487.00 | 3352.50 | 983.70 | 44.01 | 2.53 |
| 2 | | 14.90 | 15.00 | 14.90 | 8529.00 | 3330.15 | 990.90 | 44.34 | 2.56 |
| 3 | | 15.00 | 15.00 | 15.00 | 8453.00 | 3375.00 | 979.80 | 43.55 | 2.50 |
| **Mean** | | | | | | | **984.80** | **43.97** | **2.53** |

**Mix Series 3-1 Concrete grade:- C-40 Ratio:- 100%RS:0%CJS**

| No | Test age (days) | Dimension (cm) | | | Weight (gm) | Volume ($cm^3$) | Failure Load (kN) | Compressive Strength (MPa) | Unit Weight ($gm/cm^3$) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| 1 | 7 | 15.00 | 14.90 | 15.00 | 8086.00 | 3352.50 | 639.90 | 28.63 | 2.41 |
| 2 | | 14.90 | 15.10 | 15.00 | 8133.00 | 3374.85 | 716.10 | 31.83 | 2.41 |
| 3 | | 14.90 | 15.10 | 15.00 | 8235.00 | 3374.85 | 653.20 | 29.03 | 2.44 |
| **Mean** | | | | | | | **669.73** | **29.83** | **2.42** |
| 1 | 28 | 15.00 | 15.00 | 14.90 | 8060.00 | 3352.50 | 1046.10 | 46.49 | 2.40 |
| 2 | | 14.90 | 15.00 | 15.00 | 8253.50 | 3352.50 | 1099.90 | 49.21 | 2.46 |
| 3 | | 14.90 | 15.00 | 15.00 | 8189.00 | 3352.50 | 1080.00 | 48.32 | 2.44 |
| **Mean** | | | | | | | **1075.33** | **48.01** | **2.44** |
| 1 | 56 | 14.90 | 15.10 | 14.90 | 8229.00 | 3352.35 | 1076.90 | 47.86 | 2.45 |
| 2 | | 14.90 | 15.10 | 14.90 | 8199.00 | 3352.35 | 1163.90 | 51.73 | 2.45 |
| 3 | | 15.00 | 15.00 | 15.00 | 8199.00 | 3375.00 | 1164.70 | 51.76 | 2.43 |
| **Mean** | | | | | | | **1135.17** | **50.45** | **2.44** |

**Mix Series 3-2 Concrete grade:- C-40 Ratio:- 90%RS:10%CJS**

| No | Test age (days) | Dimension (cm) | | | Weight (gm) | Volume ($cm^3$) | Failure Load (kN) | Compressive Strength (MPa) | Unit Weight ($gm/cm^3$) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| 1 | 7 | 15.00 | 15.10 | 14.90 | 8273.00 | 3374.85 | 623.60 | 27.53 | 2.4514 |
| 2 | | 15.00 | 15.40 | 14.90 | 8165.00 | 3441.90 | 659.80 | 28.56 | 2.3722 |
| 3 | | 15.00 | 15.00 | 15.10 | 8366.00 | 3397.50 | 582.60 | 25.89 | 2.4624 |
| **Mean** | | | | | | | **622.00** | **27.33** | **2.43** |
| 1 | 28 | 15.00 | 15.30 | 15.10 | 8190.00 | 3465.45 | 998.90 | 43.53 | 2.3633 |
| 2 | | 15.00 | 15.20 | 14.90 | 8383.50 | 3397.20 | 948.20 | 41.59 | 2.4678 |
| 3 | | 15.00 | 15.00 | 15.10 | 8239.50 | 3397.50 | 998.70 | 44.39 | 2.4252 |
| **Mean** | | | | | | | **981.93** | **43.17** | **2.42** |
| 1 | 56 | 15.00 | 15.00 | 15.00 | 8378.00 | 3375.00 | 1039.30 | 46.19 | 2.48 |
| 2 | | 15.00 | 15.00 | 15.00 | 8288.00 | 3375.00 | 1076.50 | 47.84 | 2.46 |
| 3 | | 15.00 | 15.00 | 15.00 | 8214.00 | 3375.00 | 1049.50 | 46.64 | 2.43 |
| **Mean** | | | | | | | **1055.10** | **46.89** | **2.46** |

**Mix Series 3-3 Concrete grade:- C-40 Ratio:- 85%RS:15%CJS**

| No | Test age (days) | Dimension (cm) L | W | H | Weight (gm) | Volume ($cm^3$) | Failure Load (kN) | Compressive Strength (MPa) | Unit Weight ($gm/cm^3$) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 7 | 14.90 | 15.20 | 14.90 | 8330.00 | 3374.55 | 675.90 | 29.84 | 2.47 |
| 2 | | 14.90 | 15.00 | 14.90 | 8270.00 | 3330.15 | 638.08 | 28.55 | 2.48 |
| 3 | | 15.00 | 15.00 | 14.90 | 8280.00 | 3352.50 | 544.20 | 24.19 | 2.47 |
| **Mean** | | | | | | | **619.39** | **27.53** | **2.47** |
| 1 | 28 | 14.90 | 15.00 | 14.90 | 8350.00 | 3330.15 | 968.90 | 43.35 | 2.51 |
| 2 | | 14.90 | 15.10 | 15.00 | 8260.00 | 3374.85 | 963.20 | 42.81 | 2.45 |
| 3 | | 14.90 | 15.00 | 15.00 | 8330.00 | 3352.50 | 995.70 | 44.55 | 2.48 |
| **Mean** | | | | | | | **975.93** | **43.57** | **2.48** |
| 1 | 56 | 15.00 | 14.90 | 15.00 | 8187.00 | 3352.50 | 1083.70 | 48.49 | 2.44 |
| 2 | | 14.90 | 15.00 | 14.90 | 8329.00 | 3330.15 | 999.20 | 44.71 | 2.50 |
| 3 | | 15.00 | 15.00 | 15.00 | 8153.00 | 3375.00 | 1123.80 | 49.95 | 2.42 |
| **Mean** | | | | | | | **1068.90** | **47.71** | **2.45** |

**Mix Series 3-4 Concrete grade:- C-40 Ratio:- 75%RS:25%CJS**

| No | Test age (days) | Dimension (cm) L | W | H | Weight (gm) | Volume ($cm^3$) | Failure Load (kN) | Compressive Strength (MPa) | Unit Weight ($gm/cm^3$) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 7 | 15.10 | 15.00 | 15.00 | 8202.00 | 3397.50 | 629.90 | 27.81 | 2.41 |
| 2 | | 15.00 | 15.00 | 15.00 | 8241.00 | 3375.00 | 645.90 | 28.71 | 2.44 |
| 3 | | 15.00 | 15.10 | 15.00 | 8165.00 | 3397.50 | 631.60 | 27.89 | 2.40 |
| **Mean** | | | | | | | **635.8** | **28.13** | **2.42** |
| 1 | 28 | 15.00 | 15.00 | 14.90 | 8120.5 | 3352.5 | 1026.10 | 45.60 | 2.4 |
| 2 | | 14.90 | 15.00 | 14.90 | 8220.5 | 3330.15 | 1046.30 | 46.81 | 2.46 |
| 3 | | 15.00 | 14.90 | 15.00 | 8320.5 | 3352.5 | 1098.30 | 49.14 | 2.4 |
| **Mean** | | | | | | | **1056.9** | **47.19** | **2.46** |
| 1 | 56 | 15.10 | 15.00 | 15.10 | 8302.00 | 3420.15 | 1106.3 | 48.84 | 2.42 |
| 2 | | 14.90 | 15.00 | 15.00 | 8241.00 | 3352.5 | 1109.34 | 49.63 | 2.45 |
| 3 | | 15.00 | 15.10 | 15.10 | 8365.00 | 3420.15 | 1135.80 | 50.15 | 2.44 |
| **Mean** | | | | | | | **1117.146667** | **49.54** | **2.44** |

**Mix Series 3-5 Concrete grade:- C-40 Ratio:- 50%RS:50%CJS**

| No | Test age (days) | Dimension (cm) | | | Weight (gm) | Volume ($cm^3$) | Failure Load (kN) | Compressive Strength (MPa) | Unit Weight ($gm/cm^3$) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| 1 | 7 | 15.00 | 15.20 | 14.90 | 8155.00 | 3397.20 | 594.90 | 26.09 | 2.40 |
| 2 | | 15.00 | 14.90 | 14.90 | 8172.00 | 3330.15 | 697.50 | 31.21 | 2.45 |
| 3 | | 15.00 | 14.90 | 14.90 | 8314.00 | 3330.15 | 649.50 | 29.06 | 2.50 |
| **Mean** | | | | | | | **647.30** | **28.79** | **2.45** |
| 1 | 28 | 15.00 | 15.00 | 14.90 | 8236.50 | 3352.50 | 1078.40 | 47.93 | 2.46 |
| 2 | | 14.90 | 15.00 | 14.90 | 8257.50 | 3330.15 | 999.40 | 44.72 | 2.48 |
| 3 | | 15.00 | 14.90 | 15.00 | 8173.50 | 3352.50 | 1099.20 | 49.18 | 2.44 |
| **Mean** | | | | | | | **1059** | **47.28** | **2.46** |
| 1 | 56 | 14.90 | 15.00 | 15.00 | 8130.00 | 3352.50 | 1154.90 | 51.67 | 2.43 |
| 2 | | 14.90 | 14.90 | 15.00 | 8450.00 | 3330.15 | 1100.90 | 49.59 | 2.54 |
| 3 | | 15.00 | 15.00 | 14.90 | 8250.00 | 3352.50 | 1101.90 | 48.97 | 2.46 |
| **Mean** | | | | | | | **1119.23** | **50.08** | **2.47** |

**Mix Series 3-6 Concrete grade:- C-40 Ratio:- 25%RS:75%CJS**

| No | Test age (days) | Dimension (cm) | | | Weight (gm) | Volume ($cm^3$) | Failure Load (kN) | Compressive Strength (MPa) | Unit Weight ($gm/cm^3$) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| 1 | 7 | 14.90 | 15.00 | 14.90 | 8473.00 | 3330.15 | 705.80 | 31.58 | 2.5443 |
| 2 | | 15.00 | 15.00 | 14.90 | 8465.00 | 3352.50 | 694.80 | 30.88 | 2.5250 |
| 3 | | 15.00 | 15.00 | 15.10 | 8366.00 | 3397.50 | 651.90 | 28.97 | 2.4624 |
| **Mean** | | | | | | | **684.17** | **30.48** | **2.51** |
| 1 | 28 | 14.90 | 15.00 | 15.10 | 8190.00 | 3374.85 | 1116.90 | 49.97 | 2.4268 |
| 2 | | 15.00 | 15.20 | 14.90 | 8383.50 | 3397.20 | 1197.10 | 52.50 | 2.4678 |
| 3 | | 15.00 | 15.00 | 15.10 | 8499.50 | 3397.50 | 999.70 | 44.43 | 2.5017 |
| **Mean** | | | | | | | **1104.57** | **48.97** | **2.47** |
| 1 | 56 | 14.90 | 15.00 | 15.00 | 8478.00 | 3352.50 | 1149.30 | 51.42 | 2.53 |
| 2 | | 14.90 | 14.90 | 15.00 | 8288.00 | 3330.15 | 1080.50 | 48.67 | 2.49 |
| 3 | | 15.00 | 15.00 | 15.00 | 8414.00 | 3375.00 | 1236.50 | 54.96 | 2.49 |
| **Mean** | | | | | | | **1155.43** | **51.68** | **2.50** |

**Mix Series 3-7 Concrete grade:- C-40 Ratio:- 0%RS:100%CJS**

| No | Test age (days) | Dimension (cm) | | | Weight (gm) | Volume ($cm^3$) | Failure Load (kN) | Compressive Strength (MPa) | Unit Weight ($gm/cm^3$) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| 1 | 7 | 14.90 | 15.00 | 14.90 | 8286.00 | 3330.15 | 786.10 | 35.17 | 2.49 |
| 2 | | 14.90 | 15.10 | 14.90 | 8233.00 | 3352.35 | 776.10 | 34.49 | 2.46 |
| 3 | | 15.00 | 15.10 | 14.90 | 8335.00 | 3374.85 | 776.40 | 34.28 | 2.47 |
| **Mean** | | | | | | | **779.53** | **34.65** | **2.47** |
| 1 | 28 | 14.90 | 15.00 | 15.00 | 8290.00 | 3352.50 | 1189.90 | 53.24 | 2.47 |
| 2 | | 14.90 | 15.10 | 14.90 | 8383.50 | 3352.35 | 1167.60 | 51.90 | 2.50 |
| 3 | | 15.10 | 15.00 | 14.90 | 8489.00 | 3374.85 | 1073.40 | 47.39 | 2.52 |
| **Mean** | | | | | | | **1143.63** | **50.84** | **2.50** |
| 1 | 56 | 15.00 | 15.00 | 14.90 | 8289.00 | 3352.50 | 1293.90 | 57.51 | 2.47 |
| 2 | | 14.90 | 15.10 | 14.90 | 8350.00 | 3352.35 | 1174.10 | 52.18 | 2.49 |
| 3 | | 14.90 | 15.10 | 14.90 | 8318.50 | 3352.35 | 1155.10 | 51.34 | 2.48 |
| **Mean** | | | | | | | **1207.70** | **53.68** | **2.48** |

**Mix Series 3-8 Concrete grade:- C-40 Ratio:- 0%RS:100%CJS(unwashed)**

| No | Test age (days) | Dimension (cm) | | | Weight (gm) | Volume ($cm^3$) | Failure Load (kN) | Compressive Strength (MPa) | Unit Weight ($gm/cm^3$) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| 1 | 7 | 15.10 | 15.00 | 15.00 | 8255.00 | 3397.50 | 709.50 | 31.32 | 2.43 |
| 2 | | 15.00 | 15.00 | 15.00 | 8372.00 | 3375.00 | 657.80 | 29.24 | 2.48 |
| 3 | | 15.00 | 15.10 | 15.00 | 8314.00 | 3397.50 | 623.80 | 27.54 | 2.45 |
| **Mean** | | | | | | | **663.7** | **29.37** | **2.45** |
| 1 | 28 | 14.90 | 15.10 | 15.10 | 8386.50 | 3397.34 | 1044.80 | 46.44 | 2.46 |
| 2 | | 15.00 | 15.20 | 14.90 | 8360.00 | 3397.2 | 979.70 | 42.97 | 2.46 |
| 3 | | 15.00 | 15.00 | 15.10 | 8236.50 | 3397.5 | 998.00 | 44.36 | 2.42 |
| **Mean** | | | | | | | **1007.5** | **44.59** | **2.45** |
| 1 | 56 | 15.10 | 15.00 | 15.10 | 8302.00 | 3420.15 | 1106.3 | 48.84 | 2.42 |
| 2 | | 14.90 | 15.00 | 15.00 | 8441.00 | 3352.5 | 1039.34 | 46.50 | 2.51 |
| 3 | | 15.00 | 15.10 | 15.10 | 8365.00 | 3420.15 | 1055.80 | 46.61 | 2.44 |
| **Mean** | | | | | | | **1067.14 667** | **47.32** | **2.46** |

## B: 2 Flexural Strength Test Results

**Mix Series 1-1** **Concrete grade: - C-25** **Ratio: - 100%RS:0%CJS**

| Test age (days) | Sample no. | Dimensions (cm) | | | Failure load (kN) | Max. Moment (kNm) | Moment of Inertia ($cm^4$) | Centroidal depth (cm) | Bending Strength (MPa) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | B | D | P | M = PL/3 | I= $bd^3/12$ | c = D/2 | σ = Mc/I |
| 7 | 1 | 50.00 | 10.00 | 10.00 | 3.40 | 382.50 | 8.33E-06 | 5.00 | 2.30 |
| | 2 | 50.00 | 10.00 | 10.00 | 3.90 | 438.75 | 8.33E-06 | 5.00 | 2.63 |
| | **Mean** | | | | | | | | **2.46** |
| 28 | 1 | 10.00 | 10.00 | 5.19 | 583.88 | 8.33E-06 | 5.00 | 3.50 | 50.00 |
| | 2 | 10.00 | 10.00 | 6.59 | 741.38 | 8.33E-06 | 5.00 | 4.45 | 50.00 |
| | **Mean** | | | | | | | | **3.98** |

**Mix Series 1-6** **Concrete grade: - C-25** **Ratio: - 25%RS: 75%CJS**

| Test age (days) | Sample no. | Dimensions (cm) | | | Failure load (kN) | Max. Moment (kNm) | Moment of Inertia ($cm^4$) | Centroidal depth (cm) | Bending Strength (MPa) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | B | D | P | M = PL/3 | I= $bd^3/12$ | c = D/2 | σ = Mc/I |
| 7 | 1 | 50.00 | 10.00 | 10.00 | 3.80 | 427.50 | 8.33E-06 | 5.00 | 2.57 |
| | 2 | 50.00 | 10.00 | 10.00 | 4.90 | 551.25 | 8.33E-06 | 5.00 | 3.31 |
| | **Mean** | | | | | | | | **2.94** |
| 28 | 1 | 50.00 | 10.00 | 10.00 | 6.42 | 722.25 | 8.33E-06 | 5.00 | 4.33 |
| | 2 | 50.00 | 10.00 | 10.00 | 7.65 | 860.63 | 8.33E-06 | 5.00 | 5.16 |
| | **Mean** | | | | | | | | **4.75** |

**Mix Series 1-7** **Concrete grade: - C-25** **Ratio: - 0%RS: 100%CJS**

| Test age (days) | Sample no. | Dimensions (cm) | | | Failure load (kN) | Max. Moment (kNm) | Moment of Inertia ($cm^4$) | Centroidal depth (cm) | Bending Strength (MPa) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | B | D | P | M = PL/3 | I= $bd^3/12$ | c = D/2 | σ = Mc/I |
| 7 | 1 | 50.00 | 10.00 | 10.00 | 4.00 | 450.00 | 8.33E-06 | 5.00 | 2.70 |
| | 2 | 50.00 | 10.00 | 10.00 | 5.62 | 632.25 | 8.33E-06 | 5.00 | 3.79 |
| | **Mean** | | | | | | | | **3.25** |
| 28 | 1 | 50.00 | 10.00 | 10.00 | 7.96 | 895.50 | 8.33E-06 | 5.00 | 5.37 |
| | 2 | 50.00 | 10.00 | 10.00 | 7.60 | 855.00 | 8.33E-06 | 5.00 | 5.13 |
| | **Mean** | | | | | | | | **5.25** |

**Mix Series 2-1 Concrete grade: - C-30 Ratio: - 100%RS: 0%CJS**

| Test age (days) | Sample no. | Dimensions (cm) | | | Failure load (kN) | Max. Moment (kNm) | Moment of Inertia ($cm^4$) | Centroidal depth (cm) | Bending Strength (MPa) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | B | D | P | M = PL/3 | I= $bd^3/12$ | c = D/2 | σ = Mc/I |
| 7 | 1 | 50.00 | 10.00 | 10.00 | 3.52 | 396.00 | 8.33E-06 | 5.00 | 2.38 |
| | 2 | 50.00 | 10.00 | 10.00 | 4.12 | 463.50 | 8.33E-06 | 5.00 | 2.78 |
| | **Mean** | | | | | | | | **2.58** |
| 28 | 1 | 50.00 | 10.00 | 10.00 | 6.05 | 680.63 | 8.33E-06 | 5.00 | 4.08 |
| | 2 | 50.00 | 10.00 | 10.00 | 6.90 | 776.25 | 8.33E-06 | 5.00 | 4.66 |
| | **Mean** | | | | | | | | **4.37** |

**Mix Series 2-6 Concrete grade: - C-30 Ratio: - 25%RS: 75%CJS**

| Test age (days) | Sample no. | Dimensions (cm) | | | Failure load (kN) | Max. Moment (kNm) | Moment of Inertia ($cm^4$) | Centroidal depth (cm) | Bending Strength (MPa) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | B | D | P | M = PL/3 | I= $bd^3/12$ | c = D/2 | σ = Mc/I |
| 7 | 1 | 50.00 | 10.00 | 10.00 | 3.70 | 416.25 | 8.33E-06 | 5.00 | 2.50 |
| | 2 | 50.00 | 10.00 | 10.00 | 5.12 | 576.00 | 8.33E-06 | 5.00 | 3.46 |
| | **Mean** | | | | | | | | **2.98** |
| 28 | 1 | 50.00 | 10.00 | 10.00 | 8.05 | 905.63 | 8.33E-06 | 5.00 | 5.43 |
| | 2 | 50.00 | 10.00 | 10.00 | 7.30 | 821.25 | 8.33E-06 | 5.00 | 4.93 |
| | **Mean** | | | | | | | | **5.18** |

**Mix Series 2-7 Concrete grade: - C-30 Ratio: - 0%RS: 100%CJS**

| Test age (days) | Sample no. | Dimensions (cm) | | | Failure load (kN) | Max. Moment (kNm) | Moment of Inertia ($cm^4$) | Centroidal depth (cm) | Bending Strength (MPa) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | B | D | P | M = PL/3 | I= $bd^3/12$ | c = D/2 | σ = Mc/I |
| 7 | 1 | 50.00 | 10.00 | 10.00 | 5.45 | 613.13 | 8.33E-06 | 5.00 | 3.68 |
| | 2 | 50.00 | 10.00 | 10.00 | 4.48 | 504.00 | 8.33E-06 | 5.00 | 3.02 |
| | **Mean** | | | | | | | | **3.35** |
| 28 | 1 | 50.00 | 10.00 | 10.00 | 8.95 | 1006.88 | 8.33E-06 | 5.00 | 6.04 |
| | 2 | 50.00 | 10.00 | 10.00 | 7.90 | 888.75 | 8.33E-06 | 5.00 | 5.33 |
| | **Mean** | | | | | | | | **5.69** |

**Mix Series 3-1 Concrete grade: - C-40 Ratio: - 100%RS: 0%CJS**

| Test age (days) | Sample no. | Dimensions (cm) | | | Failure load (kN) | Max. Moment (kNm) | Moment of Inertia ($cm^4$) | Centroidal depth (cm) | Bending Strength (MPa) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | B | D | P | M = PL/3 | I= $bd^3/12$ | c = D/2 | σ = Mc/I |
| 7 | 1 | 50.00 | 10.00 | 10.00 | 5.70 | 641.25 | 8.33E-06 | 5.00 | 3.85 |
| | 2 | 50.00 | 10.00 | 10.00 | 4.53 | 509.63 | 8.33E-06 | 5.00 | 3.06 |
| | **Mean** | | | | | | | | **3.45** |
| 28 | 1 | 50.00 | 10.00 | 10.00 | 7.90 | 888.75 | 8.33E-06 | 5.00 | 5.33 |
| | 2 | 50.00 | 10.00 | 10.00 | 6.90 | 776.25 | 8.33E-06 | 5.00 | 4.66 |
| | **Mean** | | | | | | | | **5.00** |

**Mix Series 3-6 Concrete grade: - C-40 Ratio: - 25%RS: 75%CJS**

| Test age (days) | Sample no. | Dimensions (cm) | | | Failure load (kN) | Max. Moment (kNm) | Moment of Inertia ($cm^4$) | Centroidal depth (cm) | Bending Strength (MPa) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | B | D | P | M = PL/3 | I= $bd^3/12$ | c = D/2 | σ = Mc/I |
| 7 | 1 | 50.00 | 10.00 | 10.00 | 5.88 | 661.50 | 8.33E-06 | 5.00 | 3.97 |
| | 2 | 50.00 | 10.00 | 10.00 | 5.05 | 568.13 | 8.33E-06 | 5.00 | 3.41 |
| | **Mean** | | | | | | | | **3.69** |
| 28 | 1 | 50.00 | 10.00 | 10.00 | 8.45 | 950.63 | 8.33E-06 | 5.00 | 5.70 |
| | 2 | 50.00 | 10.00 | 10.00 | 7.39 | 831.38 | 8.33E-06 | 5.00 | 4.99 |
| | **Mean** | | | | | | | | **5.35** |

**Mix Series 3-7 Concrete grade: - C-40 Ratio: - 0%RS: 100%CJS**

| Test age (days) | Sample no. | Dimensions (cm) | | | Failure load (kN) | Max. Moment (kNm) | Moment of Inertia ($cm^4$) | Centroidal depth (cm) | Bending Strength (MPa) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | B | D | P | M = PL/3 | I= $bd^3/12$ | c = D/2 | σ = Mc/I |
| 7 | 1 | 50.00 | 10.00 | 10.00 | 5.93 | 667.13 | 8.33E-06 | 5.00 | 4.00 |
| | 2 | 50.00 | 10.00 | 10.00 | 6.05 | 680.63 | 8.33E-06 | 5.00 | 4.08 |
| | **Mean** | | | | | | | | **4.04** |
| 28 | 1 | 50.00 | 10.00 | 10.00 | 8.92 | 1003.50 | 8.33E-06 | 5.00 | 6.02 |
| | 2 | 50.00 | 10.00 | 10.00 | 8.40 | 945.00 | 8.33E-06 | 5.00 | 5.67 |
| | **Mean** | | | | | | | | **5.85** |

## B: 3 Cubes Compressive Strength Test Result of Mortar

**Mortar Mix series 1-1** **Sand type:- 100%RS**

| No | Test age (days) | Dimension (cm) | | | Weight (gm) | Volume ($cm^3$) | Failure Load (kN) | Compressive Strength (MPa) | Unit Weight ($gm/cm^3$) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| 1 | 3 | 5.00 | 5.00 | 4.90 | 262.00 | 122.50 | 20.72 | 8.29 | 2.14 |
| 2 | | 4.90 | 5.00 | 5.00 | 264.00 | 122.50 | 19.85 | 8.10 | 2.16 |
| 3 | | 5.00 | 5.00 | 4.90 | 262.00 | 122.50 | 24.85 | 9.94 | 2.14 |
| **Mean** | | | | | | | **21.81** | **8.78** | **2.14** |
| 1 | 7 | 4.90 | 5.00 | 4.90 | 264.00 | 120.05 | 39.24 | 16.02 | 2.20 |
| 2 | | 5.00 | 5.00 | 4.90 | 263.50 | 122.50 | 34.12 | 13.65 | 2.15 |
| 3 | | 4.95 | 5.00 | 5.00 | 256.00 | 123.75 | 35.12 | 14.19 | 2.07 |
| **Mean** | | | | | | | **36.16** | **14.62** | **2.14** |
| 1 | 28 | 4.90 | 5.00 | 4.90 | 265.00 | 120.05 | 63.30 | 25.84 | 2.21 |
| 2 | | 5.00 | 5.10 | 5.00 | 269.00 | 127.50 | 51.00 | 20.00 | 2.11 |
| 3 | | 4.95 | 5.00 | 5.00 | 256.00 | 123.75 | 50.60 | 20.44 | 2.07 |
| **Mean** | | | | | | | **54.97** | **22.09** | **3.19** |
| 1 | 56 | 5.00 | 4.90 | 4.90 | 276 | 120.05 | 74.97 | 30.60 | 2.30 |
| 2 | | 5.00 | 5.00 | 4.90 | 269 | 122.50 | 70.75 | 28.30 | 2.20 |
| 3 | | 5.00 | 5.00 | 5.00 | 276 | 125.00 | 66.19 | 26.48 | 2.21 |
| Mean | | | | | | | **70.64** | **28.46** | **2.23** |

**Mortar Mix series 1-2** **Sand type:- 100%JSS**

| No | Test age (days) | Dimension (cm) | | | Weight (gm) | Volume (cm3) | Failure Load (KN) | Compressive Strength (Mpa) | Unit Weight (gm/cm3) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| 1 | 3 | 5.00 | 5.00 | 4.90 | 271.00 | 122.50 | 40.42 | 16.17 | 2.21 |
| 2 | | 5.00 | 5.00 | 5.00 | 272.00 | 125.00 | 37.39 | 14.96 | 2.18 |
| 3 | | 5.00 | 5.00 | 5.00 | 269.00 | 125.00 | 32.39 | 12.96 | 2.15 |
| **Mean** | | | | | | | **36.73** | **14.69** | **2.18** |
| 1 | 7 | 5.00 | 4.90 | 4.90 | 268.00 | 120.05 | 52.98 | 21.62 | 2.23 |
| 2 | | 4.90 | 5.00 | 5.00 | 270.50 | 122.50 | 49.96 | 20.39 | 2.21 |
| 3 | | 5.00 | 5.00 | 4.90 | 271.00 | 122.50 | 43.96 | 17.58 | 2.21 |
| **Mean** | | | | | | | **48.97** | **19.87** | **2.22** |
| 1 | 28 | 5.00 | 5.00 | 4.90 | 266.00 | 122.50 | 63.23 | 25.29 | 2.17 |
| 2 | | 4.90 | 5.00 | 4.90 | 268.50 | 120.05 | 74.94 | 30.59 | 2.24 |
| 3 | | 5.00 | 5.00 | 4.90 | 271.00 | 122.50 | 78.94 | 31.58 | 2.21 |
| **Mean** | | | | | | | **72.37** | **29.15** | **2.21** |
| 1 | 56 | 5.00 | 5.00 | 4.90 | 270.00 | 122.50 | 86.22 | 34.49 | 2.20 |
| 2 | | 4.90 | 5.00 | 5.00 | 274.00 | 122.50 | 89.04 | 36.34 | 2.24 |
| 3 | | 5.00 | 5.00 | 4.90 | 271.00 | 122.50 | 89.04 | 35.62 | 2.21 |
| **Mean** | | | | | | | **88.10** | **35.48** | **2.22** |

**Mortar Mix series 1-3** **Sand type:- 100% unwashed JSS**

| No | Test age (days) | Dimension (cm) | | | Weigh t (gm) | Volume (cm3) | Failure Load (KN) | Compressi ve Strength (Mpa) | Unit Weight (gm/cm3) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| 1 | 3 | 5.00 | 5.00 | 5.00 | 251.00 | 125.00 | 34.76 | 13.90 | 2.01 |
| 2 | | 5.00 | 5.00 | 5.00 | 251.00 | 125.00 | 30.54 | 12.22 | 2.01 |
| 3 | | 5.00 | 5.00 | 5.00 | 250.00 | 125.00 | 30.54 | 12.22 | 2.00 |
| **Mean** | | | | | | | **31.95** | **12.78** | **2.01** |
| 1 | 7 | 5.00 | 5.00 | 5.00 | 251.00 | 125.00 | 40.76 | 16.30 | 2.01 |
| 2 | | 5.10 | 5.10 | 4.90 | 255.00 | 127.45 | 49.10 | 18.88 | 2.00 |
| 3 | | 5.00 | 5.00 | 5.00 | 252.00 | 125.00 | 44.10 | 17.64 | 2.02 |
| **Mean** | | | | | | | **44.65** | **17.61** | **2.01** |
| 1 | 28 | 4.95 | 5.00 | 5.00 | 256.00 | 123.75 | 62.41 | 25.22 | 2.07 |
| 2 | | 5.00 | 5.00 | 4.80 | 252.00 | 120.00 | 64.50 | 25.80 | 2.10 |
| 3 | | 5.00 | 5.00 | 5.00 | 251.00 | 125.00 | 65.50 | 26.20 | 2.01 |
| **Mean** | | | | | | | **64.14** | **25.74** | **2.06** |
| 1 | 56 | 5.10 | 5.10 | 4.90 | 253.00 | 127.45 | 74.88 | 28.79 | 1.99 |
| 2 | | 4.90 | 4.90 | 4.90 | 256.00 | 117.65 | 81.14 | 33.79 | 2.18 |
| 3 | | 5.00 | 5.00 | 5.00 | 253.00 | 125.00 | 81.14 | 32.46 | 2.02 |
| **Mean** | | | | | | | **79.05** | **31.68** | **2.06** |

# ANNEX C

## Sample Photo Gallery Taken During the Research

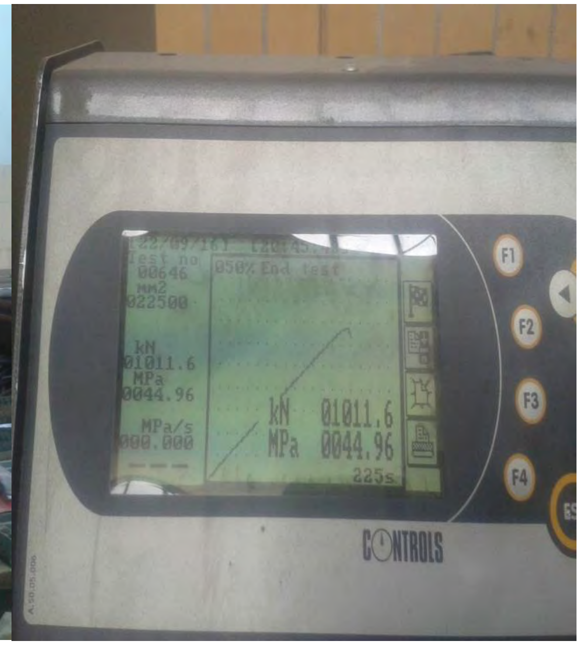
C.1 Photo: Mechanical mixer

C.2 Photo: Cube Sample

C.3 Photo: Failure Mode of river sand

C.4 Photo: Failure Mode of Jema sand

C.5 Photo: Silt content test Photo:




C.6 Photo: 28th day Compressive strength test result of C-25 with 100% CJS