JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

STRUCTURAL ENGINEERING STREAM

Experimental Study on the Properties of Concrete with an Addition of Teff Straw Fiber

A Research Submitted to School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Structural Engineering

By: Minda Kebede Biratu

JULY, 2021

JIMMA, ETHIOPIA

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Main Advisor: Dr. Kabtamu Getachew

Co – Advisor: Eng.Yehamlishet Memberu

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ETHIOPIA

DECLARATION

I, the undersigned, declare that this thesis entitled: "**Experimental Study on the Properties of Concrete with an Addition of Teff Straw Fiber.**" is my original work, and has not been presented by any other person for an award of a degree in this or any other University, and all sources of material used for this thesis have to be duly acknowledged.

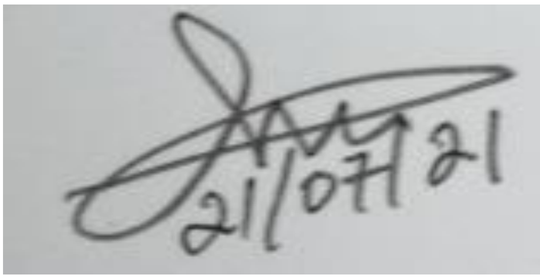
Candidate:

Mr. Minda Kebede

____________________ __________

Signature Date

As Master's Research Advisors, I hereby certify that I have read and evaluated this MSc Thesis prepared under my guidance by **Minda Kebede** entitled: **"Experimental Study on the Properties of Concrete with an Addition of Teff Straw Fiber''.**



<u>Dr. Kabtamu Getachew</u> ________________ __________

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Co - Advisor Signature Date

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FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

STRUCTURAL ENGINEERING CHAIR

EXPERIMENTAL STUDY ON THE PROPERTIES OF CONCRETE WITH THE ADDITION OF TEFF STRAW FIBER

MINDA KEBEDE

APPROVED BY BOARD OF EXAMINERS

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ABSTRACT

In the present scenario, no construction activity can be imagined without concrete. To make concrete using mix of three ingredients; aggregates, cement, and water are usual. Many structures show premature and excessive deflection due to improper use of construction material. The cost of material used in making concrete is also another important concern. Therefore, the use of other additional materials in a certain prescribed proportion, known as additives, to increase strength of concrete need attention this day. This study focused on experimental investigation of the suitability of teff straw as an additional concrete material in concrete mix.

The conventional mix had been designed for C-25 grade concrete having a target mean strength of 28 MPa with a water-cement ratio of 0.5 and within a 20-50 mm slump range. Cubical concrete unit samples of size 150×150×150 mm were prepared and tested for compressive strength; cylinder of 150mm in diameter and 300mm in length were tested for split tensile tests; 100 mm× 100 mm cross section with 500mm length prism were tested for flexure strength. Percentage addition of teff straw fiber by weight of concrete had been tested for (M_0 = 0.00 %, M_1 = 0.15 %, M_2 = 0.25 %, and M_3 = 0.35%). The concrete has been casted and the compressive strength, splits tensile strength and flexural strength tests at 7 and 28 days curing periods were tested and compared against plain concrete.

Mean flexural strength of concrete with an addition of teff straw with M_1, M_2 and M_3 addition of teff straw by weight of concrete has shown an increment of 19.38%, 4.19% and 0.66%, respectively. Compressive strength for M_1 showed an increment of 17.08% and for M_2 and M_3 showed reduction by 11.51% and 7.87% respectively .While the split tensile strength showed an increment of 5.28% and 0.30% for M_1 and M_3 respectively and 0.76% reduction for M_2. On the other hand, slump results for mix design M_1, M_2 and M_3 addition of teff straw by weight of concrete showed reduction effect by 20 %, 40% and 50% respectively. Finally, for the fresh concrete densities, a slight reduction by 2.00%, 2.32%, and 2.84% has shown, respectively due to volume addition of fresh concrete with teff straw.

Keywords: *elasticity, compressive strength, flexural strength, split tensile strength, teff straw*

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ACRONYMS AND ABBREVIATIONS

ACI	American Concrete Institute
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
D	Deph
C-25	Concrete Grade with characteristic compressive strength of 25MPa by 28th day
CA	Coarse Aggregate
CoV	Coefficient of Variation
DOE	Department of Environment
EBCS	Ethiopian Building Code of Standard
E	Modulus of Elasticity
Ec	Modulus elasticity of concrete
f’c	Compressive strength of concrete
f’cm	mean compressive strength
ECBP	Engineering Capacity Building Program
ES	Ethiopian Standard
FA	Fine Aggregate
FM	Fineness Modulus
FRC	Fiber Reinforced Concrete
G	Modulus of Rigidity
GFRC	Glass Fiber Reinforced Concrete
GGBFS	Ground Granulated Blast Furnace Slag
JiT	Jimma Institute of Technology
L	Length
M_0	Mix with 0.00% Teff straw fiber
M_1	Mix with 0.15% Teff straw fiber
M_2	Mix with 0.25% Teff straw fiber
M_3	Mix with 0.35% Teff straw fiber
MOR	Modulus Of Rupture
MSL	Mean Sea Level
NFRC	Natural Fiber Reinforced Concrete
NRMCA	National Ready Mixed Concrete Association

OD	Oven Dry condition
P	Maximum load
PCA	Portland Cement Association
PPC	Portland Pozzonala Cement
SFRC	Steel Fiber Reinforced Concrete
SSD	Saturated-Surface-Dry condition
TS	Teff Straw
TSRC	Teff straw Reinforced Concrete
w/c	Water cement ratio
Wc	Weight of concrete.
ε_1	Strain at peak stress
εc	Compressive strain
υ	Poisson’s ratio
σ_c	Compressive strength
σ_t	Modulus of rupture of flexural failure
η	Peak strain ratio

1. Introduction

1.1. Background of the Study

Concrete is a multipurpose and most popular construction material in the world. It is produced by mixing fine and coarse aggregates, cement, water and additives in a certain prescribed proportion. The traditional building construction technique in Ethiopia uses a lot of natural materials like mud and teff straw, wood from the forests before today's concrete technology. The construction materials used this day are still being modified. The current demand of concrete in construction industry is also increasing, in addition to the concrete made up of the three known concrete ingredients (aggregate, cement and water), using teff straw as additive material in concrete production is possible for which it is abundant and get environmentally friend.

The use of concrete in civil infrastructure is highly demanded in structural and nonstructural elements. The materials of concrete include reinforcing fibers (e.g., steel, polypropylene, and carbon fibers), recycled materials (e.g., tire rubber, crushed glass, plastic, industrial waste), and the organic waste such as bagasse, wheat husk, groundnut shell, sisal, Teff straw, Inorganic elements like concrete aggregates and reinforcement elements. The organics are agro-waste used as partial replacement of fine aggregate which provide additional binding property in concrete production [1]. The organic and inorganic materials can be used in a various form in concrete as partial replacement of aggregates, cement or in terms of reinforcing steel with fibers to increase the tensile strength of concrete [2]. The sustainable construction materials can reduce the amount constitutive elements of concrete required for civil structural constructions.

Concrete is one of the building industry's most prevalent manmade materials and a highly consumed construction material in the world these days since it is made of easily available ingredients except cement. The cost of preparing the material, the ease of molding it in any shape required, its ability to resist fire, less corrosion attack and other advantageous properties over other construction materials makes it preferable [3].

Due to fine and coarse aggregates such as sand and natural gravel effectively bearing the compressive load, conventional concrete is comparatively powerful in compression [4]. The most analyzed and in a sense the most important mechanical property of concrete is its compressive strength. Compressive strength is directly proportional to concrete's other positive qualities. Concrete with high compressive strength is occupied, hard, water resistant and resistant to other outside effects. By determining concrete's compressive strength, a general evaluation about concrete's quality can be reached [5].

The workability of fresh concrete gives an idea of the frictional behavior of the concrete from the time it is mixed to the time it is compacted. It has four major components like: the ability of the concrete to be mixed, transported, molded and compacted [6].

However, due to the concrete constituent materials are expensive, many of the low income of our community hardly get concrete material to use in the construction industry. Using environmentally available material like teff straw as additional concrete material can enhance properties of concrete be found. Research indicates that changes in Concrete material can change the strength and fracture engineering properties of concrete. Along with local availability and cost effectiveness sustainable approach for construction, teff straw is selected as concrete additional material.

1.1. Advantages and Disadvantages of Concrete Material in Structural

Reinforced concrete may be the most important material available for construction. It is used in one form or another for almost all structures, big or small buildings, bridges, pavements, dams, retaining walls, tunnels, viaducts, drainage and irrigation facilities, tanks, and so on. The tremendous success of this universal construction material can be understood quite easily if its numerous advantages are considered [7]. These include the following:

- It has considerable compressive strength as compared to most other materials.
- Reinforced concrete has great resistance to the actions of fire and water. During fire of average intensity, members with a satisfactory cover of concrete over the reinforcing bars suffer only surface damage without failure.
- Reinforced concrete structures are very rigid.
- It is a low-maintenance material.
- As compared with other materials, it has a very long service life. Under proper conditions reinforced concrete structures can be used indefinitely without reduction of their load-carrying abilities. This can be explained by the fact that the strength of concrete does not decrease with time but actually increases over a very long period, measured in years, due to the lengthy process of the solidification of the cement paste.
- It is usually the only economical material available for footings, basement walls, piers, and similar applications.

- A special feature of concrete is its ability to be cast into an extraordinary variety of shapes from simple slabs, beams, and columns to great arches and shells.
- In most areas concrete takes advantage of inexpensive local materials (sand, gravel, and water) and requires relatively small amounts of cement and reinforcing steel.
- A lower grade of skilled labor is required for erection as compared to other materials such as structural steel.

In all structural construction process, the concrete has unreplaceable roll. To use concrete successfully the designer must be completely familiar with its weak points as well as with its strong ones [7].

Among its disadvantages are the following:

- Concrete has a very low tensile strength, requiring the use of tensile reinforcement.
- Forms are required to hold the concrete in place until it hardens sufficiently. In addition, shoring may be necessary to keep the forms in place for roofs, walls, and similar structures until the concrete members gain sufficient strength to support themselves. Formwork is very expensive. Its costs run from one-third to two-third of the total cost of a reinforced concrete structure, with average values of about 50%.
- The low strength per unit weight of concrete leads to heavy members. This becomes an increasingly important matter for long-span structures where concrete's large deadweight has a great effect on bending moments.
- Similarly, the low strength per unit volume of concrete means members will be relatively large, an important consideration for tall buildings and long-span structures.
- The properties of concrete vary widely due to variations in its proportioning and mixing. Furthermore, the placing and curing of concrete is not as carefully controlled as the production of other materials such as structural steel and laminated wood.
- Two other characteristics that can cause problems are concrete's shrinkage and creep. These two characteristics can cause cracks in concrete members. The resulting cracks may reduce the shear strength of the members and be detrimental to the appearance of the structure. In addition, the cracks may permit the reinforcing to be exposed to the atmosphere, thereby increasing the possibility of corrosion [7].

1.2. Natural Fiber Reinforced Concrete

The current findings deals with the subject of addition of natural fibers to concrete in order to study the strength properties and also to get an improvement in engineering properties of concrete. Basically natural fibers are of two types. Natural inorganic fibers such as Basalt, Asbestos and the other are the natural organic fibers such as coconut, palm, kenaf, jute, sisal, banana, pine, sugarcane, bamboo…etc. The natural fibers are investigated by different researchers as construction materials that can be used in cement paste/mortar/concrete [8]. From natural fiber reinforced concrete material this paper gives attention to teff straw as concrete material in a structural concrete production study project.

1.3. Statement of the Problem

Making concrete is not an easy tasks, especially to achieve the desired strength properties of concrete. Many scholars and researchers are conducting research to find suitable material to produce different types of concrete with acceptable strength and engineering properties. It is also a well-known fact that the concrete constitute materials have an impact in improving concrete strength. Using locally available concrete materials is more acceptable because the cost of material, coarse aggregate, fine aggregate and cement is high in order to fulfill the demand of structural concrete in construction industry. Also the aggregate excavation need additional cost and the process degrade the land. One of the challenges faced in using concrete material is to select the environmental friendly material that can give better concrete strength with acceptable engineering properties and fair cost overruns and to improve the current concrete demand. The strength of concrete in the structural construction industry is the main requirement as the construction has to technologically improve from day to day. So this study answer how easily available material, teff straw, gained the acceptable strength with good engineering properties of concrete as additional structural material.

1.4. Research Questions

The research questions that this study was going to explain are as follows:

1. What is the significant effect of teff straw addition with concrete on the compression, split tensile and flexural strength of concrete in this study scenario?
2. How using teff straw in concrete making show potential effects on concrete modulus of elasticity and the strain- stress properties?
3. Does the experimental analysis result of the test same with international standards and specifications?

1.5. Objectives of the Study

1.5.1. General Objective

The main objective of this research is to study the properties of concrete with an addition of teff straw as concrete material.

1.5.2. Specific Objectives

The specific objectives of this research was;

- To improve the compressive strength.
- To improve split tensile strength
- To improve the flexural strength and
- To investigate the modulus of elasticity and stress-stain property of concrete with an addition of teff straw

1.6. Significance of the Study

This study was to get sustainable concrete material using teff straw which has better engineering properties in addition to other concrete material that can provide helpful information to various stakeholders as follows:

Public authors will be benefit from the study as a source of information and foundation for structural engineering work that can help to improve and control the qualities of the materials regarding standard and specifications.

Owners, contractors and consultants will be benefit from the study in civil construction work projects.

The study will provide lessons that will help the concerned body come up with appropriate measures to address problems resulting from structural construction material with teff straw as additional concrete material.

Other researchers will use the findings as a reference for further research on elastic properties and compressive strength with other engineering properties of concrete with an addition of natural fiber as concrete additive.

1.7. Scope and Limitation of the Study

It was not possible to cover all aspects concerning the concrete properties test with an addition of teff straw, the main concrete properties test considering the significant concrete behavior was analyzed. Concrete as a composite material contains different constraints in the construction development. But this study was to look at the physical properties and mechanical properties of plain concrete like compressive strength, flexural strength, split tensile strength and concrete stress-strain properties with an addition of teff straw as additional material only in normal structural concrete material. In this study the concrete tests were taken according to the standard and specification. This study include the concrete properties with an addition of teff straw in specific three different percent. Only normal strength concrete C20/25 is considered.

1.8. Research Design.

In the finding the research was designed to be in correlated manner in order to reach its objectives. It was designed to collect the data from experimental work and the data was analyzed with standards and specification which help to give clear discussion and bring influential recommendation in the research.

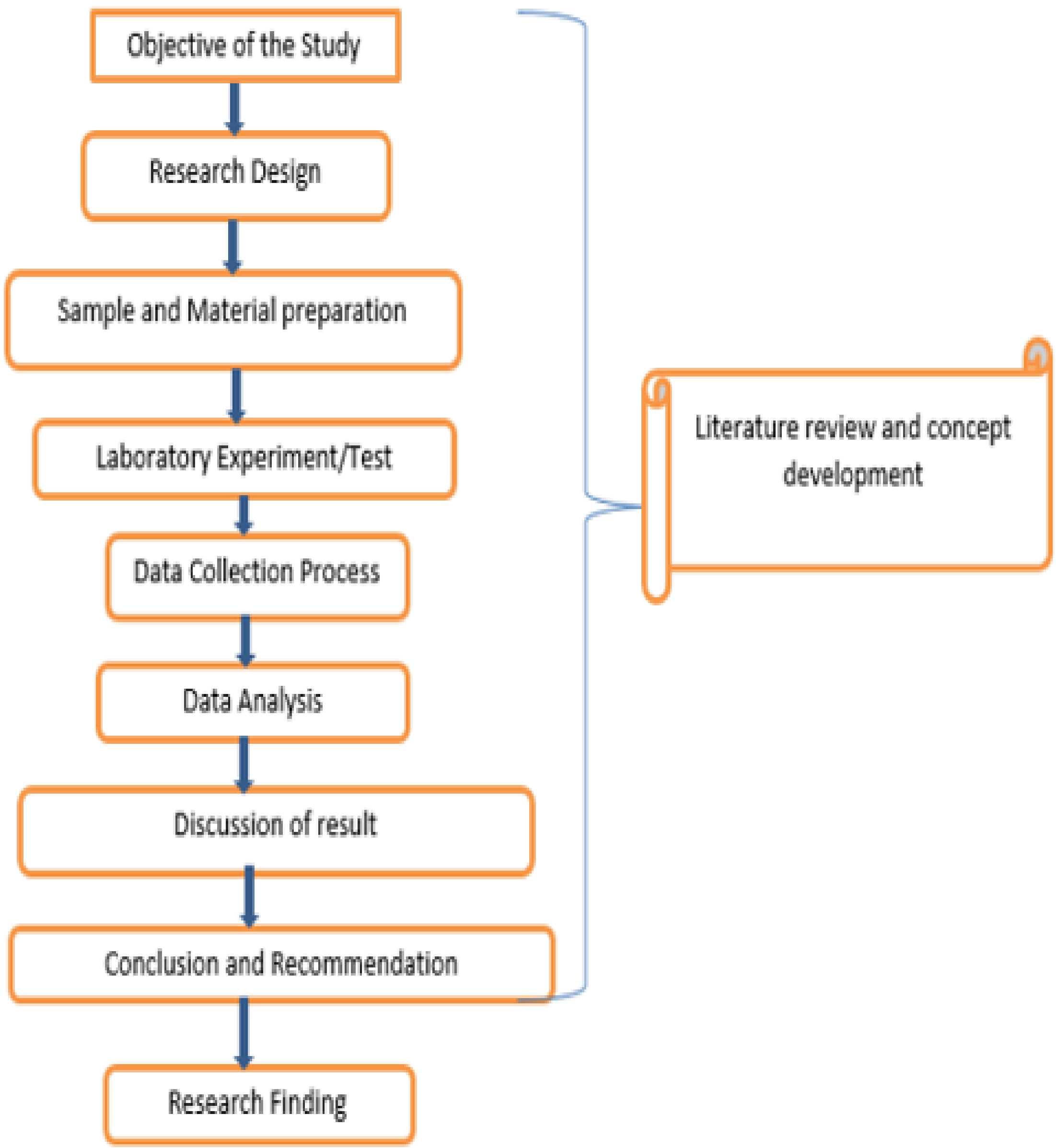

Figure 1.Schematic of Research Design.

2. Literature Review

2.1. Introduction

Literature reviews, case studies, and various papers addressing concrete material and natural reinforced concrete fibers in different construction materials were collected. The publication date of the selected papers ranged from 2001 to 2021. Overall, a total of 35 different papers were studied for this review.
Use of inappropriate materials, poor construction practices, curing and mix designs, results in concrete structures often showing serious premature deterioration. This is a global problem that annually costs public and private sectors worldwide billions of dollars. Measuring the strength of concrete to determine its engineering properties in service is challenging. It is, however, important in identifying how sustainable structures will ultimately be adopted [9]. Fibers are a valuable material additive for construction materials [10].

2.2. Types of Fiber Reinforced Concrete

Fiber is a small piece of reinforcing material possessing certain characteristic properties. It can be circular or flat and often described by a parameter called “aspect ratio”. It is the ratio of its length to its diameter which ranges from 30 to 100. Generally there are two different types of fibers i.e. natural fibers and artificial polymer based fibers. These fibers reinforcing the concrete are discussed in the following sections with their physical properties and applications. Slight increment of modulus of elasticity is shown by increasing the fiber content. When percent of fiber is increased in content by volume, there is an increment in the modulus of elasticity. The experiments assumed that strain rate was constant and has a certain value for which the test was carried out [11].
The most significant contribution of fiber reinforcement to concrete is not to compressive strength but to flexural strength of the material (total energy absorbed in breaking a specimen in flexure). The flexural strength is increased by 2.5 times using 4 percent fibers. Toughness is about 10 to 40 times increased from the plain concrete. The split tensile strength of mortar is increased 2.5 times that of unreinforced one by the inclusion of 3 percent fiber by volume. The presence of fibers increases fatigue strength of about 90 percent and 70 percent of the static strength at $2x10^6$ cycles for non- reverse and full reversal of loading respectively. The impact strength is increased 5 to 10 times that of plain concrete depending on the volume of fiber used [12].

a) Crushed Glass Mixed Concrete.

It has various characteristics such as a transparent surface, abrasion resistance, durable and easy for manufacturing. Generally, the behavior of concrete containing glass aggregate may increase its mixture workability, bleeding and segregation. However, this glass replaced concrete reduces its mechanical strength and drying shrinkage and increases its chemical and fire resistance as well as the carbonation resistance. In order to monitor material microstructure and its adherence to the concrete mixture, it is necessary to obtain multiscale microscopic images with a scanning electron microscope. Glass powder crushed [13].

b) Natural Organic and Mineral Fibers

Natural fibers were traditionally used in the past as reinforcing materials and their use so far has been traditional far more than technical. They have served useful purposes but the application of natural fiber as a reinforcing material for concrete is a new concept. Improved tensile and bending strength, , greater resistance to cracking and hence improved impact strength and toughness ,greater ductility are some of the properties of natural fiber reinforced concrete [14]. Wood, asbestos, cotton, bamboo, and rock wool. They come in wide range of sizes [15].

c) Steel Fiber Reinforced Concrete

Steel fiber reinforced concrete is advantageous than conventional reinforced concrete in use in construction. It can be used for tunnel lining rock slop stabilization and as lagging for the support of excavation. Labor is not needed for placing mesh or reinforcing bars. Straight, crimped, twisted, hooked, ringed, and paddled ends. Diameter range from 0.25 to 0.76mm of steel fiber reinforced used in concrete test. The mechanical properties of steel fibers are not affected by long term loading. The ductility of the steel fiber reinforced concrete is improved depending on the type and volume percentage of fibers present. Steel fibers improve the ductility of concrete under all modes of loading.

d) Other Synthetic Fibers

Kevlar, nylon, and polyester. Diameter ranges from 0.02 to 0.38mm. A convenient parameter describing a fiber is its aspect ratio defined as the fiber length divided by an equivalent fiber diameter. Typical aspect ratio ranges from about 30 to 150 for length of 6 to 75mm [16].

2.3. Mixing Procedure

2.4. Constitutes and Engineering properties of the Concrete

Mix design is proportioning the material from which the concrete made to determine the required and specifiable characteristics of a concrete mixture. Characteristics can include: (1) Physical property i.e. preliminary test, (2) fresh concrete properties, (3) required mechanical properties of hardened concrete such as strength and elastic requirements and the inclusion, exclusion, or limits on specific ingredients. Mix design leads to the development of a concrete specification. Mixture proportioning refers to the process of determining the quantities of concrete ingredients, using local materials, to achieve the specified characteristics of the concrete [16]. A properly proportioned concrete mix should possess these qualities:

1. Acceptable workability of the freshly mixed concrete
2. Strength and uniform appearance of the hardened concrete
3. Economy

Understanding the basic principles of mixture design is as important as the actual calculations used to establish mix proportions. Only with proper selection of materials and mixture characteristics can the above qualities be obtained in concrete construction [16]. The workability of concrete significantly decreases with the increase of the fiber content. The slump value decreases rapidly when the fiber content increases.

2.4.1. Constituent of the concrete

Structural concrete is a composite in form and composed of coarse granular material (coarse aggregate), fine aggregate that is embedded in a hard matrix of material, the cement or binder that fills the space among the aggregate particles and glues them together. Concrete quality mainly depends on the material concrete made up on, mixing method, production and implementations [17].

Construction industries are facing problems of cracking and tensile strength problems in concrete for that we have to add something in concrete to improve the engineering property. Man has known that two or more materials could be combined to form a new material with enhanced material properties for a long time which is called composite material. Composite material may be defined as the combination of two or more materials to form another useful material. Another composite material is fiber which has been used to reinforce the brittle materials since ancient times. Straws were used to reinforce sun baked bricks; horse hair was used to reinforce plaster and more recently asbestos fibers are being used to reinforce Portland cement. Adding a small amount of fibers is a good solution for this. Different types of fiber namely steel, carbon, asbestos, jute, glass, polythene, nylon, polypropylene, fly ash, polymer, epoxy, super plasticizer, etc. [12].

In the constituent of concrete referring the low tensile strength and brittle character of concrete have been bypassed by the reinforcing rods in the tensile zone of the concrete since the middle of the nineteenth century The Portland cement association (PCA) investigated fiber reinforcement in the late 1950. In addition to reinforcing rods for tensile strength the Teff straw fiber reinforced concrete also need attention since it's environmentally available. On the other hand, fiber reinforced concrete continues to sustain considerable loads even at the deflection of the plain concrete. Plain concrete fails suddenly once the deflection corresponding to the ultimate flexural strength is exceeded; Failure takes place primarily due to fiber pullout or deboning in fiber reinforced concrete and unlike plain concrete a fiber reinforced concrete does not break immediately after the initiation of the first crack. This has the effect of increasing the work of fracture, which is referred to as toughness and represented by the area under the load deflection curve. In fiber reinforced concrete, crack density is increased, but the crack size is decreased [12].

a) **Cement-** Cement to be used shall be Portland-Pozzolana or Ordinary Portland Cement according to ES EN 1992: 2015 [18]. The cement must meet the ASTM (C150 or C595) standard specification and type III (high-early strength) is recommended to reduce hardening retardation caused by the glucose present in most natural fibers. Dangote Portland Pozzolana cement (grade 32.5N) cement type complies with the requirements of Standards, ASTM Standard [19].

b) **Aggregates –** The aggregates must meet ASTM C33 gradation requirements and quality.

c) **Water and Admixtures –** The water should be clean and good quality. Admixtures such as accelerating agents may be used to decrease the influence of the glucose retardant. If mild steel rebars are not used as additional reinforcement, calcium chloride could be used. Water reducing admixtures and high range water reducing agents can be added to increase the workability when plastering. And also bacterial attack of organic fiber is prevented with the use of organic-micro biocide.

d) ***Fibers*** **–** Fiber reinforced concrete can be defined as a composite material consisting of mixtures of cement mortar or concrete and discontinuous discrete, uniformly dispersed fibers which increases its structural integrity. The fiber improves the tensile strength, flexural strength, resistance to crack, toughness, shearing strength, shock resistance, etc. It also helps make the concrete stronger and more resistant to temperature extremes [12]. The addition of small closely spaced and uniformly dispersed fibers to concrete can act as a crack arrester and improves its static and dynamic properties. This is known as fiber reinforced concrete, which can also be defined as the concrete containing fibrous materials which increases its structural performance. It contains short discrete particles; fibers, that are uniformly distributed and randomly oriented [8]. The length of fibers may vary from 1 to 20 in (25 to 500mm). Because fibers are natural materials, they are not uniform in diameter and length. Typical values of diameter for unprocessed natural fibers may vary from 0.004 to 0.03 in (0.1 to 0.75 mm).

e) ***Teff straw –*** Straw is one of the fibers and the renewable building material which is available around the world in abundance. During the use of teff straw fiber as concrete constitute it's important to wash the teff straw with potable water in order to remove dirt from it and it was subsequently air-dried for some days to ensure that it is dry. Teff straw chemical composition is primarily cellulose, just like trees. When the straw is bundled together into a bale, it becomes a solid block. That is highly resistant to decomposition in its dry form. The straw is used mainly for livestock feed but newly approved grass has become popular. In addition, straw is added to decrease drying shrinkage and prevent cracking in earth block constructions.

2.4.2. Properties of Fiber Reinforced Concrete

The fiber effect on the improvement of compressive strength is small (0 to 15%). But the failure mode is changed by the addition of fiber. Slight increment of modulus of elasticity is shown by increasing the fiber content. When percent fiber is increased in content by volume, there is an increment in the modulus of elasticity [12]. The combination of steel and polypropylene fibers improves the mechanical properties of concrete because the latter can enhance performance by crack bridging and forming fiber–cement matrix interfacial bonds [20]. Chemical and mechanical properties of fiber reinforced concrete has referred as important properties. Chemical modified jute fibers have better retention of tensile strength as compared to their raw jute counterpart. After 90 days exposure in cement paste, almost 98% of tensile strength was retained in chemically modified jute fiber [30]. The mechanical properties of concrete were mainly depend on the type and percentage of fiber. Crimped -end fibers can achieve the same properties as straight fibers using 40 percent less fibers. The same equipment and procedure as conventional concrete can be used also for fiber reinforced concrete [12].

A. Compressive Strength

Concrete has high compressive strength, corrosion and weathering effects are minimal. However, concrete has low tensile strength and easily can be cracked due to its characteristics which are brittle. Strength value depends on size and shape of the specimens, batching, mixing procedure, the methods of sampling, molding and fabrication[21]. Synthetic fibers were used as one of the effective additives to improve the tensile strength of concrete. Fresh and hardened concrete properties were studied and they observed improvement in workability and found an increase in compressive strength. The mix proportion that gave Maximum compressive strength also resulted in maximum modulus of rupture [9].

The concrete compressive strength also depends on the duration of loading when it is exposed to a constant stress. This is of practical significance because for many concrete structures the variable load is small compared to the total load, so that the stresses acting on a structural element may vary little with time. A sustained stress in the range of working stress may lead to a slight increase of the compressive strength, found when the concrete is afterwards loaded to failure in a short-term test. If, however, high sustained stresses act on the concrete, the process of micro-cracking continues and may eventually lead to failure [22]. As the sustained stress decreases, the time to failure increases while the compressive strength is loaded in KN to the area in mm^2 of cube loaded face.

$$\text{Compressive Strength} = \frac{P}{A} \quad (2.1)$$

Where; P = Failure Load (N) A = Area of loaded cube face (mm^2)

B. Flexural Strength

Flexural strength is one measure of the tensile strength of concrete. It is a measure of an amount of stress or force that a beam or slab can withstand from bending failures[23]. The load under which the specimen failed was recorded and used to obtain the flexural strength of the concrete using the formula in equation (2.2) below. The third point loading method of flexural testing of concrete beams was adopted.

$$\text{Flexural Strength} = \frac{P}{bd^2} \quad (2.2)$$

Where; P = maximum applied load indicated by the testing machine (N), L = span length (mm), b = average width of specimen (mm) and d = average depth of specimen (mm).

C. Split Tensile Strength

The concrete is very weak in tension due to its brittle nature and is not expected to resist the direct tension. The concrete develops cracks when subjected to tensile forces. Thus, it is necessary to determine the tensile strength of concrete by finding the load at which the concrete members may crack. The tensile strength of concrete is only a fraction of it compressive strength and is defined as the maximum stress that concrete can withstand when subjected to uniaxial tension. Sometimes it becomes hard to measure direct uniaxial tensile strength because it is difficult to achieve true axial tension without secondary stresses caused by the holding devices [24]. One of the concrete properties of interest to the designer is the splitting tensile strength of concrete. The most common tests of tensile strength include: 1) the direct tension test, 2) flexure test, and 3) splitting test. A method of determining the tensile strength of concrete using a cylinder which splits across the vertical diameter. It is an indirect method of testing tensile strength of concrete. Splitting test is often regarded as a simple, reliable, and convenient method for approximating the tensile strength of concrete with test results typically having a low coefficient of variation [25].

Understanding the correlation between the mix proportions, micro structural characteristics, and macro-scale properties of concrete (i.e. the process-structure properties relationship) is fundamental to achieving a more advanced understanding of how to apply and optimize this abundant engineering material. Although concrete has been traditionally evaluated by its physio-mechanical and functional properties; development of advanced and effective inspection techniques during the last decade has demonstrated that fundamental macro-level properties of concrete depend, to a great extent, on its properties at the micro- and Nano levels [26].

According to BS EN 12390-6:2009, the test in cylindrical splitting uses the universal testing machine and load applied against the specimen along its center line. The load gradually increased until failure occurred by splitting. Then the horizontal tensile stress can be calculated as given in the equation below.

$$\text{Split tensile strength} = \frac{2P}{\Pi DL} \tag{2.3}$$

Where, P = maximum applied load; D = diameter of the cylindrical specimen; and L = length of the specimen.

D. Modulus of Elasticity

Considering that the elastic parameters data of FRC is fundamental for structural design, an in-deep knowledge about their measurement methods is required [27].The other important behavior of concrete is modulus of elasticity. The modulus of elasticity of concrete is different for different mixes and the value of the static modulus of elasticity of concrete is affected by many factors. It is highly affected by the compressive strength of concrete, the type of aggregate used, unit weight of concrete, the use of admixtures and age of concrete. A study on static and dynamic modulus of young concrete shows that the type of aggregate used has a significant effect on the static modulus of elasticity. Aggregates with higher modulus of elasticity will result in concrete having higher static modulus of elasticity [3]. It is defined as the ratio between the normal stresses to normal strain below the proportional limit of a material called modulus of elasticity Ec.

Modulus of elasticity (MPa) = unit stress/unit strain

With the compressive strength test on the concrete specimen (cylinder of 15 cm diameter and 30 cm length having a volume 15 cm cube), the modulus of elasticity of concrete is calculated with the help of a stress and strain graph. But, According to ACI codes, the modulus of elasticity of concrete can be measured with the formula with normal density or weight of concrete.

$$E_c = 0.043\, w_c^{1.5}\, f'_c{}^{0.5} \qquad (3)$$

According to ACI 318–08, (Normal weight concrete) the modulus of elasticity of concrete is,

$$E_c = 4700 \sqrt{f'_c} \text{ Mpa}$$

Where, Ec = modulus elasticity of concrete (Mpa).

f'c = compressive strength of concrete.

wc = weight of concrete.

The static modulus of elasticity for the recycled aggregate concrete is lower than that of natural aggregate by a maximum margin [28]. To define the stress-strain relationship of concrete From ES EN 1992-2015 standard the strain-stress of concrete can be determined using the equation shown below. Which was used for comparison of experimental tests with an addition of teff straw as standard.

$$\frac{\sigma_c}{f_{cm}} = \frac{k\eta - \eta^2}{1 + (k-2)\eta}$$

(ESC2-2015, Expression 3.14)

$$\eta = \frac{\varepsilon_c}{\varepsilon_{c1}}$$

Where, ε_1 = strain at peak stress

$K = 1.05\, E_{cm} \times \varepsilon_1 / f'_{cm}$

Table 1. Strain- Stress used for Comparison from ES EN 1992 - 2015.

$\varepsilon c(1/1000)$	0	0.35	0.7	1.05	1.4	1.75	2
$\sigma c(MPA)$	0	7.984375	14.4375	19.35938	22.75	24.60938	25

E. Determination of Poisson ratio

Poisson ratios for the various concrete mixtures was obtained in order to determine the values of modulus of rupture of the concrete. The Poisson ratio of concrete estimated using the formula given by equation (4) below [29].

$$\upsilon = \varepsilon_t / \varepsilon_c \quad (4)$$

Where, υ = Poisson's ratio

ε_c = compressive strain at cracking

ε_t = modulus of rupture of flexural strain

F. Determination of modulus of rigidity

Similarly the modulus of rigidity for the different mix proportions of lime-cement concrete were obtained by using the equation (5).

$$G = E / 2(1 + \upsilon) \quad (5)$$

Where, G = modulus of rigidity (N/mm^2)

E = modulus of elasticity (N/mm2)

υ = poison's ratio.

3. Materials and Methods

3.1. General

Natural fiber reinforced concrete is concrete reinforced with naturally occurring fibers. Some of the best known natural fibers are sisal, coconut, sugarcane bagasse, plantain (banana), palm, etc. Natural fiber can be expressed as processed and unprocessed natural fibers. Teff straw which is natural fiber is important in reinforcing concrete to reduce the shortage of concrete material in addition to sand, aggregate and cement. In this specific study locally available teff straw was used for concrete production.

3.2. Experimental Procedure

Appropriate samples to investigate the structural concrete properties have been prepared and the important laboratory investigations were held. For C-25 normal grade concrete having target mean strength (28Mpa) mix design was proportioned using DOE (Departments of Environment) mix design method. For flexural strength test, split tensile strength test and compressive strength test samples were cast, de-molded, cured by socking in water and tested after their respective dates of curing.

Cement, coarse aggregate, fine aggregate and teff straw were mixed in the dry state until uniform color mix as per the mix design requirements later admixture and water were added and mixed again until uniform concrete is observed. The molds were greased with lubricant material to the inner surface of the mold to prevent the sticking of cement concrete to mold. The fresh concrete was casted by tamping the materials in three layers using the tamping rod of 25 mm for both compressive test and split tensile test and 35 times at a height of 50 mm for flexural compaction. These specimens were allowed to sit in the molds for 24 hours and were de-molded, immersed in a curing tank at the different curing age of concrete. A total of 24 cubical unit samples were prepared and tested according to Ethiopian codes of standards. Experimental investigations were carried out by using teff straw fiber reinforced and cement stabilized with normal materials in unit specimens with a fiber proportion of a control without teff straw and with an addition of teff straw of 0.15%, 0.25%, and 0.35 % by dry weight of concrete in mix design using other studies as references [23]. The experimental held to investigate the concrete strength tests including flexural strength, compression tests and split tensile strength and elastic properties of structural concrete according to specified standard and specification.

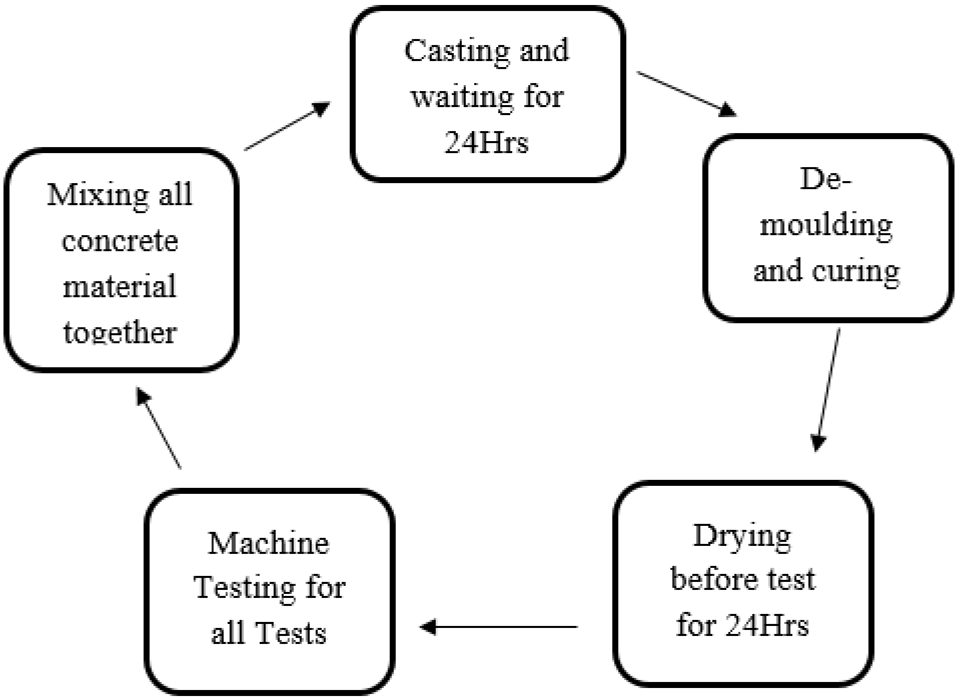

Figure 2. Experimental Work Procedure flow

3.2.1. Sample Size and Selection

This study followed a purposive sampling selection process. For the aggregate laboratory test, the samples depended on the types of test requirement and standards. For each test, quartering and weighting was used as a sampling technique. The output of the study was to compare the strength of normal weight concrete compressive strength with three different proportions of TS reinforced concrete tests.

To determine the sample size of the test it needs standards' and specifications. According to ES and ACI-ASTM 33; it requires a minimum of three samples of cub size of (150×150×150) mm^3 mold for each test of the compressive strength of concrete. Three Split Tensile strength tests of cylinder 150mm diameter with 300mm length for each mix of 7 and 28 curing days was held. Concrete beam 100mm × 100mm cross-section with 500mm length flexural capacity was tested on two samples of each mix of 7 and 28 curing days. Accordingly, a total of **64** samples was used in this specific experimental study to investigate the mechanical properties of concrete with an addition of three different percent amount of teff straw in dry weight of concrete with constant interval using references.

3.2.2. Sampling Procedure

The selected coarse aggregate was crushed stone and fine (sand) river washed aggregate was selected based on own knowledge and judgment. In choosing the samples, the number samples considered to be representative by using minimum number of samples as per ASTM C33 to take the average (mean). During evaluation of concrete strength recognized standards and specifications were referred. In this specific research C 20/25 concrete compressive strength was selected as it is a usual structural concrete strength grade.

The concrete mix ratio refers to the proportion of the components in concrete (cement, water, sand, and stone). There are two methods of concrete mixing: one is to use amount of concrete materials in volume per 1 cubic meters and the other is that the water cement ratio and concrete content of different materials per unit mass of the cases, In case of this tests amount of material per unit cubic meter adjusting the field condition of both fine and coarse aggregate moisture content was designed to mix.

Table 2. Number of Samples for each tests.

Percentage addition of TS (%)	Number of samples for compressive test	Number of samples for split tensile test	Number of samples for flexural test
0.00	6	6	4
0.15	6	6	4
0.25	6	6	4
0.35	6	6	4
Total	**24**	**24**	**16**

The number of samples of the test selected considering its representativeness to define the concrete strength property. Three sample for each proportion of compressive strength and split tensile strength, and two for flexural strength of respective curing days was studied for which it can represent the test result of the experiment. The material proportion for C25 experimental strength test using 0.00% 0.15% 0.25% and 0.35% teff straw addition was as below.

Table 3.Amount of concrete materials in mix

Cement (Kg)	Sand (Kg)	Stone(Kg)	Water(Kg)
350	678	1133	181

The mix ratio is: C: S: G=1:1.8:3, W/C=0.5.

3.2.3. Variables and Testing Procedure

In the testing procedure the newly harvested teff straw was collected locally from the nearest place in the community since it is abundantly available and added by the presence of dry concrete weight (cement, coarse aggregate and fine aggregate). Engineering properties of fresh and hardened concrete were experimentally analyzed.

The experimental equipment and machine help for the test of compressive strength, split tensile strength and flexural strength test of hardened concrete was adjusted as samples sit under machine be in proper and plugged to power for each sample tests.

The research design for this paper is experimental research having the following independent variables, dependent variables and constants or controls.

1) **Independent Variables: -** were a variable which represents the input or causes, or were tested to see if they are the cause. The following were independent variables:
   - Percentage replacement of teff straw
2) **Dependent Variables: -** were a variable which represents the output or effect, or is tested to see if it is the effect. The following were independent variables: -
   - Fresh concrete properties like workability
   - Concrete compressive strength
   - Modulus of elasticity properties of the concrete in strain-stress
3) **Constants: -** were variables which are not changing throughout the experiment once it has been assigned a value. The main constant variables in this paper were:
   - Source of teff straw from local farm (unprocessed)
   - Source of water (tap water from water supply pipe)
   - Grade of concrete
   - The volume of fine and coarse aggregate
   - Mixing and casting process

3.3. Materials and Physical Properties of Materials

Parent aggregate making materials were need to be standardized because of the strength and quality of the concrete are directly related and depend on physical properties, mechanical properties and chemical composition of the concrete making ingredients. The physical tests conducted for both fine and coarse aggregates are discussed in the following sessions.

3.3.1. Cement

Cement as it is one of important concrete material need attention of checking on its required quality and type in the production of concrete. Different sources of Cement may differ with cement properties which in turn will influence properties of concrete mix. Portland Pozzolana cement was designed for general use of structural construction work at different places. From locally produced cement Dangote Portland Pozzolana CEM I-32.5R grade cement has been used in this specific study. For both fine and coarse aggregates and ingredients, the physical characteristics of the aggregates have been done to ensure its quality.

3.3.2. Coarse Aggregate

In Portland cement concrete, 60% to 75% of the volume and 79% to 80% of the weight are made up of aggregates. The aggregates act as a load carrying material and fill the space to reduce the amount of cement paste needed in the mix. For this study crushed aggregate from the basaltic rock was used. ASTM C127 for specific gravity and absorption capacity, ASTM C566 for moisture content, and ASTM C136 for sieve analysis have been used.

To meet Ethiopian standard requirements the basaltic crushed rock aggregate with the maximum size of 19 mm and blending other particle sizes were done to fulfill the gradation range, specific gravity, water absorption, moisture content and unit weight of the aggregates.

I. Sieve analysis

Sieve analysis was for the determination of the particle size distribution of aggregates using a series of square or round openings sieves starting with the largest opening at the top. According to the Ethiopian standard coarse aggregates are those between 75mm and 4.75mm in size. Samples were prepared for particle size distribution in such a way that crushed basalt stones with 19 mm nominal maximum sizes were blended to keep graduation requirements within the range specified on Ethiopian Standard for grading coarse aggregates [30].

The fineness modulus for this coarse aggregate sample was found to be 3.92% which is within the specification [31]. Figure 2 below shows the gradation curve for coarse aggregate used in the research in comparison to the minimum and maximum quantities of coarse aggregates on each series of sieves specified in the Ethiopian Standard (ES C.D3.20). The detailed graduation test for coarse aggregates is given in Appendix C (C1) of this research.

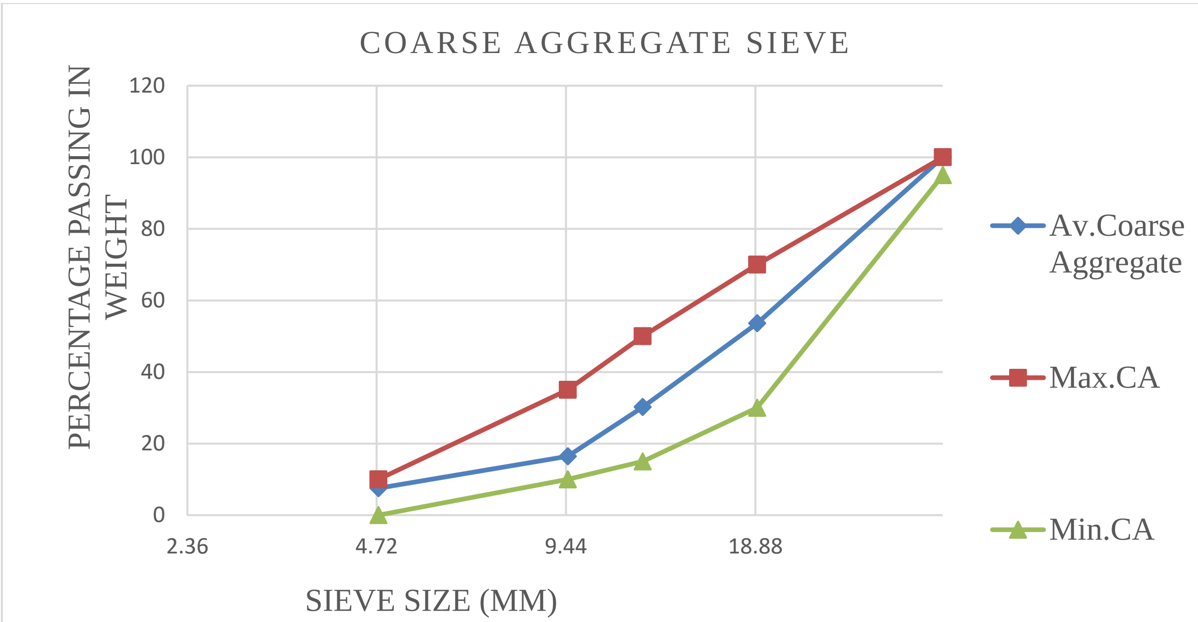

Figure 2. Gradation Curve for Coarse Aggregate.

Specific gravity is the ratio of the density of a substance to the density of a reference substance, usually water; equivalency is the ratio of the mass of a substance to the mass of water for the same given volume. Absorption is the process by which water is drawn into and tends to fill the permeable pores in a porous solid body.

An approximate coarse aggregate sample of 5 kg was acquired, by using quartering from the mass sample. All aggregate materials passing No.4 (4.75mm) sieve were rejected.

Specific gravity test results:

A = 1496.3 gm Where: A = weight of oven-dry sample in air, [g]

B = 1510.3 gm B = weight of saturated-surface-dry sample in air, [g] and

C = 985.4 gm C = weight of saturated sample in water, [gm]

Calculation:

Bulk Specific Gravity

Bulk. sp.gr. = $\frac{A}{B-C}$

Bulk sp.gr = $\frac{1496.3}{1510.3-985.4} = 2.85$

Bulk Specific Gravity (Saturated - Surface -Dry basis):

Bulk sp. gr (SSD basis) = $\frac{B}{B-C}$

Bulk sp. gr (SSD basis) = $\frac{1510.3}{1510.3-985.4} = 2.87$

Apparent Specific Gravity:

Apparent sp. gr = $\frac{A}{A-C}$

Apparent sp. gr =$\frac{1496.3}{1496.3-985.4} = 2.92$

Absorption Capacity:

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

= $\frac{1510.3-1496.3}{1510.3} * 100 = 0.93\%$

Table 4. Specific Gravities and Absorption Capacity of Coarse Aggregate.

	Bulk specific gravity	Bulk specific gravity (SSD bases)	Apparent specific gravity	Absorption capacity
Calculations	$\frac{A}{B-C}$	$\frac{B}{B-C}$	$\frac{A}{A-C}$	$\frac{B-A}{A} * 100$
Results	2.85	2.87	2.92	0.93%

II. The moisture content of coarse aggregates

In the design mix workability and water-cement ratio are affected by the moisture content of the coarse aggregate sample. Water-cement ratio in a mix design based on the assumption that aggregates were inert (neither absorb nor give water to the mixture) and hence aggregates from different sources do not comply with this assumption of the Water-cement ratio.

To know moisture content, a 1 kg coarse aggregate sample was weighted and oven-dried for about 24hrs at a temperature of 105C˚-110C˚. The sample was then removed from the oven and placed on a desiccator for about an hour in order to cool without absorbing water from the atmosphere. The average of two samples were then weighed (oven-dry weight). The moisture content of the coarse aggregate,

Weight of sample 1, (A) = 1 kg = 1000 gm

Weight of oven dry sample 1, (B) = 997.9 gm

Moisture content 1, (w %) = $\frac{A-B}{A} * 100 = \frac{1000-997.9}{1000} * 100 = 0.21\ \%$

Moisture content 2, (w %) = 0.229%

Average moisture content = (0.21%+0.229%)/2 = 0.22%

Average moisture content calculated to be 0.22%. Detailed moisture content determinations for coarse aggregates are discussed in Appendix C (C1) of this paper.

III. Unit weight of coarse aggregates:

The unit weight measures the volume that the graded aggregate occupy in concrete and includes both the solid aggregate particles and the voids between them.

The unit weight was simply measured by filling a container of known volume and weighing it. Oven-dried coarse aggregate samples were used in this specific test. In determining the unit weight of coarse aggregate, the Roding procedure was followed where it is applicable to the aggregates to the aggregates of 19 mm maximum size. Normal crushed rocks and gravels have a bulk unit weight of 1520-1860 kg/m^3 and produce normal weight concrete.

Table 5. Unit Weight Determination for Coarse Aggregate.

	Wt.of container (kg)	Wt.of sample & container (kg)	Inside dia. of container ,d (mm)	Inside height of container, h (mm)	Volume of container (m^3)	Unit wt.of coarse aggregate(kg/m^3)
Calculation	-	-	-	-	$V= \Pi d^2/4*h$	(12-6.3)/0.0033511
Result	6.3	12	154	180	0.0033511	1700.93

3.3.3. Fine Aggregate Test

The fine aggregate used was river sand obtained from river sand quarry. It is free of harmful materials. Laboratory tests were carried out to check the quality of the sand before it was taken to mix proportioning as ASTM standard documents. For specific gravity and absorption capacity ASTM C128, for fineness modulus ASTM C136 and for silt content and moisture content ASTM C566 specification and standards were considered.

I. Silt content

The distinction between silt & clay cant is based on particle size because both are microscopic having sizes finer than No. 200 (0.075) sieve and hence the significant physical properties of the two materials are related only indirectly to the size of particles. The objective of this test was to determine these fine particle contents from the mass sand sample.

Silt content test results:

A = 12 ml Where: A= amount of silt deposited above the sand

B = 310 ml B= amount of clean sand

Calculation: Silt content (%) = A/B*100

Silt content (%) = 12/310*100 =3.87% < 6%....... OK!

According to the Ethiopian standard, if the silt content of the sand is more than 6% it is recommended either to wash or to reject the sand. The sand samples in this specific study were used without washing since silt content is less than 6%.

II. Sieve analysis

Fine aggregates (FA) are those between 9.50 mm and 150 mm in size. Samples were prepared for particle size distribution in such a way that river sand with 4.75 mm nominal maximum sizes was prepared in accordance with the gradation requirement specified in the Ethiopian standard for the grading of fine aggregates. The fineness modulus for this fine aggregate sample came to be 2.8% which is within specification range of ACI [31]. The sand sample used in this specific research was tested to have a particle size distribution within the range of the Ethiopian Standard for grading of fine aggregate. Thus, it satisfies the gradation requirement.

A detailed gradation test results for fine aggregates in comparison with the requirements set in Ethiopian Standard for grading of fine aggregates (ES C.D3.201) using ranges of percentage passing through each sieve openings were presented by Appendix C (C2) of this paper. Figure 3 below shows the gradation curve for fine aggregate used in the research on a series of sieves specified in the Ethiopian standard.

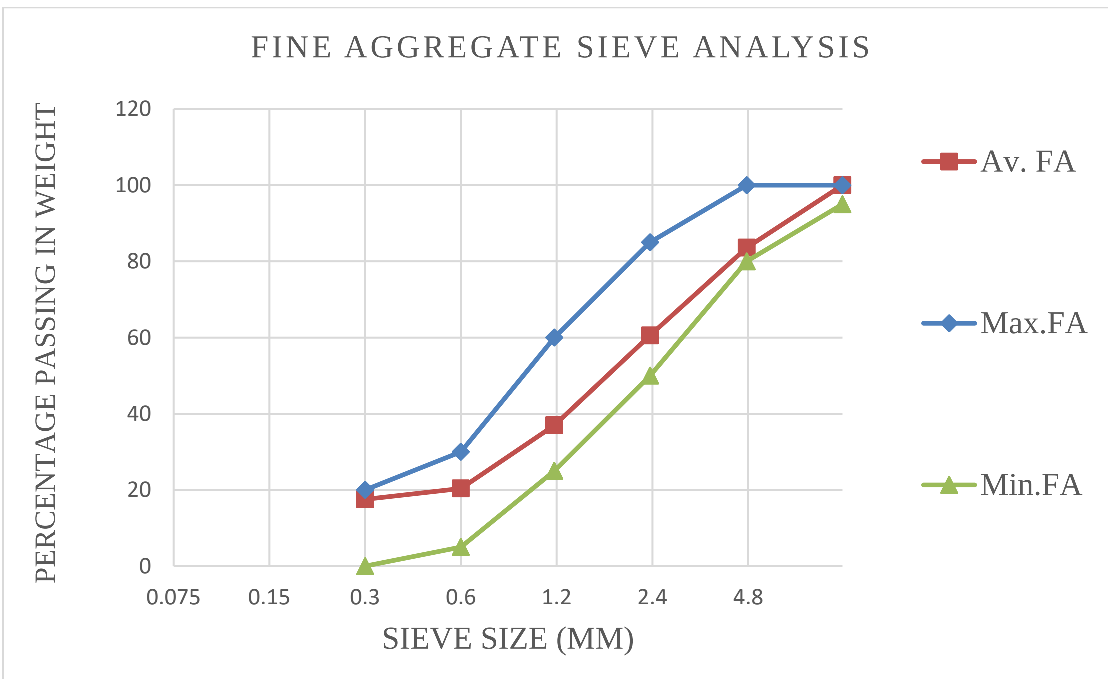

Figure 3. Gradation Curve for Fine Aggregate.

a) Specific gravity and absorption capacity

The objective of this test was to determine the bulk and apparent specific gravity, and absorption capacity of the fine aggregates.

Approximately 500gm of a fine aggregate sample from the availed mass of the total was taken by using a method of sample splitter. Sample tests were prepared and the procedures were followed in accordance with the guide of the construction materials laboratory manual.

Measured quantities:

Weight of the sample = 500gm

W = 323.21gm   Where, W= weight of pycnometer [gm]

V = 989.82 ml   V= volume of flask/container

Va = 675.76ml   Va= Volume of water added to pycnometer [cm3]

A = 479.84 gm   A = weight of oven dry sample in air [gm]

Calculation:

B = 0.9976V+W

= 0.9976*(989.82) +323.21

= **1279.72 gm**

C = 0.9976Va+500+W (Volume conversion factor = 0.9976)

= 0.9976*(675.76) + 500+323.21

= **1497.35 gm**

Where, C = weight of pycnometer filled with sample plus water, [gm]   B = weight of flask filled with water, [gm]

Table 6 shown below summarizes the test results for bulk specific gravity, bulk specific gravity (SSD bases), apparent specific gravity and absorption capacity of fine aggregates.

Table 6. Specific Gravities and Absorption Capacity of Fine Aggregate.

	Bulk specific gravity	Bulk specific gravity (SSD basis)	Apparent specific gravity	Absorption capacity
Calculations	$\frac{A}{C-B}$	$\frac{500}{C-B}$	$\frac{A}{B+A-C}$	$\frac{500-A}{A} * 100$
Results	2.19	2.29	1.83	4.2 %

III. Moisture content

To determine the moisture content, the 500gm fine aggregate sample was weighed and oven dried for about 24 hrs to remove moisture contained in the sample with a temperature of 105 C˚-110 C˚. The sample was then removed from the oven and placed on a desiccator for about an hour in order to cool without absorbing water from the atmosphere. The sample was then weighed (oven-dry weight). The moisture content of the fine aggregate in this specific research was calculated to be 1.16%. A detailed moisture content determination for fine aggregates is discussed in Appendix C (C2) of this research.

3.3.4. Teff straw Fiber.

Teff straw used as additive material in this study was collected from local community's farm and it was washed with water in order to remove any debris and cattle dung by dipping collected Teff straws in water for 15 – 20 minutes. The purpose of dipping was to remove the dust from the surface of the straw. After that, straws were air-dried until its moisture was well dried, considering the water observation capacity of teff straw and chopped to satisfy the required straw length as per aspect ratio designed to be added in concrete mix with sand, cement and stone in dry state and well mixed until the teff straw gets distributed uniformly.

Figure 4. a) Hand Chopping Collected TS b) Air-dried ready TS to mix.

The straw was also cut into pieces to produce in accordance with the standard required aspect ratio, length to diameter of fiber. In this specific the aspect ratio were examined to have a length and diameter in the ranges of (40-60) mm and (0.8-1.2) mm after measuring a representative sample with the help of a caliper. Therefore, the aspect ratio varies from 30-100 accordingly. Teff straw fiber was chopped to get 50 aspect ratio sizes which was in the range.

3.3.5. Water

The quality of water was important because contaminants can adversely affect the strength of concrete. Water used for producing and curing concrete should be reasonably clean and free from deleterious substances such as oil, acid, alkali, salt, sugar, silt, organic matter and other elements which are detrimental to the concrete. Hence potable tap water was used in this study for mixing and curing.

3.4. Mixing and Curing

A. Mixing

Mixing of concrete has been done in the laboratory either with hand or machine based on the ASTM C192 standard. Hand mixing of concrete was used because the machine was stop working. The mixing time of freshly mixed concrete takes about 8 minutes and a half seconds under room temperature. Concrete ingredients were tested, supplied separately and mixed using hand until the concrete get uniform mix.
Cube samples of size 150mm, cylindrical samples of size 150mm diameter and 300mm height and prismatic beam samples of size 100mm * 100mm * 500mm for testing compressive strength, tensile strength, and flexural strength; respectively, were cast.

Figure 5. Greased Molds, Mixed and Casted Sample.

Mix Proportions

The main aim of mix proportioning was to determine the optimum combination of concrete ingredients that can satisfy the performance requirement under a particular condition. Mass of ingredients per unit volume has been the usual concert mix proportion measurements.

Proportioning of concrete by absolute volume method involves calculating the volume of each ingredient and its contributions to making 1m^3 of concrete. Volumes were subsequently converted to design weights. These conversions to weights were accomplished by taking the known volumes of ingredients and multiplying by the specific gravity of ingredients and again multiplying by the density of water.

In this specific study, mix design of teff fiber reinforced concrete with determined ratios of cement, sand, water, coarse aggregate, and teff fiber were proportioned for C25 concrete grade based on the department of environment mix design method. The completed mix with the DOE mix design procedure is shown in Appendix A of this thesis. The wet density of 1 m^3 of concrete from the DOE mix design method was determined to be 2400 kg/m^3. Table 7. Below teff fiber by weight of concrete namely 0.0%, 0.15%, 0.25%, and 0.35%.

Table 7. Quantities of Mixed Materials in kg for 1 m^3 of Concrete.

Mix code	Teff Straw (%)	W/C ratio	For 1 m^3 of concrete				
			Cement(kg)	Water(kg)	Sand(kg)	Coarse agg.(kg)	Teff fiber (kg)
M0	0.00%	0.5	350	181	678	1133	0.00
M1	0.15%	0.5	350	181	678	1133	3.27
M2	0.25%	0.5	350	181	678	1133	5.45
M3	0.35%	0.5	350	181	678	1133	7.63

B. Curing

According to ASTM C 192/C 192/M, after the casted specimens were de-molded 24hrs of casting, cured with ponding till respective dates of testing. Curing was designed primarily to keep concrete moist, by preventing loss of moisture from the concrete during which it is gaining its strength.

Figure 6. Cube, Cylindrical and Prism Sample in Curing Bath.

3.5. Testing Procedure

In this experimental study, Testing was for both fresh concrete test and hardened concrete test. The most important experiment which gives an idea about all characteristics of concrete is that of hardened concrete tests like compressive strength tests. Test for compressive strength can carried out either on cube or cylinder specimens. Various standard codes recommend a concrete cylinder or concrete cube as the standard specimen for the test. ASTM C39/C39M provides a standard test method for compressive strength of cylindrical concrete specimens, for cube test two types of specimens either cubes of 150mm×150mm×150mm or 100mm×100mm×100mm depending upon the size of aggregate is used. In this specific study cubes of 150mm*150mm*150mm sizes were preferred due to the availability of mold types in the laboratory. These specimens were tested with a compression testing machine after 7 days curing and 28 days curing. The load was applied gradually at the rate of 140 kg/cm^2 per minute until the specimens failed. Recorded peak load divided by the loaded surface area of specimen gives the compressive strength of concrete.

Flexural strength was one measure of the tensile strength of concrete. It is a measure of an amount of stress or force that a beam or slab can withstand from bending failures. The flexural strength was expressed as Modulus of Rupture in (Mpa) and determined by standard test methods ASTM C 78 (third-point loading) or ASTM C293 (center-point loading). Beam samples having 100mm×100mm×500mm sizes were tested after 7 days and 28 days of curing according to ASTM C 78 (third-point loading) standard test methods in this specific thesis.

Splitting tensile strength tests on the concrete cylinder was a method to determine the tensile strength of concrete. The concrete is very weak in tension due to its brittle nature and is not expected to resist the direct tension. The concrete develops cracks when subjected to tensile forces. Thus, it was necessary to determine the tensile strength of concrete by finding the load at which the concrete members may crack. Split tensile strength of cylindrical samples having 300 mm height and 150 mm diameter were tested after 7 days or 28 days of curing in accordance with ASTM C496 standard testing methods.

3.5.1. Testing of Fresh Concrete

Slump test in accordance with the standard ASTM C995-94 was performed for each mix in the fresh state. The TS fiber reinforced mixes gave slump test results varying from zero to a few centimeters; however the mixes responded well to mechanical vibration and placed and compacted without much effort.

Slump cone tests were carried out to obtain the workability and consistency of fresh concrete. The obtained uniform distribution of the fibers in the concrete and the ability of being successfully casted make the fiber reinforcement efficient. Each individual fiber needs to be coated with cement to give any benefit in the concrete. Standard users of fiber reinforced concrete indicated that adding more fibers in the concrete, particularly a really small diameter, results in greater negative impact on workability and the requirement for mix design changes. The slump changed because of the different types of fibers content and form. The lower slump result is the effect of addition of fibers which form a network structure in concrete thus restrains mix from segregation and movement. As results of high content and large area of fibers, fibers were certain to absorb more concrete paste wrap around and the increased viscosity of combination mix the slump reduction.

3.5.2. Testing of Hardened Concrete

A. Compressive Strength.

Compressive strength tests were conducted after 7 and 28 days of curing and drying periods. Concrete strength tests at different time rates of submersion were conducted after 28 days of curing and drying periods. The compressive strength test results were dependent on concrete material quality and proportion, concrete mixing methods and curing period. In this specific experiment coarse aggregate, fine aggregate, cement and teff straw as concrete material are dry mixed for each mix design and a fixed amount of water is added gradually to get a uniform mix. After fresh concrete tests taken the concrete casted in greased molds and 25 blows compacted in three layers.

Figure 7. Casting and Testing for Compression Test.

The dial gauge was fixed with the equipment and change in height (ΔH) was recorded for elastic (strain-stress) properties analysis which using the original height of which is 150 mm to get the strain properties and load at each interval per loaded surface of the cube in order to get the stress properties concrete with an addition of teff straw and without teff straw for comparison of the property.

$$\text{Strain} = \frac{\Delta H}{H} \qquad \text{Stress} = \frac{P}{A}$$

Where, ΔH = change in height of cube. H = original height (150mm). P = load A = loaded area.

B. Flexural strength.

Flexural strength was also a measure of tensile strength of concrete. For testing, total 16 beams of size 100×100 mm cross section having 500 mm length. The flexural strength specimen was tested under four point loading. The beam size was c/c (L) distance 400mm, width (b) of the specimen 100 mm and depth (d) of the specimen 100mm.

The flexural specimen ready for test was longitudinally marked into four spaces 50 mm from both edges and the effective span of beam 400 mm was divided into three. Then aligned two supports above and two supports below. Two specimens were tested at each age to obtain the flexural strength. Test failure line is shown in figure 8 below.

Figure 8. Position of flexural beam failure line.

C. Split Tensile

Dimension of cylindrical specimen with diameter (D) of 150 mm and length (L) of the specimen 300 mm was laterally adjust for test split tensile property of concrete with different percentage of teff straw and without (as control) addition of teff straw.

.

Figure 9. Concrete cylinder setup for split tensile test

3.6. **Modulus of Elasticity Property of**

It is elastic property that indicate the ability of the material to come back to its original position (size and shape) after releasing forces. The elasticity behavior is different for different materials by applying forces, the lattice of material changes its shape and size and goes back to its original positions after releasing force. There is less research work done in Ethiopia regarding the elasticity properties of concrete with addition of natural fiber like teff straw. The elastic deformations of concrete largely depend on its composition (especially the aggregates). Some of the literature reviewed in this paper was meant to show the factors that affect the elastic and plastic properties of concrete developing strain-stress behavior using teff straw as additional concrete material [32].

3.7. Validity and Reliability

To verify and confirm whether the experimental data within the range or not the author tries to analyze its variability of test results with statistical method. It's already presented in the next chapter under discussion subtopics. Convenient tools to be used for engineering research however, a further research with a large experimental database is needed to propose a more general strain model for confined concrete [33]. For the unconfined concrete test held in this specific research. Some sort of formulas used to validate comparing the output experimental result with the empirical formula.

The fourth point loading flexural tensile strength result was validated using.

$$\sigma = \frac{Mc}{I} = \frac{\frac{PL}{6} * \frac{D}{2}}{\frac{bd^3}{12}}$$

Where,

σ - Compressive strength, M – moment, I- moment of inertia and c – neutral distance

3.8. Methods of Data Analysis

Data is the information that is collected for the purposes of answering the research question. Statistics is a mathematical tool for quantitative analysis of data, and as such it serves as the means by which we extract useful information from data. In this research it was concerned with data that are generated via experimental measurement. Statistical analysis was used to summarize those observations by estimating the average, which provides an estimate of the true mean. Another important statistical calculation for summarizing the observations was the estimate of the variance, which quantifies the uncertainty in the measured variable. Sometimes we have measured two different things and we want to know whether there really is a difference between the two measured values. Analysis of variance was used to estimate the probability that the underlying phenomena were truly different. Finally, it has been measured one variable under a variety of conditions with regard to a second variable in the context of typical experimental measurements in the field of engineering [34]. Thus, the experimental data collected in this research was analyzed using mathematical quantitative statistical method and presented with tabulated and graphical method.

4. Results and Discussions

4.1. Results

Under these chapter the test result and discussions of compressive strength, split tensile strength and flexural strength and elastic properties of each test with an addition of teff straw and plain concrete is depicted.

Slump test and fresh concrete density tests were investigated. Among the fresh concrete properties for each present teff straw addition of concrete mixture (0.00%, 0.15%, 0.25% and 0.35%) by weight of concrete. Table 8 below shows slump and fresh concrete densities for each mix.

Table 8. Slump and Fresh Concrete Density Test Results.

Mix-code	Teff straw (%)	Slump (mm)	Fresh Concrete density (kg/m^3)
M_0	0.00%	50	2412.6
M_1	0.15%	40	2364.3
M_2	0.25%	30	2356.7
M_3	0.35%	25	2344.2

Slump results for mixes M_1, M_2 and M_3 in the table above were reduced by 20%, 40% and 50% respectively. Slump results of all the mixes presented in the above table comply with the slump range originally assumed in the mix design i.e. (20-50mm) and hence do not cause workability problems with the amount of teff straw fiber used in the experiment.

Fresh concrete density for mix M_1 (mix with 0.15% teff straw) was reduced by 2.00 %, mix M_2 (mix with 0.25% teff straw) reduced by 2.32% and mix M_3 (mix with 0.35% teff straw) was reduced by 2.84% compared to a reference plain concrete.

The balling effect during the mix happened due to high volume percentages of teff straw addition size and quality of coarse aggregate, water-cement ratio, and method of mixing. The balling effect in addition of teff straw to concrete occurred in mixes M_2 and M_3. Most additive concrete material balling occurs during the material addition process and this can be eliminated by care in the sequence and rate of material addition.

Even though the slump test reveals that all mixes are workable, the Volume percentage of teff straw, size, and quantity of coarse aggregates intensified balling tendencies. Friction between the additive material and aggregates controls the added material orientation and distribution.

4.1.1. Compressive Strength Tests Results

Three 150mm sized cube samples were tested for each percentage addition of teff straw fiber in this specific thesis. A correction factor is not used in the European standard and 100, 150 or 200mm cubes can be used without correction to the compressive strength obtained from the test when checking for strength class conformity. Typical failure loads and compressive strength of TFRC by the 28th day of 150mm cube samples are presented in Table 9 as shown below. Detailed test results of compressive strength at the age of 7th and 28th for teff fiber reinforced concrete are presented in Appendix C1 at the end of this thesis.

Table 9. 28th-Day Compressive Strength Test Results.

Mix-code	**Sample No.**	**The Failure load of 150mm cubes (KN)**	**Compressive Strength of 150mm cubes (MPa)**
	1	557.38	24.77
	2	742.14	32.98
	3	629.17	27.96
	Mean	**642.90**	**28.57**
	1	736.79	32.75
	2	762.86	33.90
	3	752.68	33.45
	Mean	**750.75**	**33.37**
	1	587.23	26.10
	2	515.64	22.92
	3	603.39	26.82
	Mean	**568.75**	**25.28**
	1	572.14	25.43
	2	609.42	27.09
	3	594.76	26.43
	Mean	**592.11**	**26.32**

4.1.2. Split Tensile Strength Test Results

Split tensile strength is carried out on a standard cylindrical specimen, tested on its side in diametric compression. In split tensile strength testing, four different percentage addition of teff straw fiber by weight of concrete namely; 0.00%, 0.15%, 0.25%, and 0.35% were undertaken. Three cylindrical samples were tested for each percentage addition of teff straw fiber. Typical failure loads the tensile strength of 28th day under tensile loading was presented in Table 10 as shown below. Detailed test results of split tensile strength at the age of 7th and 28th for teff straw as additional concrete material are presented in Appendix C2 at the end of this thesis document.

Table 10. 28th Day Split Tensile Strength Test Results.

Mix-code	**Sample No.**	**Failure load (KN)**	**Splitting Tensile Strength (Mpa)**
	1	147.98	2.54
	2	149.87	2.10
	3	149.11	2.31
	Mean	**148.98**	**2.11**
	1	156.49	2.21
	2	151.67	2.15
	3	162.59	2.30
	Mean	**156.92**	**2.22**
	1	135.46	1.92
	2	159.78	2.26
	3	148.69	2.10
	Mean	**147.98**	**2.09**
	1	162.12	2.29
	2	150.47	2.13
	3	135.94	1.92
	Mean	**149.51**	**2.12**

4.1.3. Flexural Strength Test Results

The flexural strength test gives another way of estimating the tensile strength of concrete. During pure bending, the member resisting the action is subjected to internal stresses (shear, tensile and compressive). For a bending force applied downward for a member simply supported at its two ends, fibers above the neutral axis are generally subjected to compressive stress and those below the neutral axis undergo tensile stresses. For this load and support system, portions near the supports are subjected to relatively higher shear stresses than tensile stresses. For the sake of testing two prismatic samples each for percentage addition of teff straw fiber by weight of concrete namely; 0.00%, 0.15%, 0.25%, and 0.35% were tested with third-point loading in accordance with ASTM C78 standard. Typical failure loads and bending strength of 28th day TFRC samples under third-point loading are presented in Table 11 as shown below. Detailed test results of flexural strength at the age of 7th and 28th for teff fiber reinforced concrete are presented in Appendix C3 at the end of this thesis.

Table 11. 28th Day Flexural Strength Test Results

Mix-code	**Sample No.**	**Failure load (KN)**	**Bending Strength (Mpa)**
	1	9.48	4.74
	2	8.66	4.33
	Mean	**9.07**	**4.54**
	1	9.20	4.60
	2	12.46	6.23
	Mean	**10.83**	**5.42**
	1	8.14	4.07
	2	10.79	5.40
	Mean	**9.47**	**4.73**
	1	9.40	4.70
	2	8.86	4.43
	Mean	**9.13**	**4.57**

4.1.4. Results for Modulus of Elasticity

Modulus of elasticity for each mix with an addition of teff straw was calculated from the secant slop of cube strain-stress graph to be compared with the control concrete modulus of elasticity.

Table 12. Modulus of Elasticity for Cube Test Results.

Percentage of TS (%)	0.00%	0.15%	0.25%	0.35%
Max. Stress (Mpa)	28.57	33.37	25.28	26.32
Cube Ec. (Mpa)	333612.0	399794.0	314813.0	330295.0

The elastic modulus found from the stress-strain graph using secant line.

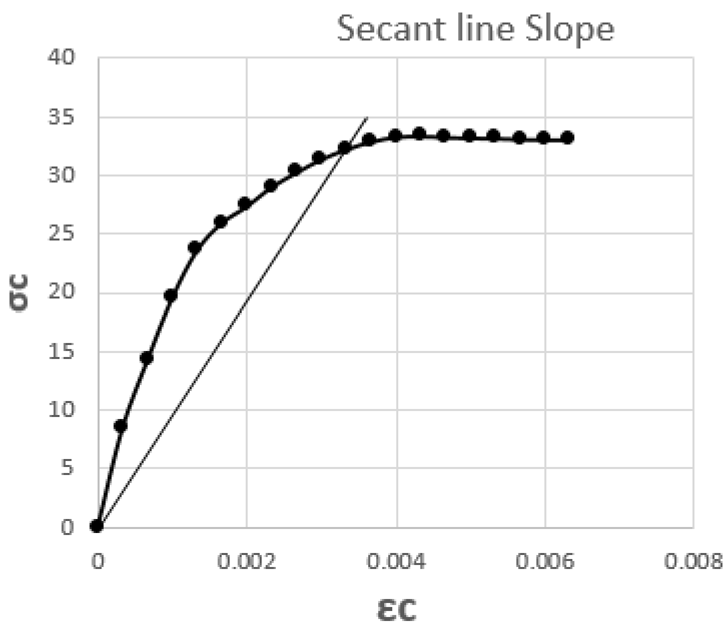

Figure 10.Secant line of stress-strain graph.

4.1.5. Strain-Stress of Cube Concrete Results

Strain-stress result of 150mm×150mm×150mm cube concrete was recorded using dial gauge with 0.05mm change in depth of longitudinal cube sample while compressive strength testing was going on.

At each change in longitudinal depth of 0.005mm, the load reading was recorded in interval to get stain-stress of concrete properties for each addition of teff straw mix proportion by weight of concrete (0.00%, 0.15%, 0.25% and 0.35%) before and after failure load reach. Then the strain-stress properties of control of concrete without an addition of TS was compared with the standard ES EN1992-2015 as shown below.

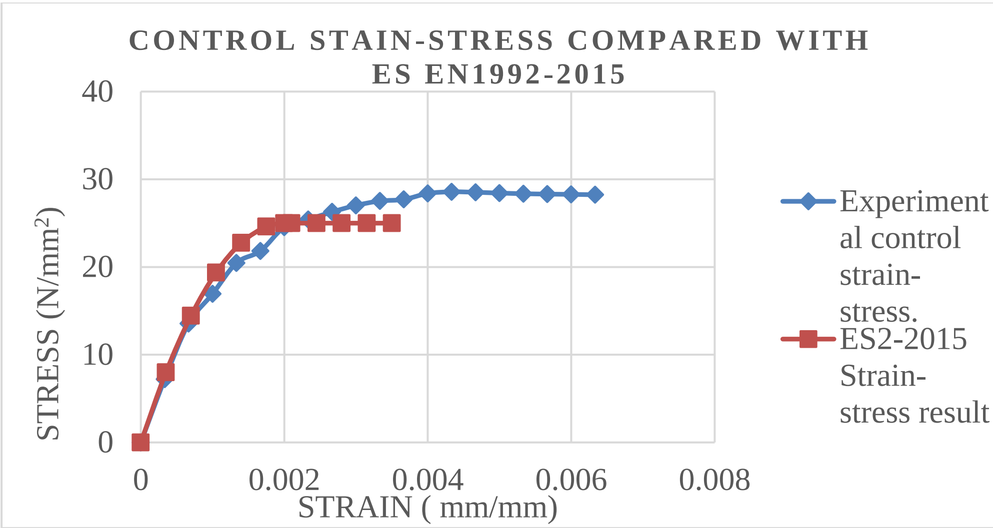

Figure 11. Stress-Strain of Control Test Compared with ES EN1992-2015.

For the other teff straw addition proportion the strain-stress was compared with the control experimental test related with ES EN1992-2015 and showed below.

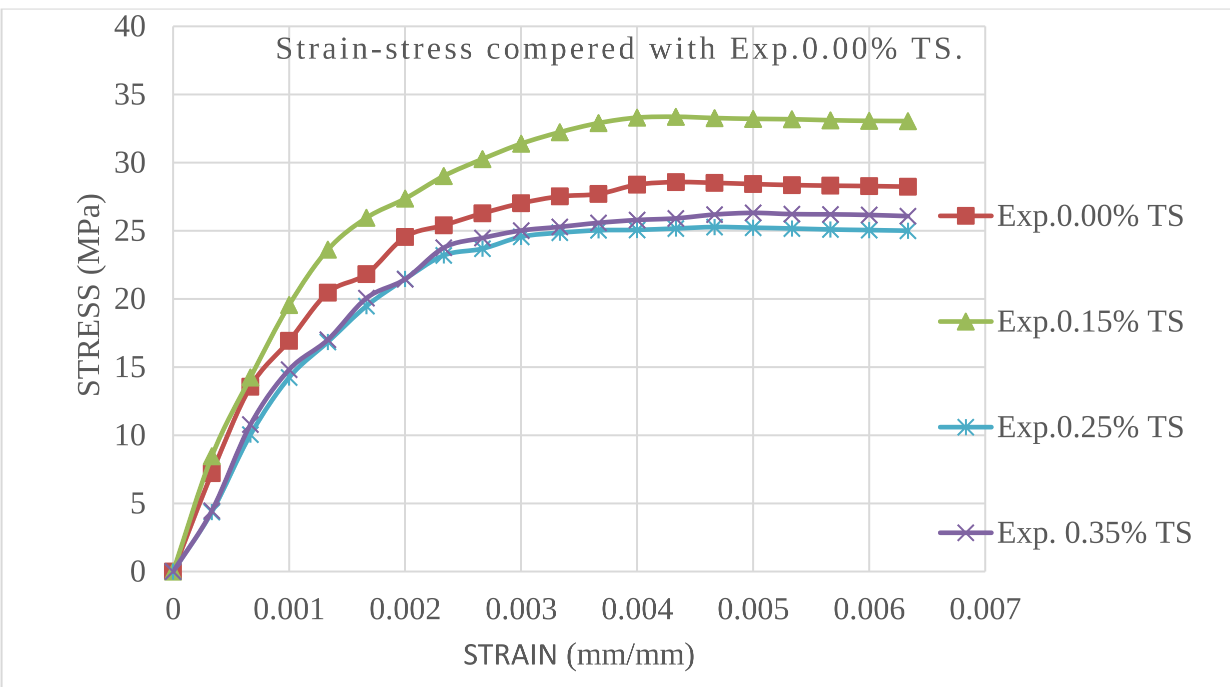

Figure 12. Stress-Strain Test with TS Compared with Control Rest.

4.2. Discussions

4.2.1. Variability of Test Results

A strength test result is defined as the average strength of all specimens of the same age, fabricated from a sample taken from a single batch of concrete. A strength test cannot be based on only one test specimen; a minimum of two test samples are required for each test. Testing two or three samples preserves the confidence level of the average strength.

Concrete tests for strength are typically treated as if they fall into a distribution pattern similar to the normal frequency distribution curve. As variation in strength results increases, the spread in the data increases and the normal distribution curve becomes lower and wider.

The normal distribution can be fully defined mathematically by statistical parameters like mean, standard deviation and coefficient of variation.

Mean: is the average strength test results.

Standard deviation: is the most generally recognized measure of the dispersion of the individual test data from their average.

Coefficient of variation: the sample standard deviation expressed as a percentage of the average strength is called the coefficient of variation.

Table 13 below shows values of Mean, Standard deviation and Coefficient of variation calculated for a set of cubical specimens cast for the compressive strength test.

Table 13. Statistical Values of Parameters in Compressive Strength Test.

Mixcode	Sample No.	150mm cube comp. strength (Mpa)	Mean comp. strength (Mpa)	Standard deviation (s)	Coefficient of variation (v) (%)
	1	24.77			
	2	32.98			
	3	27.96			
	1	32.75			
	2	33.90			
	3	33.45			

M_2	1	26.10	25.28	1.69	6.70
	2	22.92			
	3	26.82			
	1	25.43			
	2	27.09			
	3	26.43			

Table 14 below shows values of Mean, Standard deviation and Coefficient of variation calculated for a set of cylindrical specimens cast for the split tensile strength test.

Table 14. Statistical Values of Parameters in Split Tensile Test.

Mix code	**Sample No.**	**Split tensile strength (MPa)**	**Mean strength (MPa)**	**Standard deviation (S)**	**Coefficient of variation (V) (%)**
	1	2.09			
	2	2.121			
	3	2.11			
	1	2.21			
	2	2.15			
	3	2.3			
	1	1.92			
	2	2.26			
	3	2.1			
	1	2.29			
	2	2.13			
	3	1.92			

Table 15 below shows values of Mean, Standard deviation and Coefficient of variation calculated for a set of prismatic (beam) specimens cast for the flexural strength test.

Table 15. Statistical Values of Parameters in Flexural Strength Test.

`	Sample No.	Flexural strength (MPa)	Mean strength (Mpa)	Standard deviation (S)	Coefficient of variation (V) (%)
	1	4.74			
	2	4.33			
	1	4.60			
	2	6.24			
	1	4.07			
	2	5.40			
	1	4.7			
	2	4.43			

A single strength test result of a concrete mixture, however, does not provide sufficient data for statistical analysis. As with any statistical estimator, the confidence in the estimate is a function of the number of test results, According to ACI 214R-02 within-test, the standard deviation is estimated from the average range of at least 10, and preferably more, strength test results of a concrete mixture tested at the same age. Even though within test variability requires more data, it is desired to check the variations of strength test results with the help of statistical parameters and hence analysis with the help of coefficient of variations using two beams, three cubes and three cylinders for each mix were made [35].

From the calculated results of statistical parameters, especially, coefficient of variations presented in the above tables (Table 12, Table 13 and Table 14) are within test variability ranges for strength test data, which are discussed below.

Within the test variability of compressive strength, tests are in an excellent range where the coefficient of variation is less than 2% for M_1 and very good for M_3. Within test variability of split tensile strength tests for mix M_0 lies in an excellent range (CoV < 2%) and very good for M_1, whereas within test variability lies in poor range (CoV > 6%) for M_2 and M_3. Within the test variability of flexural strength tests for mixes M_3 lies in an excellent range (CoV < 3%) and very good for M_0 while M_1 & M_2 are poor.

Most of the within test variability ranges are excellent and very good for most of the strength test results in this specific study. But some of the strength test results fail to comply with the requirement range [35]. This invariability (within test variability of poor range) occurs due to different reasons; some of these are lack of having similar sample molds, faulty test procedures like in the case of flexural strength testing, variations of ingredients due to techniques of batching, mixing and sampling and etc.

4.2.2. Discussion on Compressive Strength

The mean compressive strength of TFRC with 0.15% addition of teff straw fiber by weight of concrete has shown an increment of 17.08% compared to plain concrete. TFRC with 0.25% teff straw fiber has shown a compressive strength reduction of 11.51%. TFRC with 0.35% teff straw fiber has shown a compressive strength reduction of 7.87%. The mean failure loads with 0.15% increased by 16.78% while, 0.25% & 0.35% teff straw fiber were also decreased by 11.53% & 7.89% respectively, compared to the failure load of a plain concrete. The 28th day means compressive strength test results for various ratios of teff straw fiber addition by weight of concrete are compared with plain concrete as shown in figure 13 below.

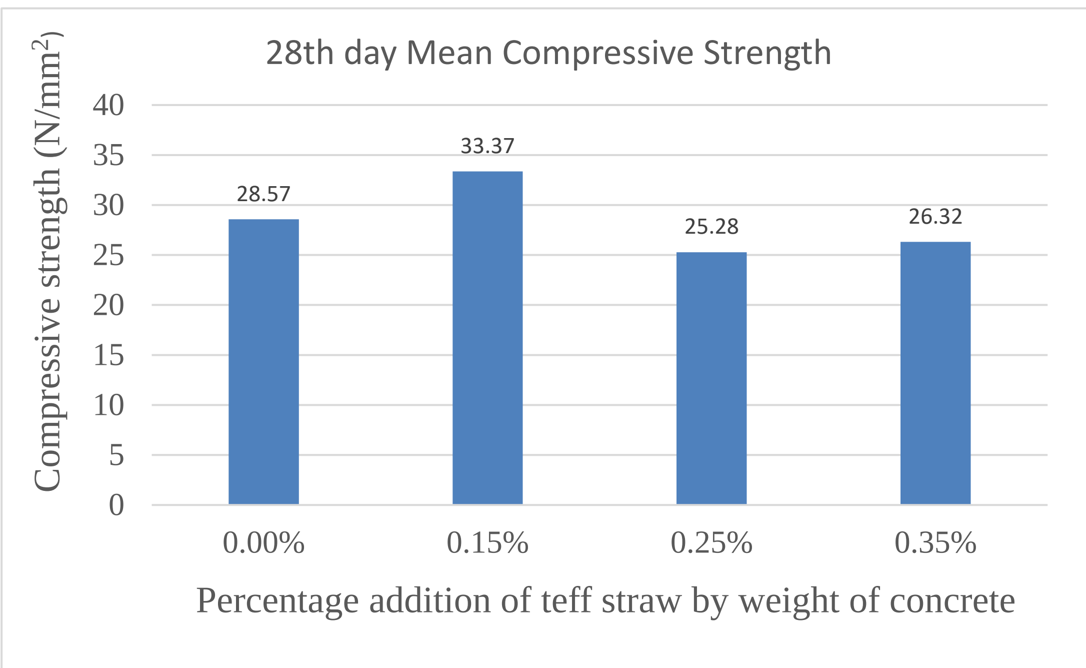

Figure 13. Compressive Strength Chart for Each Percentage of TS Addition.

4.2.3. Discussion on Splitting Tensile Strength.

Mean splitting tensile strength of TFRC with 0.15% and 0.35% addition of teff fiber by weight of concrete has shown an increment by 5.28% and 0.30% compared to plain concrete which was an improvement. But TFRC with 0.25% teff straw fiber has shown tensile strength 0.76% decrement. The mean failure loads with 0.15% and 0.35% teff straw fiber were also increased by 5.28% and 0.36%; respectively compared to the failure load of plain concrete. But the main failure loads with 0.25% teff straw fiber were reduced by 0.68% compared to plain concrete. The 28th day means splitting tensile strength test results for various ratios of teff straw fiber addition by weight of concrete were compared with plain concrete as shown in figure 14 below.

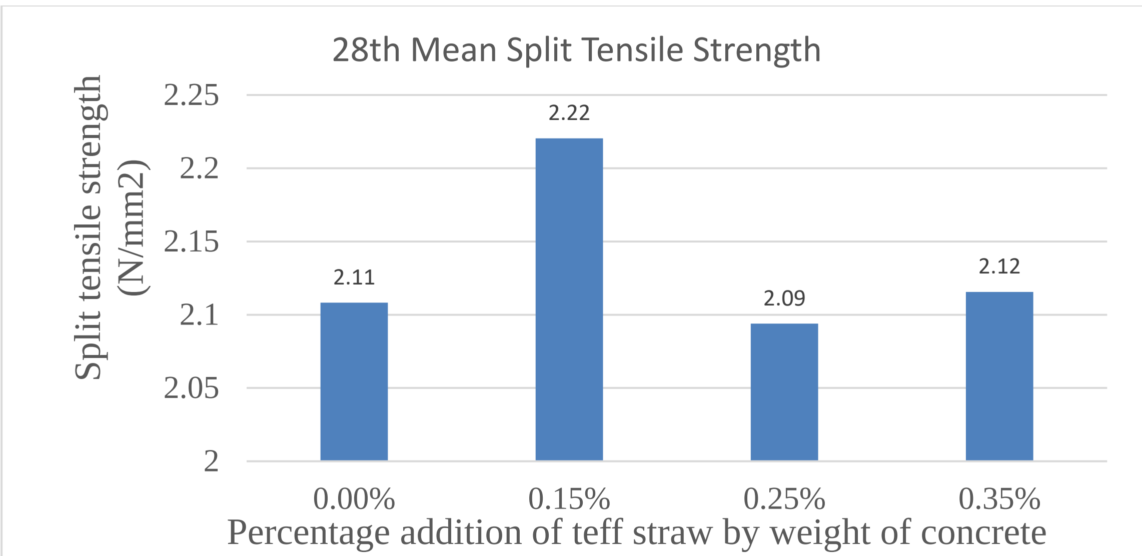

Figure 14. Split Tensile Strength Chart for Each Percentage of TS Fiber Addition.

4.2.4. Discussion on Flexural Strength.

The mean flexural strength of TFRC with 0.15%, 0.25% and 0.35% addition of teff straw fiber by weight of concrete has shown an increment by 19.38%, 4.19% and 0.66% respectively. The mean failure loads with 0.15%, 0.25% and 0.35% teff straw fiber were also shows an increment by 19.40%, 4.19%, and 0.66%; respectively, compared to the failure load of plain concrete. The 28th day means flexural strength test results for various ratios of teff straw fiber addition by weight of concrete were compared with plain concrete as shown in figure 15 below.

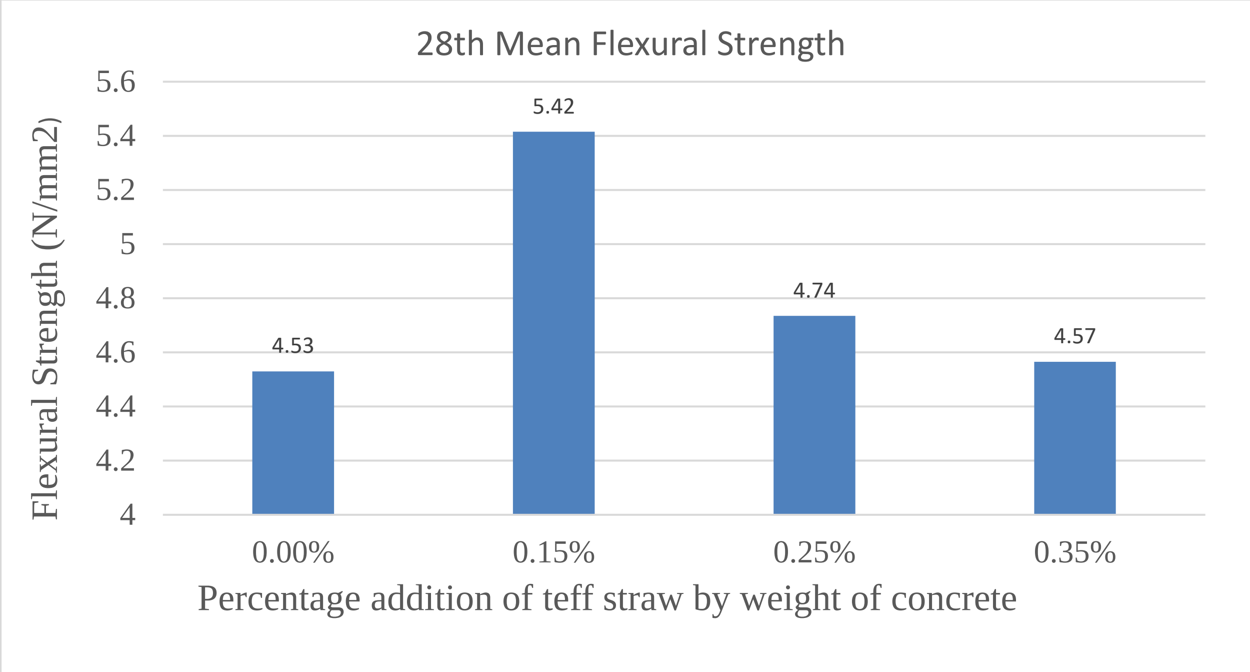

Figure 15. Flexural Strength Chart for Each Percentage of TS Addition.

Comparison between teff straw fiber reinforced concrete and reference plain concrete with regard to the strength parameters of hardened concrete; namely, compressive strength, split tensile strength and flexural strength are discussed above. The following paragraphs are general discussions and interrelations forwarded on the values of strength tests.

If the same material was subjected to only tensile forces, then all the fibers in the material are at the same stress and failure will initiate when the weakest fiber reaches its limiting tensile stress. Therefore, it is common for flexural strengths to be higher than tensile strengths.

For 0.35% teff straw fiber addition flexural strength of TFRC was reduced in contrary to the split tensile strength of TFRC with the same percentage of teff straw fiber addition. This contrary in strength variation between split tensile strength and flexural strength might have happened due to the following combination effect of factors; defect in materials and molds that affect testing procedures, inconsistent and non-uniform concrete mix and unevenly distribution of fibers. Results from the split cylinder tensile strength test (ASTM C 496) for FRC specimens are difficult to interpret after the first matrix cracking and should not be used beyond the first crack because of unknown stress distributions after the first crack. But, the flexural strength test of FRC specimens is interpreted after the first cracks are developed because of fibers acting toward cracks propagation.

4.2.5. Discussion on Cube Modulus of Elastic

Modulus of elasticity of the cube with different percentage of teff straw was determined and compared with control cube depending on the maximum compressive strength test and indicates improvement by 19.84% for M_1 (0.15%) teff straw addition. But, it is reduced by 5.63% and 0.99% for M_2 (0.25%) and M_3 (0.35%) respectively. This indicates that the modulus of elasticity of cube concrete with 0.15% addition of teff straw showed an improvement. While more addition of teff straw showed the reduction of modulus of elasticity.

4.2.6. Discussions on Stress-Strain Graph

The Stress-strain graph of cube control (M_0) was related to the standard of ES2-2015. Comparing for the other M_1, M_2 and M_3 with the strain-stress graph of control mix it showed the improvement for 0.15% addition of teff strew. The other graph for M2 and M3 the graph is below the control strain- stress graph.

5. Conclusion and Recommendations

5.1. Conclusions

Based on the laboratory investigations of both fresh concrete (slump test, fresh density) and hardened concrete conclusions are drawn and recommendations are forwarded on the effect of teff straw fiber addition in concrete.

Improvement of compressive strengths of concrete showed with 0.15% addition of teff straw fiber; by 17.08% whereas 0.25% & 0.35% addition of teff straw showed the reduction by 11.51% & 7.87%; respectively, A higher percentage addition of teff straw fiber has not improved the split tensile strength as in the case of 0.35%; which showed a reduced tensile strength result compared to a plain concrete.

Split tensile strength of a teff straw fiber reinforced concrete show increment of 5.28% and 0.30% by 28th day at 0.15% and 0.35% teff straw fiber addition which is improvement compared to plain concrete. The split tensile strength of TFRC with 0.25% teff straw fiber has reduced by 0.76% which is less compared to the plain concrete.

The 28th-day test results of TFRC incorporating 0.15%, 0.25% and 0.35% teff straw fiber showed flexural strength increment of standard prisms by 19.38%, 4.19%, and 0.66%; respectively, compared to the reference plain concrete.

The slump test of concrete mixes with 0.15%, 0.25% and 0.35%, teff straw fibers addition showed reduction by 20.00%, 40.00% and 50.00% respectively at a constant water-cement ratio compared to the reference plain concrete. The slump values for the three mixes are yet within the acceptable range and workable according to the assumption from the DOE mix design. Fresh concrete density for TFRC with 0.15%, 0.25% and 0.35% teff straw fiber showed reductions of 2.00%, 2.32% and 2.84% respectively, compared to the reference plain concrete. These reductions are not significant and due to the lesser specific gravity of the teff straw fiber used as a reinforcement.

From the test result of experiment on three different proportions studied under investigation of teff straw fiber additions by weight of concrete, 0.15% teff straw fiber addition indicates a maximum strength increment in all strength test results. Therefore 0.15% teff straw fiber addition is an optimum proportion for this specific research which results 17.08%,5.28% and 19.38% by 28th day which shows improvement compressive, split tensile and flexural strength tests held in the study compared to plain concrete.

5.2. Recommendations

- This research studied only on 0.00%, 0.15%, 0.25% and 0.35% of teff straw by weight of total concrete. So, further studies are required in different dosages of teff straw addition as concrete material on different properties of concrete to obtain the maximum strength.
- In this investigation C25 grade of concrete is tested further work can be carried out by testing higher grades of concrete i.e.C30, C40 etc.
- The other engineering properties of Teff straw like shear and Torsion property of the material need another study.
- Creep and shrinkage Teff straw fiber reinforced concrete for long term application can be studied.
- Durability and other concrete properties with and addition of teff straw need further study.
- Natural fiber reinforced concrete Vs micro-structural morphology of plain concrete can be studded.

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Appendix A: Mix Design

For this specific thesis, the C25 grade of concrete proportion was designed based on the DOE mix design manual. Since the aggregates were neither at SSD condition nor at OD condition in the field, it is necessary to adjust the aggregates' weight for the amount of water contained in the aggregate and absorption capacity. As proportioned with this specific mix design; weights of constituent materials are listed with Table 16. A. as shown below:

Table 16. A: Quantities of Materials used in Concrete Mix Design.

Materials	**Weight per 1m^3 of concrete**
Water	185 kg
Cement	350 kg
Coarse aggregate	1122.66 kg
Fine aggregate	676.5 kg

But in the actual condition, the aggregate is not in SSD condition. Therefore, predetermined moisture contents and absorption capacity of aggregates are:

Table 17. A: Moisture Content and Absorption Capacity of Aggregate.

Aggregates	**Moisture content**	**Absorption capacity**	**Net Result for adjustment**
Fine Aggregate	0.22%	1.36%	2.16%, Absorption
Coarse aggregate	1.16%	0.96%	0.20%, Moisture

Weight of coarse aggregate = 1122.66* (1+0.96/100) = **1133** kg

Weight of fine aggregate = 676.5* (1+0.22/100) = **678 kg**

Adjusted water content = 185 – (1133*0.96/100) + (678*0.22/100) = **181** kg

Lastly, the quantities have been used for the trial mix per 1m^3 of concrete are shown in Table 18. A. Below.

Table 18.A: Adjusted Quantities of Materials to be used in Concrete Mixing.

Materials	**Weight per 1 m^3 of concrete**
Water	**181 kg**
Cement	**350 kg**
Coarse aggregate	**1133 kg**
Fine aggregate	**678 Kg**

Appendix B: Test Results

B1: Compressive Strength Tests.

Mix code: M_0 (0.00% Teff straw Fiber)

Table 19.B: 7th & 28th-day Compressive Strength Test Results for 0.00% Teff Straw.

Test age (days)	SN	Dimensions (mm)			Area (mm^2)	Failure load (kN)	150mm cube comp. strength (MPa)
		L	B	D			σ = P/A
	1	150	150	150	22500	405.66	18.03
	2	150	150	150	22500	520.16	23.12
	3	150	150	150	22500	512.82	22.79
Mean							**21.31**
	1	150	150	150	22500	557.38	24.77
	2	150	150	150	22500	742.14	32.98
	3	150	150	150	22500	629.17	27.96
Mean							**28.57**

Mix code: M_1 (0.15% Teff straw Fiber)

Table 20. B: 7th & 28th-Day Compressive Strength Test Results for 0.15% Teff Straw.

Test age (days)	SN	Dimensions (mm)			Area (mm^2)	Failure load (KN)	150mm cube comp. strength (MPa)
		L	B	D			σ = P/A
	1	150	150	150	22500	487.22	21.65
	2	150	150	150	22500	561.21	24.94
	3	150	150	150	22500	523.42	23.26
Mean							**23.28**
	1	150	150	150	22500	736.79	32.75
	2	150	150	150	22500	762.86	33.90
	3	150	150	150	22500	752.68	33.45
Mean							**33.37**

Mix code: M_1 (0.25% Teff straw Fiber)

Table 21.B: 7th & 28th-Day Compressive Strength Test Results for 0.25% Teff Straw.

Test age (days)	SN	Dimensions (mm)			Area (mm^2)	Failure load (KN)	150mm cube comp. strength (MPa)
		L	B	D			σ = 2P/∏LD
	1	150	150	150	22500	384.3	17.08
	2	150	150	150	22500	352.7	15.68
	3	150	150	150	22500	369.6	16.43
Mean							**16.397**
	1	150	150	150	22500	587.23	26.10
	2	150	150	150	22500	515.64	22.92
	3	150	150	150	22500	603.39	26.82

Mean		25.28

Mix code: M_3 (0.35% Teff Straw Fiber)

Table 22.B: 7th & 28th-Day Compressive Strength Test Results for 0.35% Teff Straw.

Test age (days)	SN	Dimensions (mm)			Area (mm^2)	Failure load (KN)	150mm cube comp. strength (MPa)
		L	B	D			σ = 2P/∏LD
	1	150	150	150	22500	357.32	15.88
	2	150	150	150	22500	341.63	15.18
	3	150	150	150	22500	352.87	15.68
Mean							**15.58**
	1	150	150	150	22500	572.14	25.43
	2	150	150	150	22500	609.42	27.09
	3	150	150	150	22500	594.76	26.43
Mean							**26.32**

B2: Splitting Tensile Strength Tests.

Mix code: M_0 (0.00% Teff Straw Fiber)

Table 23.B: 7th & 28th Day Split Tensile Strength Test Results for 0.00% Teff Straw.

Test age (days)	Sample No.	Length (mm)	Diameter (mm)	Volume (mm3)	Failure load (KN)	Splitting tensile strength (MPa)
		L	D			σ = 2P/∏LD
	1	300	150	5301437.6	126.24	1.786
	2	300	150	5301437.6	119.51	1.692
	3	300	150	5301437.6	132.34	1.873

Mean						**1.784**
	1	300	150	5301437.6	147.98	2.09
	2	300	150	5301437.6	149.87	2.12
	3	300	150	5301437.6	149.11	2.11
Mean						**2.11**

Mix code: M_1 (0.15% Teff Straw Fiber)

Table 24.B: 7th & 28th Day Split Tensile Strength test Results for 0.15% Teff Straw.

Test age (days)	Sample No.	Length (mm)	Diameter (mm)	Volume (mm3)	Failure load (KN)	Splitting tensile strength (MPa)
		L	D			σ = 2P/∏LD
	1	300	150	5301437.6	115.22	1.630
	2	300	150	5301437.6	120.75	1.709
	3	300	150	5301437.6	110.30	1.561
Mean						**1.633**
	1	300	150	5301437.6	156.49	2.21
	2	300	150	5301437.6	151.67	2.15
	3	300	150	5301437.6	162.59	2.30
Mean						**2.22**

Mix code: M_1 (0.25% Teff Straw Fiber)

Table 25.B: 7th & 28th day Split Tensile Strength Test Results for 0.25% Teff Straw Fiber.

Test age (days)	Sample No.	Length (mm)	Diameter (mm)	Volume (mm3)	Failure load (KN)	Splitting tensile strength (MPa)
		L	D			σ = 2P/∏LD
	1	300	150	5301437.6	96.82	1.37
	2	300	150	5301437.6	119.87	1.70
	3	300	150	5301437.6	99.76	1.41

Mean						**1.493**
	1	300	150	5301437.6	135.46	1.92
	2	300	150	5301437.6	159.78	2.26
	3	300	150	5301437.6	148.69	2.10
Mean						**2.09**

Mix code: M_3 (0.35% Teff Straw Fiber)

Table 26.B: 7th & 28th Day Split Tensile Strength Test Results for 0.35% Teff Straw.

Test age (days)	Sample No.	Length (mm)	Diameter (mm)	Volume (mm3)	Failure load (KN)	Splitting tensile strength (MPa)
		L	D			σ = 2P/∏LD
	1	300	150	5301437.6	89.95	1.27
	2	300	150	5301437.6	94.54	1.34
	3	300	150	5301437.6	95.97	1.36
Mean						**1.32**
	1	300	150	5301437.6	162.12	2.29
	2	300	150	5301437.6	150.47	2.13
	3	300	150	5301437.6	135.94	1.92
Mean						**2.12**

B3: Flexural Strength Tests.

Mix code: M_0 (0.00% Teff Straw Fiber)

Table 27.B: 7th & 28th-Day Flexural Strength Test Results for 0.00% Teff Straw.

Test age (days)	Sample No.	Dimensions (mm)			Failure load (kN)	Failure distance from nearest support(mm)	Bending Strength (MPa)
		L	B	D	P	a ≥ 130	$\sigma = PL/bd^2$
	1	500	100	100	7.11	164	3.56
	2	500	100	100	6.50	169	3.25
	Mean						**3.40**
	1	500	100	100	9.48	168	4.74
	2	500	100	100	8.66	171	4.33
	Mean						**4.53**

Mix code: M_1 (0.15% Teff Straw Fiber)

Table 28.B: 7th & 28th-Day Flexural Strength Test Results for 0.15% Teff Straw Fiber.

Test age (days)	Sample no.	Dimensions (mm)			Failure load (kN)	Failure distance from nearest support (mm)	Bending Strength (MPa)
		L	B	D	P	a ≥130	$\sigma = PL/bd^2$
	1	500	100	100	10	150	3.78
	2	500	100	100	7.476	153	3.74
	Mean						**3.76**
	1	500	100	100	9.20	151	4.60
	2	500	100	100	12.46	149	6.23
	Mean						**5.42**

Mix code: M_3 (0.25% Teff Straw Fiber)

Table 29.B: 7th & 28th-Day Flexural strength test results for 0.25% Teff Straw.

Test age (days)	Sample no.	Dimensions (mm)			Failure load (kN)	Failure distance from nearest support(mm)	Bending Strength (MPa)
		L	B	D	P	$a \geq 130$	$\sigma = PL/bd^2$
	1	500	100	100	8.04	167	4.02
	2	500	100	100	7.692	164	3.85
	Mean						**3.93**
	1	500	100	100	8.14	152	4.07
	2	500	100	100	10.79	149	5.40
	Mean						**4.73**

Mix code: M_3 (0.35% Teff Straw Fiber)

Table 30.B: 7th & 28th-Day Flexural Strength Test Results for 0.35% Teff Straw.

Test age (days)	Sample no.	Dimensions (mm)			Failure load (kN)	Failure distance from nearest support(mm)	Bending Strength (MPa)
		L	B	D	P	$a \geq 130$	$\sigma = PL/bd^2$
	1	500	100	100	8.175	164	4.09
	2	500	100	100	7.826	169	3.91
	Mean						**7.20**
	1	500	100	100	9.40	151	4.70
	2	500	100	100	8.86	155	4.43
	Mean						**7.07**

B4: Modulus of Elasticity and strain-stress test.

Table 31. B: 28th Day Cube Modulus of Elasticity of Concrete Results

Percentage of TS (%)	0.00%	0.15%	0.25%	0.35%
Max. Stress (Mpa)	28.57	33.37	25.28	26.32
Cube Ec. (Mpa)	3336.12	3997.94	3148.13	3302.95

Cube Strain-stress determination.

Table 32 B. 28th-Day Cube 0.00% Stain-Stress of Concrete Results

P1	P2	P3	Pav.(KN)	Area (mm2)	ΔH (mm)	H(mm)	**ε = ΔH/H**	σ = (N/mm2)
0	0	0	0	22500	0	150	0	0
163	161	163	162.3333	22500	0.05	150	0.000333	7.21
298	321	296	305	22500	0.1	150	0.000667	13.56
378	381	384	381	22500	0.15	150	0.001	16.93
456	463	462	460.3333	22500	0.2	150	0.001333	20.46
487	495	491	491	22500	0.25	150	0.001667	21.82
553	556	548	552.3333	22500	0.3	150	0.002	24.55
575	568	572	571.6667	22500	0.35	150	0.002333	25.41
593	592	589	591.3333	22500	0.4	150	0.002667	26.28
610	618	596	608	22500	0.45	150	0.003	27.02
619	626	613	619.3333	22500	0.5	150	0.003333	27.53
625	631	614	623.3333	22500	0.55	150	0.003667	27.70
637	641	638	638.6667	22500	0.6	150	0.004	28.39
557.38	742.14	629.17	642.8967	22500	0.65	150	0.004333	28.57
640	643	642	641.6667	22500	0.7	150	0.004667	28.52

638	642	639	639.6667	22500	0.75	150	0.005	28.43
641	635	638	638	22500	0.8	150	0.005333	28.36
635	639	637	637	22500	0.85	150	0.005667	28.31
634	639	636	636.3333	22500	0.9	150	0.006	28.28
633	638	635	635.3333	22500	0.95	150	0.006333	28.24

Table 33.B. 28th-Day Cube 0.15% Strain-Stress of Concrete Results.

P1	P2	P3	Pav.(KN)	Area (mm2)	ΔH	H(mm)	**ε = ΔH/H**	σ = (N/mm2)
0	0	0	0	22500	0	150	0	0
183	197	191	190.3333	22500	0.05	150	0.000333	8.46
326	317	318	320.3333	22500	0.1	150	0.000667	14.24
450	436	434	440	22500	0.15	150	0.001	19.56
527	530	537	531.3333	22500	0.2	150	0.001333	23.61
585	589	578	584	22500	0.25	150	0.001667	25.96
610	623	614	615.6667	22500	0.3	150	0.002	27.36
652	659	648	653	22500	0.35	150	0.002333	29.02
684	681	678	681	22500	0.4	150	0.002667	30.27
709	698	712	706.3333	22500	0.45	150	0.003	31.39
727	729	720	725.3333	22500	0.5	150	0.003333	32.24
743	740	738	740.3333	22500	0.55	150	0.003667	32.90
750	752	746	749.3333	22500	0.6	150	0.004	33.30
736.79	762.86	752.68	750.7767	22500	0.65	150	0.004333	33.37
750	747	749	748.6667	22500	0.7	150	0.004667	33.27
746	747	749	747.3333	22500	0.75	150	0.005	33.21
749	745	746	746.6667	22500	0.8	150	0.005333	33.18
744	750	741	745	22500	0.85	150	0.005667	33.11
747	742	743	744	22500	0.9	150	0.006	33.07
743	748	740	743.6667	22500	0.95	150	0.006333	33.052

Table 34.B. 28th-Day Cube 0.25% Strain-Stress of Concrete Results.

P1	P2	P3	Pav. (KN)	Area (mm2)	ΔH	H(mm)	**ε = ΔH/H**	σ = (N/mm2)
0	0		0	22500	0	150	0	0
105	96	94	98.3333	22500	0.05	150	0.000333	4.37
229	231	218	226	22500	0.1	150	0.000667	10.04
321	328	312	320.3333	22500	0.15	150	0.001	14.24
387	382	368	379	22500	0.2	150	0.001333	16.84
449	438	428	438.3333	22500	0.25	150	0.001667	19.48
490	477	482	483	22500	0.3	150	0.002	21.47
517	528	521	522	22500	0.35	150	0.002333	23.20
533	537	529	533	22500	0.4	150	0.002667	23.69
556	564	538	552.6667	22500	0.45	150	0.003	24.56
556	553	569	559.3333	22500	0.5	150	0.003333	24.86
564	569	557	563.3333	22500	0.55	150	0.003667	25.04
563	561	568	564	22500	0.6	150	0.004	25.07
575	565	559	566.3333	22500	0.65	150	0.004333	25.18
587.23	515.64	603.39	568.7533	22500	0.7	150	0.004667	25.28
569	570	564	567.6667	22500	0.75	150	0.005	25.23
568	566	565	566.3333	22500	0.8	150	0.005333	25.17
562	569	563	564.6667	22500	0.85	150	0.005667	25.096
564	567	560	563.6667	22500	0.9	150	0.006	25.051
565	562	561	562.6667	22500	0.95	150	0.006333	25.0074

Table 35.B. 28th-Day .Cube Strain-Stress of Concrete Results.

P1	P2	P3	Pav.(KN)	Area (mm2)	ΔH	H (mm)	**ε = ΔH/H**	σ = (N/mm2)
		0	0	22500	0	150	0	0
95	113	93	100.3333	22500	0.05	150	0.000333	4.46

239	248	241	242.6667	22500	0.1	150	0.000667	10.79
335	338	327	333.3333	22500	0.15	150	0.001	14.81
381	379	388	382.6667	22500	0.2	150	0.001333	17.01
450	456	448	451.3333	22500	0.25	150	0.001667	20.06
491	476	481	482.6667	22500	0.3	150	0.002	21.45
535	527	542	534.6667	22500	0.35	150	0.002333	23.76
550	548	554	550.6667	22500	0.4	150	0.002667	24.47
561	566	562	563	22500	0.45	150	0.003	25.02
570	572	565	569	22500	0.5	150	0.003333	25.29
574	581	572	575.6667	22500	0.55	150	0.003667	25.58
583	582	576	580.3333	22500	0.6	150	0.004	25.79
586	588	575	583	22500	0.65	150	0.004333	25.91
590	593	585	589.3333	22500	0.7	150	0.004667	26.19
572.14	609.42	594.76	592.1067	22500	0.75	150	0.005	26.32
589	589	592	590	22500	0.8	150	0.005333	26.22222
591	590	588	589.6667	22500	0.85	150	0.005667	26.20741
587	590	589	588.6667	22500	0.9	150	0.006	26.16296
585	589	586	586.6667	22500	0.95	150	0.006333	26.07407

Appendix C: Tests for Constituent Materials

Aggregate needs to be standardized because concrete strength and quality depend on physical properties, mechanical properties and chemical composition of the parent aggregate making materials. All physical tests conducted for both fine & coarse aggregates were discussed by the following session.

C1: Tests for Coarse Aggregates.

Basaltic crushed stones of nominal maximum size 19mm were prepared for the use in this specific research physical properties like gradation, specific gravity, water absorption, moisture content and unit weight of the aggregates were tested.

I. Sieve Analysis

Sieve Analysis is a procedure for the determination of the particle size distribution of aggregates using a series of square or round openings starting with the largest. According to the Ethiopian Standard coarse aggregates are those between 75 and 4.75 mm in size.

Sieve Analysis Test Result.

Table 36.C: Particle Size Distribution for Coarse Aggregate.

Sieve Size (mm)	Wt. of Sieve	Wt. of Sieve and Retained	Wt. of Retained	Percentage Wt. of Retained (%)	Percentage Wt. of Cumulative Retained (%)	Percentage Wt. of Passing (%)
37.5			0	0	0	100
19	1389	3174	1785	46.41	46.41	53.58
12.5	1166	2065.9	899.9	23.39	69.81	30.18
9.5	1173	1701.7	528.7	13.74	83.55	16.44
4.75	1175	1517.7	342.7	8.91	92.46	7.53
Pan	735	1024.6	289.6	7.50	100	0
Total			3845.9		392.25	

Calculation $F.M = \frac{\text{Cumulative coarser}(\%)}{100} = \frac{392}{100} = 3.92\%$

Where: F.M = the Fineness Modulus of the aggregate.

A requirement from the Ethiopian Standard for grading coarse aggregate regarding ranges of percentage passing through each sieve is presented in Table 36. C as shown below.

Table 37. C: Ethiopian Standard for grading of coarse aggregate (ES C.D3.201).

Nominal size of Aggregate, mm.	Percentage passing through test sieves having square openings						
	75mm.	63mm.	37.5mm.	19mm.	13.2mm.	9.5mm.	4.75mm.
38_5	100	_	95_100	30_70	_	10_35	0_5
19_5	_	_	100	95_100	_	25_55	0_10
13_5	_	_	_	100	90_100	40_85	0_10

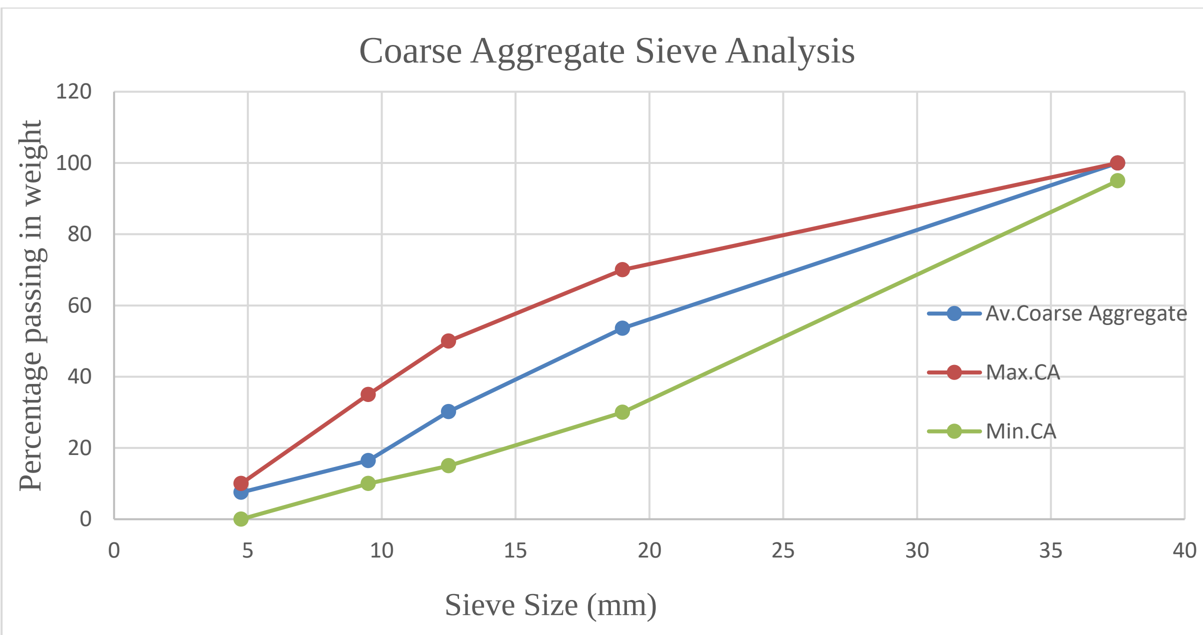

Figure 16. C: Gradation for Coarse Aggregate ASTM C33.

Comment

All the coarse aggregate samples were blended to keep gradation requirement within the range and hence it is basic to prepare good quality concrete.

I. Specific gravity and water absorption.

The specific gravity of a substance is the ratio between the weight of the substance and that of the same volume of water. Absorption is the process by which water is drawn into and tends to fill the permeable pores in a porous solid body.

An approximate aggregate sample of 5kg was acquired, by using quartering from the mass sample. All aggregate materials passing No. 4 (4.75 mm) sieve were rejected.

Specific Gravity Test Results:

A= 4936 gm

B = 5027 gm

Where: A = weight of oven-dry sample in air, [gm]

B = weight of saturated-surface-dry sample in air, [gm] and

C = weight of saturated sample in water, [gm] C = 3230 gm

Calculation:

Bulk Specific Gravity

$$\text{Bulk sp gr} = \frac{A}{B - C}$$

$$\text{Bulk sp gr} = \frac{4936}{5027 - 3230} = \mathbf{2.76}$$

Bulk Specific Gravity (Saturated - Surface - Dry basis);

$$\text{Bulk sp gr (SSD bases)} = \frac{B}{B - C}$$

$$Bulk\ sp\ gr\ (SSD\ basis) = \frac{5027}{5027 - 3230} = \mathbf{2.80}$$

Apparent Specific Gravity:

$$\text{Apparent sp. gr.} = \frac{A}{A - C}$$

$$\text{Apparent sp gr} = \frac{4936}{4936 - 3230} = \mathbf{2.89}$$

Absorption Capacity:

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

$$\text{Absorption Capacity (\%)} = \frac{5027 - 4936}{4936} * 100 = \mathbf{1.84\%}$$

II. **Moisture Content of coarse aggregate:**

The objective of this test is to determine the moisture content of coarse aggregate

Moisture Content Test Results:

A = 2000 g

B = 1960 g

Where: A = weight of original sample [g]

B = weight of oven dry sample [g]

w = Moisture content (%)

$$w\ \% = \frac{A-B}{B}$$

Calculation: $\frac{200-1960}{1960} * 100 = 2.04$

Comment:

Aggregates were washed to remove dirt particles, and hence well dried in the sun. Moisture content and absorption capacity of the coarse aggregate samples are used in concrete mix-design to specify the amount of mixing water and water-cement ratio.

Unit weight of aggregates

The unit weight measures the volume that the graded aggregate will occupy in concrete and includes both the solid aggregate practices and the voids between them. This method is applicable to aggregates of 40mm maximum size.

Test results:

Weight of the Measuring apparatus = 4841 gm.

Weight of sample + Measuring apparatus = 28054gm.

Calculation:

Unit weight of Coarse Aggregate

Weight of the Measuring apparatus = 6300 gm.

Weight of sample + Measuring apparatus = 12000gm.

Weight of sample = 5700gm = 5.7 kg

h = 180 mm   D = 154 mm

$$V = \frac{\pi D^2 h}{4} = \frac{3.14*(0.15)2*1.18}{4} = 0.0033512 \text{ m}^3$$

$$\text{Unit weight} = \frac{5.7 \text{ kg}}{0.0033512} = 1700.88 \text{ kg/m}^3$$

C2: Tests for Fine Aggregates.

I. Silt Content

The objective of this test is to determine the silt (finer than No. 200 sieve) content in sand.

Silt Content Test results:

A = 10ml

B = 290ml

Where: A = Amount of silt deposited above the sand

B = Amount of clean sand

Calculation;

$$\text{Silt content (\%)} = \frac{A}{B} * 100 = \frac{10}{290} * 100 = 3.45 < 6\% \ldots\ldots\text{ok!!}$$

According to the Ethiopian Standard, if the silt content of the sand is more than 6% it is recommended either to wash or to reject the sand. The sand in this specific research can be used without washing since silt content is less than 6%.

II. Sieve analysis

The objective of the test is to determine the particle size distribution of fine aggregates. Table 38.C. and Figure 17.C. below summarizes the particle size distribution as per the Ethiopian Standard for the grading of fine aggregate.

<u>Sieve Analysis Test results:</u>

Table 38.C: Particle size distribution for fine aggregate.

Sieve Size (mm)	Wt. of Sieve	Wt. of sieve and retained	Wt. of Retained.	Percentage Retained %	Percentage Cumulative Retained %	Percentage Passing %
9.5	281.6	281.6	0	0	0	100
4.75	303.6	361.83	58.23	11.69	0	100
2.36	304.4	408	103.6	20.80	16.41	83.59
1.18	278.9	393.57	114.67	23.02	39.434	60.56
0.6	271.4	388.9	117.5	23.59	63.027	36.97
0.3	257.9	340.5	82.6	16.58	79.61	20.38
0.15	287.9	302.13	14.23	2.85	82.47	17.52
0.075	249.8	254.67	4.87	0.97	83.448	16.55
Pan	227	229.33	2.33	0.46	83.915	16.08
Total			498.03		280.48	

$$\text{F.M} = \frac{280.48}{100} = 2.8$$

Where: F.M = the Fineness Modulus of the aggregate.

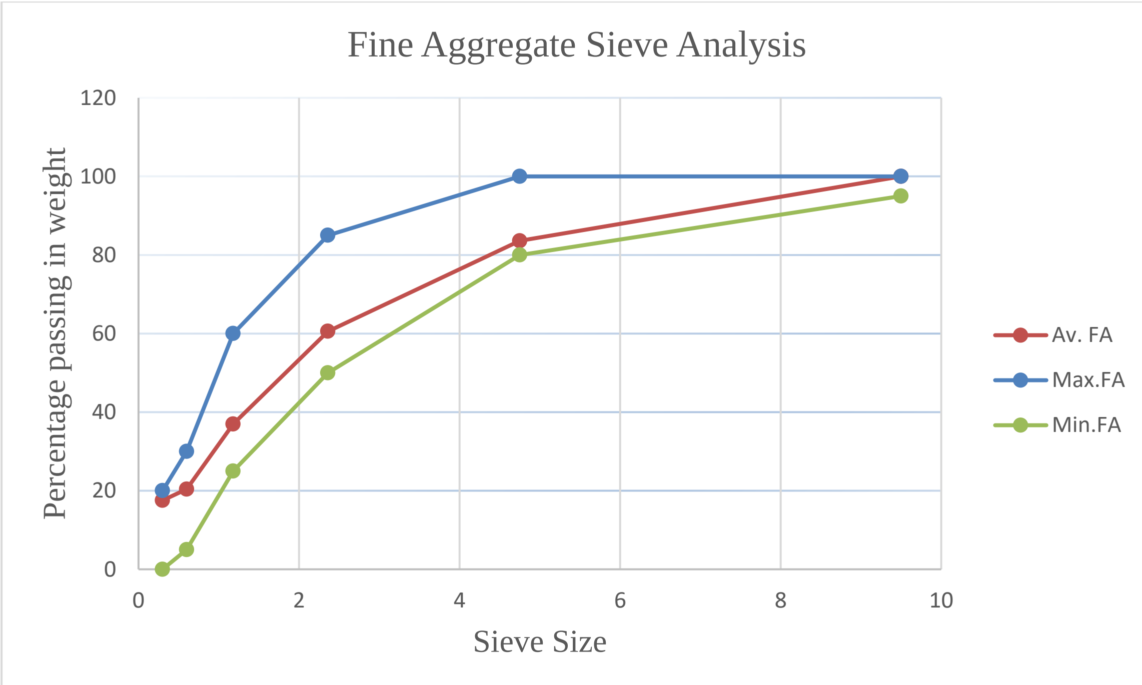

Figure 17. C: Ethiopian Standard for grading of fine aggregate (ES C. D3. 201).

Comment:

The sand sample purchased was tested to check if the material has a particle size distribution within the range of the Ethiopian Standard for the grading of fine aggregate. Thus it satisfies the gradation requirement.

III. Specific gravity and absorption capacity

The objective of this test is to determine the bulk and apparent specific gravity, and absorption capacity of the fine aggregates.

Sample tests were prepared and the procedures for the setup were followed in accordance with the guide of Construction Materials Laboratory. Test results were presented as shown below.

Test results:

Weight of the sample = 500g

Test results for the computation of specific gravity & absorption of fine aggregate

W = 320g

V = 975.39 ml Va

=769.80 ml

A = 475 g Where,

W = weight of pycnometer, gm.

V = volume of flask/container

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

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

Calculation:

C = 0.9976Va + 500 +W

= 0.9976*(769.80) + 500 + 320

= 1587.95g

B = 0.9976V + W

= 0.9976*(975.39) + 320

= 1293.05g

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

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

Bulk specific gravity:

$$Bulk\ sp\ gr = \frac{A}{B + 500 - C}$$

$$Bulk\ sp\ gr = \frac{475}{1293.05 + 500 - 1587.95} = \mathbf{2.32}$$

Bulk Specific gravity (Saturated- Surface-Dry):

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

$$Bulk\ sp\ gr\ (SSD\ Basis) = \frac{500}{1293.05 + 500 - 1587.95} = \mathbf{2.44}$$

Apparent Specific gravity:

Apparent sp. Gr (SSD Basis) = $\frac{\text{A}}{\text{B+A−C}}$

$$= \frac{475}{\text{B}1295.05+475-1587.95} = 2.64$$

NB: In the computation of quantities for concrete mixes it is the specific gravity of Saturated Surface Dry (SSD) aggregates that are always used.

Absorption:

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

$$Absorption\ Capacity\ (\%) = \frac{500 - 475}{475} x100 = \mathbf{5.26}$$

Moisture content

The objective of this test is to determine the moisture content of fine aggregate.

Test results:

A = 500 g

B = 485 g

Where: A = weight of original sample [g]

B = weight of oven-dry sample [g]

Calculation:

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

$$w(\%) = \frac{500-485}{485} * 100$$

w(%) = 3.1 Where: w = Moisture content (%)

Appendix D: Sample photo gallery taken during the Research

Photo: Cement used in concrete mix.

Photo: Ready lubricated molds

Photo: proportioning sample for test.

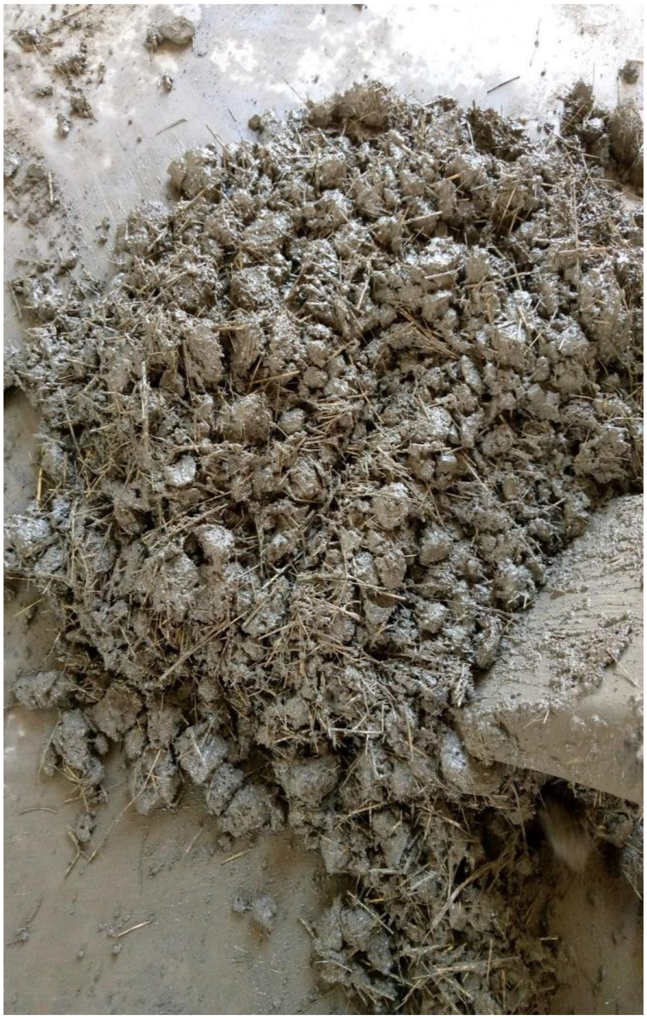

Photo: Mixed fresh concrete and casted concrete

Photo: Slump Test and the fall reading

Photo: Sample curing in bath.

Photo: Demolding and air drying for 24 hours before testing

Photo: The setting for compressive and split tensile strength in calibrated testing machine.

Photo: Line of beam failure under third-point loading flexural strength testing