JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIROMENTAL ENGINEERING

STRUCTURAL ENGINEERING STREAM

TEFF STRAW ASH AS PARTIAL CEMENT REPLACEMENT MATERIALS IN CONCRETE PRODUCTION

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

DESTA MELKA BIRRU

JUNE, 2024

JIMMA, ETHIOPIA

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DECLARATION

This research proposal is my original work and has not been presented for a degree master's of Science in any other universities.

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ABSTRACT

One of the most extensively utilized building materials in the world, concrete is used for everything from roads and dams to buildings and bridges. Cement is one element which serves as binder in concrete. Cement prices are rising daily in low-income countries like Ethiopia these days. There are major environmental effects associated with the production of cement, however attempts are being undertaken to mitigate these effects by using more sustainable production techniques and alternative materials. The objective of this study was to examine how partially replacing cement with TSA affect the mechanical properties and workability of concrete. Three different mixes, each featuring a teff straw ash replacement of 0% to 15% in place of cement, were developed for the C-25/30 grade of concrete, in addition to a control mix. Slump, a measure of the fresh concrete's workability, was observed decreasing as the amount of TSA increased. According to the test results, by day 28th, the concrete's compressive strength increased by 6.2 % for TSA of 5%, 5.4% for TSA of 10%, and at TSA of 15% decreased by 7.05%. In regard to split tensile strength, the test result at 28th day indicates a 1.17% increase in strength for TSA content of 5%, 0.29% for TSA content of 10%, and a 5.63% decrease in strength for TSA content of 15%. Similarly, flexural strength test result at 28th days shows an increase in strength by 3.48% for 5% of TSA, 6.82% for 10% of TSA and reduction in strength 14.15% for 15% of TSA. All percentage of TSA parabolic compressive Stress-strain curve at all days of curing as like ES EN 1992's code of standards. Therefore, it can said that replacing 5% of cement TSA produce concrete with similar quality to *the control test and it is the optimum replacement.*

Keywords: *Teff straw Ash (TSA), Compressive strength, Split tensile strength and Flexural strength*

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TABLE OF CONTENT

DECLARATION 3

ABSTRACT i

ACKNOWLEDGEMENT ii

TABLE OF CONTENT iii

LIST OF TABLE ix

LIST OF FIGURES xii

ACRONYMS AND ABBRIVATIONS xiv

CHAPTER ONE 1

INTRODUCTION 1

1.1 Back ground of the study 1

1.2 Statement of the problem 2

1.3 Research question 2

1.4 Objectives of the study 2

1.4.1 General objective 2

1.4.2 Specific objectives 3

1.5 Significance of the study 3

1.6 Scope and limitation of the study 3

CHAPTER TWO 5

LITERATURE REVIEW 5

2.1 Basic concepts of concrete 5

2.2 Property of concrete 5

2.2.1 Fresh concrete 5
2.2.1.1 Workability 6
2.2.2 Harden properties 7
2.2.2.1 Compressive strength 7
2.2.2.2 Split tensile strength 8
2.2.2.3 Flexural tensile strength 8
2.3 Concrete stress and strain 9
2.4 Components of concrete with partial replacement of cement by teff straw ash 9
2.4.1 Cement 10
2.4.1.1 Type of cement 10
2.4.1.2 Properties of cement 11
2.4.2 Aggregate 13
2.4.3 Water 14
2.4.4 Teff straw ash 15
2.4.4.1 Availability of teff straw ash in Ethiopia 16
2.5 Supplementary cementation materials (SCMs) 17
2.5.1. Coffee ash as cementation of material [31] 17
2.5.2 Bamboo leaf ash as cementation material[30] 18
2.5.3 Teff straw ash as cementation material [26] 18
2.6 Pozzolanic property of teff straw ash 19
2.7 Research gaps/summary 20
CHAPTER THREE 21

RESEARCH METHODOLOGY 21
3.1 Study area 21
3.2 Research design 21
3.3 Study variables 23
3.3.1 Dependent variables 23
3.3.2 Independent variables 23
3.4 Population and sampling method 23
3.5 Sources of data 24
3.5.1 Primary data 24
3.5.2 Secondary data 24
3.6 Data collection procedure 24
3.7 Data presentation and analysis 25
3.8 Data quality assurance 25
3.9 Ethical consideration 25
3.10 Source of material 25
3.11 Physical properties of materials 26
3.11.1 Fine aggregate 26
3.11.1.1 Sieve analysis 26
3.11.1.2 Fineness modulus 27
3.11.1.3 Silt content 27
3.11.1.4 Moisture content 28
3.11.1.5 Specific gravity and Water absorption 28

3.11.1.6 Unit weight of fine aggregate 29
3.11.2 Coarse aggregate 30
3.11.2.1 Sieve analysis 30
3.11.2.2 Moisture content 31
3.11.2.3 Specific gravity and Water absorption 31
3.11.2.4 Unit weight of coarse aggregate 32
3.11.3 Cement 32
3.11.4 Teff straw ash 32
3.11.5 Water 34
3.12 Experimental procedure 34
3.12.1 Mix design 34
3.13 Mixing and curing 36
3.14 Tests conduct on concrete 38
3.14.1 Workability 38
3.14.2 Compressive strength 40
3. 14.2.1 Standard for compressive strength of concrete at various ages 41
3.14.3 Split tensile strength 44
3.14.3.1 Standard for split tensile strength of concrete at various ages 45
3.14.4 Flexural strength 47
3.14.5 Compressive stress-strain relationship of concrete 49
CHAPTER FOUR 50
RESULT AND DISCUSSIONS 50

4.1 Result on physical properties of material 50
4.1.1 Sieve analysis 50
4.2 Result and discussions on Teff straw ash (TSA) and Cement blend pastes 52
4.2.1 Consistency of blended pastes 52
4.2.2 Setting time of blended pastes 53
4.3 Effect of TSA on fresh concrete properties 53
4.3.1 Workability 53
4.4 The impact of Teff straw ash on the density of hardened concrete 54
4.5 Effect of TSA on harden concrete properties 56
4.5.1 Compressive strength test result 56
4.5.2. Split tensile strength test result 59
4.5.2.1 Split tensile strength test result analysis by linear regression 60
4.5.3 Flexural strength test result 62
4.5.4 Stress strain relationship for compressive strength test result 63
4.5.4.1 Analysis test result using linear regression on excel for 7^{th}, 14th and 28^{th} days .. 65
4.5.4.2 Stress versus strain curve for 7^{th}, 14^{th} and 28^{th} days 67
4.6 Optimum usage of TSA as a partial replacement of cement in concrete production 69
CHAPTER FIVE 70
CONCULUSION AND RECOMMENDATION 70
5.1 Conclusion 70
5.2 Recommendation 71
REFERENCES 73

APPENDICES 78

APPENDIX-A Physical properties of materials 78

APPENDIX-B Normal consistency of cement, fineness of cement and slump test result on fresh concrete 84

APPENDIX-C Mass and density of specimen 86

APPENDIX-D Hardened concrete test result 88

APPENDIX-E Stress versus strain relationship of cube test on 7^{th} day 93

APPENDIX-F Stress versus strain relationship of cube test on 14^{th} day 99

APPENDIX-G Stress versus strain relationship of cube test on 28^{th} day 104

APPENDIX-H Strength and deformation characteristics for concrete 110

APPENDIX-I Photo Gallery 111

LIST OF TABLE

Table 3.1 Summary of total population 24

Table 3.2 Volume of ingredient used..... 35

Table 3.3 Proportion before adjustment for field condition 35

Table 3.4 Final design proportion..... 36

Table 4.1 Summary of water absorption, specific gravity, unit weight and moisture content of aggregate 51

Table 4.2 Physical properties of cement 52

Table 4.3 Normal consistency of cement containing TSA 52

Table 4.4 Setting time of pastes containing TSA 53

Table 4.5 Mass and density of cube specimens 55

Table 4.6 Compressive strength test result on 7^{th} day..... 56

Table 4.7 Compressive strength test result on 14^{th} day 57

Table 4.8 Compressive strength test result on 28^{th} day 57

Table 4.9 Average compressive strength values of concrete summary 58

Table 4.10 Split tensile strength test result on 7^{th} day 59

Table 4.11 Split tensile strength test result on 14^{th} day 59

Table 4.12 Split tensile strength test result on 28^{th} day 59

Table 4.13 7^{th} day average compressive stress and strain at peak load 64

Table 4.14 14^{th} day average compressive stress and strain at peak load 64

Table 4.15 28^{th} day average compressive stress and strain at peak load 64

Table 4.16 Summary of stress strain result 65

Table A - 1 Specific gravity and water absorption of coarse aggregate 79

Table A- 2 Specific gravity and water absorption of fine aggregate 80

Table A-3 Unit weight of fine and coarse aggregate 80

Table A-4 Moisture content of coarse aggregate 81

Table A-5 Moisture content of fine aggregate (sand) 81

Table A-6 Particle size distribution test for coarse aggregates 82

Table A-7 Particle size distribution test for fine aggregates 83

TableA-8 standard test method for fine and coarse aggregate 84

TableA-9 Silt content 84

Table B-1 Normal consistency of blended pastes containing TSA 84

Table B-2 Fineness of cement result 85

Table B-3 Slump test result 86

Table C- 1 7^{th} day density of concrete cube (150*150*150)mm with TSA 86

Table C- 2 14^{th} day density of concrete cube (150*150*150)mm with TSA 86

Table C- 3 28^{th} day density of concrete cube (150*150*150)mm with TSA 86

Table C- 4 7^{th} day density of concrete cylinder (100*200)mm with TSA 87

Table C- 5 14^{th} day density of concrete cylinder (100*200)mm with TSA 87

Table C- 6 28^{th} day density of concrete cylinder (100*200)mm with TSA 87

Table C- 7 7^{th} day density of concrete flexural (100*100*500)mm with TSA 87

Table C- 8 14^{th} day density of concrete beam (100*100*500)mm with TSA 88

Table C- 9 28^{th} day density of concrete beam (100*100*500)mm with TSA 88

Table D-1 Average compressive stress and strain for 7th day test result 88

Table D-2 Average compressive stress and strain for 14th day test result 89

Table D-3 Average compressive stress and strain for 28th day test result 90

Table D-4 Split tensile strength on 7th day 90

Table D-5 Split tensile strength on 14th day 91

Table D-6 Split tensile strength on 28th day 91

Table D-7 Flexural strength test result of 7th day 92

Table D- 8 Flexural strength test result of 14th day 92

Table D-9 Flexural strength test result of 28th day 93

Table E-1 Stress versus strain relationship of cube test on 7th day for control..... 93

Table E-2 Stress versus strain relationship of cube test on 7th day for 5% TSA 95

Table E-3 Stress versus strain relationship of cube test on 7th day for 10% TSA 96

Table E-4 Stress versus strain relationship of cube test on 7th day for 15% TSA 97

Table F-1 Stress versus strain relationship of cube test on 14th day for control 99

Table F-2 Stress versus strain relationship of cube test on 14th day for 5%..... 100

Table F-3 Stress versus strain relationship of cube test on 14th day for 10%..... 101

Table F-4 Stress versus strain relationship of cube test on 14th day for 15%..... 102

Table G-1 Stress versus strain relationship of cube test on 28th day for control 104

Table G-2 Stress versus strain relationship of cube test on 28th day for 5% 105

Table G-3 Stress versus strain relationship of cube test on 28th day for 10% 106

Table G-4 Stress versus strain relationship of cube test on 28th day for 15% 108

Table H-1 Strength and deformation characteristics for concrete [38]..... 110

LIST OF FIGURES

Figure 2.1 Type of slump[5] 7

Figure 2.2 Complete stress-strain curve including post-peak response[9] 9

Figure3.1 Flow chart for laboratory work..... 22

Figure 3.2 Sieve analyses for fine aggregate 27

Figure 3.4 Specific gravity and absorption test 29

Figure 3.5 Unit weight test for fine aggregate 30

Figure 3.6 Sieve analysis for coarse aggregate..... 31

Figure 3.7 Specific gravity and water absorption test for coarse aggregate 31

Figure 3.8 Unit weight test for coarse aggregate 32

Figure 3.8 Teff straw burning at furnace and teff straw ash (TSA)..... 33

Figure 3.9 Mixing and casting 37

Figure 3.10 Demolding and curing casted specimen..... 38

Figure 3.11 Slump test on concrete..... 40

Figure 3.12 Compressive strength tests machine..... 40

Figure 3.13 Split tensile strength tests machine..... 45

Figure 3.14 Flexural strength tests machine 48

Figure 4.1 Sieve analysis test result for coarse aggregate 50

Figure 4.2 Sieve analysis test result for fine aggregate 51

Figure 4.3 Slump test result for control and TSA..... 54

Figure 4.4 Unite weight cube versus percentage of TSA 55

Figure4.6 Compressive strength at different curing age..... 58

Figure 4.7 split tensile strength..... 60

Figure 4.8 linear regressions for 7th split tensile strength 61

Figure 4.9 linear regressions for 14th split tensile strength 61

Figure 4.10 linear regressions for 28th split tensile strength 62

Figure 4.11 Flexural strength test result 63

Figure 4.12 linear regressions for 7th day's stress test result 65

Figure 4.13 linear regressions for 28th day's stress test result 66

Figure 4.14 Stress vs strain for 7th day compressive strength test 67

Figure 4.15 Stress vs strain for 14th day compressive strength test 67

Figure 4.16 Stress vs strain for 28th day compressive strength test 68

ACRONYMS AND ABBRIVATIONS

ACI	American Concrete Institute
BLA	Bamboo Leaf Ash
CHA	Coffee Husk Ash
CO_2	Carbon dioxide
JIT	Jimma Institute of Technology
PPC	Pozzolanic Portland cement
SCM	Supplementary Cementation Material
TSA	Teff Straw Ash
C25/30	Concrete grade with the cylindrical strength of 25MPa, Cube strength of 30MPa
ASTM	American Society for Testing and Materials
ES EN	Ethiopian Standard based on Euro Norm
W/C	Water to cement ratio
MPa	Mega pascal
SSD	Saturated surface dried
FM	Fineness Modulus
CaO	Calcium Oxide
AL_2O_3	Aluminum tri Oxide
$Fe_2 O_3$	Iron tri Oxide
LOI	Loss on Ignition
K_2O	Potassium Oxide
MgO	Magnesium Oxide
SiO_2	Silicon di Oxide

CHAPTER ONE

INTRODUCTION

1.1 Back ground of the study

Ethiopia's building sector is experiencing rapid growth, with concrete being the most widely used building material for various civil engineering works such as concrete pavements, domes, apartments, and bridges worldwide [1]. The popularity of concrete is increasing due to urbanization and industrialization. However, resource scarcity and environmental contamination have led scientists worldwide to focus on practical ways of using waste resources as a partial substitute for cement in concrete production [2].

Cement constitutes 10%–15% of the volume of concrete and the construction sector currently faces two main challenges: the scarcity and rising cost of cement [3]. Although cement is expensive and not environmentally friendly, it is an essential ingredient in concrete, which is in high demand in Ethiopia. With growing environmental concerns, researchers are actively seeking alternative methods to reduce pollution caused by the cement industry [4].

In order to maximize production cost and efficiency, it is crucial to utilize agricultural leftovers that share similar properties and purposes. One such overlooked agricultural leftover in Ethiopia is teff straw. Research suggests that brown teff straw ash contains significant amounts of silica, making it a potential pozzolanic reaction agent. In this study, teff straw ash was extracted through heat treatment to partially replace cement [5].

Overall, the production of cement has significant environmental impacts, and efforts are being made to reduce these impacts through the use of alternative materials and more sustainable production methods. The partial replacement of cement with teff straw ash (TSA) has the potential to enhance the strength of cement.

1.2 Statement of the problem

Cement manufacturing involves using natural resources and releases a significant amount of carbon dioxide. Additionally, Ethiopia is currently experiencing a rise in cement costs. The goal of this investigation is to find a partial substitute for cement by using agricultural residue. The aim is to reduce cement prices, environmental preservation, and decrease the consumption of natural resources. The scientific significance of this study lies in exploring the use of teff straw ash (TSA) as a new pozzolanic cement replacement material.

To address this problem, many researchers have attempted to use agricultural waste materials as cement substitutes while maintaining certain properties of concrete. However, there is a gap in the research concerning the use of TSA. Therefore, new research is needed to clearly identify the improvement of compressive strengths, split tensile strength, and flexural strength of concrete when TSA is used as a partial replacement for cement. Additionally, the basic relationship between stress and strain in concrete after partial cement replacement with TSA needs to be determined.

1.3 Research question

The study intended to answer the following question/s

- What effect does TSA have on the workability of fresh concrete?
- What is the significant effect of teff straw ash partially replacing cement in concrete on the spilt tensile strength, compressive and flexural strength of concrete?
- What is similarity between experimental specimens' compressive strain-stress diagram and compressive strain-stress diagram?
- What is the optimum percentage of teff straw ash (TSA) replacing cement?

1.4 Objectives of the study

1.4.1 General objective

The general objective of this study was being to investigate the strength characteristics of concrete in which cement is partially replaced by teff straw ash (TSA).

1.4.2 Specific objectives

- To investigate the effect of TSA on the workability of fresh concrete.
- To evaluate the various strength parameters like compressive strength, spilt tensile strength and flexural strength.
- To find out the basic relationship of concrete stress and strain diagram after partial replacement
- What is the optimum percentage value of teff straw ash(TSA)

1.5 Significance of the study

Currently, it is widely understood that many developing nations are confronted with a dearth of post-consumer disposal waste facilities, resulting in a highly critical predicament. Consequently, it has become imperative to regenerate and utilize waste products as valuable resources in order to mitigate environmental contaminations[1].

The importance of this study deals with the effect of using partial replacement of teff straw ash (TSA) as cement in concrete mix which specifically for fresh concrete considers for hardened concrete compressive and split tensile strength. After laboratory test result, the determination and compression of stress –strain in the concrete section based on partially replacing cement with teff straw ash (TSA) will be considered.

On the other hand, this research suggests the findings as a reference for further research on assessing environmental friendly alternative construction material of concrete.

1.6 Scope and limitation of the study

The scope of this research is to investigate the effect of addition of different percentage of value of teff straw ash (TSA) on mechanical property of concrete, to get optimum percentage of teff straw ash (TSA) and to investigate stress strain of concrete.

The research was be done by adding different percentage value of TSA, such as 0%, 5%, 10% and 15% by weight of cement, on the concrete mix of C25 grade of concrete. Three specimens were cast for each test will conduct at the age of 7^{th}, 14^{th} and 28^{th} days.

CHAPTER TWO

LITERATURE REVIEW

2.1 Basic concepts of concrete

Concrete is amidst the most extensively utilized building materials worldwide in various civil engineering works, including concrete pavement, domes, residential structures, and bridges. Following water, concrete stands out as the most commonly used material globally. The cement and concrete industries are collectively estimated to contribute between 6% and 8% of the world's man-made CO2 emissions, primarily due to the substantial volume of materials involved in their manufacturing processes. It is expected that in the upcoming years, these emissions are likely to rise, particularly as the less developed regions of South America, Asia, and Africa undergo extensive industrialization or continue to do so. It is notable that, typically, the manufacturing of Portland cement results in the discharge of 0.84 tons of CO2 for each ton of cement made.

The most widely used building material in the world; concrete is becoming more and more popular as a result of urbanization and industrialization. Because of resource scarcity and ongoing environmental contamination, the majority of scientists worldwide are currently focusing their attention on practical ways to adopt materials from vast volumes of waste resources as a partial substitute for cement in the manufacturing of concrete[1].

2.2 Property of concrete

The most important properties of concrete with partial replacement of cement by using teff straw ash (TSA) analyzed within this study are:

- Fresh Properties and
- Harden Properties.

2.2.1 Fresh concrete

Fresh concrete, also known as green concrete or plastic concrete, refers to the state of concrete after it has been mixed but before it has hardened or set. During this stage, the concrete is still workable and can be easily molded, placed, compacted, and finished into its final form.

2.2.1.1 Workability

Workability is defined as "that property of freshly mixed concrete or mortar that determines the ease with which it can be mixed, placed, consolidated, and finished to a homogenous condition" by the American Concrete Institute (ACI 116R-00) (ACI 116R, 2000). Workability can be assessed using the Kelly ball test, VeBe test, flow table test, slump test, and compaction factor test. It is among the crucial factors to consider while gauging the consistency of recently mixed concrete. The most used technique for determining the consistency of concrete is the slump test.[4].

Slump test

Tests conducted on freshly mixed concrete provide insight into the mix's workability. The workability is determined by doing a slump cone test. Before concrete is put, the slump will be checked using the slump cone test to make sure it complies with the criteria. This is done to determine the consistency of the concrete.[4].

The most popular and extensively used test technique for determining how workable fresh concrete is is the slump test. On construction sites, the low-cost consistency test is used to quickly decide whether to accept or reject a batch of concrete. Globally, the test method is widely standardized, as seen in ASTM C143 in the US and EN 12350-2 in Europe.

The device is comprised of a mold shaped like a cone frustum, measuring 8 inches in diameter at the base, 4 inches in diameter at the top, and 12 inches in height.

Slump types often come in four different types.

- ✓ True slump- the concrete just sinks while roughly retaining its shape
- ✓ Shear slump-which occurs when the cone's upper half shears off and slides sideways down an inclined plane
- ✓ Collapse slump- in which the concrete entirely falls
- ✓ Zero slump-There is no dip or subsidence.

Three equal-volume layers of concrete are put into the mold. Each layer is compressed with twenty-five tamping rod strokes. After raising the slump cone mold vertically, the concrete's height variation is measured. There are four common forms of slumps, as Figure 2.1 illustrates. Often called the "true" slump, this is the only kind of slump allowed by ASTM C143 in which the concrete still has its symmetry and integrity. The workability range that the slump test can

evaluate excludes both a zero slump and a collapsed slump. In particular, ASTM C143 recommends using care when interpreting test findings that are less than ½ inch and more than 9 inches. Should a portion of the concrete shear[5].

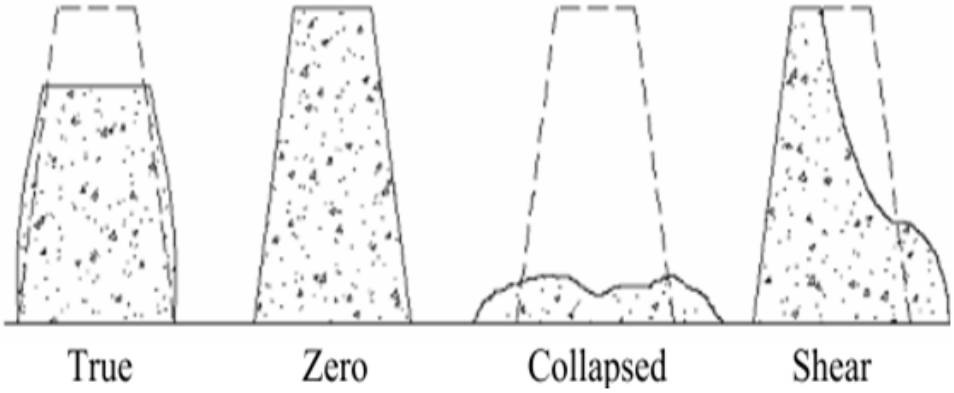

Figure 2.1 Type of slump[5]

2.2.2 Harden properties

Harden properties of concrete refer to its ability to increase in strength and durability over time. This process is known as hydration, where the cement in the concrete mix reacts with water to form a crystalline structure that binds the aggregates together. As the concrete hardens, it becomes stronger and more resistant to wear and tear. Factors that influence the hardening properties of concrete include the water-cement ratio, curing conditions, and the type of cement used.

2.2.2.1 Compressive strength

The quality of cement concrete work is controlled and conformed to in large part by the compressive strength of the concrete. The compressive strength of concrete is the primary determinant of its use in construction. Strength, or the capacity to withstand compression loads, is one of the primary characteristics of hardened concrete. Concrete's compressive strength is widely regarded as the primary factor and is frequently regarded as the foundation of the material's entire excellence. The compression load per unit cross section area of the specimen over which the load is applied determines the compressive strength of concrete.[6].

The main purpose of concrete is to withstand compressive forces. In the construction sector, concrete compressive strength is frequently utilized for quality control and specification purposes. Due to the high void content, the compressive strength of porous concrete is comparatively lower. The order in which the size of the aggregate is increased, the ratios or values of the mixture, and the amount of work put into compaction during concrete casting all have an impact on the compressive strength of porous concrete. Therefore, the total amount of cementitious material, the presence of additives like mineral admixtures and polymeric additives, and their combined effect promote the formation of porosity[7].

Cube specimens of 150 mm x 150 mm x 150 mm were assessed using a compression device. Sand and other debris were removed from the specimen's surface, and the machine's bearing surface was meticulously cleaned. The specimen was positioned within the apparatus so that the opposing sides of the cubes, rather than their top and bottom, received the load. The applied force was increased gradually and at a constant rate until the specimen's resistance to the increasing load collapsed and could no longer be sustained. It was recorded what the specimen's greatest load was [8].

2.2.2.2 Split tensile strength

Concrete has a relatively low stress strength compared to other materials. Cylindrical concrete specimens are positioned using compressive testing apparatus during. In order for its axis to be horizontal between the testing machine's plates[4].

2.2.2.3 Flexural tensile strength

An explanation of the ASTM-based concrete flexural test is provided. The tensile strength of concrete is indirectly measured by flexural testing. It measures a concrete beam or slab's resistance to bending failure in the absence of reinforcement. The modulus of rupture (MR) in MPa or psi represents the results of a flexural test conducted on concrete. As per ASTM recommendations, the specimen's dimensions should be 150 mm in width, 150 mm in depth, and its overall length shouldn't be more than three times its depth [4].

2.3 Concrete stress and strain

A displacement or strain controlled testing equipment can be used to get the descending component of the stress-strain curve, or the post-peak response of the concrete. A steady rate of load is applied to the specimen in most load-controlled equipment. Therefore, any additional load that exceeds the specimen's maximum capacity causes it to collapse catastrophically. The specimen is given tiny displacement increments in a displacement-controlled machine. Therefore, it is also possible to record the decreasing load after the peak load. Figure 2.2 illustrates that for concrete of standard strength, the strain at failure is normally approximately 0.005.

In actuality, the post peak behavior depends on the rate of strain as well as the testing apparatus's stiffness in proportion to the test specimen's stiffness. Concrete becomes more brittle as it gets stronger, as evidenced by a decrease in the strain at failure[9].

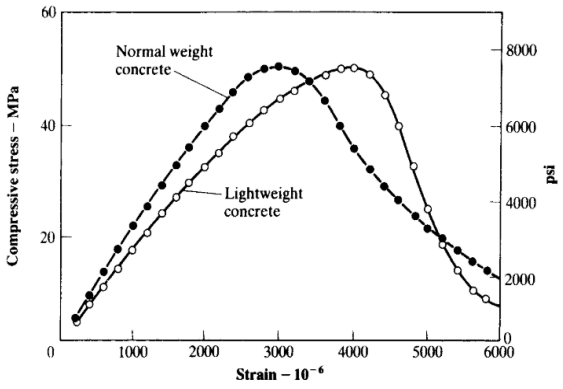

Figure 2.2 Complete stress-strain curve including post-peak response[9]

2.4 Components of concrete with partial replacement of cement by teff straw ash

The composition of concrete involves the partial replacement of cement with a combination of Teff straw ash, cement, aggregate, and water.

2.4.1 Cement

Both the amount of production and consumption in the cement sector is growing globally. The demand for cement from civil engineering is growing significantly due to the government's increased investment in both the residential and public works sectors, which in turn allows cement manufacturers to produce cement on a large scale and increase consumption volume [4]. The increase in construction activities is also driving up demand for cement. The process of making cement releases a great deal of heat and carbon dioxide, endangering the environment. The calcination process, which turns limestone (CaCO3) into free lime (CaO) and carbon dioxide (CO2), uses half of the heat input of the kiln system [10].

The binder in concrete and mortar that binds fine and coarse aggregates, as well as other ingredients, into a solid mass is called cement. Concrete's characteristics are determined by the types and amounts of its constituent materials. Since cement is the most expensive and active ingredient in concrete, choosing and using it correctly is crucial to getting the right balance of qualities for a given concrete mixture at the lowest possible cost[6].

2.4.1.1 Type of cement

Depending on their composition, how they are made (burning, grinding, etc.), and the relative amounts of the various components, there are several types of binder or cement [11].

The following varieties are most common

Ordinary Portland cement (OPC) – is employed in various kinds of building, including slabs and foundation walls.

Rapid hardening Portland cement (RHC) – In three days, maximum strength is attained. This cement has a higher percentage of 3CaSiO2 and finer grains. RHC is utilized in unique constructions that call for an early strength.

Low heat cement (LHC) **-** contains more silica and iron and less line than regular portland cement. About one-third less heat is produced during hydration than during OPC, and it does so far more slowly. Large-scale constructions like dams use LHC.

Quick setting cement (QSC) – doesn't include gypsum, so it sets and hardens in around 30 minutes. It is employed in underwater construction.

Pozzuolana cement (PPC) – is created through mixing OPC Clinker and Pozzolanic material, then grinding the mixture in a cement mill. Because of its increased resistance to sulphates and the corrosive effects of seawater, it is employed in construction along the coast.
Portland cement is one of these varieties and the most often used one; it is further classified into various cement classes.

Portland cement

The most widely used modern cement is Portland cement, which is created by carefully combining particular raw components to create a final product that satisfies ASTM C150 specifications for one of eight different cement kinds. The raw ingredients are composed of two minor compounds, gypsum (CaSO4 2H2O) and magnesia (MgO), and four important compounds, namely lime (CaO), iron (Fe2O3), silica (SiO2), and alumina (Al2O3). Typically, shale, marl, calcite, or limestones are the sources of calcareous (CaO) minerals. The sources of argillaceous (SiO2 and Al2O3) minerals are sand, clay, and shale. The location of the manufacturing facility and the availability of raw resources determine the materials utilized to make any particular cement. Different industrial by products can be used for the production of Portland cement[12].

2.4.1.2 Properties of cement

Physical properties of cement

Cement specifications set limits for its chemical composition as well as its physical attributes. Comprehending the importance of certain physical qualities is useful when evaluating cement test results. Specifications, which vary depending on the type of cement, restrict the qualities of cement. Throughout the manufacturing process, cement's chemistry and the following characteristics are constantly observed and tracked[13].

Cement specifications specify boundaries on its physical characteristics. The significance of certain physical attributes, including as consistency, finesse, and setting time, should be understood in order to properly interpret cement test results. It is best to assess the cement's qualities through tests of its physical characteristics rather than the concrete's. The qualities are restricted by the type of cement specified in the requirements. Samples of cement should be taken in compliance with ASTM C 183[14].

a. Particle size and fineness

In cement, "fineness" refers to the overall distribution of particle sizes, which influences the pace of hydration and the amount of heat released. Strengthening is facilitated by higher cement fineness, which is smaller particle size and increases cement hydration rate. During the first seven days, the impacts of fineness on paste strength become most apparent. Cement with finer particles has more surface area; fineness is a measure of the surface area of the cement particles per unit mass. Portland cement is the result of grinding clinker in a mill to produce individual, angular particles of different sizes. Ninety-five percent of cement particles are less than 45 micrometers, with an average particle size of about 15 micrometers [13].

b. Normal consistency

Consistency is the ability of freshly prepared mortar or cement paste to flow. According to ASTM C 187, a paste with a normal consistency is made for cement testing, with a Vicat plunger penetration of 10 ± 1 mm suggested. The normal consistency approach is used to regulate the water content of pastes. This makes it possible to compare different substances with the same penetration [13].

c. Setting time

Determining the paste's first and final sets is the goal of setting time. Final set is the period of time needed for a paste to reach a specific hardness level, whereas initial set is the period of time that counts from the moment water is introduced until the paste stops being fluid.

This test is carried out using either the Vicat apparatus or the Gillmore needle in ASTM C 191 or AASHTO and ASTM C 266 or AASHTO 154, respectively, to ascertain if a cement sets based on the time constraints in cement specifications[13].

d. Specific gravity (density and relative density)

The density of cement is defined as the mass of a unit volume of solid particles or particles less air between the particles. Mega grams per cubic meter are how it is said. Cement density determined by means of ASTM C 188 or AASHTO T 133 is primarily used in mixture proportioning calculations; it does not reveal the quality of the material. Expressing the density as relative or specific gravity, a dimensionless value that may be calculated by dividing the density of cement by the density of water at 4°C (1.0 g/cm3 or 1000 kg/m3), may be more helpful. The average particle density of Portland cement, which is utilized in volumetric calculations of concrete mix proportioning, falls between 3.10 to 3.25 mg/m3[13].

2.4.2 Aggregate

It is essential to use the appropriate aggregates in terms of both type and quality. The fine and coarse aggregates have a significant impact on the qualities of the freshly mixed and hardened concrete, mixing proportions, and economy. Typically, they make up 60% to 75% of the concrete volume (70% to 85% by mass)[15].

For optimal engineering application, aggregates must meet specific requirements. These include being hard, hard strong, and durable particles free of absorbed chemicals, clay coatings, and other fine components in proportions that can alter the cement paste's hydration and binding. It is not desired to have friable or splittable aggregate particles. Avoid using aggregates that contain significant percentages of shale or other shaly rocks, as these are soft and porous materials. Certain forms of chert should be avoided in particular because they are more susceptible to weathering and can result in surface flaws like popouts.

Minerals and rocks combine to form naturally occurring concrete aggregates. A naturally occurring solid material having a narrow range of chemical composition and an organized internal structure is called a mineral. Depending on their place of origin, rocks can be

categorized as igneous, sedimentary, or metamorphic. Typically, rocks are made up of a variety of minerals [16].

Aggregates are classified as coarse aggregate and fine aggregate.

Coarse aggregate

The use of coarse aggregate in concrete is essential. According to research, coarse aggregate can alter the strength and fracture characteristics of concrete. Coarse aggregate usually makes up more than one-third of the volume of concrete. Understanding the effects of aggregate type, aggregate size, and aggregate content is necessary to forecast how concrete will behave under general loading. This knowledge can only lbe acquired by means of intensive experimentation and monitoring [17].

Fine aggregate (sand)

The majorities of the particles in fine aggregates are less than 5 mm and are often crushed stone or natural sand. The relative sharpness or angularity of a particle's edges and corners is measured by its roundness. The amount of water needed to create a mix using a particular aggregate is greatly influenced by the form and texture of that aggregate. The influence on the water need is very clear if these characteristics of fine aggregate are reflected indirectly by the way it is packed, that is, by the percentage of voids in a loose condition[18].

Fine aggregate must be devoid of harmful substances in order to function satisfactorily. Aggregates may contain harmful substances, coatings, and weak or unsound particles, which are the three types of harmful materials. If fine aggregates include organic substances, even though they are robust and wear-resistant enough, they might not be suitable for use in concrete[19].

2.4.3 Water

Water is one of the main ingredients of concrete. The cement is hydrated in part with the mixing water; concrete requires balanced water to work. This is why it is essential to closely monitor the amount and quality of water. Concrete's strength and durability are weakened and shortened by chemical pollutants in water. The guidelines generally recommended using drinking water while

making concrete. A feasible approach would be to test the concrete's strength and setting time between the water under consideration and the water of known quality.

Different types of water

- Potable water: Water which is suitable for consumption of human being.
- Recycled water: Water which is treated up to acceptable limit which is suitable for its intended use.
- Blackish water: Wastewater generated from toilets and urinals that is directly contaminated with human excreta.
- Gray water: Wastewater from sinks, showers, laundry, and kitchens.

Function of water in concrete

- To wet the aggregate surfaces to promote adhesion, as cement paste sticks to wet surfaces more rapidly and satisfactorily than it does to dry ones.
- To mix the components into a plastic combination and give the concrete workability so that it can be placed in the proper location and
- Water is also required for the cementing ingredients' hydration in order for them to set and harden throughout the curing process.

The amount of water in the mixture has a significant impact on the concrete's strength. Certain types of water can negatively impact concrete that has hardened. It is important to distinguish between the influence on hardened concrete and the quality of the mixing water since sometimes they may not be harmless or even advantageous during mixing[20].

2.4.4 Teff straw ash

These characteristics make teff straw a particularly valuable agricultural residue that is extensively accessible in Ethiopia and other east African countries [21],[22]. Research has been done on the use of amorphous silica derived from biomass ash as an additive in the cement industry. It increases the resistance of concrete to corrosion and prevents it from cracking. Reinforced materials show characteristics including reduced crystallinity, increased residual carbon content, and coarse grains when biomass ash is injected at the highest flux content[23],[24].

In Ethiopia, teff is the main grain crop that is consumed by people. Its ability to make injera is highly prized. Teff's composition reveals that it has a considerable number of minerals and a greater than average amount of important amino acids. In addition, the crop grows effectively in conditions of water stress and moisture deprivation. It can also thrive in a variety of soil types, temperatures, and rainfall patterns from sea level to 2800 meters. Teff can be grown in a variety of broad agro-ecologies. Teff is mostly farmed during the main rainy season (Meher), while certain regions grow the crop during the short rainy season (Belg). Depending on the variety and altitude, the length of the growing period (LGP) can vary from 60 to 180 days, with an ideal duration of 90 to 130 days[25].

Many researches have been conducted all over the world on the utilization of agricultural residue wastes and how they can be converted into ash in varying amounts to replace cement. Although teff is one of the most widely grown cereals in Ethiopia, its additional uses outside of cow feed have gotten very little attention[26].

2.4.4.1 Availability of teff straw ash in Ethiopia

In Ethiopia, teff is one of the most significant and common staple grain crops. 71% of all cultivated land is used for cereal crops, which account for roughly 61% of all agricultural output. Teff is the second most produced cereal crop after maize, despite being an uncultivated crop. About 28.4% of the total cultivated area of cereal crops and 50% of the total quantity of cereals produced were made up of teff. The area used to produce Teff is still growing, and more farmers are doing so. In 2013, almost 6.3 million farmers were cultivating Teff, up from 4.4 million in 2001/2002. Comparably, from 1.8 million hectares in 1997 to 2.7 million hectares in 2013, more land was designated for Teff cultivation[27].

The world's largest producer of Teff is Ethiopia. Teff makes up 24% of the grain area in 2017, with maize coming in second at 17% and sorghum third at 15%[28].

Teff accounted for 22.6% (or roughly 3.2 million hectares annually) of Ethiopia's grain crop area in 2013–14. The Teff straw yield per year is expected to be approximately 16 million tonnes, based on an average yield of 5000 kg/ha[21]. Thus, Teff straw is available in high quantity may use for making Teff Straw Ash.

2.5 Supplementary cementation materials (SCMs)

Materials known as supplemental cementitious materials (SCMs) can be added to concrete in addition to cement to enhance its characteristics. These substances may be natural or by products of industry. Concrete is mixed with additional cementitious components to complete the cementitious system. They can be used in addition to or partially in place of Portland cement or mixed cement, depending on the properties of the components and the desired result for the concrete [29]. To reduce energy consumption and CO_2 emissions, substituting part of the cement with SCMs is probably the most effective approach. Supplementary cementing materials (SCMs) partially replace Portland cement in concrete. Among the SCMs are met kaolin, fly ash, slag cement, and silica fume [3],[9].

The process for producing cement uses a lot of energy and pollutes the atmosphere with toxic gases released into the atmosphere. The quantity of energy and environmental effect will be decreased by partially replacing cement with materials that are easy to find locally. Utilizing plant residue, an industrial by product, and agricultural waste in place of Portland cement is a good approach to decrease raw material consumption, save the environment, and improve cement quality in part [30].

In order to guide my study, I have seen some Book, article and international journal related with my topic which describes the replacement of cement in concrete using coffee ash, bamboo leaf ash, Rice husk ash and teff straw ash.

Some of them discussed below according to their view:

2.5.1. Coffee ash as cementation of material [31]

Significance of Findings:

- The study examined at whether coffee husk ash (CHA) may replace some of the regular Portland cement (OPC) used in the manufacturing of concrete.
- The results suggested that CHA might achieve advanced compressive strength at all test ages when up to 10% of OPC was replaced.

- CHA can lower cement production costs and help save energy costs.
- Concrete made from CHA has a great deal of potential as an environmentally friendly cementitious material that lowers pollution and offers a viable coffee husk waste management option.

Overall, the study's findings indicate the possibility of partially substituting coffee husk ash for cement in the manufacture of concrete, which could have positive effects on the environment and economy.

2.5.2 Bamboo leaf ash as cementation material[30]

Significance of the finding:

- The study's conclusion is important because it demonstrates that, up to a 10% replacement level, bamboo leaf ash (BLA) can be utilized in place of cement in the manufacturing of concrete.
- This conclusion is significant given the difficulties facing Ethiopia's construction industry as a result of the shortage and rising cost of cement.
- The study indicates that building costs can be decreased without affecting the quality of the concrete by substituting BLA for cement.
- The study also discovered that the BLA-blended concrete's water absorption and sulfate attack improved, and that the concrete's compressive strength at 5% and 10% replacement of BLA reached the ideal average strength.
- These results have implications for lowering the cost of housing and resolving the issue of rising cement prices in Ethiopia's construction industry..

2.5.3 Teff straw ash as cementation material [26]

Teff straw serves multiple purposes, including being used as mulch and being combined with mud to build walls for buildings and grain storage facilities. Recently, teff straw (Eragrostis tef) has been studied as a potential source of biosilica. Sadly, over 2 million tons of teff straw is discarded in Ethiopia each year, seemingly considered as waste. Teff itself receives little attention from international agricultural research centers like the Consultative Group of International Agricultural Research (CGIAR). This lack of attention is mainly due to these

centers focusing on major international crops such as maize, wheat, and rice, which do not include teff [32].

Teff is a fine-stemmed and tufted annual grass with a broad crown, a shallow varied root system, and a dense shoot system. Its grain is oval and is 0.7–1.0mm in diameter and 0.9–1.7mm in length. Individual teff grains weigh between 0.2 and 0.4 mg, and 1 gram of teff contains 2500–3000 seeds. One hundred fifty teff grains weigh the same as one grain of wheat, making it the world's smallest grain among carbo- hydrate-rich kernels teff containing nutrients. Although it is popular in Ethiopia, teff grain is threshed, and the straw is utilized as animal feed, particularly during the dry season [33]**.**

Significance of findings

- The potential for alternative cement binders to lower production costs and environmental impact makes them important for the construction industry.
- Since the manufacture of cement contributes significantly to greenhouse gas emissions and global warming, it can be beneficial to discover environmentally acceptable alternatives.
- By maximizing the use of agricultural residues like teff straw ash—as cement substitute materials, waste may be minimized and sustainable management techniques can be supported.
- The study primarily examines teff straw ash's capacity to substitute cement to some extent, which may have consequences for Ethiopia's construction industry given teff straw's widely accessible there.
- The goal of the study is to provide light on the viability and efficiency of utilizing teff straw ash as a substitute for cement by examining its impact on the compressive strength of mortar mixtures.

2.6 Pozzolanic property of teff straw ash

The combined chemical composition for BTSA-600^{0}C; $SiO_2 + Al_2O_3 + Fe_2O_3 = 65.12 > 50\%$ will be categorized under Class C pozzolanic materials as per ASTM C- 618 specifications.

The combined chemical composition for BTSA-750^{0}C; SiO2 + Al2O3 + Fe2O3 = 77.59 > 70% will be categorized under Class F pozzolanic materials as per ASTM C- 618 specifications.
The combined chemical composition for BTSA-900^{0}C; SiO2 + Al2O3 + Fe2O3 = 70.64 > 70% will be categorized under Class F pozzolanic materials as per ASTM C- 618 specifications.
The silicate content of the ash increases when temperature increases from 600^{0}C to 750^{0}C and decreases from 750^{0}C to 900^{0}C. This decrease in silicate content at 900^{0}C occurred because of decomposition of minerals at high temperature as it can be seen from the Loss on ignition Value[26].

2.7 Research gaps/summary

TSA as cement replacing materials by analyzing the effect on the compressive strength of mortar mixes. In addition to the compressive strength of mortar cubes, other properties such as compressive & flexural strength of concrete cubes and spilt tensile strength can be improved using TSA. Further research is recommended in this regard[26].

So, in order to solve this problem many researcher are try to use this agricultural waste materials as cement replacement with sustain some property of concrete. Here is the gap that researcher did not done and I want try to do; new research to clearly identify using TSA to improve the compressive strengths, spilt tensile strength and flexural strength of concrete. And also to find out the basic relationship of concrete stress - strain diagram after partial replacement cement by TSA.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Study area

This study was conducted at JiT University in Jimma, Ethiopia. Oromia Region in Ethiopia the old Kingdom of Jimma, which was incorporated into the former province of Kaffa in 1932, is the source of the name Jimma. Jimma shares borders with the Southern Nations, Nationalities and Peoples Region to the south, Buno Bedele to the northwest, East Wollega to the north, and West Shewa to the northeast. The Gibe River forms part of the boundary with East Shewa. In this zone, Mount Maigudo (2,386 m) is the highest peak. Jimma is home to the cities and towns of Agaro, Genet, and Saqqa.

3.2 Research design

This research was an experimental research design method in order to investigate the effect of teff straw ash (TSA) on the mechanical properties of concrete, determine the optimum percentage of TSA used in concrete, and find out the basic relationship between concrete stress and strain.

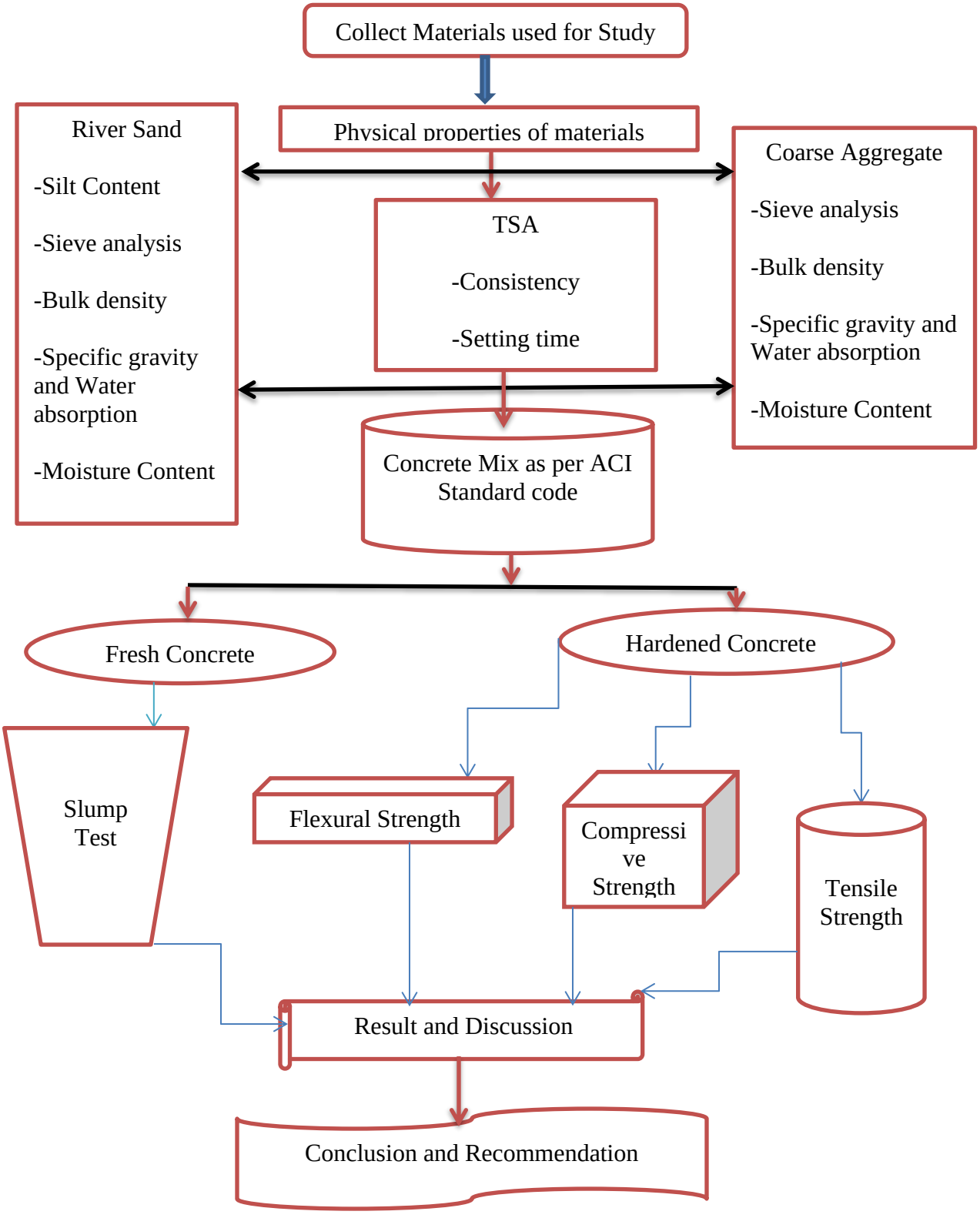

Figure3.1 Flow chart for laboratory work

3.3 Study variables

3.3.1 Dependent variables

For this research, dependent variable was being considered as:

- Workability
- Compressive strength
- Spilt tensile strength and
- Flexural strength
- Stress-strain diagrams

3.3.2 Independent variables

It is a variable which could bring a difference between dependent variables of samples. The independent variable was being considered as:

- Percentage of Teff straw ash(TSA)

3.4 Population and sampling method

C-25/30 is the concrete grade that was employed in this study. To prepare samples for different tests, different percentage values of TSA were added to the concrete. Purposive sampling was used in the study, and ASTM and ACI guidelines were adhered to. Accordingly, on each test day, a minimum of three cube samples were collected. Samples were cured using the ponding method and tested on the 7^{th}, 14^{th}, and 28^{th} days to measure compressive strength, split tensile strength, and flexural strength for each of the four groups (0%, 5%, 10%, and 15%) where TSA was used in place of cement to some extent.

The samples that were used have the following dimensions: Cubes measuring 150 x 150 x 150 mm for compressive strength and 100 mm in diameter and 200 mm in length for split tensile strength and beams measuring 100mm x 100mm x 500mm for flexural strength. A total of 108 specimens were casted for the mix control, compressive strength test, split tensile strength, and flexural strength. The samples used to determine the mix control (0% replacement) and partially replaced concrete are summarized in Table 3.1.

Table 3.1 Summary of total population

Type of Specimen	Types and number of tests on 7th, 14th and 28th days			Total specimen
	Compressive	Split Tensile	flexure Beam	
control	9	9	9	27
5% of TSA	9	9	9	27
10% of TSA	9	9	9	27
15% of TSA	9	9	9	27
Total				108

3.5 Sources of data

3.5.1 Primary data

The primary data source was be from field study for material source determination and sample size, test result obtained on physical properties of material, mix design result for both control and experimental group and laboratory chronological test result of specimens.

3.5.2 Secondary data

The secondary data come from various published and unpublished source, Books, Journals and Research reports.

3.6 Data collection procedure

Descriptive and analytical methods were used in the study to collect data. Using the descriptive method, secondary data was gathered from books, conferences, published journals, and standard manuals. The main techniques for gathering data were laboratory analyses to evaluate the physical characteristics of materials and field research to identify the sources of the resources. Furthermore, specimens were tested and cured in the lab at varied TSA ratios (0%, 5%, 10%, and 15%) throughout a range of timeframes. Data was recorded and tagged with the appropriate code for 7th, 14th, and 28th days after the specimens were tested according to their curing and casting times.

3.7 Data presentation and analysis

After gathering the necessary materials for concrete production, including cement, aggregates, clean water, Teff straw ash, and the laboratory experiment proceeded. The researcher then analyzed the data obtained from the laboratory by comparing and contrasting the effects of the teff straw ash concrete with the control group. Microsoft Word and Excel were utilized for this analysis. The results were presented using charts, figures, and tables. Furthermore, this research paper presents the laboratory findings and recommends the optimal percentage of teff straw ash to be used as a partial replacement for cement in concrete.

3.8 Data quality assurance

The quality of the data was improved and verified by collecting an adequate number of specimens for each replacement level, in accordance with the standards. Additionally, the testing instrument was regularly checked before and during the progress of the experiment to prevent any errors. Furthermore, a well-prepared checklist or sheet was used to record the sample results, preventing any confusion during the writing of the final paper.

3.9 Ethical consideration

A formal letter should be obtained from the JiT Postgraduate and research program office and submitted to the JiT laboratory office to request official permission and to facilitate the use of the laboratory for conducting various tests. Proper credit was being given to the authors of previous journals by acknowledging them through citations and referencing their materials. It is important for the author to avoid plagiarism by properly citing the work of others.

3.10 Source of material

- **Cement**: The type of Cement used in the concrete mix was Dangote Pozzolanic Portland Cement (PPC), which has a cement grade of 32.5N and is commercially available.
- **Coarse aggregate**: The coarse aggregate used was "Agaro" crushed stone with a maximum nominal size of 20mm, which is commonly used in Jimma Town.
- **Sand**: The sand used was sourced from Worabe and is available in Jimma Town.

- **Water**: Drinkable (potable) water was sourced from the Jimma University Jimma Institute of Technology laboratory.
- **Teff straw ash (TSA)**: The TSA used was sourced from around woliso town and collected from the farmer.

3.11 Physical properties of materials

Physical properties of materials test done following the ASTM standard method[34]

3.11.1 Fine aggregate

The fine aggregate used in this study was obtained from Worabe River. The river sand has a maximum diameter of 4.75mm. In order to meet the mix design specifications, the physical properties of the fine aggregate were tested in the laboratory. However, as the aggregate was extracted from the riverside, it was covered in a layer of dust. To address this, the fine aggregates were thoroughly washed and dried in the open air outside the laboratory until they reached a saturated surface dry (SSD) state. The physical property tests conducted on the fine aggregates are discussed below.

3.11.1.1 Sieve analysis

This procedure is used to determine the particle size distribution of aggregate and the fineness modulus (FM), which indicates the coarseness, fineness, and uniformity of the aggregates. These properties have a significant impact on the quality of concrete. According to ASTM C33 (standard specification for concrete aggregates), sand with a fineness modulus between 2.3 and 3.1 is considered good sand or a good fine aggregate. However, depending on their size, crushed sand can be classified as coarse sand with a fineness modulus between 2.9 and 3.1, medium sand with a fineness modulus of 2.6 to 2.9, and fine sand with a fineness modulus of 2.2 to 2.6 [35].

Figure 3.2 Sieve analyses for fine aggregate

3.11.1.2 Fineness modulus

According to the requirements of ESC-D3-201, the fineness modulus of sand should not be less than 2.0 and more than 3.5. The fineness modulus is often calculated using the results of sieve analysis. It is determined by adding up the total percentages that are coarser than each specified series of sieves, and then dividing by 100.

$$\text{Fineness Modulus (FM)} = \frac{\sum \%\text{Retained on sieves}}{100} \quad \text{.....eq3.1}$$

3.11.1.3 Silt content

According to ASTM C 33, any material in fine aggregates that is finer than 75μm is typically considered silt. The presence of silt in concrete sand has a significant impact on the quality of the concrete. It primarily affects the workability and also reduces its strength. The Ethiopian standard recommends washing or rejecting sand with a silt content exceeding 6%.calculate the percentage of silt content using the following formula:

$$\text{Average silt content (\%)} = \frac{w1-w2}{w1} * 100 \text{.....eq3.2}$$

Where w2=weight of oven dry (gm)

w1= weight of oven dry(gm)

3.11.1.4 Moisture content

It is crucial to keep in mind that the aggregate in the concrete mix should be devoid of water and should not take in moisture from the surrounding air while constructing the mixture. Sand can upset the originally intended water-to-cement ratio and weaken the concrete if it is added without first being tested for moisture content and water absorption. As a result, experiments must be carried out to ascertain the precise water content needed to achieve the appropriate compressive strength and workability of fresh concrete. The ASTM C-566 test method can be used to determine the sand's moisture content. The ideal range for the moisture content is 0% to 10%.

Calculate total moisture content as follows:

$$\text{Total moisture content (P)} = \frac{A-B}{B} * 100 \ldots\ldots\ldots \text{eq3.3}$$

Where: p = total moisture content of sample, percent,

A = mass of original sample, g, and

B = mass of dried sample, g.

3.11.1.5 Specific gravity and Water absorption

The "Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate," ASTM C128 was followed in the performance of this test. After being cooled in the air and dried to a consistent mass at 100 to 110°C (212 to 230°F), the fine aggregate is submerged in water for a whole day. Part of the sample is put in a mold and tamped after it is regularly swirled until it almost flows freely. When the mold is lifted, the fine aggregate will stay in its molded form as long as there is surface moisture. Testing and drying are carried out repeatedly until the tamped fine aggregate slightly slumps when the mold is removed. This signifies that the state has attained saturated surface dryness, or SSD.

Figure 3.4 Specific gravity and absorption test

These values are then used to calculate bulk specific gravity, bulk SSD specific gravity, apparent specific gravity, and absorption. Relative density (specific gravity) is computed from the equation.

$$\text{Bulk Relative Gravity} = \frac{A}{A+C-D} \qquad \text{.....eq3.4}$$

$$\text{Bulk Relative Gravity (SSD)} = \frac{B}{B+C-D} \text{.....eq3.5}$$

Where A = is the mass of the oven-dry sample in air

B = is the mass of the SSD sample in air

C = is the mass of the jar or flask filled with water; and.

D= is the mass of the jar or flask with specimen and water to the Calibration or filling mark

3.11.1.6 Unit weight of fine aggregate

Unit weight can be defined as the weight of a given volume of graded aggregate; thus, a measurement of density is also known as bulk density. The unit weight tests of the fine aggregate samples were carried out according to ASTM C 29 and simply measured by filling a container of known volume and weighing it. Then, dividing the aggregate weight by the volume of the container provides the unit weight of the aggregate.

Figure 3.5 Unit weight test for fine aggregate

3.11.2 Coarse aggregate

The coarse aggregate sample was dried in the sun to minimize its effects on the concrete. In all of the concrete mixes, we used the same coarse aggregate called "Agaro crushed stone." This aggregate is commonly used in the Jimma Town area and is readily available, making it the best choice to simulate normal construction practices in the region.

3.11.2.1 Sieve analysis

The particles were divided into various sizes using a sieve analysis test to determine the gradation or particle size distribution. This analysis was conducted following ASTM C 33 guidelines.

Figure 3.6 Sieve analyses for coarse aggregate

3.11.2.2 Moisture content

To determine the necessary amount of water needed to achieve the desired strength and workability of concrete, tests must be conducted. The moisture content of coarse aggregates was determined by drying a sample of coarse aggregate (2000gm) in an oven at a temperature of 1100c for 24hrs, and then dividing the weight difference by the oven-dry weight.

3.11.2.3 Specific gravity and Water absorption

A specific gravity of a material is the ratio between the weight of the material and that of the same volume of water tests done according to ASTM C 128-93 (2001) standard test method.

Figure 3.7 Specific gravity and water absorption test for coarse aggregate

3.11.2.4 Unit weight of coarse aggregate

Unit weight, also known as bulk density, refers to the weight of a specific volume of graded aggregate. The unit weight tests for the coarse aggregate samples were conducted following ASTM C-29 standards.

Figure 3.8 Unit weight test for coarse aggregate

3.11.3 Cement

The cement used to produce the samples for this study was Portland cement (PPC), specifically Cement Grade 32.5N, which is readily available in the market. The specific gravity of the Dangote PPC was known to have 2.9.

3.11.4 Teff straw ash

Sergegna or Brown (mixture of red and white) Teff Straw used in this study are collected from farmer around Woliso town, Ethiopia. It was filled in sacks and transported to the research Centre at JiT Construction Laboratory.

The Teff straw used in this study was obtained from the south west shoa Zone, woliso in Ethiopia. A metric ton of teff straw was collected from the farmer and treated by sodium hydroxide then wash through portable water and sun-dried for 24 hours[36]. It was burned in an open environment and later in a furnace for two hours at 600°C. The purpose of this process was to remove excess carbon in the ash and obtain amorphous silica. The teff straw ash was produced at the JIT laboratory. After burning, the teff straw was sieved through a 75μm sieve.

Advantage of using sodium hydroxide

There are a number of benefits to treating teff straw with sodium hydroxide before burning it to replace cement in concrete.

- **Improved bonding**: Teff straw's lignin is broken down by the sodium hydroxide treatment, which makes it possible for it to function as a natural adhesive when combined with cement. By doing this, the cement matrix and teff straw may link better, making the concrete stronger and longer-lasting.
- **Enhanced fire resistance**: By eliminating volatile ingredients and raising the carbon content of teff straw, the sodium hydroxide treatment can make it more fire resistant. By doing this, the likelihood of structural damage can be decreased and the concrete's fire resistance increased.
- **Reduced shrinkage**: During the burning process, the treatment can aid in lessening the shrinking of teff straw. Reducing shrinkage helps strengthen the concrete's overall integrity and durability because it can cause cracks and damage the structure.
- **Improved moisture resistance**: Teff straw can be treated with sodium hydroxide to increase its resistance to absorbing moisture. This can lessen the chance of deterioration and increase the lifespan of the concrete by keeping water from seeping through.

a. adjust furnace b. burning at furnace c. TSA after burning at furnace

Figure 3.8 Teff straw burning at furnace and teff straw ash (TSA)

3.11.5 Water

A potable water used for drinking supplied from Jimma town water supply and sewerage authority was used for washing aggregate, mixing and curing of concrete.

3.12 Experimental procedure

3.12.1 Mix design

Concrete mix design is a process that involves preparing a mixture of ingredients to achieve the desired strength and durability for a concrete structure.

In this study, C-25 grade concrete was used, and the mix design followed ACI procedures. The control mix had a ratio of 1:1.99:2.83 (cement: fine aggregate: coarse aggregate), which was used for this work with a constant water-cement ratio of 0.5. Various amounts of TSA were added to the mix, with ash proportions of 5%, 10%, and 15% by weight of the cement in the concrete. The following steps were followed for the mix design, as per the ACI code [37]

Step 1: collected data for mix design:-

- Fineness modulus of selected fine aggregate = 2.80
- Rodded Unit weight of coarse aggregates =1650 kg/m3
- Specific gravity of coarse and fine aggregate in saturated surface dry condition is 2.70 and 2.6 respectively.
- Absorption characteristic of both fine and coarse aggregate is 1.27%and 0.4% respectively
- Specific gravity of Portland pozolana cement = 2.90
- Free surface moisture in sand and Corse aggregate is 0.5 % & 1.4% respectively

Step 2: Determination of water to cement ratio

Effective water cement ratio from strength point of view is 0.62 and from exposure point of view is 0.5. So, by adopt water to cement ratio is 0.50 for the exposure condition.

Step 3: Maximum size of aggregate and workability

Maximum size of coarse aggregate is 20mm.

Slump value is assumed 50-100mm and air content 2%

Step 4: Cement content

For the slump of 50-100mm and 20mm maximum size of aggregate, the maximum water content is 185.

Cement content =185/0.5=370 kg/m3 kg/m3.

Step 5: weight of coarse aggregate

From ACI table, for maximum size of 20mm coarse aggregate and fineness modulus of sand 2.8, the dry rodded bulk volume of coarse aggregate is 0.63 per unit volume of concrete.

The weight of coarse aggregate = 0.63*1650 kg/m3= 1039.5kg/m3

Step 6: weight of fine Aggregate

Table 3.2 Volume of ingredient used

Item No	Ingredient	Weight(kg/m^3)	volume (cm^3)	volume (m^3)
1	Cement	370	$127.59*10^3$	0.12063
2	Water	185	$185*10^3$	0.185
3	Gravel	1039.5	$384.77*10^3$	0.385
4	Air	_	$20*10^3$	0.02
Total			$717.586*10^3$	

Therefore, absolute volume of fine aggregate = $(1000-717.586)*10^3= 282.414*10^3$

Weight of fine aggregate = 282.414*2.6= 734.276 kg/m^3

Step 7: Proportions

Table 3.3 Proportion before adjustment for field condition

Ingredients	Cement	sand	gravel	water
quantity (kg/m^3)	370	734.276	1039.5	185
Ratio	1	1.98	2.81	0.50
Quantity in kg,	50	99.23	140.47	25.0

Step 8: Adjustment for field condition

Fine aggregate has surface moisture of 0.5 % and absorbs 1.27%

Weight of fine aggregates = $(754.045+0.005*754.045)kg/m^3$ = 757.82 kg/m^3

Coarse aggregate absorbs 0.74% of water and surface moisture 1.4%

Weight of coarse aggregate = (1039.5+0.0074*1039.5) kg/m^3= 1047.19 kg/m^3

Adjust the amount of water based on moisture content

The required mixing water =185 -757.82*(0.005-0.0074) - 1047.19*(0.0014-0.00127) = 186.635

Step 9: Final design proportion

Table 3.4 Final design proportion

Ingredients		Cement	sand	gravel	water
quantity (kg/m^3)		370	737.95	1047.19	186.63494
Ratio		1	1.99	2.83	0.50
One bag cement		50	100	142	25.2

3.13 Mixing and curing

The procedure for mixing teff straw ash blended concrete is the same as that of normal concrete. All the ingredients are measured according to the required volume of concrete. A total of nine mix types are prepared.

The volume of concrete mixed consists of three cubes, three cylinders, and three flexure; a result of total volume of 0.012343m3. The teff straw ash is mixed properly with cement, followed by the addition of sand. The cement mixed with ash is then dry mixed.

Next, the coarse aggregate is added gradually with a small amount of water, while continuously mixing, until achieving a uniform mixture of teff straw ash blended concrete.

Firstly, different sizes of specimens were prepared using cast iron and wooden moulds. The cubes measured 150 x 150 x 150 mm, the beams were 100 x 100 x 500 mm, and the cylinders had a diameter of 100 mm and a length of 200 mm. Wooden moulds were also utilized to increase the number of available molds for flexure testing.

Figure 3.9 Mixing and casting

Before pouring the concrete into the moulds, the mating surfaces and interiors of the moulds were coated with a thin layer of oil to prevent the concrete from sticking. The moulds were then positioned correctly and compacted until the specified conditions were met.

The specimens should be stored in moist air for 24 hours. After 24 hours, the specimens should be removed from the mould and marked. They should then be submerged in clear fresh water until they are taken out from the curing tank just prior to the test. Before testing, the concrete should be surface dry for two hours, while still in a moist condition.

The average compressive strength of the three specimens, which were made with the same concrete mixture and tested at the same age, is considered as the characteristic compressive strength of the mixture. According to ASTM C39, the concrete was surface dried for two hours before testing it in a moist condition. The mass weight of the specimen was measured.

The image below show cases the various types of casted specimens, including beams, cylinders, and cubes.

Figure 3.10 Demolding and curing casted specimen

3.14 Tests conduct on concrete

Two different tests are conducted on concrete for this experiment. The first test focuses on the fresh concrete properties, specifically the workability achieved through the slump cone. The second test examines the hardened concrete, including tests for compressive strength, flexural strength, and split tensile strength.

3.14.1 Workability

The workability of a concrete mix refers to how easy it is to place, compact, and finishes the concrete without the materials separating or segregating. Workability is important for two reasons:

1. If the concrete mixture is too wet, the coarse aggregates settle at the bottom, causing an uneven composition.
2. If the concrete mixture is too dry, it becomes challenging to handle and position.

Slump test

The concrete slump test is used to measure the consistency of fresh concrete before it hardens. This test is performed to assess the workability of newly mixed concrete, which determines how easily it can be poured and flows.

Apparatus

The equipment needed for the slump test includes a slump cone, a non-porous base plate, a measuring scale, and a temping rod. The mold used for the test is shaped like a frustum of a cone, with a height of 30 cm, a bottom diameter of 20 cm, and a top diameter of 10 cm.

Procedures followed during slump cone test are:

- Prepare a clean, wide, flat mixing pan.
- Place the dampened slump cone on one side of the pan and ensure it is held firmly in place by the operator standing on the two foot pieces.
- Pour the newly mixed concrete prepared for the test in three layers, with each layer being approximately one third of the volume of the mold.
- Rod each layer with 25 strokes of the tamper, making sure to distribute the strokes evenly across the cross section of the mold. Each stroke should penetrate just into the underlying layer. In the case of the bottom layer, this may require inclining the rod slightly and making approximately half of the strokes spirally towards the center of the mold throughout its depth.
- When filling and rodding the top layer, heap the concrete above the mold before starting the rodding process
- Measure the slump immediately by determining the difference between the height of the mold and the height of the vertical axis (not the maximum height) of the specimen.

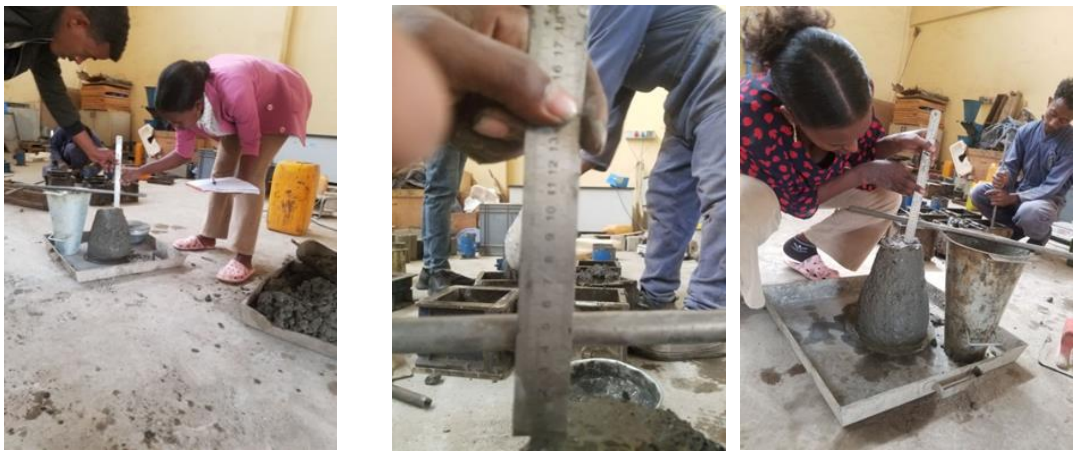

Figure 3.11 Slump test on concrete

3.14.2 Compressive strength

The compressive strength test of concrete is the most common test type for the hardened concrete. The reasons for these are; many codes and design manuals are based on this property, many other properties of concrete depend on the compressive strength and when compared to other tests this is an easy one. The size of specimen is 15×15×15 cm was cast for C25 grade of concrete added with TSA, these cubes were tested on compression testing machine (UTM).

The compressive strength is given by:

$$\text{Compressive stress } (\sigma) = \frac{\text{Peak load}}{cross\ sectional\ area} = \frac{P}{A} = \frac{P}{b*d} \ldots\ldots\ldots\ldots\ldots \text{eq3.6}$$

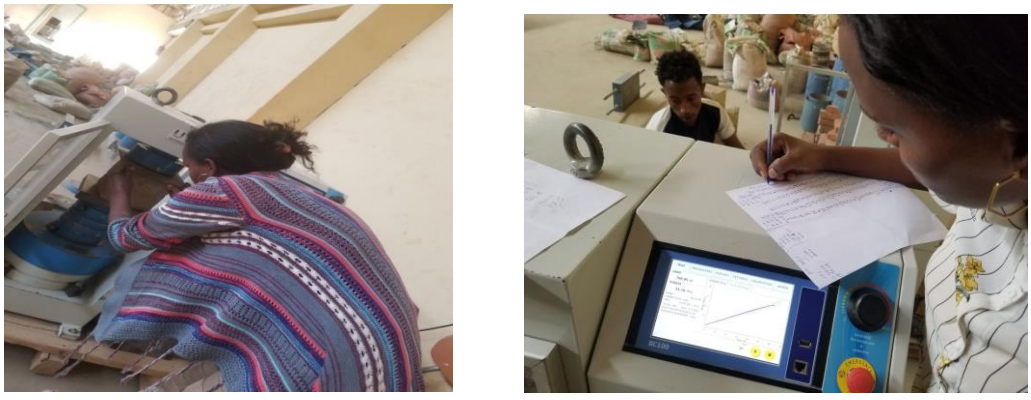

Figure 3.12 Compressive strength tests machine

3. 14.2.1 Standard for compressive strength of concrete at various ages

The compressive strength test of concrete is the most common test type for the hardened concrete. To specify the concrete compressive strength, fck(t), at time t for a number of stages (e.g. demoulding, transfer of prestress) [38].

Where fck(t)=fcm(t)-8(MPa) for 3 <t <28 days

fck(t)=fck for t ≥28 days

The compressive strength of concrete at an age t depends on the type of cement, temperature and curing conditions. For a mean temperature of 20°C and curing in accordance with EN 12390 the compressive strength of concrete at various ages fcm(t) may be estimated from Expressions (3.1) and (3.2) [38].

$$\text{fcm}(t) = \beta cc(t) fcm \text{.....eq3.7}$$

$$\beta cc\,(t) = \exp\left\{ s\left[1 - \left(\frac{28}{t}\right)^{1/2}\right]\right\} \text{.....eq3.8}$$

Where (t)- is the mean concrete compressive strength at an age of t days

fcm- is the mean compressive strength at an age of 28 days

(t)- is coefficient which depends on the age of the concrete t

t- is age of the concrete in day

s- is coefficient which depends on the type of the cement

= 0.20 for cement of strength Classes CEM 42.5 R, CEM 52.5 N & CEM 52.5R (Class R)

= 0.25 for cement of strength Classes CEM 32.5 R, CEM 42.5 N (Class N)

= 0.38 for cement of strength Classes CEM 32.5 N (Class S)

For this study Dangote PPC grade 32.5N was used and the value of s =0.38

Where the concrete does not conform to the specification for compressive strength at 28 days the use of Expressions (eq3.7) and (eq3.8) is not appropriate.

7th day Concrete conform the specification

$$\beta cc\,(t) = \exp\left\{ s\left[1 - \left(\frac{28}{t}\right)^{1/2}\right]\right\}$$

$$s = 0.38 \; and$$

$$for\ 7^{th}\ day\ t = 7$$

$$\beta cc\ (7) = \exp\left\{0.38\left[1-\left(\frac{28}{7}\right)^{1/2}\right]\right\}$$

$$\beta cc(7) = \underline{0.6839}$$

$$fcm(t) = \beta cc(t) fcm$$

$$fcm\ for\ concrete\ C25/30 = 33MPa$$

$$fcm\ (7) = 0.6839 * 33$$

$$fcm(7) = \underline{22.5687MPa}$$

$$fcm\ (t) = (t) - 8(MPa) \qquad for\ 3 < t < 28\ days$$

$$fcm\ (7) = 22.5687MPa - 8MPa$$

$$fcm\ (7) = \underline{14.5686MPa}$$

To convert the 7th day compressive strength of concrete using cylinder to its value by cube 1.25 factor used based on ESEN-2:2015 for C25/30.

$$\boldsymbol{fck,cube} = \mathbf{1.25} * \boldsymbol{fck}$$

$$\boldsymbol{fck},(\mathbf{7}) = \mathbf{1.25 * 14.5687} \quad \boldsymbol{fck},(\mathbf{7}) = \underline{\mathbf{18.211MPa}}$$

14th day Concrete conform the specification

$$\beta cc\ (t) = \exp\left\{s\left[1-\left(\frac{28}{t}\right)^{1/2}\right]\right\}$$

$$s = 0.38\ and$$

$$for\ 14^{th}\ day\ t = 14$$

$$\beta cc\ (14) = \exp\left\{0.38\left[1-\left(\frac{28}{14}\right)^{1/2}\right]\right\}$$

$$\beta cc\ (14) = \underline{0.8544}$$

$$fcm(t) = \beta cc(t) fcm$$

$$fcm\ for\ concrete\ C25/30 = 33MPa$$

$$fcm\ (7) = 0.8544 * 33$$

$$fcm\ (7) = \underline{28.1952MPa}$$

$$fcm\ (t) = fcm\ (t) - 8(MPa) \qquad for\ 3 < t < 28\ days$$

$$fcm\ (7) = 28.1952MPa - 8MPa$$

$$fcm\ (7) = \underline{20.195MPa}$$

To convert the 14th day compressive strength of concrete using cylinder to its value by cube 1.25 factor used based on ESEN-2:2015 for C25/30.

$$\boldsymbol{fck,cube} = \mathbf{1.25} * \boldsymbol{fck}$$

$$\boldsymbol{fck,(14)} = \mathbf{1.25 * 20.195} \quad \boldsymbol{fck,cube(14)} = \underline{\boldsymbol{25.244MPa}}$$

28th day Concrete conform the specification

$$\beta cc\ (t) = \exp\left\{s\left[1 - \left(\frac{28}{t}\right)^{1/2}\right]\right\}$$

$$s = 0.38\ and$$

$$for\ 28^{th}\ day\ t = 28$$

$$\beta cc\ (28) = \exp\left\{0.38\left[1 - \left(\frac{28}{28}\right)^{1/2}\right]\right\} = 1$$

$$\beta cc\ (28) = 1$$

$$fcm(t) = \beta cc(t) fcm$$

$$fcm\ for\ concrete\ C25/30 = 33MPa$$

$$fcm\ (28) = 1 * 33$$

$$fcm\ (28) = \underline{33MPa}$$

$$fcm\ (t) = fcm\ (t) - 8(MPa) \qquad for\ 3 < t < 28\ days$$

$$fcm\ (28) = 33MPa - 8MPa$$

$$fcm\ (28) = \underline{25MPa}$$

$$fcm\ (28) = fck \qquad for \geq 28\ days$$

$$fck\ for\ concrete\ C25/30 = 25MPa$$

To convert the 28th day compressive strength of concrete using cylinder to its value by cube 1.25 factor used based on ESEN-2:2015 for C25/30.

$$\boldsymbol{fck,cube} = \mathbf{1.25} * \boldsymbol{fck}$$

$$\boldsymbol{fck,cube(28)} = \mathbf{1.25 * 25} \quad \boldsymbol{fck,cube(28)} = \underline{\mathbf{31.25MPa}}$$

3.14.3 Split tensile strength

The tensile strength of concrete is crucial for concrete structures, as they are highly susceptible to cracking under tension caused by various factors and applied loads. However, it is important to note that the tensile strength of concrete is significantly lower compared to its compressive strength.

The split-cylinder test is an indirect method used to determine the tensile strength of concrete. In this test, a horizontal cylinder measuring 100mm by 200mm in length is placed on a compression testing machine. The load is applied uniformly and diametrically along the entire length of the cylinder. To ensure an even distribution of the load and prevent excessive compressive stress at the point of application, plywood strips are placed between the specimen and the compressive surface of the testing machine. The compression testing machine used has a capacity of 2000 KN. The load is gradually increased and maintained until the specimens fail. The maximum load applied to each specimen is recorded.

Figure 3.13 Split tensile strength tests machine

The splitting tensile stress is obtained using the following formula.

$$T = \frac{2P}{\pi LD} \ldots\ldots\ldots\ldots\ldots\ldots \text{eq3.9}$$

Where, T= the spilt tensile strength of the concrete

P= compressive load on the cylinder

L= length of the cylinder

D= diameter of the cylinder

3.14.3.1 Standard for split tensile strength of concrete at various ages

The split-cylinder test is an indirect method used to determine the tensile strength of concrete. In this test, the splitting tensile strength (fct,sp) is measured, and it can be considered as an approximate value for the axial tensile strength (fct).

$$fct = 0.9fct,\text{sp} \ldots\ldots\ldots\ldots eq\ 3.10$$

The development of tensile strength with time is strongly influenced by curing and drying conditions as well as by the dimensions of the structural members [38]. As a first approximation it may be assumed that the tensile strength fctm (t) is equal to:

$$\text{fctm}(t) = (\beta\text{cc}(t))^{\alpha} * fctm \ \ldots\ldots eq\ 3.11$$

Where (t) follows from Expression (3.2) and

$$\alpha = 1\ for\ t < 28$$

$$\alpha = 2/3\ for\ t \geq 28$$

95 % fractile $fctk,0.95 = 1.3 * fctm$

7th day Concrete conform the specification

$$\beta\text{cc}(t) = \exp\left\{s\left[1 - \left(\frac{28}{t}\right)^{1/2}\right]\right\}$$

$$s = 0.38\ and\ for\ 7^{th}\ day\ t = 7\ \alpha = 1$$

$$\beta\text{cc}(7) = \exp\left\{s\left[1 - \left(\frac{28}{7}\right)^{1/2}\right]\right\} = \underline{0.6839}$$

$$\text{fctm}(t) = (\beta\text{cc}(t))^{\alpha}.fctm \qquad fctm \text{ for } C25/30 = 2.6$$

$$\text{fctm (t)} = (0.6839)^{1} * 2.6$$

$$\text{fctm(t)} = \underline{1.778}$$

$$fctk,0.95 = 1.3 * 1.778$$

$$fctk,0.95 = \underline{2.312}\ for\ 7th\ day$$

14th day Concrete conform the specification

$$\beta\text{cc}(t) = \exp\left\{s\left[1 - \left(\frac{28}{t}\right)^{1/2}\right]\right\}$$

$$s = 0.38\ and\ for\ 14^{th}\ day\ t = 14\ \alpha = 1$$

$$\beta\text{cc}(7) = \exp\left\{0.38\left[1 - \left(\frac{28}{14}\right)^{1/2}\right]\right\} = \underline{0.8545}$$

$$\text{fctm}(t) = (\beta\text{cc}(t))^{\alpha}.fctm \qquad fctm \text{ for } C25/30 = 2.6$$

$$fctm(t) = (0.8545)^{1} * 2.6$$

$$fctm(t) = \underline{\underline{2.222}}$$

$$fctk,0.95 = 1.3 * fctm$$

$$fctk,0.95 = 1.3 * 2.222$$

$$fctk,0.95 = \underline{\underline{2.889}}\ for\ 14th\ day$$

28th day Concrete conform the specification

$$\beta cc(t) = \exp\left\{s\left[1 - \left(\frac{28}{t}\right)^{1/2}\right]\right\}$$

$$s = 0.38\ and\ for\ 28^{th}\ day\ t = 28\ \alpha = 2/3$$

$$\beta cc(28) = \exp\left\{0.38\left[1 - \left(\frac{28}{28}\right)^{1/2}\right]\right\} = \underline{\underline{1}}$$

$$fctm\ (t) = (\beta cc(t))^{\alpha}.fctm \qquad fctm \text{ for } C25/30 = 2.6$$

$$fctm\ (t) = (1)^{2/3} * 2.6$$

$$fctm\ (t) = \underline{\underline{2.6}}$$

$$fctk,0.95 = 1.3 * fctm$$

$$fctk,0.95 = 1.3 * 2.6$$

$$fctk,0.95 = \underline{\underline{3.38}}\ for\ 28^{th}\ day$$

3.14.4 Flexural strength

The concrete beam specimen, measuring 100 mm x 100 mm x 500 mm, was loaded at one-third of the distance from the support and at its interior location. The load was gradually increased until failure using a bending testing machine. The failure load, as per ASTM C 42, was recorded to determine the tensile stress at which the member failed.

A two-point loaded flexural strength testing machine with a capacity of 2000KN was used. The

beam sample was marked at 10cm from each end and at the mid span. The loads were applied at one-third of the distance from the support on both sides, as shown in the following flexural strength setup.

Figure 3.14 Flexural strength tests machine

The strength was determined from the general formula of flexural stress.

a) If failure with in the middle third of the span

$$M.R = \frac{\mathrm{PL}}{bd^2} \ldots\ldots\ldots\ldots\ldots\ldots \text{eq3.12}$$

b) If the failure occurs outside the middle third of the span length by not more than 5% of the span length

$$M.R = \frac{3\mathrm{PA}}{bd^2} \ldots\ldots\ldots\ldots\ldots \text{eq3.13}$$

Where: M.R= modulus of rupture

P = maximum applied load, N

L = span length, mm

b = average width of specimen, mm

d = average depth of specimen, mm

A = average distance between line of fracture and the nearest support measured on the tension surface of the beam

3.14.5 Compressive stress-strain relationship of concrete

The stress-strain relationship is a crucial property of a material as it indicates the internal stress induced by an applied force and the resulting strain from the material's deformation. This property is specific to each material and is commonly represented by a stress-strain curve. In this study, dial gauge ESEN-2:2015 was utilized to measure and determine the strain corresponding to each stress level obtained [38].

ES EN 1992-2015 standard for Stress –strain of concrete at various ages

The relation between $\boldsymbol{\sigma c}$ and $\boldsymbol{\varepsilon c}$ (compressive stress and shortening strain) for short term uniaxial loading is described by the equation below

$$\frac{\sigma c}{fcm} = \frac{k\eta - \eta 2}{1+(k-2)\eta} \ldots\ldots\ldots\ldots eq\ 3.14$$

$$where\ \eta = \frac{\varepsilon c}{\varepsilon c1}$$

$$\varepsilon c1\ is\ the\ strain\ at\ peak\ stress$$

$$k = 1.05 * \frac{Ecm * |\varepsilon c1|}{fcm} \ldots\ldots\ldots\ldots\ldots eq\ 3.15$$

$$\frac{\sigma c}{fcm} = \frac{\left[1.05 * \frac{Ecm * |\varepsilon c1|}{fcm}\right]\eta - \eta 2}{1 + \left[\left(1.05 * \frac{Ecm * |\varepsilon c1|}{fcm}\right) - 2\right]\eta}$$

$$\text{and } \eta = \frac{\varepsilon c}{\varepsilon c1}$$

$$\frac{\sigma c}{fcm} = \frac{\left[1.05 * \frac{Ecm * |\varepsilon c1|}{fcm}\right]\frac{\varepsilon c}{\varepsilon c1} - \left(\frac{\varepsilon c}{\varepsilon c1}\right)^2}{1 + \left[\left(1.05 * \frac{Ecm * |\varepsilon c1|}{fcm}\right) - 2\right]\frac{\varepsilon c}{\varepsilon c1}}$$

CHAPTER FOUR

RESULT AND DISCUSSIONS

This experimental study aimed to investigate the effect of TSA on the characteristics of normal concrete. The study utilized readily available construction materials and maintained a constant water-cement ratio. Various percentages of TSA ash were used in place of cement, specifically 0%, 5%, 10%, and 15%, by weight. The study assessed how utilizing TSA ash affected the workability, compressive, split tensile strength and flexural strength of concrete C-25/30.

4.1 Result on physical properties of material

4.1.1 Sieve analysis

Sieve analysis for coarse aggregate

The maximum aggregate size used in the analysis was 20mm. The sieve sizes used for the coarse aggregate ranged from 20mm to 4.75mm, in accordance with ASTM C33 standards. Figure 4.1 displays the upper and lower limits of the coarse aggregate grading. Appendix A, Table A-6 provides a brief summary of the cumulative percentage passing, percentage retained, and the specified range of requirements.

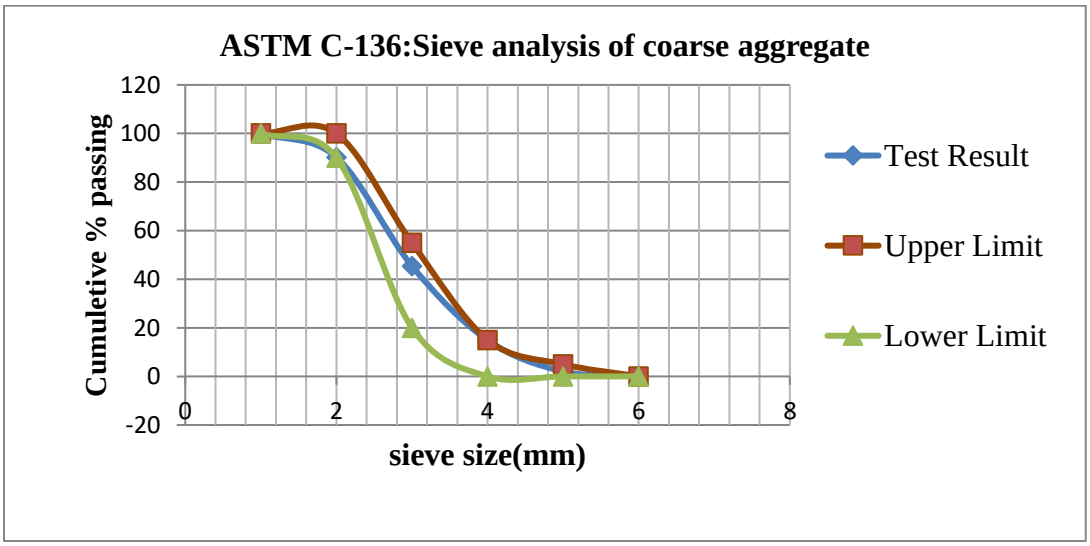

Figure 4.1 Sieve analysis test result for coarse aggregate

Sieve analysis for fine aggregate

Fine aggregate fully pass through a sieve with a size of 9.5mm was used. The average fineness modulus, which measures the uniformity of grading, was calculated using the particle size distribution data. Figure 4.2 shows the upper and lower limits of the fine aggregate grading, while Appendix A, Table A-7 provides detailed information such as the cumulative percentage passing, percentage retained, fineness modulus, and the required range according to [39].

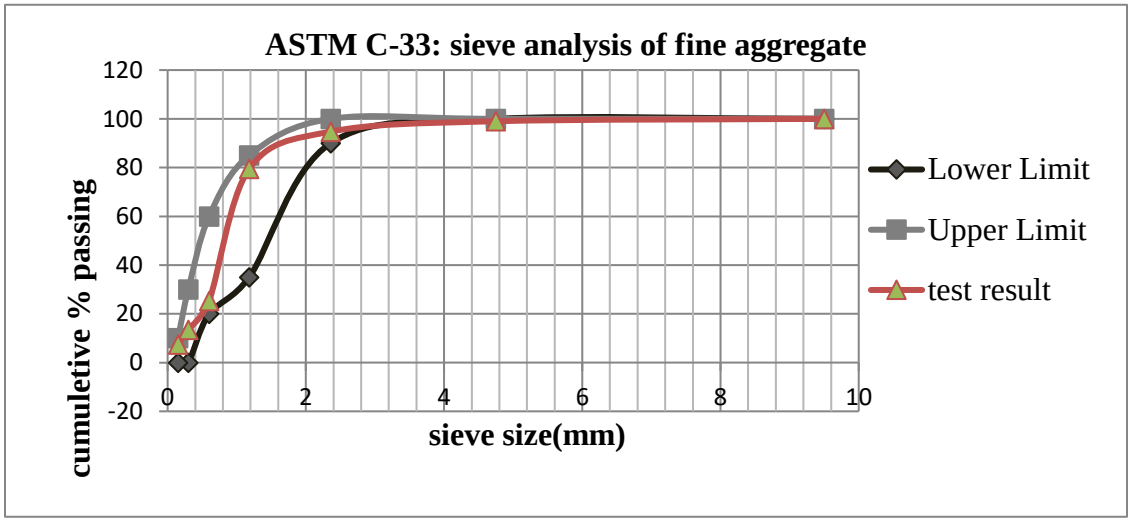

Figure 4.2 Sieve analysis test result for fine aggregate

The detailed procedure for finding aggregate properties illustrated under Appendix-A, Table A-1, TableA-2, TableA-3, TableA-4 and TableA-5. The following Table 4.1shows summary of physical properties of aggregates

Table 4.1 Summary of water absorption, specific gravity, unit weight and moisture content of aggregate

Aggregate	Apparent specific gravity	Bulk specific gravity (SSD)	Bulk specific gravity (oven dry)	Absorption capacity (%)	Unit weight (Kg/m^3)	Moisture content (%)
Fine	2.72	2.7	2.68	0.4	1585	0.5
Coarse	2.63	2.6	2.58	0.74	1650	0.4

Table 4.2 Physical properties of cement

Cement brand	PPC
Initial setting time(min)	150
Final setting time(min)	270
Specific gravity(g/cm^3)	2.9

4.2 Result and discussions on Teff straw ash (TSA) and Cement blend pastes

4.2.1 Consistency of blended pastes

Cement hardens into a solid mass when mixed with water through a process called hydration. It can bind together two or more substances that do not naturally stick together. To conduct various tests on cement, a neat cement paste of standard consistency must be made by mixing the cement with the correct amount of water. The correct amount of water is determined using a vicat apparatus, which measures the resistance of the paste to the penetration of a 300gm plunger released onto the surface of the paste. The water-cement ratio is important in determining the rate of hydration and setting of the cement.

The quantity or percentage of mixing water required to prepare a cement paste of standard consistency is determined. The detailed procedure for finding consistency of cement illustrated under Appendix-B, Table B-1.

Table 4.3 Normal consistency of cement containing TSA

Sample No.	Percentage of replacement (%)	Consistency (%) (ASTM C187)
1	Control	29
2	5%	30
3	10%	31
4	15%	33

4.2.2 Setting time of blended pastes

The Ethiopian standard sets a minimum initial setting time of 45 minutes and a maximum final setting time of 10 hours for cement. The results shown in Table 4.3 indicate that the addition of teff straw ash slows down the setting process of concrete, or retards the setting time. However, this retardation stays within the limits specified by the Ethiopian standard. The setting time shows a trend of increasing as the content of teff straw ash increases.

The reason for this increase in setting time could be the water absorption by the teff straw ash. The higher the proportion of teff straw ash, the more water is absorbed, increasing the normal consistency. This, in turn, slows down the setting process of concrete or retards the setting time of the paste.

Table 4.4 Setting time of pastes containing TSA

Sample No.	Code	Initial setting time(minute)	Final setting time(minute)
1	Control	150	270
2	5%	154	276
3	10%	166	286
4	15%	180	307

4.3 Effect of TSA on fresh concrete properties

4.3.1 Workability

Slump test

It was found from the test findings that the concrete's slump decreased as the amount of TSA content increased. The reason for this decline is TSA's great absorption capacity. Particularly, the measurements for the slumps were 55, 50, and 44 mm for TSA replacements at 5%, 10%, and 15%, respectively. The decline at 5% TSA replacement revealed a minor decrease of 0.05% in comparison to the control. The reduction was 0.14% at 10% and 0.24% at 15%, respectively. The range given by ACI 211 concrete, which establishes a minimum slump height of 25mm, is still within these values, it is vital to remember that. Figure 4.3, Appendix-B, Table B-3, provides a detailed process for determining the slump result.

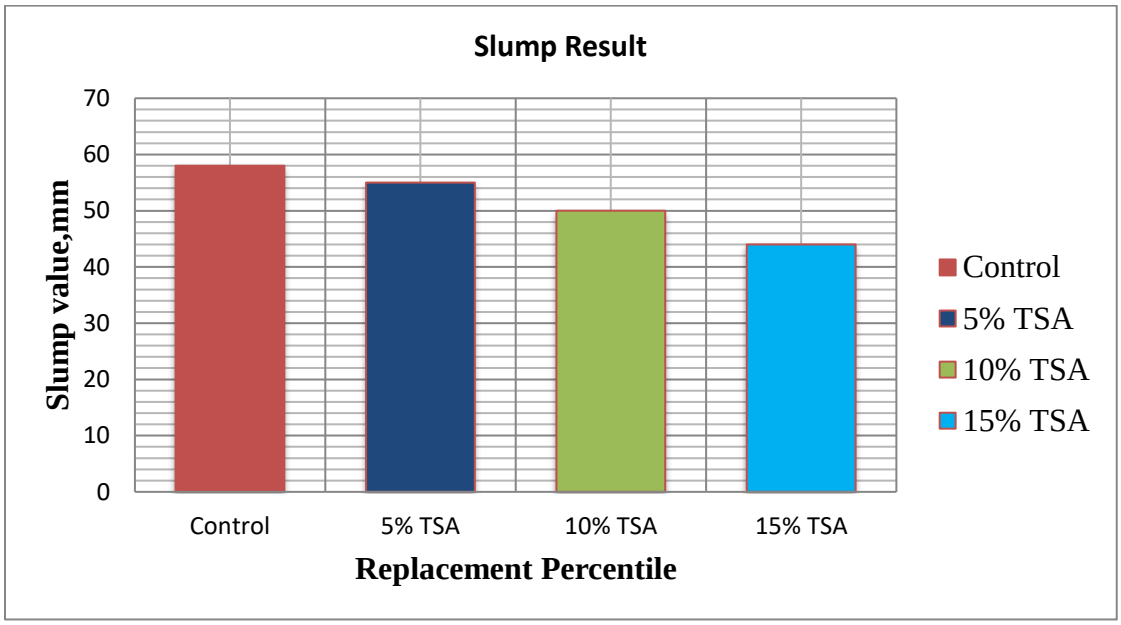

Figure 4.3 Slump test result for control and TSA

As observed from Figure 4.3, the slumps of the concrete containing teff straw ash decrease as the percentage of ash content increases. To achieve a similar slump for the control mix and PPC-TSA concrete, the water content needs to be increased as the TSA content increases. Table 4.1 (normal consistency) also shows that the normal consistency of the blended pastes increases with an increase in TSA, indicating that PPC-TSA blended concretes require a higher water content than concrete without TSA to achieve a certain slump. This is likely because TSA has a lower density and higher porosity, resulting in a greater need for water. According to [40],concretes with slumps less than 15 mm may not have adequate plasticity, while concretes with slumps greater than about 230 mm may not have adequate cohesiveness for this test to be significant. Therefore, since the slump of the study falls within the range of 44-58 mm, TSA concrete exhibits good plastic and cohesive properties. Consequently, TSA concrete is effective in minimizing segregation of fresh concrete during placement and consolidation.

4.4 The impact of Teff straw ash on the density of hardened concrete

The weight and dimensions of the concrete cubes, cylinders, and beams are measured right before testing them for compressive strength, split tensile strength, and flexural strength. The

results for weight and dimensions can be found in Appendix C, Table C-1, Table C-2 and Table C-3. The unit weight of the specimens is calculated based on the average mass of specimens on the 7th, 14th and 28th at age of curing.

Table 4.5 Mass and density of cube specimens

% added of TSA	7th day		14th		28th	
	Average mass	Density(Kg/m3)	Average mass	Density(Kg/m3)	Average mass	Density(Kg/m3)
control	8.490	2515.56	8.693	2575.8	8.760	2595.56
1	8.333	2469.14	8.443	2501.73	8.713	2581.73
2	8.103	2400.99	8.360	2477.04	8.533	2528.4
3	7.657	2268.64	8.067	2390.12	8.167	2419.75

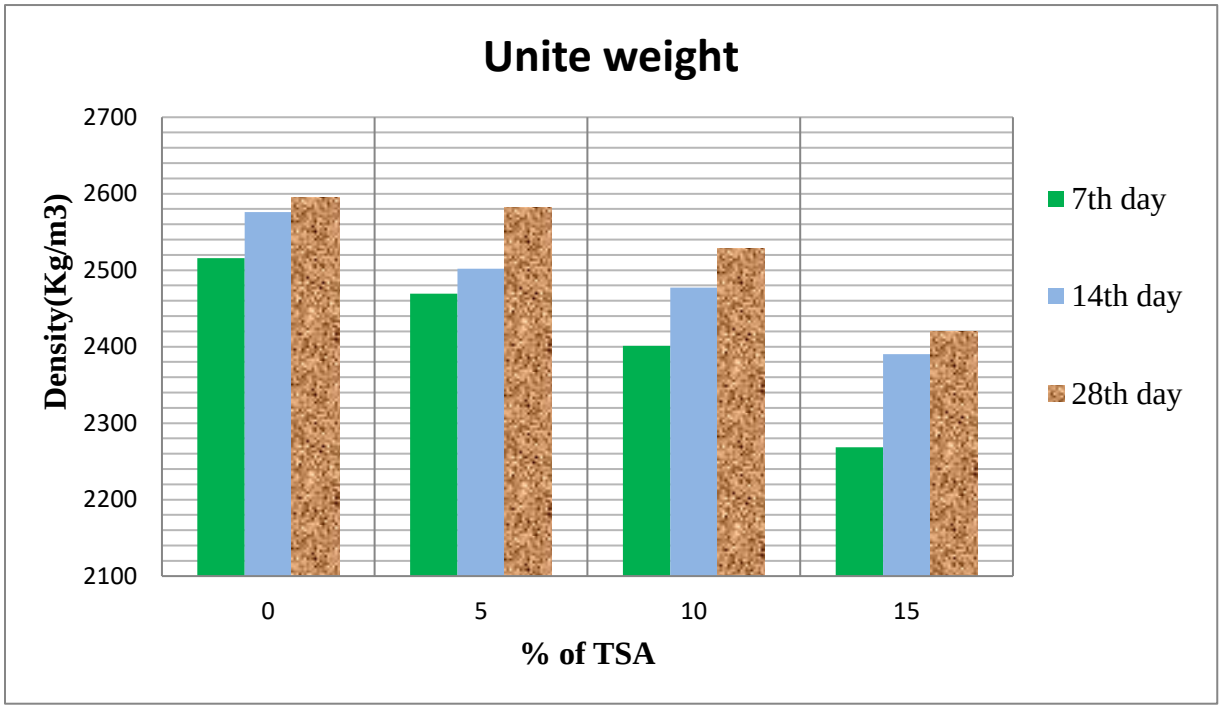

Figure 4.4 Unite weight cube versus percentage of TSA

The results indicate that as the percentage of teff straw ash (TSA) replacement increases, there is a reduction in density. The table shows that when 5% TSA was added, the control concrete

experienced a density reduction of 0.53%. This reduction continued up to 2.53% when 15% of the cement was replaced with TSA. Additionally, a reduction of 6.77% was observed with 10% TSA replacement.

Therefore, as a result, the concrete using TSA has a lower unit weight. A low density concrete has many advantage over dense concrete. Reduce the dead load of the structure and equivalent reduction in foundation size. Similarly for density of cylinder and beam also detailed illustrated under Appendix-C, Table C-4, Table C-5, Table C-6, Table C-7, Table C-8 and Table C-9.

4.5 Effect of TSA on harden concrete properties

4.5.1 Compressive strength test result

Table 4.6 Compressive strength test result on 7th day

Compressive strength test result on 7th day							
Mix no.	% of ash added	Avg. peak load(KN)	Avg. stress (mpa)	Variation from standard (%)	fck, cube (28)	Min. required fck,cube(28)	Remark
1	Control	499.89	22.08	17.52	22.08	18.211	conform the specification
2	5%	481.52	21.36	14.74	21.36	18.211	conform the specification
3	10%	441.32	19.54	6.8	19.54	18.211	conform the specification
4	15%	396.37	17.33	-5.08	17.33	18.211	not conform the specification

Table 4.7 Compressive strength test result on 14th day

Compressive strength test result on 14th day							
Mix no.	% of ash added	Avg. peak load(KN)	Avg. stress (mpa)	Variation from standard (%)	fck, cube (28)	Min. required fck,cube(28)	Remark
1	Control	627.38	27.51	8.2	27.51	25.244	conform the specification
2	5%	612.58	26.71	5.4	26.71	25.244	conform the specification
3	10%	570.86	25.27	0.12	25.27	25.244	conform the specification
4	15%	468.54	20.78	-21.48	20.78	25.244	not conform

Table 4.8 Compressive strength test result on 28th day

Compressive strength test result on 28th day							
Mix no.	% of ash added	Avg. peak load(KN)	Avg. stress (mpa)	Variation from standard (%)	fck, cube (28)	Min. required fck,cube(28)	Remark
1	Control	775.73	34.46	9.3	34.46	31.25	conform the specification
2	5%	753.07	33.33	6.2	33.33	31.25	conform the specification
3	10%	751.02	33.04	5.42	33.04	31.25	conform the specification
4	15%	636.37	29.19	-7.05	29.19	31.25	not conform

The compressive strengths of concrete cubes show a decrease with an increase in the proportion of TSA, according to test data. Comparing the addition of TSA to the control mix, the compressive strength decreases. The decline becomes more noticeable as the percentage of ash increases. When percent of the cement is substituted with an equivalent volume of TSA on the 28th day, the compressive strength test results reveal losses of 6.2% at 5%, 5.42% at 10%, and 7.05% at 15%, respectively. But for every % of TSA substitution, the compressive strengths rise with the number of curing days.

Table 4.9 Average compressive strength values of concrete summary

Mix No.	percentage of replacement	Average compressive strength (N/mm^2)			Loss of strength in % due to increasing TSA			Increment of strength due to aging of cubes from 7days - 28 days (%)
		7^{th}day	14^{th}day	28^{th}day	7^{th}day	14^{th}day	28^{th}day	
1	Control	22.08	27.51	34.46	0	0	0	35.93
2	5%	21.36	26.71	33.33	3.26	2.91	3.02	35.91
3	10%	19.54	25.27	33.04	11.5	8.14	4.21	40.86
4	15%	17.33	20.78	28.29	21.51	24.46	16.53	38.74

The decrease in TSA concrete compressive strength is likely due to the significant replacement of cement with TSA. This reduces the amount of cement in the mixture, leading to a decrease in the hydration reaction. Additionally, the high TSA content increases the water requirement, resulting in water being unavailable for cement hydration. The trend in concrete compressive strength is illustrated in Figure 4.6.

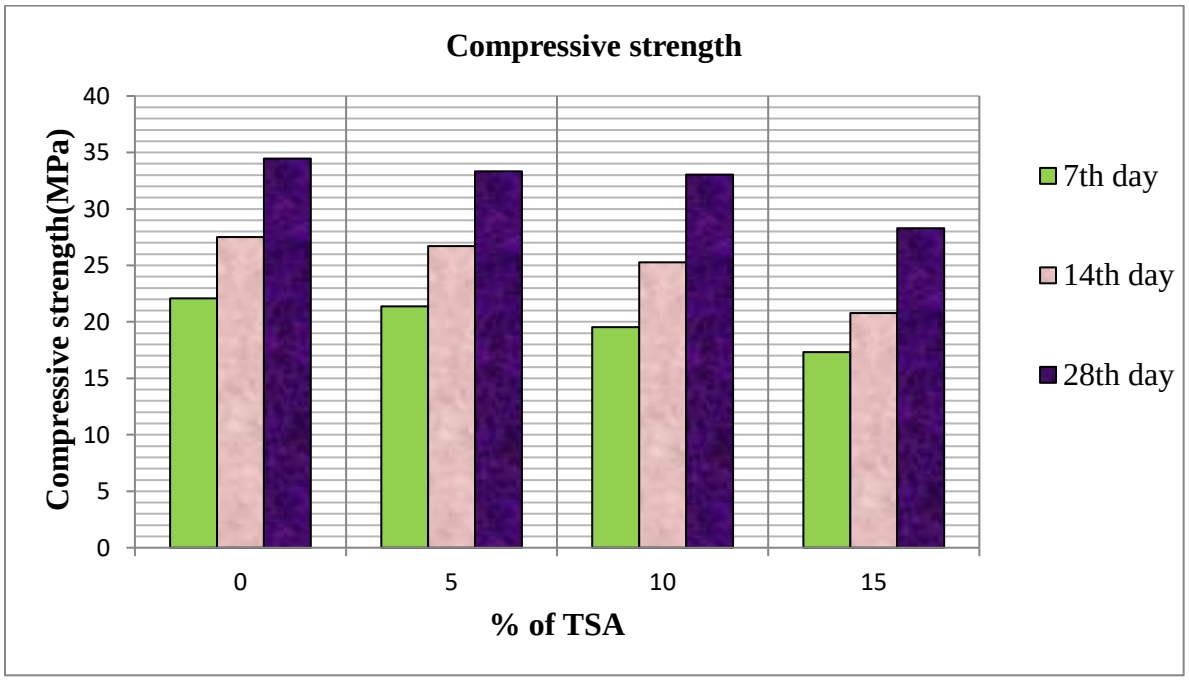

Figure4.6 Compressive strength at different curing age

Although the addition of TSA has significantly decreased the compressive strength values, as shown in Table 4.8 and Figure 4.5, the values still fall within a reasonable range up to 10%. However, for a 15% replacement, the values slightly fail to reach the targeted grade of concrete C-25.

As shown on Table, the compressive strength on the 28th day slightly decreased with an increased TSA, ranging from 3.02% to 16.53% compared to the control mix.

4.5.2. Split tensile strength test result

Table 4.10 Split tensile strength test result on 7th day

Split tensile strength test result on 7th day								
mix no	% of ash added	Avg. peak load(KN)	Avg.stress (mpa)	Variation from control (%)	fct,sp	fct(7)	Min. required fctk,(7)	Remark
1	Control	87.76	2.795	0	2.795	2.516	2.312	ok
2	5%	86.83	2.765	1.08	2.765	2.489	2.312	ok
3	10%	83.72	2.666	4.61	2.666	2.399	2.312	ok
4	15%	77.27	2.461	11.96	2.461	2.215	2.312	not conform

Table 4.11 Split tensile strength test result on 14th day

mix no	% of ash added	Avg. peak load(KN)	Avg. stress (mpa)	Variation from control (%)	fct(14)= 0.9*fct, sp	Min. required fctk, (14)	Remark
1	Control	109.65	3.492	0	3.14	2.889	ok
2	5%	106.68	3.397	2.7	3.06	2.889	ok
3	10%	101.65	3.237	4.7	2.91	2.889	ok
4	15%	90.96	2.897	11.96	2.61	2.889	not conform

Table 4.12 Split tensile strength test result on 28th day

mix no	% of ash added	Avg. peak load(KN)	Avg. stress (mpa)	Variation from control (%)	fct(28)= 0.9*fct, sp	Min. required fctk, (28)	Remark
1	Control	121.46	3.87	0	3.48	3.38	ok
2	5%	119.37	3.8	1.81	3.42	3.38	ok
3	10%	118.14	3.76	2.84	3.39	3.38	ok
4	15%	112.96	3.6	6.98	3.2	3.38	not conform

A clear relationship was observed between the split tensile strength of the control mix and the TSA content, as shown in Table 4.6, Table 4.7, Table 4.8, and Figure 4.8. With an increase in TSA content, the split tensile strength on the 7th, 14th, and 28th day decreased proportionally. However, even with a decrease, the values remained within a reasonable range up to 10% replacement. At 15% replacement, the split tensile strength slightly fails to reach the targeted grade of concrete C-25, indicating that TSA concrete does not conform to the specifications.

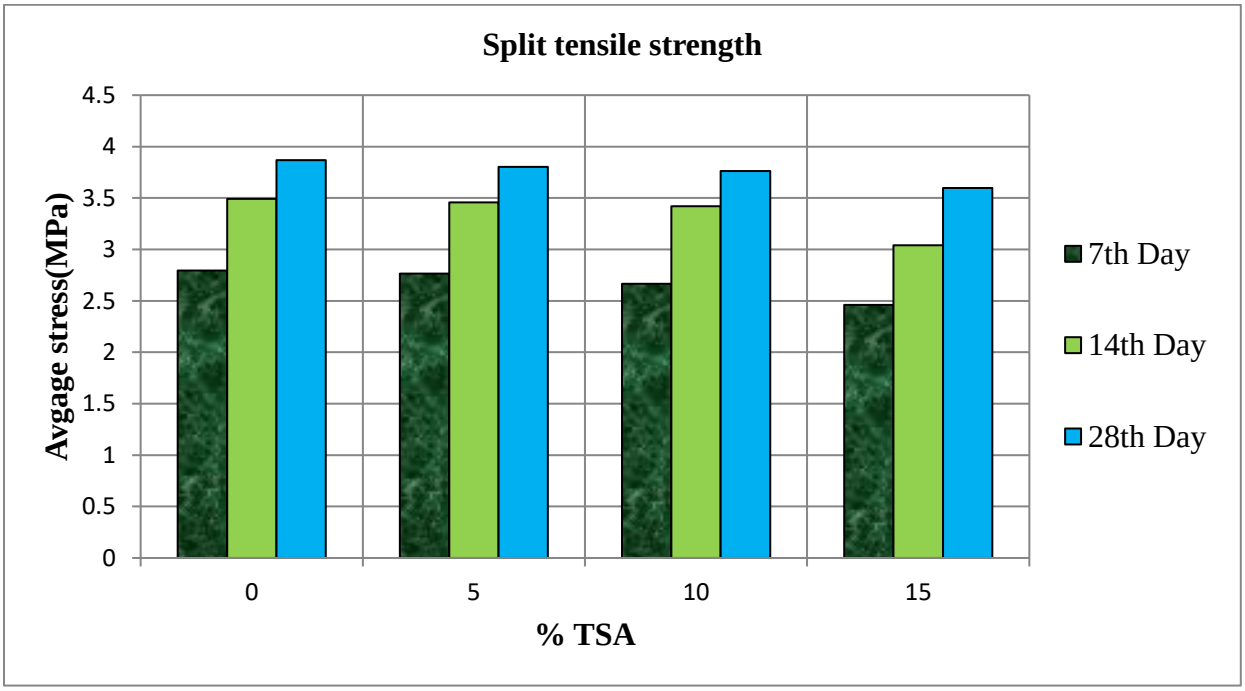

Figure 4.7 split tensile strength

As shown on result spilt tensile strength on the 28th was slightly decreased with an increasing TSA within range 1.08% to 6.98% as compere to control mix.

4.5.2.1 Split tensile strength test result analysis by linear regression

Linear regressions result for 7th days

As figure 4.8 shows the peak point for stress compere to the ES EN 1992-2015 fails at point of the minimum values for 7th days of standard is 2.312

$$y = -2.74x + 2.6417\,, \qquad y = 2.312$$

$$2.312 = -2.74x + 2.6417$$

$$x = 12.03\%$$

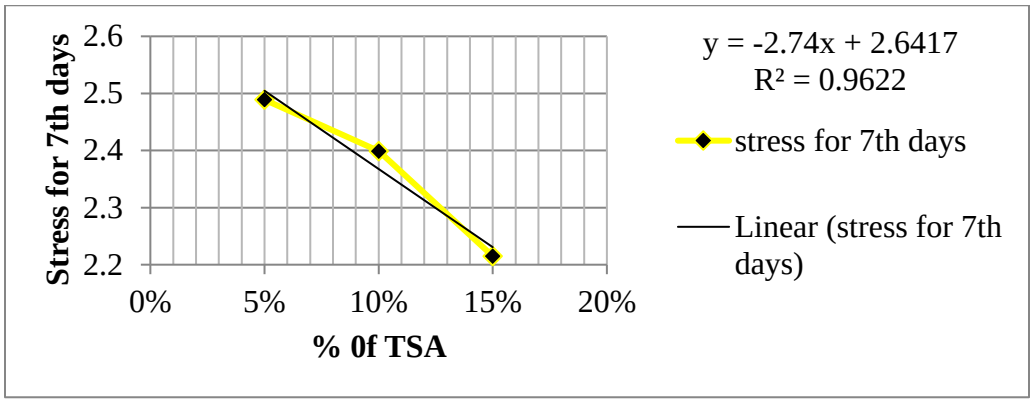

Figure 4.8 linear regressions for 7th split tensile strength

As figure4.9 shows the peak point for stress compere to the ES EN 1992-2015 fails at point of the minimum values for 14th days of standard is 2.889

$$y = -2.74x + 2.6417\,, \qquad y = 2.312$$

$$2.312 = -2.74x + 2.6417$$

$$x = 12.03\%$$

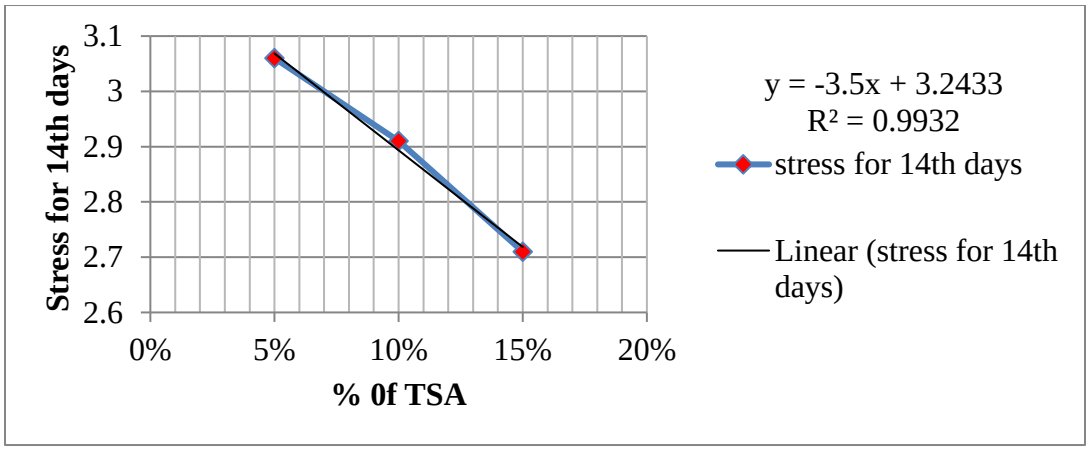

Figure 4.9 linear regressions for 14th split tensile strength

As figure4.10 shows the peak point for stress compere to the ES EN 1992-2015 fails at point of the minimum values for 28th days of standard is 3.38

$$y = -0.7x + 3.4567, \qquad y = 3.38$$

$$3.38 = -0.7x + 3.4567$$

$$x = 10.95\%$$

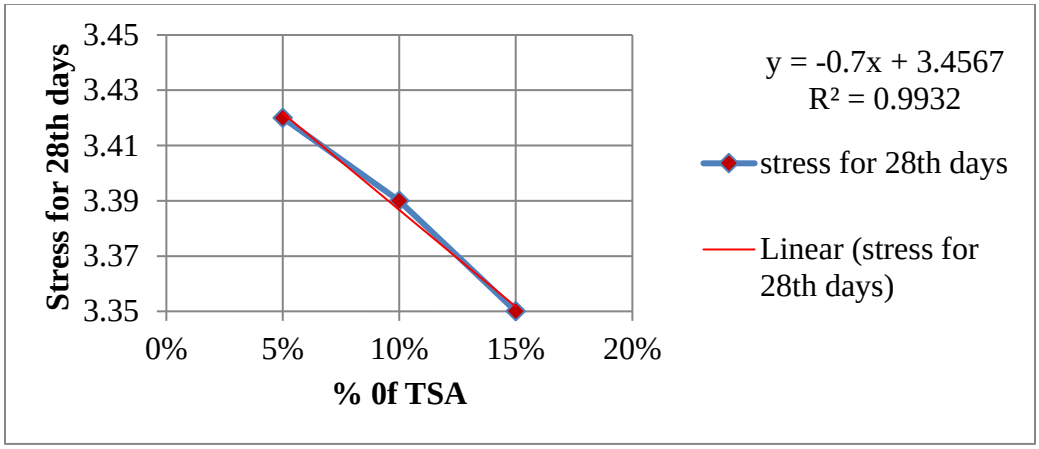

Figure 4.10 linear regressions for 28th split tensile strength

4.5.3 Flexural strength test result

The flexural bending strength is another characteristic that can reflect concrete's tensile capacity, and the flexural test evaluates the tensile strength of concrete indirectly. Two-point loading flexural tests were conducted experimentally. It tests the ability of a plain concrete beam to withstand failure in bending. The results of the flexural test on concrete are expressed as a modulus of rupture denoted as (MR) in MPa or psi.

The average flexural stresses were calculated from the average rupture loads recorded from the testing machine, and flexural stresses are determined for each sample. The average flexural strength test result for 7th, 14th and 28th days are shown in figure 4.8 the detail flexural test result are tabulated under Appendex-C,TableC-7,TableC-8 and TableC-9.

The observed flexural strength of the Control mix and TSA blended concrete is clearly displayed in the discussions derived from figure 4.11.

It was found that as curing ages increased, as well concrete's flexural strength. Positive percentage differences were noted between the 7th, 14th, and 28th day test results for 5%, 10%, and 15% TSA in relation to the control mix. For the control the 28th day result yielded the maximum flexural strength of 7.15 MPa.

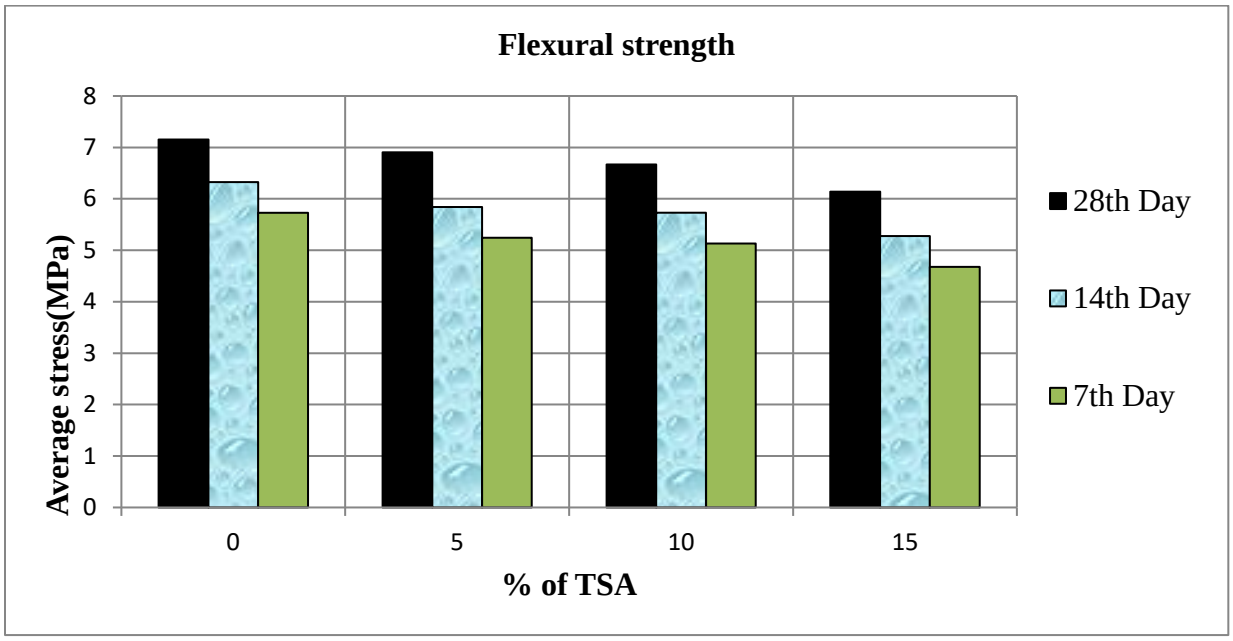

Figure 4.11 Flexural strength test result

4.5.4 Stress strain relationship for compressive strength test result

The strain values for each corresponding stress were determined using equation 3.14 in scilab-6.1.1. Table 4.13, 4.14 and 4.15 shows the average compressive stress and average strain values for the four experimental group samples on the 7th, 14th, and 28th day. The detailed cube stress-strain relationship for the 7th, 14th, and 28th days test is listed under Appendix-E, Appendix-F and Appendix-G.S

From the below Table 4.16 results show that from 7th day test result the maximum average strain obtained at 22.08MPa compressive strength is 0.002095. This result is greater than or equal to 0.001864 which is the requirement of ES EN 1992-2015 code standard. From 14th day test result the maximum average strain obtained at 27.51MPa compressive strength is 0.0020486 for control mix concrete this result is greater than or equal to 0.002 which is the requirement of ES EN 1992-2015 code standard. Similarly for 28th day test result the maximum average strain obtained at34.46 compressive strength is 0.0021617 which is greater than or equal to 0.002118 which is the requirement of ES EN 1992-2015 code standard.

Table 4.13 7th day average compressive stress and strain at peak load

Mix No.	percentage of replacement	Average peak load(KN)	Average Compressive Stress(MPa)	Average strain	standard stress at 7th day	standard strain at 7th day
1	Control	499.89	22.08	0.002095	18.211	0.001864
2	5%	481.52	21.36	0.0019273	18.211	0.001864
3	10%	441.32	19.54	0.0018908	18.211	0.001864
4	15%	396.37	17.33	0.001847	18.211	0.001864

Table 4.14 14th day average compressive stress and strain at peak load

Mix No.	percentage of replacement	Average peak load(KN)	Average Compressive Stress(MPa)	Average strain	standard stress at 14th day	standard strain at 14th day
1	Control	627.38	27.51	0.0020486	25.244	0.002
2	5%	612.58	26.71	0.0020276	25.244	0.002
3	10%	570.86	25.27	0.0020025	25.244	0.002
4	15%	468.54	20.78	0.001916	25.244	0.002

Table 4.15 28th day average compressive stress and strain at peak load

Mix No.	percentage of replacement	Average peak load(KN)	Average Compressive Stress(MPa)	Average strain	standard stress at 28th day	standard strain at 28th day
1	Control	775.73	34.46	0.00216	31.25	0.00212
2	5%	753.07	33.33	0.00212	31.25	0.00212
3	10%	751.02	33.04	0.00214	31.25	0.00212
4	15%	636.37	28.19	0.00206	31.25	0.00212

Table 4.16 Summary of stress strain result

No.	7th days		14th days		28th days	
	stress	strain	stress	strain	stress	strain
standard	18.211	0.001864	25.24	0.002	31.25	0.002118
control	22.08	0.002095	27.51	0.002049	34.46	0.002162
5%	21.36	0.001927	26.71	0.002028	33.33	0.002122
10%	19.54	0.001891	25.27	0.002003	33.04	0.002143
15%	17.33	0.001847	20.78	0.001916	28.19	0.002064

4.5.4.1 Analysis test result using linear regression on excel for 7th, 14th and 28th days

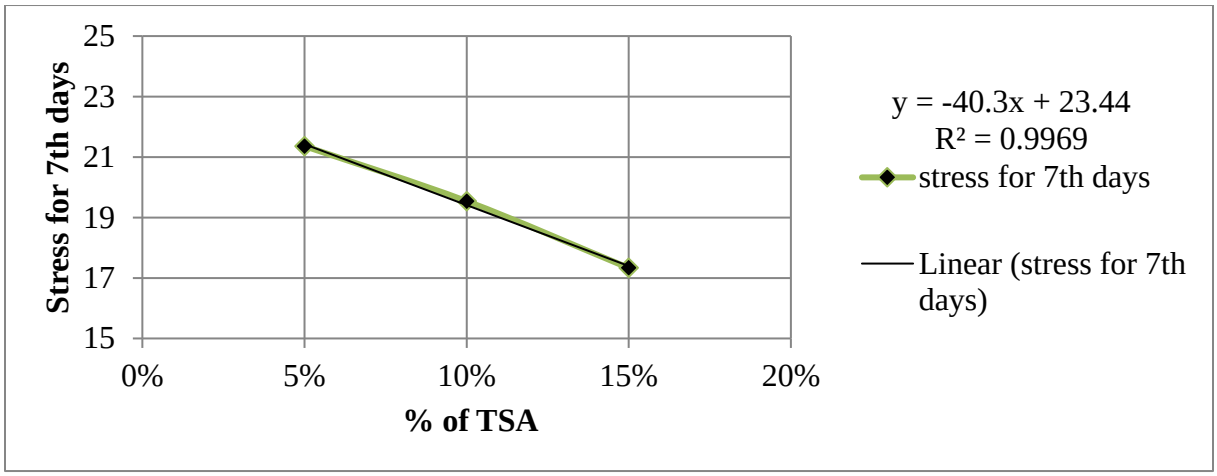

Figure 4.12 linear regressions for 7th day's stress test result

As analysis result shows the peak point for stress compere to the ES EN 1992-2015 fails at point of the minimum values for 7th days of standard is 18.211

$$y = -40.3x + 23.44\,, \qquad y = 18.211$$

$$18.211 = -40.3x + 23.44$$

$$x = 12.98\%$$

Linear regressions result for 14th day's stress test result

As analysis result shows the peak point for stress compere to the ES EN 1992-2015 fails at point of the minimum values for 14th days of standard is 25.24

$$y = -29.6 + 28.203\,, \qquad y = 25.24$$

$$25.24 = -29.6 + 28.203$$

$$x = 10.01\%$$

Linear regressions result for 28th day's stress test result

As analysis result shows the peak point for stress compere to the ES EN 1992-2015 fails at point of the minimum values for 28th days of standard is 31.25

$$y = -51.4x + 36.66\,, \qquad y = 31.25$$

$$31.25 = -51.4x + 36.66$$

$$x = 10.53\%$$

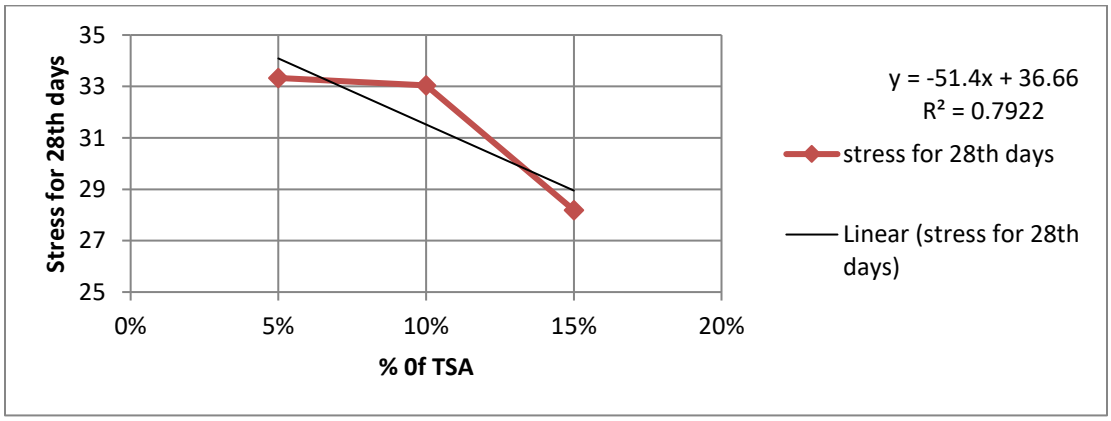

Figure 4.13 linear regressions for 28th day's stress test result

4.5.4.2 Stress versus strain curve for 7th, 14th and 28th days

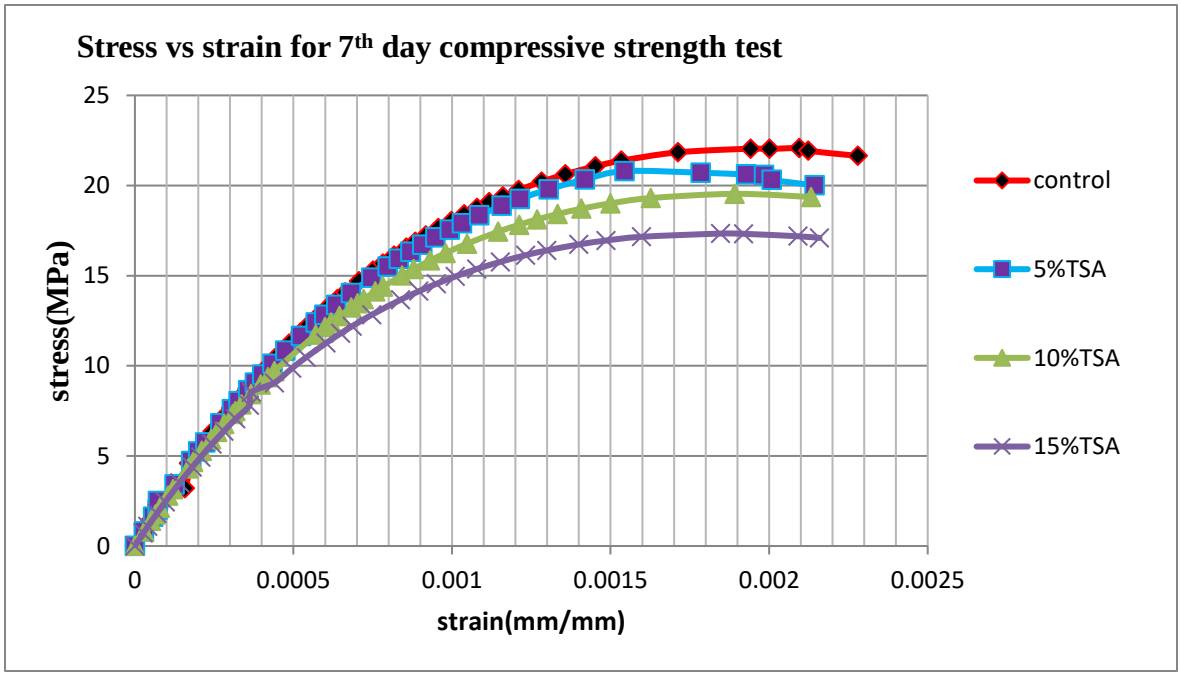

Figure 4.14 Stress vs strain for 7th day compressive strength test

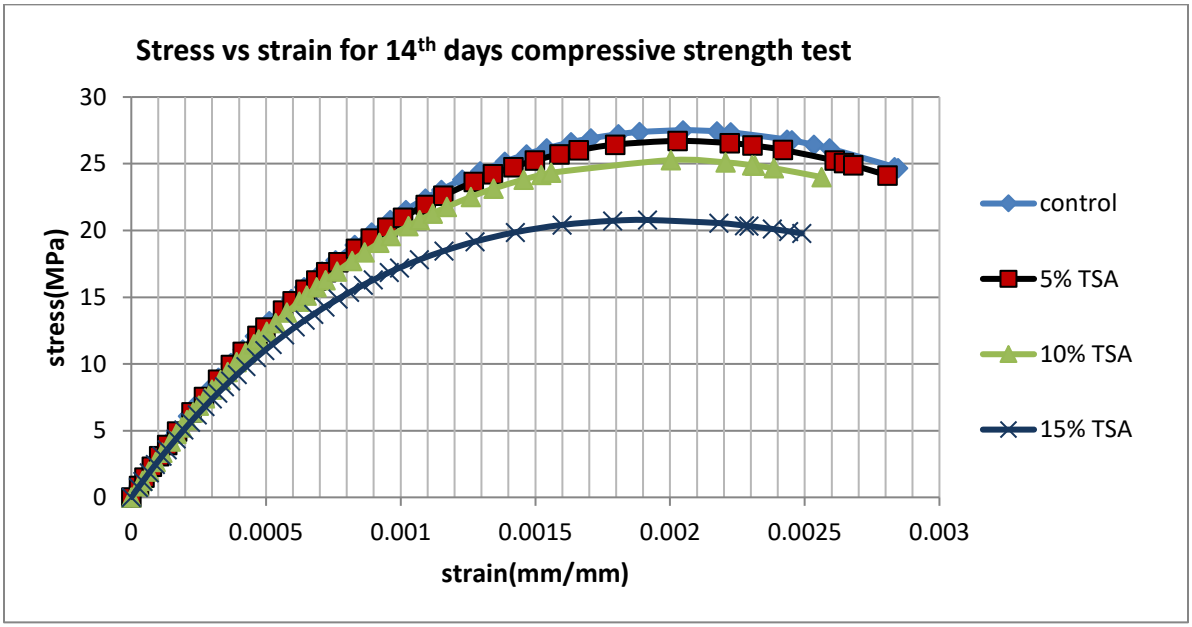

Figure 4.15 Stress vs strain for 14th day compressive strength test

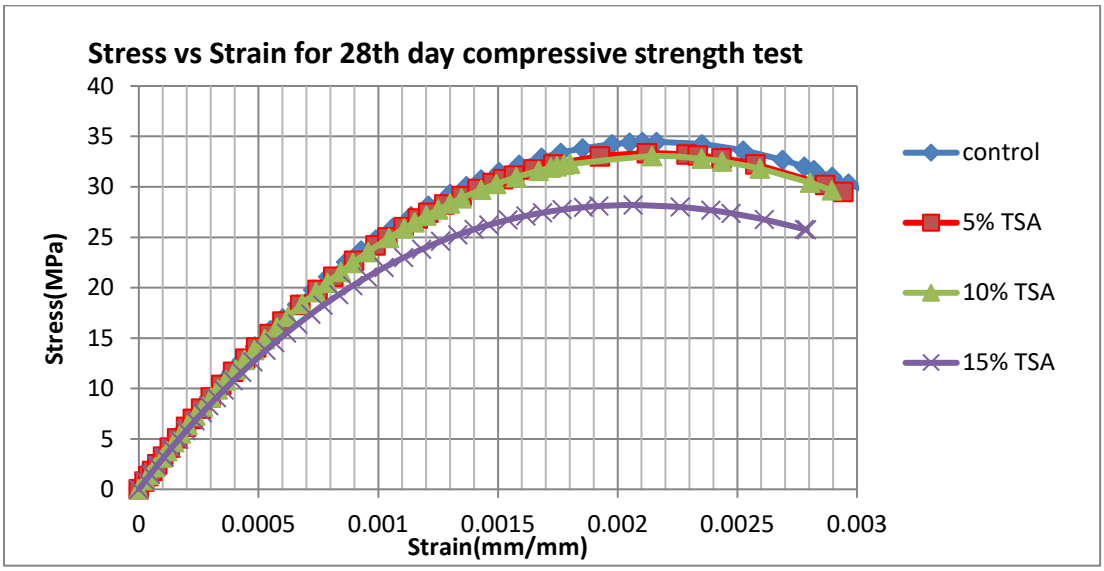

Figure 4.16 Stress vs strain for 28th day compressive strength test

We computed the average stress and strains for every mix that is displayed in Appendix D, Tables D-1, D-2, and D-3. Plotting the stress-strain curve for the 5% TSA, 10% TSA, and 15% TSA mixes throughout the 28-day compressive strength test allowed for comparison with the control. The peak compressive stress and matching strain for the test results from the 28th day are shown in Figure 4.11. Appendix E, F, and G contain the detailed cube stress-strain relations and stress-strain curve for the 7th, 14th, and 28th day testing, respectively.

The following conclusions can be drawn from the stress-strain graph above: the average compressive strength and strain of the concrete increase with increasing curing time. It is shown on the curve for each combination that all of the graphs overlap and that, to some extent, the compressive stress and the corresponding strain are exactly proportionate. This shows the concrete's elastic range.

The load carrying capability (ductile characteristics) of the concrete varies for each mix until the ultimate load is attained, depending upon the variation and the percent of ash replacement. For teff straw ash concrete, the duration of strain up to the point of rupture is smaller than the control's failure point after the point of ultimate load. The minimum average strain and minimum average stress were obtained after 15% TSA was added to the cement.

4.6 Optimum usage of TSA as a partial replacement of cement in concrete production

From the investigation, the optimum recommended limit of TSA replacing of cement for the mixture to produce acceptable strength is achieved up to 5% at the age of 28^{th} days by about 3.18% satisfies the requirement of ES EN 1992 code of standard. 15% TSA replacing of cement for the mixture not fulfilling the strength requirement of ES EN 1992-2015 codes of standard. But for low concrete strength it is recommended.

CHAPTER FIVE

CONCULUSION AND RECOMMENDATION

5.1 Conclusion

The research aimed to study the normal concrete using different percentage values 0-15% of TSA as partial replacement of cement. The study aimed is to find the effect of TSA on C-25 concrete such as workability, compressive strength, split tensile strength, flexural strength and relation between the stress strains. Therefore based on the finding of the study, the following conclusions are drawn.

From the result, the workability of TSA replacement is reduced when the percentage of TSA increases the slump value is decreased by 5.17%, 13.79% and 24.14% at 5%, 10% and 15% of TSA due to the absorption capacity of TSA it required more water.

The compressive strength increases curing period and decreases with the increased amount of TSA. For this TSA concrete, the test result shows that the addition of TSA slightly reduced in compressive strength, split tensile strength and flexural strength compere with control concrete. But with reference to ES EN 1992-2015 strength requirement at 28^{th} day of concrete in which cement is partially replaced showed that for compressive strength there was increment of 6.2% to 5% of TSA and 5.42% to 10% of TSA and a reduction of 7.05% from 15%of TSA, for split tensile test result shows an increment in 1.17% to 5% of TSA and 0.29% to 10% of TSA and reduction of 5.63% to 15% of TSA, similarly for flexural test result shows an increment in 3.4% to 5% of TSA and 6.82% to 10% of TSA and 14.15 % to 15% of TSA.

The compressive stress-strain curves as the date of curing increases the average compressive strength and strain of concrete increases. The duration of strain up to the point of rapture for TSA concrete was less than the point of failure of control mix, but with reference to ES EN 1992-2015 it is more up to 10%.

In general, it can be conclude that, C-25/30 concrete grade with replacing of cement up to 10% by weight of TSA is good in concrete properties such as workability, compressive strength, split

tensile strength and flexural strength .the result showed that the optimum percentage of cement replacement with teff straw ash (TSA) is up to 10%.

5.2 Recommendation

The results of the study lead to the following suggestions being sent out: In a reasonable range for the normal grade of concrete, the TSA as studied in this study can replace cement up to 10% in terms of compressive strength, split tensile strength, and flexural strength. Therefore, it is important to raise awareness about this prospective cement substitute material and encourage its standardized production and usage among relevant parties, such as Ethiopian construction and chemicals institutions, government organizations, Farmer, and cement companies.

A research team should be formed to investigate the use of TSA as a cement substitute material further by bringing together the country's cement manufacturers, farmer (produce teff straw), and higher education institutions. The use of local materials like teff straw ash (TSA) as pozzolans should be encouraged in concrete production.

For further study

The results of this study can be used as a guide by other researchers to confirm, enhance, and uncover more concrete qualities. Thus, some of the areas of interest for additional research are:

- Additional research on concrete plasticity variables for TSA-containing concrete is needed to confirm the experimental findings numerically using finite element analysis.
- Investigation on employing various additives to enhance the mechanical qualities of concrete that contains TSA.
- Investigation on the cost of TSA as compared to cost of cement in Ethiopia.
- Teff straw from different source.
- The test results used in this study were derived from data collected on the 7th, 14th, and 28th days following the test samples' typical curing period. To determine the appropriate features related to the age of the concrete, research on the long-term effects of TSA concrete is necessary.

For future Jimma University Institute of Technology should deliver additional testing machines to analyze the performance of concrete for wider applications. These machines are similar to the strain gauge, biaxial testing machine, comprehensive silicate analysis equipment, and concrete durability testing equipment. Another researcher can investigate the areas stated for more research if the institution offers the machines on the list.

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APPENDICES

APPENDIX-A Physical properties of materials

Specific gravity and Water absorption test for aggregates.

Coarse aggregate

- Start by rejecting any materials that pass through a 4.75mm sieve. Then, use a sample splitter to measure 2 kgs of aggregate. It is important to wash the sample to remove any fine particles.
- Take the sample and place it in a basket. Immerse the basket in distilled water and let it soak for 24 hours at a constant temperature.
- After the 24-hour period, place the basket in a tank with water. Make sure there is 50mm of water above the top of the basket. To remove any trapped air, lift the basket 25mm above the base of the tank and allow it to drop 25 times, at a rate of one drop per second.
- After the jolting process, weigh the basket with the sample in water. Then, remove the sample from the water and let it drain. Next, place the empty basket back in the water and jolt it 25 times. Finally, weigh the empty basket in water.
- Dry the surface of the sample aggregate using a cloth and weigh it. Then, place the sample in an oven and let it dry for 24 hours.
- Once the 24 hours have passed, remove the sample from the oven and let it cool for one hour. Finally, weigh the dried sample. Use the following formula to calculate the specific gravity and absorption capacity for the coarse aggregate.

  The results can be tabulated on table A-1.

  Apparent specific gravity = $\frac{MD}{MD-MW}$

  Bulk specific gravity = $\frac{MD}{MSSD-MW}$ oven dry

  % of water absorption = $\frac{MSSD-MD}{MD}$*100

  Weight of aggregate in wate(WW) = $(Wa - WB)$

  Where: MW Weight in water of the saturated aggregate

  MSSD Weight in air of the saturated surface dry aggregate

  MD Weight in air of oven dried aggregate

SSD Saturated surface dry

Table A - 1 Specific gravity and water absorption of coarse aggregate

It.N	Description	Trial1	Trial2	Trial3	Mean
1	MW=Weight in water of saturated aggregate (kg)	1.234	1.235	1.236	1.235
2	MSSD=Weight in air of saturated surface dry (kg)	2.0085	2.0077	2.008	2.008
3	MD=Weight in air of oven dried aggregate (kg)	1.993	1.992	1.995	1.993
4	Specific gravity of coarse aggregate (Gsa)	2.59	2.60	2.60	**2.60**
5	Water absorption capacity (%)	0.78	0.79	0.65	**0.74**

Fine aggregate

A sample of 500g fine aggregate which is at free-flowing condition without moisture measured and placed into the pycnometer then filled up with water 90 % capacity of the pycnometer.

- Using rod the air bubbles are eliminated with adjusted temperature and the water level of pycnometer filled up to its calibrated capacity.
- The total weight of the pycnometer, sample and water recorded.

$$C = 0.9976V\ a + 500 + w$$

Where C –Weight of pycnometer filled with sample plus water

Va– Volume of water added to pycnometer

W - Weight of the pycnometer empty

- Oven dried the aggregate removed from pycnometer at 105±5℃for an hour then cooled and measured

$$B = 0.9976V + W$$

$Where\ B$ – weight of flask filled with water

V – volume of flask

W – weight of the flask

Bulk specific gravity = $\frac{A}{B+500-C}$

Bulk specific gravity = $\frac{500}{B+500-C}$ (saturated surface dry basis)

Apparent specific gravity = $\frac{A}{B+A-C}$

$$\text{Absorption} = \frac{500-A}{A} * 100$$

Where A – Weight of oven dried sample

B – Weight of pycnometer filled with water

Table A- 2 Specific gravity and water absorption of fine aggregate

It.N	Description	Observations			Mean
1	Weight of saturated & surface dry sand (gm)	500	500	500	500
2	Weight of pycnometer+sample+water (C) (gm)	1868.5	1869	1868.0	1868.5
3	Weight of pycnometer+water (B) (gm)	1554	1554	1554	1554.0
4	Weight of oven dry sand (A) (gm)	498.5	498	497.5	498.0
5	Bulk specific gravity=A/(B+500-C)	2.69	2.69	2.67	**2.68**
6	Bulk specific gravity (sat.sur.dry basis)=500/(B+500-C)	2.70	2.70	2.69	**2.70**
7	Apparent specific gravity=A/(B+A-C)	2.71	2.72	2.72	**2.72**
8	Absorption capacity(%)=((500-A)/A)*100	0.30	0.40	0.50	**0.40**

Unit weight of aggregate

The unit weight is the ratio of weight to volume of given graded fine and coarse aggregate. Laboratory procedures were conducted to determine the unit weight of the fine and coarse aggregate used for this study. The overall procedures include filling the aggregate into three layers using a cylindrical metal and tamping it 25 times for each layer.

The cylindrical metal used has a constant volume. Finally, the net weights of the aggregate measurements were recorded for fine and coarse aggregate.

The formula for unit weight is as follows:

Unit weight = M/V

Where: M is the mass of the sand and

V is the volume of the cylindrical metal.

Table A-3 Unit weight of fine and coarse aggregate

S.No	Description	Observations			
		1	2	3	Mean

1	Loose unit weight of sand, (kg/m3)	1420.0	1413.0	1431.5	**1415.5**
2	Rodded unit weight of sand, (kg/m3)	1590.0	1586.0	1579.5	**1585.16**
3	Loose unit weight of coarse aggregat, (kg/m3)	1572.5	1555.0	1561.5	**1563.0**
4	Rodded unit weight of coarse aggregate, (kg/m3)	1671.0	1640.5	1638.5	**1650.0**

Moisture content of coarse aggregate

During this investigation, the moisture content of a 2kg sample of coarse aggregates is determined. The sample is first dried in an oven at a temperature of 110oC+5oC for 24 hours. After removing the sample from the oven, it is allowed to cool for a few minutes before the mass is measured. The resulting mass is provided below.

Table A-4 Moisture content of coarse aggregate

Item.No	Description	Observations			
		1	2	3	Mean
1	Weight of original sample ,A,(g)	2000	2000	2000	2000
2	Weight of Oven dried sample ,B,(g)	1992.0	1991.5	1992.5	1992.0
3	Moisture content of coarse aggregate%=((A-B)/B)*100	0.40	0.43	0.38	**0.40**

Moisture content of fine aggregate (sand)

1. Measure 500g of sand (A).

2. Place the measured sand samples in an oven and allow them to dry for 24 hours.

3. After 24 hours, remove the samples from the oven and measure their weight, recording it as the dry weight (B).

4. Finally, calculate the moisture content of the sand using the following formula:

% moisture content = $(A - B) / B * 100$

Where:

A = weight of the original sample

B = weight of the oven-dried sample (in grams)

Table A-5 Moisture content of fine aggregate (sand)

Item.No	Description	Observations			
		1	2	3	Mean
1	Weight of original sample ,A,(g)	500	500	500	500
2	Weight of Oven dried sample ,B,(g)	497.5	498.0	497.0	497.5
3	Moisture content of sand %=((A-B)/B)*100	0.50	0.40	0.60	**0.50**

Particle size distribution test for coarse aggregate

1. Take a sample of 5kg coarse aggregate.
2. Arrange the sieves in descending order of size, from top to bottom.
3. Place the measured samples of coarse aggregate on the top sieve and shake using a mechanical sieve shaker for 10-15 minutes. Then, weigh the material retained on each sieve.
4. Calculate the cumulative percentage retained.
5. Finally, calculate the percentage weight that has passed through each sieve.

Table A-6 Particle size distribution test for coarse aggregates

ASTM C-136 Gradation of Coarse aggregate							
Sieve Size [mm]	Mass retained (gm)				% Retained	Cumulative % retained	% Passing
	Trial 1	Trial 2	Trial 3	Mean			
25.0	0.0	0.0	0.0	0.0	0.00	0.00	100.00
19.0	507.5	455.5	503.0	488.7	9.77	9.77	90.23
12.5	2258.5	2164.0	2294.5	2239.0	44.78	54.55	45.45
9.5	1510.5	1570.0	1500	1526.8	30.54	85.09	14.91
4.75	642.0	653	635.0	643.3	12.87	97.96	2.04
Pan	81.5	156.5	66.5	101.5	2.03	99.99	0.01
TOTAL	5000.0	4999	4999	4999	100.0	_	_

Particle size distribution test for fine aggregate

Sieve analysis is performed to determine the particle size distribution in a sample of aggregates. The apparatus used for this analysis consists of eight different types of sieves: 9.5mm, 4.75mm,

2.36mm, 1.18mm, 0.6mm, 0.3mm, 0.15mm, and a pan sieve for fine aggregates. In addition to the sieves, an electric shaker and a weighing balance are also used.

The procedure for conducting the sieve analysis is as follows:

1. Measure 2000g of sand from the sample that will be studied.
2. Arrange the sieves in descending order of size, from top to bottom.
3. Place the measured sample of sand on the top sieve and shake it for 10 minutes.
4. After 10-15 minutes, stop the shaker. Record the weight of the retained sand particles on each sieve by using the weighing balance.
5. Calculate the percentage of weight retained on each sieve, as well as the cumulative percentage retained.
6. Determine the percentage of weight that has passed through each sieve.
7. Finally, calculate the fineness modulus of the sand.

Table A-7 Particle size distribution test for fine aggregates

Sieve Size [mm]	Mass retained (gm)				% Retained	Cumulative % retained	% Passing	ASTM C-33 Limits
	Trial 1	Trial 2	Trial 3	Avg.				
9.5	0	0	0	0	0.00	0.00	100.00	100.00
4.75	13.0	26.0	20.0	19.67	0.98	0.98	99.02	95-100
2.36	82.0	86.0	87.5	85.17	4.26	5.24	94.76	80-100
1.18	310.0	302.0	306.0	306.00	15.30	20.54	79.46	50-85
0.60	1092.0	1075.5	1080.0	1082.50	54.13	74.67	25.33	25-60
0.30	242.0	238.0	233.5	237.83	11.89	86.56	13.44	530
0.15	115.0	118.0	129.0	120.67	6.03	92.59	7.41	0-10
Pan	146.0	154.5	144.0	148.17	7.41	100.00	0.00	_
TOTAL	2000.0	2000.0	2000.0	2000.0		**280.58**	_	_
Fineness modulus of Sand = 280.34/100 **~2.80**								

$$\textit{Fineness modulus} = \sum \frac{cumuletive\ \%\ retained}{100} = \frac{(0.98+5.24+20.54+74.67+86.56+92.59)}{100}$$

$$= \frac{280.01}{100} \sim 2.8$$

TableA-8 standard test method for fine and coarse aggregate

Tests	Standard
sieve analysis for fine and coarse aggregate	ASTMC136[41],C33[35]
Unit weight for fine and coarse aggregate	ASTMC29[42]
Specific gravity and water absorption for fine and coarse aggregate	ASTMCC128,127[43]
moisture content for fine and coarse aggregate	ASTMC566[44]
silt content of fine aggregate	ASTMC117[45]

TableA-9 Silt content

Sample	1	2	3
Weight of original sample(w1)gm	1000	1000	1000
Weight of oven-dry(w2)gm	980	978	975
silt content((w2-w1)/w2)*100	2	2.2	2.5
Average	2.23		

APPENDIX-B Normal consistency of cement, fineness of cement and slump test result on fresh concrete

Table B-1 Normal consistency of blended pastes containing TSA

Trial	Percentage of replacement	Cement quantity (g)	Water quantity	Ash quantity(g)	w/c	penetration depth	% age of water for normal consistency
1	control	400	112	0	0.28	10	28
2		400	116	0	0.29	9	29
3		400	124	0	0.31	11	31
1	5%	380	116	20	0.29	9	29
2		380	120	20	0.3	11	30
1		360	124	40	0.31	10	31

2	10%	360	128	40	0.32	9	32
1	15%	340	128	60	0.32	8	32
2		340	132	60	0.33	9	33

Procedure to determine the fineness of cement and TSA

1. Collect a sample of cement and rub it by hand.
2. Take 100g of the cement sample and record its weight as W1.
3. Place 100g of the cement in a 90 µm sieve and cover it with a lid.
4. Shake the sieve by hand for 15 minutes.
5. After that, weigh the cement retained on the 90 µm sieve as W2.
6. Finally, calculate the fineness of the cement using the following formula:

$$\text{Fineness} = \frac{W2}{W1} * 100$$

The table below shows the values for the fineness of cement.

Table B-2 Fineness of cement result

Trial	Weight of cement sample(w1)	Weight of cement sample retained on 90 µm sieve(w2)	Fineness of cement (%)
1	100g	3.05	3.05
2	100g	2.89	2.89
3	100g	2.92	2.92
Average			2.95

The standard value for the fineness of cement should be less than 10%. In this case, the fineness of the cement was found to be 2.95%, indicating that it falls within the prescribed limit. Consequently, the Dangote PPC used for the investigation meets the requirement. Additionally, since only TSA passing through a 90µm sieve size was used, there was no residual material retained on the sieve. This further confirms that the fineness of the teff straw ash also meets the requirement.

Table B-3 Slump test result

Mix No.	percentage of TSA added	Amount of cement (%)	observed result(mm)
1	Control	100	58
2	5%	95	55
3	10%	90	50
4	15%	85	44

APPENDIX-C Mass and density of specimen

Table C- 1 7th day density of concrete cube (150*150*150)mm with TSA

mix no	% added of TSA	Mass of cube(kg) for 7th day				volume (m3) =l*b*d	Density (Kg/m3) =mass/volume
		sample1	sample2	sample3	Average mass		
1	Control	8.54	8.52	8.41	8.49	0.003375	2515.56
2	5%	8.29	8.21	8.5	8.33	0.003375	2469.14
3	10%	8.01	7.98	8.32	8.10	0.003375	2400.99
4	15%	7.63	8.01	7.33	7.66	0.003375	2268.64

Table C- 2 14th day density of concrete cube (150*150*150)mm with TSA

mix no	% added of TSA	Mass of cube(kg) for 14th day				volume (m3) =l*b*d	Density (Kg/m3) =mass/volume
		sample 1	sample 2	sample 3	Average mass		
1	Control	8.74	8.58	8.76	8.69	0.003375	2575.80
2	5%	8.33	8.36	8.64	8.44	0.003375	2501.73
3	10%	8.25	8.11	8.72	8.36	0.003375	2477.04
4	15%	7.98	8.22	8	8.07	0.003375	2390.12

Table C- 3 28th day density of concrete cube (150*150*150)mm with TSA

mix no	% added of TSA	Mass of cube(kg) for 28th day	volume (m3) =l*b*d	Density (Kg/m3) =mass/volume

		sample 1	sample 2	sample 3	Average mass		
1	Control	8.74	8.66	8.88	8.76	0.003375	2595.56
2	5%	8.96	8.41	8.77	8.71	0.003375	2581.73
3	10%	8.74	8.01	8.85	8.53	0.003375	2528.40
4	15%	7.97	8.55	7.98	8.17	0.003375	2419.75

Table C- 4 7th day density of concrete cylinder (100*200)mm with TSA

mix no	% added of TSA	Mass of cylinder(kg) for 7th day				volume (m3)	Density (Kg/m3)
		sample 1	sample 2	sample 3	Average mass		
1	Control	3.82	3.57	3.74	3.71	0.00157	2363.06
2	5%	3.66	3.72	3.61	3.66	0.00157	2333.33
3	10%	3.56	3.7	3.68	3.65	0.00157	2322.72
4	15%	3.67	3.52	3.41	3.53	0.00157	2250.53

Table C- 5 14th day density of concrete cylinder (100*200)mm with TSA

mix no	% added of TSA	Mass of cylinder(kg) for 14th day				volume (m3)	Density (Kg/m3)
		sample 1	sample 2	sample 3	Average mass		
1	Control	3.78	3.64	3.89	3.77	0.00157	2401.27
2	5%	3.74	3.75	3.76	3.75	0.00157	2388.54
3	10%	3.67	3.74	3.63	3.68	0.00157	2343.95
4	15%	3.67	3.52	3.6	3.60	0.00157	2290.87

Table C- 6 28th day density of concrete cylinder (100*200)mm with TSA

mix no	% added of TSA	Mass of cylinder(kg) for 28th day				volume (m3)	Density (Kg/m3)
		sample 1	sample 2	sample 3	Average mass		
1	Control	3.89	3.67	3.99	3.85	0.00157	2452.23
2	5%	3.72	3.8	3.75	3.76	0.00157	2392.78
3	10%	3.68	3.55	3.95	3.73	0.00157	2373.67
4	15%	3.78	3.43	3.62	3.61	0.00157	2299.36

Table C- 7 7th day density of concrete flexural (100*100*500)mm with TSA

mix no	% added of TSA	Mass of Beam(kg) for 7th day				volume (m3)	Density (Kg/m3)
		sample1	sample2	sample3	Average mass		
1	Control	12.72	12.59	13.6	12.97	0.005	2594
2	5%	12.6	12.51	13.33	12.81333	0.005	2562.667
3	10%	12.51	13	12.6	12.70333	0.005	2540.667
4	15%	12.87	12.05	12.45	12.45667	0.005	2491.333

Table C- 8 14th day density of concrete beam (100*100*500)mm with TSA

mix no	% added of TSA	Mass of Beam(kg) for 14th day				volume (m3)	Density (Kg/m3)
		sample1	sample2	sample3	Average mass		
1	Control	12.78	12.62	13.58	12.9933	0.005	2598.67
2	5%	12.64	12.63	13.64	12.97	0.005	2594
3	10%	12.51	13.33	12.54	12.7933	0.005	2558.67
4	15%	12.87	12.05	12.45	12.4567	0.005	2491.33

Table C- 9 28th day density of concrete beam (100*100*500)mm with TSA

mix no	% added of TSA	Mass of Beam(kg) for 28th day				volume (m3)	Density (Kg/m3)
		sample1	sample2	sample3	Average mass		
1	Control	12.79	12.7	13.51	13	0.005	2600
2	5%	12.66	12.67	13.59	12.9733	0.005	2594.67
3	10%	13.36	12.53	12.56	12.8167	0.005	2563.33
4	15%	12.78	12.89	12.48	12.7167	0.005	2543.33

APPENDIX-D Hardened concrete test result

Table D-1 Average compressive stress and strain for 7th day test result

Compressive strength test result on 7th day						
Mix No.	percentage of TSA added	sample	Peak Load(KN)	Compressive stress(MPa)	Avg. compressive stress(MPa)	Avg. strain

1	Control	1	572.23	25.4324	22.08	0.002095
		2	514.34	22.5778		
		3	413.11	18.3604		
2	5%	1	568.36	25.2604	21.365	0.001927
		2	465.01	20.6671		
		3	411.11	18.2716		
3	10%	1	469.05	20.8467	19.538	0.001891
		2	488.8	21.724		
		3	366.12	16.272		
4	15%	1	398.18	17.6969	17.333	0.001847
		2	396.82	17.6364		
		3	394.11	17.516		

Table D-2 Average compressive stress and strain for 14th day test result

Compressive strength test result on14th day						
Mix No.	percentage of TSA added	sample	Peak Load(KN)	Compressive stress(MPa)	Avg. compressive stress(MPa)	Avg. strain
1	Control	1	663.01	29.4671	27.511	0.0020489
		2	576.02	25.601		
		3	643.11	28.583		
2	5%	1	588.08	26.137	26.7111	0.002028
		2	646.22	28.721		
		3	603.44	26.8196		
3	10%	1	526.34	23.393	25.27407	0.002003
		2	584.01	25.956		
		3	602.22	26.765		
4	15%	1	497.55	22.113	20.7844	0.001916
		2	496.95	22.087		

		3	411.11	18.272		

Table D-3 Average compressive stress and strain for 28th day test result

Compressive strength test result on 28th day						
Mix No.	percentage of TSA added	sample	Peak Load(KN)	Compressive stress(MPa)	Avg. compressive stress(MPa)	Avg. strain
1	Control	1	813.01	36.3	34.37	0.00205
		2	765.27	34.01		
		3	748.92	33.28		
2	5%	1	830.72	36.92	33.33	0.002122
		2	743.47	33.04		
		3	685.01	30.45		
3	10%	1	783.83	34.83	33.04	0.002143
		2	711.01	31.6		
		3	779.23	34.63		
4	15%	1	624.94	27.77	28.19	0.002064
		2	641.23	28.5		
		3	642.95	28.78		

Table D-4 Split tensile strength on 7th day

Split tensile strength test result on 7th day							
Mix No.	% of TSA added	sample	Peak Load(KN)	Split tensile stress(MPa)	Avg. peak load(KN)	Avg. Split tensile stress(MPa)	Variation from control (%)
1	Control	1	85.67	2.728	87.763	2.795	0
		2	91.04	2.899			
		3	86.58	2.757			

2	5%	1	83.99	2.675	86.827	2.765	1.08
		2	90.13	2.870			
		3	86.36	2.750			
3	10%	1	81.25	2.588	83.717	2.666	4.61
		2	80.54	2.565			
		3	89.36	2.846			
4	15%	1	76.34	2.431	77.267	2.461	11.96
		2	74.19	2.363			
		3	81.27	2.588			

Table D-5 Split tensile strength on 14th day

Split tensile strength test result on 14th day							
Mix No.	% of TSA added	sample	Peak Load(KN)	Split tensile stress(MPa)	Avg. Split tensile stress(MPa)	Avg. peak load(KN)	Variation from control (%)
1	Control	1	111.11	3.539	109.647	3.492	0
		2	105.45	3.358			
		3	112.38	3.579			
2	5%	1	114.55	3.648	106.677	3.397	2.7
		2	105.25	3.352			
		3	100.23	3.192			
3	10%	1	106.62	3.396	101.65	3.237	4.7
		2	99.44	3.167			
		3	98.89	3.149			
4	15%	1	94.78	3.018	90.963	2.897	11.96
		2	92.46	2.945			
		3	85.65	2.728			

Table D-6 Split tensile strength on 28th day

Mix no.	% of Ash added	sample	peak load(KN)	split tensile stress(Mpa)	Avg. peak load(KN)	Avg.stress (Mpa)	Varation from control (%)
		1	118.25	3.766	121.463	3.868	
		2	124.12	3.953			
1	control	3	122.02	3.886			0
		1	117.77	3.751	119.370	3.802	
		2	121.09	3.856			
2	5%	3	119.25	3.798			2.7
		1	117.99	3.758	118.140	3.762	
		2	123.11	3.921			
3	10%	3	113.32	3.609			4.7
		1	111.11	3.539	112.957	3.597	
		2	109.99	3.503			
4	15%	3	117.77	3.751			11.96

Table D-7 Flexural strength test result of 7th day

Flexural strength test results on 7th day							
Mix No	% of Ash added	Sample	Peak load (kN)	flexural stress (MPa)	Avg Peak load (kN)	Avg stress (MPa)	Variation from control (%)
		1	19.21	5.763	19.087	5.726	
		2	17.85	5.355			
1	Control	3	20.2	6.06			0
		1	16.21	4.863	17.473	5.242	
		2	17.99	5.397			
2	5%	3	18.22	5.466			8.45
		1	16.97	5.091	17.103	5.131	
		2	15.56	4.668			
3	10%	3	18.78	5.634			10.39
		1	14.66	4.398	15.590	4.677	
		2	15.03	4.509			
4	15%	3	17.08	5.124			18.32

Table D- 8 Flexural strength test result of 14th day

Flexural strength test results on 14th day			

Mix No	% of Ash added	Sample	Peak load (kN)	flexural stress (MPa)	Avg Peak load (kN)	Avg stress (MPa)	Variation from control (%)
		1	21.21	6.363	21.087	6.326	
		2	19.85	5.955			
1	Control	3	22.20	6.66			0
		1	18.21	5.463	19.473	5.842	
		2	19.99	5.997			
2	5%	3	20.22	6.066			7.65
		1	18.97	5.691	19.103	5.731	
		2	17.56	5.268			
3	10%	3	20.78	6.234			9.4
		1	16.66	4.998	17.590	5.277	
		2	17.03	5.109			
4	15%	3	19.08	5.724			16.58

Table D-9 Flexural strength test result of 28th day

Flexural strength test results on 28th day							
Mix No	% of Ash added	Sample	Peak load (kN)	flexural stress (MPa)	Avg Peak load (kN)	Avg stress (MPa)	Variation from control (%)
		1	22.21	6.663	23.847	7.154	
		2	25.34	7.602			
1	Control	3	23.99	7.197			0
		1	21.54	6.462	23.017	6.905	
		2	23.5	7.05			
2	5%	3	24.01	7.203			3.48
		1	21.11	6.333	22.220	6.666	
		2	23.44	7.032			
3	10%	3	22.11	6.633			6.82
		1	21.22	6.366	20.473	6.142	
		2	20.22	6.066			
4	15%	3	19.98	5.994			14.15

APPENDIX-E Stress versus strain relationship of cube test on 7th day

Table E-1 Stress versus strain relationship of cube test on 7th day for control

Stress versus strain of cube test on 7th day for Control								
Load(KN)			Area (mm2)	Stress,Mpa				Strain
Sample1	Sample2	Sample3		Sample1	Sample2	Sample3	Avg. stress	
0	0	0		0	0	0	0	0
18	17	20	22500	0.8000	0.7556	0.8889	0.8148	0.000028
32	35	29	22500	1.4222	1.5556	1.2889	1.4222	0.000050
56	46	35	22500	2.4889	2.0444	1.5556	2.0296	0.000072
62	55	43	22500	2.7556	2.4444	1.9111	2.3704	0.000084
88	76	52	22500	3.9111	3.3778	2.3111	3.2000	0.000157
119	130	61	22500	5.2889	5.7778	2.7111	4.5926	0.000171
136	141	67	22500	6.0444	6.2667	2.9778	5.0963	0.000191
151	153	70	22500	6.7111	6.8000	3.1111	5.5407	0.000210
182	170	78	22500	8.0889	7.5556	3.4667	6.3704	0.000246
204	198	85	22500	9.0667	8.8000	3.7778	7.2148	0.000283
215	209	93	22500	9.5556	9.2889	4.1333	7.6593	0.000304
231	226	97	22500	10.2667	10.0444	4.3111	8.2074	0.000330
241	240	109	22500	10.7111	10.6667	4.8444	8.7407	0.000355
255	249	111	22500	11.3333	11.0667	4.9333	9.1111	0.000374
273	263	119	22500	12.1333	11.6889	5.2889	9.7037	0.000404
291	285	127	22500	12.9333	12.6667	5.6444	10.4148	0.000441
318	308	132	22500	14.1333	13.6889	5.8667	11.2296	0.000486
345	315	139	22500	15.3333	14.0000	6.1778	11.8370	0.000521
361	322	147	22500	16.0444	14.3111	6.5333	12.2963	0.000549
377	329	156	22500	16.7556	14.6222	6.9333	12.7704	0.000578
391	336	162	22500	17.3778	14.9333	7.2000	13.1704	0.000603
406	341	178	22500	18.0444	15.1556	7.9111	13.7037	0.000639
419	347	184	22500	18.6222	15.4222	8.1778	14.0741	0.000664
434	359	198	22500	19.2889	15.9556	8.8000	14.6815	0.000707
456	363	212	22500	20.2667	16.1333	9.4222	15.2741	0.000751
466	371	221	22500	20.7111	16.4889	9.8222	15.6741	0.000782
477	379	231	22500	21.2000	16.8444	10.2667	16.1037	0.000817
488	384	245	22500	21.6889	17.0667	10.8889	16.5481	0.000855
493	395	251	22500	21.9111	17.5556	11.1556	16.8741	0.000884
499	401	263	22500	22.1778	17.8222	11.6889	17.2296	0.000917
505	415	270	22500	22.4444	18.4444	12.0000	17.6296	0.000956
510	422	285	22500	22.6667	18.7556	12.6667	18.0296	0.000998
514	431	297	22500	22.8444	19.1556	13.2000	18.4000	0.001038
517	445	304	22500	22.9778	19.7778	13.5111	18.7556	0.001079

521	453	313	22500	23.1556	20.1333	13.9111	19.0667	0.001117
525	460	324	22500	23.3333	20.4444	14.4000	19.3926	0.001160
529	465	339	22500	23.5111	20.6667	15.0667	19.7481	0.001210
535	479	350	22500	23.7778	21.2889	15.5556	20.2074	0.001282
544	486	362	22500	24.1778	21.6000	16.0889	20.6222	0.001357
547	500	375	22500	24.3111	22.2222	16.6667	21.0667	0.001452
553	508	382	22500	24.5778	22.5778	16.9778	21.3778	0.001534
561	514.34	399	22500	24.9333	22.8596	17.7333	21.8421	0.001713
567	513	408	22500	25.2000	22.8000	18.1333	22.0444	0.001941
568	506	413.11	22500	25.2444	22.4889	18.3604	22.0313	0.002109
572.23	505	413	22500	25.4324	22.4444	18.3556	21.9259	0.002395
565	503	412	22500	25.1111	22.3556	18.3111	21.4143	0.002628
560	501	400	22500	24.8889	22.2667	17.7778	20.8451	0.002880

Table E-2 Stress versus strain relationship of cube test on 7th day for 5% TSA

Stress versus strain of cube test on 7th day for 5% TSA								
Load(KN)			Area (mm2)	Stress(Mpa)				Strain
Sample1	Sample2	Sample3		Sample1	Sample2	Sample3	Avg.	
0	0	0	22500	0	0	0	0	0
17	19	18	22500	0.7556	0.8444	0.8000	0.8000	0.000028
40	37	33	22500	1.7778	1.6444	1.4667	1.6296	0.000058
47	48	41	22500	2.0889	2.1333	1.8222	2.0148	0.000072
61	57	50	22500	2.7111	2.5333	2.2222	2.4889	0.000073
87	78	65	22500	3.8667	3.4667	2.8889	3.4074	0.000125
118	132	68	22500	5.2444	5.8667	3.0222	4.7111	0.000178
135	143	76	22500	6.0000	6.3556	3.3778	5.2444	0.000200
150	155	83	22500	6.6667	6.8889	3.6889	5.7481	0.000222
181	172	107	22500	8.0444	7.6444	4.7556	6.8148	0.000270
203	200	109	22500	9.0222	8.8889	4.8444	7.5852	0.000306
214	211	117	22500	9.5111	9.3778	5.2000	8.0296	0.000327
230	228	125	22500	10.2222	10.1333	5.5556	8.6370	0.000357
240	242	130	22500	10.6667	10.7556	5.7778	9.0667	0.000379
254	251	137	22500	11.2889	11.1556	6.0889	9.5111	0.000402
272	265	145	22500	12.0889	11.7778	6.4444	10.1037	0.000434
290	287	154	22500	12.8889	12.7556	6.8444	10.8296	0.000475
317	310	160	22500	14.0889	13.7778	7.1111	11.6593	0.000524
344	317	176	22500	15.2889	14.0889	7.8222	12.4000	0.000570
360	324	182	22500	16.0000	14.4000	8.0889	12.8296	0.000598

376	331	196	22500	16.7111	14.7111	8.7111	13.3778	0.000635
390	338	219	22500	17.3333	15.0222	9.7333	14.0296	0.000681
433	343	229	22500	19.2444	15.2444	10.1778	14.8889	0.000746
455	349	243	22500	20.2222	15.5111	10.8000	15.5111	0.000797
465	361	249	22500	20.6667	16.0444	11.0667	15.9259	0.000833
476	365	261	22500	21.1556	16.2222	11.6000	16.3259	0.000869
487	373	268	22500	21.6444	16.5778	11.9111	16.7111	0.000906
492	381	283	22500	21.8667	16.9333	12.5778	17.1259	0.000947
504	386	295	22500	22.4000	17.1556	13.1111	17.5556	0.000993
509	397	302	22500	22.6222	17.6444	13.4222	17.8963	0.001032
513	403	322	22500	22.8000	17.9111	14.3111	18.3407	0.001086
520	417	337	22500	23.1111	18.5333	14.9778	18.8741	0.001157
528	424	348	22500	23.4667	18.8444	15.4667	19.2593	0.001214
543	433	360	22500	24.1333	19.2444	16.0000	19.7926	0.001305
546	447	380	22500	24.2667	19.8667	16.8889	20.3407	0.001418
552	455	397	22500	24.5333	20.2222	17.6444	20.8000	0.001544
566	465.01	406	22500	25.1556	20.6671	18.0444	21.2890	0.001784
567	464	411.11	22500	25.2000	20.6222	18.2716	21.3646	0.001927
568.36	448	400	22500	25.2604	19.9111	17.7778	20.9831	0.002066
560	440	398	22500	24.8889	19.5556	17.6889	20.7111	0.002100
540		375	22500	24.0000		16.6667	20.3333	0.002280
532		370	22500	23.6444		16.4444	20.0444	0.002339

Table E-3 Stress versus strain relationship of cube test on 7th day for 10% TSA

Stress versus strain of cube test on 7th day for 10% TSA								
Load(KN)			Area (mm2)	Stress,Mpa				Strain
Sample1	Sample2	Sample3		Sample1	Sample2	Sample3	Avg.	
0	0	0		0	0	0	0	0
17	20	17	22500	0.7556	0.8889	0.7556	0.8000	0.000029
37	31	26	22500	1.6444	1.3778	1.1556	1.3926	0.000051
44	42	32	22500	1.9556	1.8667	1.4222	1.7481	0.000064
50	53	40	22500	2.2222	2.3556	1.7778	2.1185	0.000079
76	64	49	22500	3.3778	2.8444	2.1778	2.8000	0.000105
77	78	58	22500	3.4222	3.4667	2.5778	3.1556	0.000120
141	86	64	22500	6.2667	3.8222	2.8444	4.3111	0.000168
155	93	67	22500	6.8889	4.1333	2.9778	4.6667	0.000184
171	111	75	22500	7.6000	4.9333	3.3333	5.2889	0.000211
198	119	82	22500	8.8000	5.2889	3.6444	5.9111	0.000240

209	128	90	22500	9.2889	5.6889	4.0000	6.3259	0.000260
226	137	94	22500	10.0444	6.0889	4.1778	6.7704	0.000281
240	148	106	22500	10.6667	6.5778	4.7111	7.3185	0.000309
242	155	108	22500	10.7556	6.8889	4.8000	7.4815	0.000317
245	169	116	22500	10.8889	7.5111	5.1556	7.8519	0.000336
267	177	124	22500	11.8667	7.8667	5.5111	8.4148	0.000366
290	186	129	22500	12.8889	8.2667	5.7333	8.9630	0.000397
297	199	136	22500	13.2000	8.8444	6.0444	9.3630	0.000420
304	207	144	22500	13.5111	9.2000	6.4000	9.7037	0.000440
311	220	261	22500	13.8222	9.7778	11.6000	11.7333	0.000570
318	234	268	22500	14.1333	10.4000	11.9111	12.1481	0.000600
323	241	273	22500	14.3556	10.7111	12.1333	12.4000	0.000618
329	253	279	22500	14.6222	11.2444	12.4000	12.7556	0.000645
341	269	283	22500	15.1556	11.9556	12.5778	13.2296	0.000683
345	275	289	22500	15.3333	12.2222	12.8444	13.4667	0.000702
353	281	291	22500	15.6889	12.4889	12.9333	13.7037	0.000722
361	297	295	22500	16.0444	13.2000	13.1111	14.1185	0.000758
366	302	303	22500	16.2667	13.4222	13.4667	14.3852	0.000782
377	325	311	22500	16.7556	14.4444	13.8222	15.0074	0.000842
383	338	316	22500	17.0222	15.0222	14.0444	15.3630	0.000879
397	345	327	22500	17.6444	15.3333	14.5333	15.8370	0.000931
404	360	333	22500	17.9556	16.0000	14.8000	16.2519	0.000980
413	372	347	22500	18.3556	16.5333	15.4222	16.7704	0.001047
427	396	354	22500	18.9778	17.6000	15.7333	17.4370	0.001146
430	414	359	22500	19.1111	18.4000	15.9556	17.8222	0.001212
436	423	364	22500	19.3778	18.8000	16.1778	18.1185	0.001268
439	439	365	22500	19.5111	19.5111	16.2222	18.4148	0.001333
447	450	366.12	22500	19.8667	20.0000	16.2720	18.7129	0.001408
450	463	370	22500	20.0000	20.5778	16.4444	19.0074	0.001499
452	478	373	22500	20.0889	21.2444	16.5778	19.3037	0.001627
464	488.8	366	22500	20.6222	21.7244	16.2667	19.5378	0.001891
469.05	488	350	22500	20.8467	21.6889	15.5556	19.3637	0.002132
469	487	342	22500	20.8444	21.6444	15.2000	19.2296	0.002215
452	486	340	22500	20.0889	21.6000	15.1111	18.9333	0.002351
422	425		22500	18.7556	18.8889		18.8222	0.002393
410			22500	18.2222			18.2222	0.002585
405			22500	18.0000			18.0000	0.002646

Table E-4 Stress versus strain relationship of cube test on 7th day for 15% TSA

Stress versus strain of cube test on 7th day for 15% TSA								
Load(KN)			Area (mm2)	Stress(Mpa)				Strain
Sample1	Sample2	Sample3		Sample1	Sample2	Sample3	Avg.	
0	0	0	22500	0	0	0	0	0
19	14	15	22500	0.8444	0.6222	0.6667	0.7111	0.000027
22	25	26	22500	0.9778	1.1111	1.1556	1.0815	0.000041
47	40	35	22500	2.0889	1.7778	1.5556	1.8074	0.000070
53	62	50	22500	2.3556	2.7556	2.2222	2.4444	0.000096
100	70	67	22500	4.4444	3.1111	2.9778	3.5111	0.000142
125	85	85	22500	5.5556	3.7778	3.7778	4.3704	0.000181
137	90	106	22500	6.0889	4.0000	4.7111	4.9333	0.000208
151	106	125	22500	6.7111	4.7111	5.5556	5.6593	0.000244
166	125	139	22500	7.3778	5.5556	6.1778	6.3704	0.000281
196	134	146	22500	8.7111	5.9556	6.4889	7.0519	0.000318
217	151	158	22500	9.6444	6.7111	7.0222	7.7926	0.000361
233	177	166	22500	10.3556	7.8667	7.3778	8.5333	0.000368
252	186	173	22500	11.2000	8.2667	7.6889	9.0519	0.000440
266	198	201	22500	11.8222	8.8000	8.9333	9.8519	0.000495
279	216	211	22500	12.4000	9.6000	9.3778	10.4593	0.000539
311	229	220	22500	13.8222	10.1778	9.7778	11.2593	0.000603
329	233	234	22500	14.6222	10.3556	10.4000	11.7926	0.000649
338	240	245	22500	15.0222	10.6667	10.8889	12.1926	0.000685
346	257	263	22500	15.3778	11.4222	11.6889	12.8296	0.000747
357	278	287	22500	15.8667	12.3556	12.7556	13.6593	0.000838
366	289	299	22500	16.2667	12.8444	13.2889	14.1333	0.000895
371	309	302	22500	16.4889	13.7333	13.4222	14.5481	0.000951
379	318	312	22500	16.8444	14.1333	13.8667	14.9481	0.001010
383	328	326	22500	17.0222	14.5778	14.4889	15.3630	0.001078
388	337	339	22500	17.2444	14.9778	15.0667	15.7630	0.001152
392	344	353	22500	17.4222	15.2889	15.6889	16.1333	0.001232
395	352	360	22500	17.5556	15.6444	16.0000	16.4000	0.001299
398.18	360	371	22500	17.6969	16.0000	16.4889	16.7286	0.001399
398	371	375	22500	17.6889	16.4889	16.6667	16.9481	0.001485
396	379	383	22500	17.6000	16.8444	17.0222	17.1556	0.001597
395	385	390	22500	17.5556	17.1111	17.3333	17.3333	0.001847
385	390	394.11	22500	17.1111	17.3333	17.5160	17.3201	0.001920
373	393	394	22500	16.5778	17.4667	17.5111	17.1852	0.002090
365	396.82	392	22500	16.2222	17.6364	17.4222	17.0936	0.002159

	388	380	22500	0.0000	17.2444	16.8889	17.0667	0.002177
	380	375	22500	0.0000	16.8889	16.6667	16.7778	0.002331

APPENDIX-F Stress versus strain relationship of cube test on 14th day

Table F-1 Stress versus strain relationship of cube test on 14th day for control

Stress versus strain of cube test on 14th day for Control								
Load(KN)			Area (mm2)	Stress,Mpa				Strain
Sample1	Sample2	Sample3		Sample1	Sample2	Sample3	Avg.	
0	0	0		0	0	0	0	0
19	19	19	22500	0.8444	0.8444	0.8444	0.8444	0.000027
34	22	24	22500	1.5111	0.9778	1.0667	1.1852	0.000038
46	43	47	22500	2.0444	1.9111	2.0889	2.0148	0.000066
62	65	58	22500	2.7556	2.8889	2.5778	2.7407	0.000091
79	77	77	22500	3.5111	3.4222	3.4222	3.4519	0.000115
107	90	92	22500	4.7556	4.0000	4.0889	4.2815	0.000144
122	104	104	22500	5.4222	4.6222	4.6222	4.8889	0.000166
149	125	137	22500	6.6222	5.5556	6.0889	6.0889	0.000211
172	149	158	22500	7.6444	6.6222	7.0222	7.0963	0.000249
203	166	174	22500	9.0222	7.3778	7.7333	8.0444	0.000286
234	178	194	22500	10.4000	7.9111	8.6222	8.9778	0.000324
268	196	216	22500	11.9111	8.7111	9.6000	10.0741	0.000370
296	216	236	22500	13.1556	9.6000	10.4889	11.0815	0.000414
326	233	257	22500	14.4889	10.3556	11.4222	12.0889	0.000459
355	255	282	22500	15.7778	11.3333	12.5333	13.2148	0.000512
412	276	315	22500	18.3111	12.2667	14.0000	14.8593	0.000594
439	297	327	22500	19.5111	13.2000	14.5333	15.7481	0.000642
462	323	358	22500	20.5333	14.3556	15.9111	16.9333	0.000708
486	337	377	22500	21.6000	14.9778	16.7556	17.7778	0.000758
514	358	405	22500	22.8444	15.9111	18.0000	18.9185	0.000830
532	385	423	22500	23.6444	17.1111	18.8000	19.8519	0.000893
551	398	455	22500	24.4889	17.6889	20.2222	20.8000	0.000962
564	418	472	22500	25.0667	18.5778	20.9778	21.5407	0.001019
583	438	491	22500	25.9111	19.4667	21.8222	22.4000	0.001092
594	451	511	22500	26.4000	20.0444	22.7111	23.0519	0.001151
606	472	530	22500	26.9333	20.9778	23.5556	23.8222	0.001228
617	483	549	22500	27.4222	21.4667	24.4000	24.4296	0.001295
629	497	572	22500	27.9556	22.0889	25.4222	25.1556	0.001386

638	513	585	22500	28.3556	22.8000	26.0000	25.7185	0.001468
647	524	595	22500	28.7556	23.2889	26.4444	26.1630	0.001543
655	537	604	22500	29.1111	23.8667	26.8444	26.6074	0.001632
661	542	613	22500	29.3778	24.0889	27.2444	26.9037	0.001706
663.01	553	621	22500	29.4671	24.5778	27.6000	27.2150	0.001808
660	559	629	22500	29.3333	24.8444	27.9556	27.3778	0.001887
654	568	635	22500	29.0667	25.2444	28.2222	27.5111	0.002049
641	572	639	22500	28.4889	25.4222	28.4000	27.4370	0.002174
629	576.02	642	22500	27.9556	25.6009	28.5333	27.3633	0.002226
593	574	643.11	22500	26.3556	25.5111	28.5827	26.8164	0.002435
	570	634	22500		25.3333	28.1778	26.7556	0.002452
	564	625	22500		25.0667	27.7778	26.4222	0.002534
	558	619	22500		24.8000	27.5111	26.1556	0.002592
	557		22500		24.7556		24.7556	0.002834
	555		22500		24.6667		24.6667	0.002847

Table F-2 Stress versus strain relationship of cube test on 14th day for 5%

Stress versus strain of cube test on 14th day for 5% TSA								
Load(KN)			Area (mm2)	Stress,Mpa				Strain
Sample1	Sample2	Sample3		Sample1	Sample2	Sample3	Avg.	
0	0	0		0	0	0	0	0
21	18	20	22500	0.9333	0.8000	0.8889	0.8741	0.000029
29	37	34	22500	1.2889	1.6444	1.5111	1.4815	0.000049
37	65	53	22500	1.6444	2.8889	2.3556	2.2963	0.000076
51	79	79	22500	2.2667	3.5111	3.5111	3.0963	0.000104
67	91	108	22500	2.9778	4.0444	4.8000	3.9407	0.000134
88	112	134	22500	3.9111	4.9778	5.9556	4.9481	0.000170
116	155	159	22500	5.1556	6.8889	7.0667	6.3704	0.000224
137	184	188	22500	6.0889	8.1778	8.3556	7.5407	0.000270
172	212	211	22500	7.6444	9.4222	9.3778	8.8148	0.000322
193	246	231	22500	8.5778	10.9333	10.2667	9.9259	0.000370
218	267	252	22500	9.6889	11.8667	11.2000	10.9185	0.000414
233	319	265	22500	10.3556	14.1778	11.7778	12.1037	0.000468
241	341	277	22500	10.7111	15.1556	12.3111	12.7259	0.000498
255	402	289	22500	11.3333	17.8667	12.8444	14.0148	0.000563
267	415	310	22500	11.8667	18.4444	13.7778	14.6963	0.000599
279	447	324	22500	12.4000	19.8667	14.4000	15.5556	0.000646
298	461	339	22500	13.2444	20.4889	15.0667	16.2667	0.000687

310	474	356	22500	13.7778	21.0667	15.8222	16.8889	0.000724
329	487	373	22500	14.6222	21.6444	16.5778	17.6148	0.000769
347	519	391	22500	15.4222	23.0667	17.3778	18.6222	0.000834
361	536	412	22500	16.0444	23.8222	18.3111	19.3926	0.000888
376	563	426	22500	16.7111	25.0222	18.9333	20.2222	0.000950
388	581	446	22500	17.2444	25.8222	19.8222	20.9630	0.001009
407	605	468	22500	18.0889	26.8889	20.8000	21.9259	0.001093
422	616	488	22500	18.7556	27.3778	21.6889	22.6074	0.001158
455	625	516	22500	20.2222	27.7778	22.9333	23.6444	0.001271
466	632	537	22500	20.7111	28.0889	23.8667	24.2222	0.001343
481	639	551	22500	21.3778	28.4000	24.4889	24.7556	0.001418
494	644	566	22500	21.9556	28.6222	25.1556	25.2444	0.001498
512	646	578	22500	22.7556	28.7111	25.6889	25.7185	0.001590
521	646.22	589	22500	23.1556	28.7209	26.1778	26.0181	0.001661
536	645	603.44	22500	23.8222	28.6667	26.8196	26.4361	0.001797
558	642	603	22500	24.8000	28.5333	26.8000	26.7111	0.002028
571	630	591	22500	25.3778	28.0000	26.2667	26.5481	0.002222
588.08	619	573	22500	26.1369	27.5111	25.4667	26.3716	0.002306
588	605	565	22500	26.1333	26.8889	25.1111	26.0444	0.002418
586		550	22500	26.0444		24.4444	25.2444	0.002611
580		548	22500	25.7778		24.3556	25.0667	0.002646
560			22500	24.8889			24.8889	0.002680
543			22500	24.1333			24.1333	0.002808

Table F-3 Stress versus strain relationship of cube test on 14th day for 10%

Stress versus strain of cube test on 14th day for 10% TSA								
Load(KN)			Area (mm2)	Stress,Mpa				Strain
Sample1	Sample2	Sample3		Sample1	Sample2	Sample3	Avg.	
0	0	0		0	0	0	0	0
20	19	17	22500	0.8889	0.8444	0.7556	0.8296	0.000028
28	31	26	22500	1.2444	1.3778	1.1556	1.2593	0.000042
36	56	39	22500	1.6000	2.4889	1.7333	1.9407	0.000065
50	79	50	22500	2.2222	3.5111	2.2222	2.6519	0.000090
66	91	69	22500	2.9333	4.0444	3.0667	3.3481	0.000115
87	114	82	22500	3.8667	5.0667	3.6444	4.1926	0.000146
100	125	97	22500	4.4444	5.5556	4.3111	4.7704	0.000168
112	136	107	22500	4.9778	6.0444	4.7556	5.2593	0.000186
123	150	119	22500	5.4667	6.6667	5.2889	5.8074	0.000208

136	167	127	22500	6.0444	7.4222	5.6444	6.3704	0.000230
144	182	139	22500	6.4000	8.0889	6.1778	6.8889	0.000251
159	193	150	22500	7.0667	8.5778	6.6667	7.4370	0.000273
170	210	165	22500	7.5556	9.3333	7.3333	8.0741	0.000300
191	222	181	22500	8.4889	9.8667	8.0444	8.8000	0.000331
202	239	194	22500	8.9778	10.6222	8.6222	9.4074	0.000358
218	251	216	22500	9.6889	11.1556	9.6000	10.1481	0.000392
227	278	227	22500	10.0889	12.3556	10.0889	10.8444	0.000424
238	299	238	22500	10.5778	13.2889	10.5778	11.4815	0.000455
245	309	246	22500	10.8889	13.7333	10.9333	11.8519	0.000473
258	321	260	22500	11.4667	14.2667	11.5556	12.4296	0.000502
272	333	277	22500	12.0889	14.8000	12.3111	13.0667	0.000536
290	356	289	22500	12.8889	15.8222	12.8444	13.8519	0.000578
315	367	308	22500	14.0000	16.3111	13.6889	14.6667	0.000624
326	380	315	22500	14.4889	16.8889	14.0000	15.1259	0.000651
338	398	327	22500	15.0222	17.6889	14.5333	15.7481	0.000688
350	411	338	22500	15.5556	18.2667	15.0222	16.2815	0.000722
363	429	351	22500	16.1333	19.0667	15.6000	16.9333	0.000764
381	446	370	22500	16.9333	19.8222	16.4444	17.7333	0.000820
393	461	386	22500	17.4667	20.4889	17.1556	18.3704	0.000866
408	486	394	22500	18.1333	21.6000	17.5111	19.0815	0.000921
416	495	412	22500	18.4889	22.0000	18.3111	19.6000	0.000964
429	516	428	22500	19.0667	22.9333	19.0222	20.3407	0.001028
435	528	440	22500	19.3333	23.4667	19.5556	20.7852	0.001070
444	537	455	22500	19.7333	23.8667	20.2222	21.2741	0.001119
452	549	468	22500	20.0889	24.4000	20.8000	21.7630	0.001171
471	563	486	22500	20.9333	25.0222	21.6000	22.5185	0.001261
488	575	499	22500	21.6889	25.5556	22.1778	23.1407	0.001346
506	584.01	518	22500	22.4889	25.9560	23.0222	23.8224	0.001456
521	583	527	22500	23.1556	25.9111	23.4222	24.1630	0.001522
526.34	581	535	22500	23.3929	25.8222	23.7778	24.3310	0.001559
526	580	600	22500	23.3778	25.7778	26.6667	25.2741	0.002003
521	571	602.22	22500	23.1556	25.3778	26.7653	25.0996	0.002207
519		602	22500	23.0667		26.6667	24.8667	0.002315
518		600	22500	23.0222		26.7653	24.8938	0.002305
		555	22500	0.0000		24.6667	24.6667	0.002386
		540	22500			24.0000	24.0000	0.002563

Table F-4 Stress versus strain relationship of cube test on 14th day for 15%

Stress versus strain of cube test on 14th day for 15% TSA								
Load(KN)			Area (mm2)	Stress,Mpa				Strain
Sample1	Sample2	Sample3		Sample1	Sample2	Sample3	Avg.	
0	0	0		0	0	0	0	0
16	18	17	22500	0.7111	0.8000	0.7556	0.7556	0.000027
27	30	24	22500	1.2000	1.3333	1.0667	1.2000	0.000043
41	47	37	22500	1.8222	2.0889	1.6444	1.8519	0.000067
55	62	49	22500	2.4444	2.7556	2.1778	2.4593	0.000090
68	79	62	22500	3.0222	3.5111	2.7556	3.0963	0.000114
81	93	68	22500	3.6000	4.1333	3.0222	3.5852	0.000134
99	118	80	22500	4.4000	5.2444	3.5556	4.4000	0.000167
111	132	98	22500	4.9333	5.8667	4.3556	5.0519	0.000195
126	148	107	22500	5.6000	6.5778	4.7556	5.6444	0.000221
137	165	116	22500	6.0889	7.3333	5.1556	6.1926	0.000245
152	180	128	22500	6.7556	8.0000	5.6889	6.8148	0.000274
165	197	137	22500	7.3333	8.7556	6.0889	7.3926	0.000301
177	204	146	22500	7.8667	9.0667	6.4889	7.8074	0.000321
189	216	155	22500	8.4000	9.6000	6.8889	8.2963	0.000346
198	229	163	22500	8.8000	10.1778	7.2444	8.7407	0.000369
209	242	170	22500	9.2889	10.7556	7.5556	9.2000	0.000393
222	259	181	22500	9.8667	11.5111	8.0444	9.8074	0.000426
241	268	199	22500	10.7111	11.9111	8.8444	10.4889	0.000465
258	275	210	22500	11.4667	12.2222	9.3333	11.0074	0.000495
263	288	222	22500	11.6889	12.8000	9.8667	11.4519	0.000523
281	300	241	22500	12.4889	13.3333	10.7111	12.1778	0.000569
293	313	256	22500	13.0222	13.9111	11.3778	12.7704	0.000609
308	322	267	22500	13.6889	14.3111	11.8667	13.2889	0.000645
315	335	276	22500	14.0000	14.8889	12.2667	13.7185	0.000677
327	352	284	22500	14.5333	15.6444	12.6222	14.2667	0.000719
336	369	298	22500	14.9333	16.4000	13.2444	14.8593	0.000767
349	381	307	22500	15.5111	16.9333	13.6444	15.3630	0.000811
364	396	314	22500	16.1778	17.6000	13.9556	15.9111	0.000861
375	405	320	22500	16.6667	18.0000	14.2222	16.2963	0.000899
388	417	333	22500	17.2444	18.5333	14.8000	16.8593	0.000957
397	423	341	22500	17.6444	18.8000	15.1556	17.2000	0.000995
410	436	356	22500	18.2222	19.3778	15.8222	17.8074	0.001069
426	454	367	22500	18.9333	20.1778	16.3111	18.4741	0.001161
446	465	383	22500	19.8222	20.6667	17.0222	19.1704	0.001277

460	472	409	22500	20.4444	20.9778	18.1778	19.8667	0.001425
483	484	411.11	22500	21.4667	21.5111	18.2716	20.4164	0.001599
492	496	411	22500	21.8667	22.0444	18.2667	20.7259	0.001787
497	496.95	409	22500	22.0889	22.0867	18.1778	20.7844	0.001916
497.55	492	398	22500	22.1133	21.8667	17.6889	20.5563	0.002181
497	490	388	22500	22.0889	21.7778	17.2444	20.3704	0.002276
485	430		22500	21.5556	19.1111		20.3333	0.002293
480	425		22500	21.3333	18.8889		20.1111	0.002380
474	423		22500	21.0667	18.8000		19.9333	0.002441
445			22500	19.7778			19.7778	0.002489

APPENDIX-G Stress versus strain relationship of cube test on 28th day

Table G-1 Stress versus strain relationship of cube test on 28th day for control

Stress versus strain of cube test on 28th day for Control								
Load(KN)			Area (mm2)	Stress(Mpa)				Strain
Sample1	Sample2	Sample3		Sample1	Sample2	Sample3	Avg.	
0	0	0		0	0	0	0	0
18	19	17	22500	0.8000	0.8444	0.7556	0.8000	0.000024
33	29	39	22500	1.4667	1.2889	1.7333	1.4963	0.000045
55	43	95	22500	2.4444	1.9111	4.2222	2.8593	0.000088
70	62	136	22500	3.1111	2.7556	6.0444	3.9704	0.000123
88	85	161	22500	3.9111	3.7778	7.1556	4.9481	0.000154
109	106	187	22500	4.8444	4.7111	8.3111	5.9556	0.000187
129	131	210	22500	5.7333	5.8222	9.3333	6.9630	0.000221
155	163	238	22500	6.8889	7.2444	10.5778	8.2370	0.000265
169	191	252	22500	7.5111	8.4889	11.2000	9.0667	0.000294
209	235	273	22500	9.2889	10.4444	12.1333	10.6222	0.000350
223	268	296	22500	9.9111	11.9111	13.1556	11.6593	0.000388
245	299	318	22500	10.8889	13.2889	14.1333	12.7704	0.000430
274	333	349	22500	12.1778	14.8000	15.5111	14.1630	0.000485
310	376	379	22500	13.7778	16.7111	16.8444	15.7778	0.000550
337	405	403	22500	14.9778	18.0000	17.9111	16.9630	0.000601
368	443	426	22500	16.3556	19.6889	18.9333	18.3259	0.000661
407	477	452	22500	18.0889	21.2000	20.0889	19.7926	0.000728
443	507	473	22500	19.6889	22.5333	21.0222	21.0815	0.000791
478	538	505	22500	21.2444	23.9111	22.4444	22.5333	0.000865
513	566	520	22500	22.8000	25.1556	23.1111	23.6889	0.000928

545	589	538	22500	24.2222	26.1778	23.9111	24.7704	0.000990
574	615	561	22500	25.5111	27.3333	24.9333	25.9259	0.001061
612	634	582	22500	27.2000	28.1778	25.8667	27.0815	0.001136
633	653	612	22500	28.1333	29.0222	27.2000	28.1185	0.001210
668	672	637	22500	29.6889	29.8667	28.3111	29.2889	0.001301
693	688	649	22500	30.8000	30.5778	28.8444	30.0741	0.001368
716	702	657	22500	31.8222	31.2000	29.2000	30.7407	0.001430
733	715	676	22500	32.5778	31.7778	30.0444	31.4667	0.001504
753	727	693	22500	33.4667	32.3111	30.8000	32.1926	0.001589
773	738	708	22500	34.3556	32.8000	31.4667	32.8741	0.001682
784	749	719	22500	34.8444	33.2889	31.9556	33.3630	0.001762
794	755	733	22500	35.2889	33.5556	32.5778	33.8074	0.001854
804	761	745	22500	35.7333	33.8222	33.1111	34.2222	0.001977
808	765	747	22500	35.9111	34.0000	33.2000	34.3704	0.002049
811	765.27	748	22500	36.0444	34.0120	33.2444	34.4336	0.002103
813	764	748.92	22500	36.1333	33.9556	33.2853	34.4581	0.002162
813.01	757	740	22500	36.1338	33.6444	32.8889	34.2224	0.002352
805	731	732	22500	35.7778	32.4889	32.5333	33.6000	0.002525
793	686	725	22500	35.2444	30.4889	32.2222	32.6519	0.002689
787	656	716	22500	34.9778	29.1556	31.8222	31.9852	0.002780
779	650	708	22500	34.6222	28.8889	31.4667	31.6593	0.002820
770	630	691	22500	34.2222	28.0000	30.7111	30.9778	0.002896
		682	22500			30.3111	30.3111	0.002965
		671	22500			29.8222	29.7123	0.000295

Table G-2 Stress versus strain relationship of cube test on 28th day for 5%

Stress versus strain of cube test on 28th day for 5% TSA								
Load(KN)			Area (mm2)	Stress,Mpa				Strain
Sample1	Sample2	Sample3		Sample1	Sample2	Sample3	Avg.	
0	0	0	22500	0	0	0	0	0
18	16	17	22500	0.8000	0.7111	0.7556	0.7556	0.000023
26	29	33	22500	1.1556	1.2889	1.4667	1.3037	0.000040
35	37	51	22500	1.5556	1.6444	2.2667	1.8222	0.000056
47	57	64	22500	2.0889	2.5333	2.8444	2.4889	0.000077
61	82	76	22500	2.7111	3.6444	3.3778	3.2444	0.000101
87	103	89	22500	3.8667	4.5778	3.9556	4.1333	0.000129
108	128	106	22500	4.8000	5.6889	4.7111	5.0667	0.000160
135	146	137	22500	6.0000	6.4889	6.0889	6.1926	0.000198

160	165	147	22500	7.1111	7.3333	6.5333	6.9926	0.000225
187	189	164	22500	8.3111	8.4000	7.2889	8.0000	0.000260
229	209	177	22500	10.1778	9.2889	7.8667	9.1111	0.000300
260	237	201	22500	11.5556	10.5333	8.9333	10.3407	0.000345
303	267	217	22500	13.4667	11.8667	9.6444	11.6593	0.000394
344	296	234	22500	15.2889	13.1556	10.4000	12.9481	0.000445
379	324	246	22500	16.8444	14.4000	10.9333	14.0593	0.000490
427	354	259	22500	18.9778	15.7333	11.5111	15.4074	0.000546
467	382	274	22500	20.7556	16.9778	12.1778	16.6370	0.000599
518	418	298	22500	23.0222	18.5778	13.2444	18.2815	0.000674
562	444	329	22500	24.9778	19.7333	14.6222	19.7778	0.000746
604	472	347	22500	26.8444	20.9778	15.4222	21.0815	0.000813
650	503	377	22500	28.8889	22.3556	16.7556	22.6667	0.000899
692	533	408	22500	30.7556	23.6889	18.1333	24.1926	0.000988
700	559	427	22500	31.1111	24.8444	18.9778	24.9778	0.001038
722	582	451	22500	32.0889	25.8667	20.0444	26.0000	0.001106
736	604	472	22500	32.7111	26.8444	20.9778	26.8444	0.001166
743	625	483	22500	33.0222	27.7778	21.4667	27.4222	0.001209
759	646	502	22500	33.7333	28.7111	22.3111	28.2519	0.001276
768	664	531	22500	34.1333	29.5111	23.6000	29.0815	0.001349
779	681	550	22500	34.6222	30.2667	24.4444	29.7778	0.001415
785	696	569	22500	34.8889	30.9333	25.2889	30.3704	0.001478
792	706	578	22500	35.2000	31.3778	25.6889	30.7556	0.001522
800	712	589	22500	35.5556	31.6444	26.1778	31.1259	0.001568
818	719	603	22500	36.3556	31.9556	26.8000	31.7037	0.001648
827	726	621	22500	36.7556	32.2667	27.6000	32.2074	0.001732
830.72	731	667	22500	36.9209	32.4889	29.6444	33.0181	0.001925
830	741	679	22500	36.8889	32.9333	30.1778	33.3333	0.002122
815	742	685	22500	36.2222	32.9778	30.4444	33.2148	0.002288
807	743.47	685.01	22500	35.8667	33.0431	30.4449	33.1182	0.002335
796	742	678	22500	35.3778	32.9778	30.1333	32.8296	0.002433
784	737	653	22500	34.8444	32.7556	29.0222	32.2074	0.002575
	727	631	22500		32.3111	28.0444	30.1778	0.002867
	700	627	22500		31.1111	27.8667	29.4889	0.002943
		622	22500			27.6444	27.6444	0.003120
		617	22500			27.4222	27.4222	0.003139
		591	22500			26.2667	26.2667	0.003234

Table G-3 Stress versus strain relationship of cube test on 28th day for 10%

Stress versus strain of cube test on 28th day for 10% TSA								
Load(KN)			Area (mm2)	Stress,Mpa				Strain
Sample1	Sample2	Sample3		Sample1	Sample2	Sample3	Avg.	
0	0	0	22500	0	0	0	0	0
19	21	20	22500	0.8444	0.9333	0.8889	0.8889	0.000027
32	29	36	22500	1.4222	1.2889	1.6000	1.4370	0.000044
58	37	53	22500	2.5778	1.6444	2.3556	2.1926	0.000068
82	51	79	22500	3.6444	2.2667	3.5111	3.1407	0.000098
97	67	91	22500	4.3111	2.9778	4.0444	3.7778	0.000118
121	88	106	22500	5.3778	3.9111	4.7111	4.6667	0.000147
133	116	124	22500	5.9111	5.1556	5.5111	5.5259	0.000176
145	137	148	22500	6.4444	6.0889	6.5778	6.3704	0.000204
156	172	165	22500	6.9333	7.6444	7.3333	7.3037	0.000237
172	193	188	22500	7.6444	8.5778	8.3556	8.1926	0.000268
186	218	211	22500	8.2667	9.6889	9.3778	9.1111	0.000301
198	233	238	22500	8.8000	10.3556	10.5778	9.9111	0.000330
217	241	271	22500	9.6444	10.7111	12.0444	10.8000	0.000363
237	255	310	22500	10.5333	11.3333	13.7778	11.8815	0.000405
261	267	337	22500	11.6000	11.8667	14.9778	12.8148	0.000442
289	279	365	22500	12.8444	12.4000	16.2222	13.8222	0.000482
311	288	406	22500	13.8222	12.8000	18.0444	14.8889	0.000527
335	310	439	22500	14.8889	13.7778	19.5111	16.0593	0.000577
358	329	468	22500	15.9111	14.6222	20.8000	17.1111	0.000624
394	347	499	22500	17.5111	15.4222	22.1778	18.3704	0.000683
421	361	538	22500	18.7111	16.0444	23.9111	19.5556	0.000740
454	376	553	22500	20.1778	16.7111	24.5778	20.4889	0.000788
488	388	579	22500	21.6889	17.2444	25.7333	21.5556	0.000844
521	407	587	22500	23.1556	18.0889	26.0889	22.4444	0.000893
566	422	601	22500	25.1556	18.7556	26.7111	23.5407	0.000957
613	455	615	22500	27.2444	20.2222	27.3333	24.9333	0.001045
654	466	627	22500	29.0667	20.7111	27.8667	25.8815	0.001109
672	481	634	22500	29.8667	21.3778	28.1778	26.4741	0.001151
697	494	641	22500	30.9778	21.9556	28.4889	27.1407	0.001201
716	512	646	22500	31.8222	22.7556	28.7111	27.7630	0.001251
738	521	654	22500	32.8000	23.1556	29.0667	28.3407	0.001300
750	536	663	22500	33.3333	23.8222	29.4667	28.8741	0.001348
761	570	674	22500	33.8222	25.3333	29.9556	29.7037	0.001430
773	589	682	22500	34.3556	26.1778	30.3111	30.2815	0.001493

783	612	695	22500	34.8000	27.2000	30.8889	30.9630	0.001577
783.83	630	719	22500	34.8369	28.0000	31.9556	31.5975	0.001670
781	645	727	22500	34.7111	28.6667	32.3111	31.8963	0.001721
765	671	744	22500	34.0000	29.8222	33.0667	32.2963	0.001802
714	683	765	22500	31.7333	30.3556	34.0000	32.0296	0.001746
694	699	779.23	22500	30.8444	31.0667	34.6324	32.1812	0.001777
	708	779	22500		31.4667	34.6222	33.0444	0.002143
	711.01	764	22500		31.6004	33.9556	32.7780	0.002350
	710	753	22500		31.5556	33.4667	32.5111	0.002437
	692	739	22500		30.7556	32.8444	31.8000	0.002594
	684		22500		30.4000		30.4000	0.002804
	667		22500		29.6444		29.6444	0.002894

Table G-4 Stress versus strain relationship of cube test on 28th day for 15%

Stress versus strain of cube test on 28th day for 15% TSA								
Load(KN)			Area (mm2)	Stress,Mpa				Strain
Sample1	Sample2	Sample3		Sample1	Sample 2	Sample 3	Avg.	
0	0	0	22500	0	0	0	0	0
20	18	19	22500	0.8889	0.8000	0.8444	0.8444	0.000027
34	44	24	22500	1.5111	1.9556	1.0667	1.5111	0.000049
53	56	47	22500	2.3556	2.4889	2.0889	2.3111	0.000075
79	77	58	22500	3.5111	3.4222	2.5778	3.1704	0.000104
108	89	77	22500	4.8000	3.9556	3.4222	4.0593	0.000135
134	108	92	22500	5.9556	4.8000	4.0889	4.9481	0.000167
159	119	114	22500	7.0667	5.2889	5.0667	5.8074	0.000198
188	134	137	22500	8.3556	5.9556	6.0889	6.8000	0.000235
211	143	158	22500	9.3778	6.3556	7.0222	7.5852	0.000265
231	155	174	22500	10.2667	6.8889	7.7333	8.2963	0.000293
252	168	194	22500	11.2000	7.4667	8.6222	9.0963	0.000325
265	184	216	22500	11.7778	8.1778	9.6000	9.8519	0.000356
277	213	236	22500	12.3111	9.4667	10.4889	10.7556	0.000394
289	237	257	22500	12.8444	10.5333	11.4222	11.6000	0.000431
310	261	282	22500	13.7778	11.6000	12.5333	12.6370	0.000477
324	292	315	22500	14.4000	12.9778	14.0000	13.7926	0.000532
339	315	327	22500	15.0667	14.0000	14.5333	14.5333	0.000568
356	333	358	22500	15.8222	14.8000	15.9111	15.5111	0.000617
373	356	377	22500	16.5778	15.8222	16.7556	16.3852	0.000664

391	376	405	22500	17.3778	16.7111	18.0000	17.3630	0.000718
412	397	423	22500	18.3111	17.6444	18.8000	18.2519	0.000770
426	422	455	22500	18.9333	18.7556	20.2222	19.3037	0.000835
446	445	472	22500	19.8222	19.7778	20.9778	20.1926	0.000894
468	463	491	22500	20.8000	20.5778	21.8222	21.0667	0.000955
488	486	511	22500	21.6889	21.6000	22.7111	22.0000	0.001025
516	505	530	22500	22.9333	22.4444	23.5556	22.9778	0.001106
537	521	549	22500	23.8667	23.1556	24.4000	23.8074	0.001181
551	537	572	22500	24.4889	23.8667	25.4222	24.5926	0.001260
566	552	585	22500	25.1556	24.5333	26.0000	25.2296	0.001332
578	567	595	22500	25.6889	25.2000	26.4444	25.7778	0.001400
589	577	604	22500	26.1778	25.6444	26.8444	26.2222	0.001462
603	588	613	22500	26.8000	26.1333	27.2444	26.7259	0.001542
612	598	621	22500	27.2000	26.5778	27.6000	27.1259	0.001617
617	606	629	22500	27.4222	26.9333	27.9556	27.4370	0.001686
621	616	635	22500	27.6000	27.3778	28.2222	27.7333	0.001768
624	625	639	22500	27.7333	27.7778	28.4000	27.9704	0.001857
624.94	629	642	22500	27.7751	27.9556	28.5333	28.0880	0.001922
623	637	642.95	22500	27.6889	28.3111	28.5756	28.1919	0.002064
616	640	634	22500	27.3778	28.4444	28.1778	28.0000	0.002261
602	641	625	22500	26.7556	28.4889	27.7778	27.6741	0.002390
588	641.23	619	22500	26.1333	28.4991	27.5111	27.3812	0.002474
571	639	596	22500	25.3778	28.4000	26.4889	26.7556	0.002613
568	592	581	22500	25.2444	26.3111	25.8222	25.7926	0.002780
	580	578	22500		25.7778	25.6889	25.7333	0.002789
	585	563	22500		26.0000	25.0222	25.5111	0.002823
	570		22500		25.3333		25.3333	0.002849
	551		22500		24.4889		24.4889	0.002962

APPENDIX-H Strength and deformation characteristics for concrete

Table H-1 Strength and deformation characteristics for concrete [38]**.**

	Strength classes for concrete															Analytical relation / Explanation
f_{ck} (MPa)	12	16	20	25	30	35	40	45	50	55	60	70	80	90		
$f_{ck,cube}$ (MPa)	15	20	25	30	37	45	50	55	60	67	75	85	95	105		
f_{cm} (MPa)	20	24	28	33	38	43	48	53	58	63	68	78	88	98	$f_{cm} = f_{ck} + 8$ (MPa)	
f_{ctm} (MPa)	1.6	1.9	2.2	2.6	2.9	3.2	3.5	3.8	4.1	4.2	4.4	4.6	4.8	5.0	$f_{ctm} = 2.12 \ln[1+(f_{cm}/10)]$ ≥ C50/60	
$f_{ctk,0.05}$ (MPa)	1.1	1.3	1.5	1.8	2.0	2.2	2.5	2.7	2.9	3.0	3.1	3.2	3.4	3.5	$f_{ctk,0.05} = 0.7 \times f_{ctm}$ 5 % fractile	
$f_{ctk,0.95}$ (MPa)	2.0	2.5	2.9	3.3	3.8	4.2	4.6	4.9	5.3	5.5	5.7	6.0	6.3	6.6	$f_{ctk,0.95} = 1.3 \times f_{ctm}$ 95 % fractile	
E_{cm} (GPa)	27	29	30	31	33	34	35	36	37	38	39	41	42	44	$E_{cm} = 22[(f_{cm})/10]^{0.3}$ (f_{cm} in MPa)	
ε_{c1} (‰)	1.8	1.9	2.0	2.1	2.2	2.25	2.3	2.4	2.45	2.5	2.6	2.7	2.8	2.8	See Figure 3.2 ε_{c1} (‰) = $0.7 f_{cm}^{0.31} \leq 2.8$	
ε_{cu1} (‰)	3.5									3.2	3.0	2.8	2.8	2.8	See Figure 3.2 for $f_{ck} \geq 50$ MPa ε_{cu1} (‰) = 2.8 + 27[(98 - f_{cm})/100]^4	
ε_{c2} (‰)	2.0									2.2	2.3	2.4	2.5	2.6	See Figure 3.3 for $f_{ck} \geq 50$ MPa ε_{c2} (‰) = $2.0 + 0.085[(f_{ck}-50)^{0.53}]$	
ε_{cu2} (‰)	3.5									3.1	2.9	2.7	2.6	2.6	See Figure 3.3 for $f_{ck} \geq 50$ MPa ε_{cu2} (‰) = 2.6 + 35[(90 - f_{ck})/100]^4	
n	2.0									1.75	1.6	1.45	1.4	1.4	for $f_{ck} \geq 50$ MPa n = 1.4 + 23.4 [(90 - f_{ck})/100]^4	
ε_{c3} (‰)	1.75									1.8	1.9	2.0	2.2	2.3	See Figure 3.4 for $f_{ck} \geq 50$ MPa ε_{c3} (‰) = 1.75 + 0.55[(fck - 50)/40]	
ε_{cu3} (‰)	3.5									3.1	2.9	2.7	2.6	2.6	See Figure 3.4 for $f_{ck} \geq 50$ MPa ε_{cu3} (‰) = 2.6 + 35[(90 - f_{ck})/100]^4	

APPENDIX-I Photo Gallery

Photo: 1 Collecting Teff straw and prepare TSA

Photo: 2 Sieve TSA and Teff straw ash sample

Photo:3 Consistency and sodium hydroxide sample

TEST
PARAMETERS
RESULTS
SETTINGS
CALIBRATION
ADMIN
LOAD
748.92 kN
STRESS
33.29 MPa
FRAME 1
NO ALERT
COMPRESSION - CUBE
AREA : 22500.000 mm2
Test No : 645
Pace : 6.75 kN/s
08.05.2024 13:58:34-14:00:43
TEST is FINISHED..
Auto
STRESS-Time
PLOT SETTINGS
Stress (MPa)
Time (s)
BC100

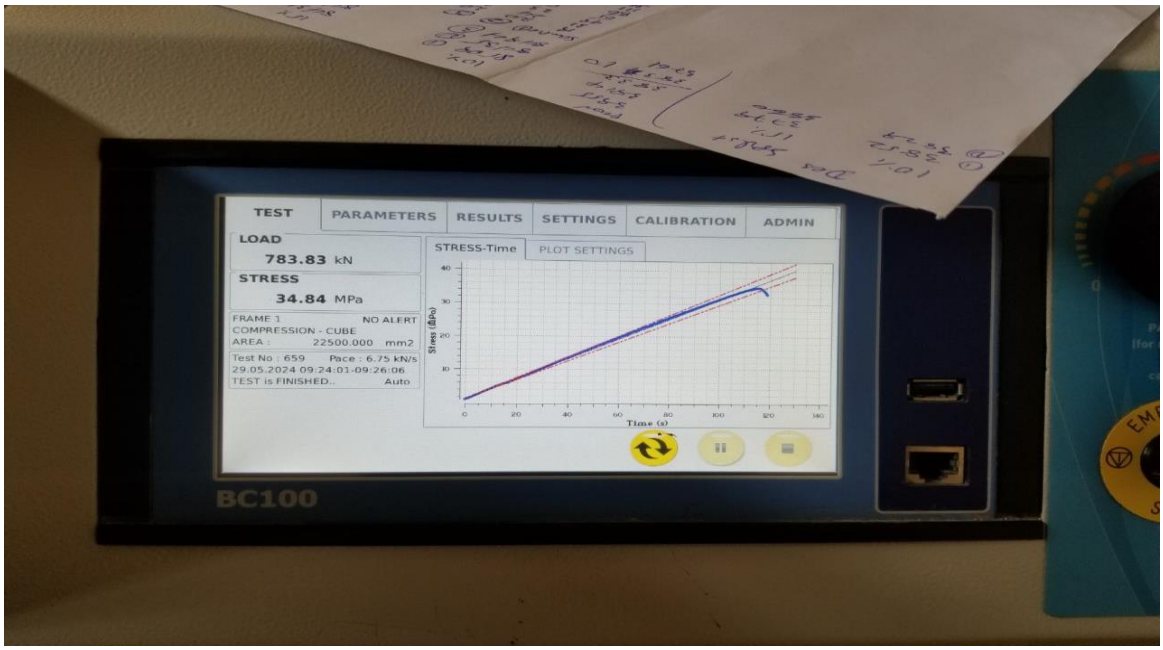

Photo 4: Test result on cube strength

Photo 5: test result for split tensile strength

Photo 6: Flexural test result

```
--> X=poly([0 1],'x','c')
 X  =

  x

--> A=287811.527*X^2-(1526.84-453.963*18.211/18.211)*X+18.211/18.211
 A  =

  1 -1072.877x +287811.53x²

--> Ec=roots(A)
 Ec  =

   0.0018639 + 0.0000234i
   0.0018639 - 0.0000234i

--> X=poly([0 1],'x','c')
 X  =

  x

--> A=250000*X^2-(1208-208*25.244/25.244)*X+25.244/25.244
 A  =

  1 -1000x +250000x²

--> Ec=roots(A)
 Ec  =

   0.002 + 0.i
   0.002 + 0.i
-> X=poly([0 1],'x','c')
X  =

 x

-> A=222919.51*X^2-(1040.60
A  =

 1 -944.287x +222919.51x²

-> Ec=roots(A)
Ec  =

  0.002118 + 0.0000007i
  0.002118 - 0.0000007i
```

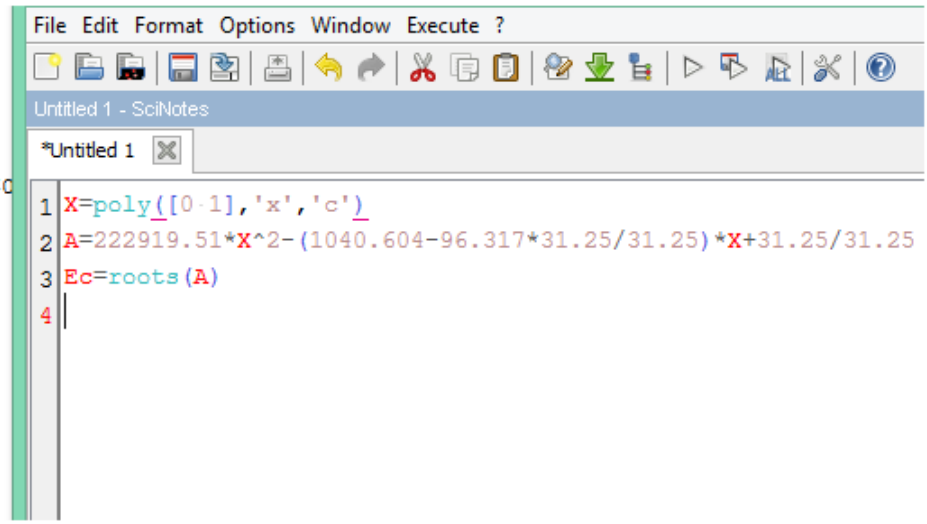

Photo 7: Scilab-6.1.1 analysis for strain stress-strain