JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

STRUCTURAL ENGINEERING STREAM

EXPERIMENTAL STUDY ON THE EFFECT OF HYBRID OF EGGSHELL POWDER AND SAWDUST ASH AS PARTIAL REPLACEMENT OF CEMENT IN CONCRETE

A Thesis 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

TESFAYE SEIFU

JULY, 2021

JIMMA, ETHIOPIA

JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

STRUCTURAL ENGINEERING STREAM

EXPERIMENTAL STUDY ON THE EFFECT OF HYBRID OF EGGSHELL POWDER AND SAWDUST ASH AS PARTIAL REPLACEMENT OF CEMENT IN CONCRETE

A Thesis 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

TESFAYE SEIFU

ADVISOR: **Dr. KABTAMU GETACHEW (**PhD**)**

CO-ADVISOR: **Engr. ABEBECH DEME** (MSc)

JULY, 2021

JIMMA, ETHIOPIA

JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIROMENTAL ENGINEERING

STRUCTURAL ENGINEERING STREAM

EXPERIMENTAL STUDY ON THE EFFECT OF HYBRID OF EGG SHELL POWDER AND SAWDUST ASH AS A PARTIAL REPLACEMENT OF CEMENT IN CONCRETE

TESFAYE SEIFU SHIKUR

APPROVED BY BOARD OF EXAMINERS

1. Dr. Kabtamu Getachew, PhD Main Advisor	21/07/21 Signature	21/07/2021 Date
2. Engr. Abebechi Deme, MSc Co-Advisor	Signature	27/07/2021 Date
3. Dr. Badrinarayan Ratha, PhD External Examiner	Rath Signature	16/07/2021 Date
4. Engr. Asanti Keno, MSc Internal Examiner	Signature	22/07/201 Date
5. Engr. Abinet Alemseged, MSc Chairperson	Signature	15/11/2013 Date

DECLARATION

I declare that this thesis entitled ''**Experimental Study on The Effect of Hybrid of Eggshell Powder and Sawdust Ash as Partial Replacement of Cement in Concrete''** is my original work and has not been presented by anyone for an award of degree at any university.

Tesfaye Seifu	______________	July 27, 2021
Name	Signature	Date

This thesis has been submitted for examination with my approval as University supervisor.

Dr. Kabtamu Getachew (PhD)	______________	July23, 2021
Advisor	Signature	Date
Engr.Abebech Deme (MSc.)	______________	July 27,2021
Co-Advisor	Signature	Date

ABSTRACT

Throughout the world, concrete, the backbone of the infrastructure development of a nation, is being widely used for the construction of most buildings, bridges, etc. And cement which is ingredient of concrete has greenhouse effect and unsustainability of its raw materials problem. So, cement has been partially replaced with hybrid of Egg shell powder sawdust ash to reduce impacts.

The aim of this research was to investigate the effects when cement partially replaced with hybrid of eggshell powder and saw dust on the workability and strength of concrete.
In investigation of mechanical properties of samples cube crushing test, split tensile test and bending test were done on cubes, cylinders and beam with various percentages of hybrids of ESP and SDA of as 5%, 10%, and 15% by weight with equal amount of ESP and SDA. For Each H-0%, H-5%, H-10% and H-15% three beams, three cylinders and three cubes were casted for each 7^{th}*,* 14^{th} *and* 28^{th} *days of test in laboratory to examine their mechanical properties.*
By the testing workability fresh concrete, it has been found that there was reduction in of 6.06% for H-5%, 15.15% for H-10% and 21.21% for H-15% with respect to H-0%.

The result of mechanical strength test on the concrete in which cement is partially replaced showed that for compressive strength at 28^{th} *day there was increment in 4.9% for H-5, and 0.1% for H-10 and reduction in 6.6% for H-15% with respect to ES EN 1992's compressive strength at 28th day. The 28th day splitting tensile strength test result shows that increment in 6.1% for H-5% and 3.9% for H-10 but reduction with 22.9% for* H-15% *with reference of ES EN 1992's splitting tensile strength requirement at* 28^{th} *day. For flexural tensile strength at* 28^{th} *day there was increment in 0.2% for H-5, and neither increment nor decrement for H-10 and reduction in 5.9% for H-15% with respect to ES EN 1992's flexural tensile* strength at 28^{th} *day.*

All percentage of hybrid have parabolic Compressive stress- strain curve at all days of curing as like ES EN 1992's Code of standard.

In general, it can be concluded that the replacing of cement up to 10% by weight with hybrid of ESP and SDA fulfill the Compressive, Splitting Tensile and Flexural tensile strength requirement of ES EN 1992's Code of standard.

Key Words: Egg Shell Powder; **Saw Dust Ash**, **Compressive Stress- Strain**

ACKNOWLEDGEMENT

Before all things, I would like to thank almighty God for his very existence in every moment of my life and for giving me health plus strength to reach this stage; without his help, nothing would happen.

My next sincere and deepest gratitude goes to my principal advisor Dr. Kabtamu Getachew, for his excellent guidance and also, I would like to thank my Co-Advisor Engr. Abebech Deme for her essential and helpful advice when this thesis prepared.

Last but certainly not least, I would like to thank my family members, especially my wife Selamawit Shimelis, colleagues and friends who helped me in giving information on this study and their encouragement throughout my study. And moreover, my gratitude goes to Dire Dawa University, Ministry of Science and Higher Education and Jimma University, Structural Engineering Stream.

TABLE OF CONTENTS

LIST OF TABLE

LIST OF FIGURES

ACRONYM

ACI	American Concrete Institute
Al_20_3	Aluminum tri Oxide
ASTM	American Standard Testing Material
CaO	Calcium Oxide
C20/25	Concrete grade with the cylindrical strength of 20 MPa, cubic strength of 25 MPa
EN	European Norm
ES EN	Ethiopian standard based on Euro Norm
ESP	Egg Shell Powder
Fe_20_3	Iron tri Oxide
FRSDA	Fibre Reinforced Sawdust Ash
H-0%	Hybrid of 0% ESP and SDA replacing cement
H-5%	Hybrid of 5% ESP and SDA replacing cement
H-10%	Hybrid of 10% ESP and SDA replacing cement
H-15	Hybrid of 15% ESP and SDA replacing cement
JiT	Jimma Institute of Technology
K_20	Potassium Oxide
LOI	Loss On Ignition
Mgo	Magnesium Oxide
Na_20	Sodium Oxide
PPC	Pozzolana Portland Cement
RHA	Rice Husk Ash
SDA	Sawdust Ash
SF	Steel Fibre
Sio_2	Silicon di Oxide

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Concrete is being widely used for the construction of structures due to its structural stability and strength. It is the backbone of the infrastructure development of a nation. At present, for a variety of reasons, the concrete industry is unsustainable. Firstly, it consumes a huge number of natural resources due to which no virgin material will be left for the future generation. Secondly, the major component of concrete is cement and a large number of greenhouse gases are being emitted in the manufacturing process of cement. Thirdly, concrete structure suffers from durability problem due to which natural resources are wasted. The cost of conventional building materials continues increasing as the majority of the population continues falling below the poverty line. Thus, there is the need to search for local construction materials as alternatives for functional and low-cost both in the rural and urban areas. Some of the waste products which possess pozzolanic properties and which have been investigated for use in blended types of cement include fly ash, Silica fume, volcanic ash, Rice husk ash, Corn Cob Ash. **[1]**

In the past, in Ethiopia, legends told that buildings like “Fasiledes”, a castle of Gondar, and “Ye Egzier Dildiy”, Bridge in Arbaminch, were built by using materials that didn’t include cement at all. They used other materials like eggs and limestone instead of concrete. And somehow it was strong enough to stay for a long time without collapse. **[2]**

Cement is one of the materials that form concrete, as it has positive contributions it also has negative impacts. This negative impact of cement is during the production of cement high amounts of energy is needed; they use non-renewable resources like limestone.

Therefore, to reduce environmental problems the need for more inexpensive and green materials that partially or fully replace cement would be developed. Industrial wastes like silica fume, fly ash and blast furnace slag are used most widely in concrete and mortar productions due to their pozzolanic behaviors. Not only industrial wastes are used in cement replacement but also agricultural wastes like eggshell powder, bone powder, coconut shell, rice husk ash, etc. have been used fruitfully to replace cement. **[3].**

Eggshell powder, which is calcium-rich, is a poultry waste and majority of it deposited in landfills. Besides, in landfills, it attracts vermin due to the attached membrane and causes problems associated with bodily health and the environment **[3]**

Sawdust is a waste material resulting from the mechanical milling or processing of timber into various shapes and sizes. The dust is usually used as domestic fuel. form of pozzolana ash that formed is called known as Saw Dust Ash (SDA). Sawdust ash consists of non-crystalline silicon dioxide with a high specific surface area and high pozzolanic reactivity. Moreover, calcium-rich eggshell is a poultry waste with a chemical composition nearly the same as that of limestone**[4].**

Hence, the use of these materials in concrete can accept benefits like minimizing the use of cement, conserving natural lime, and the utilization of waste materials.

And also, concrete strength has its limitations when it comes to the excessive force exerted that may lead to concrete failure. To overcome the problem, the identification of various researches on the discovery of new materials has been made. This research addressed the effects on the strength of concrete by partial replacement cement with hybrid mix of eggshell powder and sawdust ash with equal proportion in the concrete mix.

The objective of this research meted by determine the optimum percentage of a mix of eggshell powder (ESP) and sawdust ash (SDA) that can partially replace cement that can enhance mechanical properties of concrete.

1.2 STATEMENT OF THE PROBLEM

Concrete has many features that define it, from that durability, fire resistance capacity, and good compressive strength, and so on are its good quality. On other hand, its tensile and flexural strength is very weak compared to its compressive strength. Furthermore, concrete has low ductile property, low energy absorption capacity, and is also affected by shrinkage.

Cement, components of concrete, is one of the three primary producers of carbon dioxide, a major greenhouse gas, and become the most expensive

Since wastes create acute environmental problems both in terms of their treatment and disposal. If wastes are not disposed of correctly, it will lead to many negative impacts in terms of environmental pollution and water pollution. Also, All the landfills had waste related to the aesthetic problem, contamination, landfill gas, or odor problems. Even though almost all the waste is disposed of using the landfill method and the majority of the sites have poor management.

In Ethiopia, some sayings tell that structures like "Fasiledes", the castle of Gondar, and "Ye Egzier Dildiy", God's Bridge in Arbaminch, were built from materials that did not include cement. The sayings describe the structures built from sand, lime, and egg parts, as a binder. Those sayings and excess availability of sawdust in Jimma are the motivating cases for this research to investigate the effect of Hybrid of Egg Shell Powder and Sawdust Ash on Property of Concrete.

So, identify waste material and use it in concrete production in the construction industry could be a wide idea and can bringing a lot of benefits like to improve weaknesses of concrete, especially the tensile and flexural strength, and make the environment a safe place for humankind. Besides, it is a solution for Land scarcity which dramatically increased the price of landfills.

Therefore, Eggshell and sawdust ashes are waste products or by-products those may give better solution for all problems concerning to concrete weakness and cement's environmental pollution and expensiveness.

This research paper presents the investigation result for the effects of the addition of ESP/SDA mix in the concrete mix and suggested the optimum percentage of ESP/SDA mix that can replace cement.

1.3 RESEARCH QUESTIONS

This study ostensibly be aimed to answer the following questions:

1. What is the effect of hybrid of Eggshell Powder and Sawdust Ash on workability of Concrete?
2. What is the effect of hybrid of Eggshell Powder and Sawdust Ash on mechanical properties of Concrete?
3. What is similarity between experimental specimens' Compressive Stress-strain diagram and Compressive Stress-strain diagram for concrete of ES EN 1992:2015 (3.1.5).
4. What is the optimum percentage of Hybrid of Eggshell Powder and Sawdust Ash that can replace cement and fulfill strength requirement of ES EN 1992:2015 (3.1.2)'s Code of standard?

1.4 OBJECTIVES OF THE STUDY

1.4.1. GENERAL OBJECTIVE

The main objective of this study was to investigate the Effect of Hybrid of Eggshell Powder and Sawdust Ash on the Property of Concrete.

1.4.2. SPECIFIC OBJECTIVES

1. To test workability of the concrete with and without Hybrid of Eggshell Powder and Sawdust Ash
2. To test Compressive, Splitting tensile and flexural tensile strength of the concrete with and without Hybrid of Eggshell Powder and Sawdust Ash and compare with strength requirement of ES EN 1992:2015 (3.1.2)'s Code of standard.
3. To investigate Compressive Stress-strain diagram of specimens and compare with curve shape of Compressive Stress-strain relation diagram for concrete of ES EN 1992: 2015 (3.1.5).
4. To determine the optimum percentage of Hybrid of Eggshell Powder and Sawdust Ash that can replace cement and fulfill strength requirement of ES EN 1992:2015 (3.1.2)'s Code of standard?.

1.5 SIGNIFICANCE OF THE STUDY

The aim of the present study was to contribute to the Ethiopian construction industry by the various merits like; Re-using wastes of Eggshell and sawdust ash material as an ingredient in concrete to produce green structures by reducing the adverse impacts on the environment worldwide.

It also serves as a good waste disposal method by saving the economy that will be used for the removal of the waste.

Furthermore depending on the result obtained from the experiment, conclusion has been made and using those hybrids for sustainable construction development in addition to the output enhances knowledge and experiences in research. The research can be used by researchers; the findings can be used in literature review of future researches.

1.6 SCOPE AND LIMITATION OF THE STUDY

The scope of this study was done to study the workability on fresh concrete and on identifying the effect of Mix of ESP and SDA from 0% to 15% by weight of cement on compressive, Splitting tensile and flexural tensile strength of concrete at 7^{th}, 14^{th} and 28^{th} days of age for C20/25 grade of concrete in the laboratory.

Experimentally investigated strength test results checked whether percentage of Hybrid of Eggshell Powder and Sawdust Ash that can replace cement and fulfill strength requirement of ES EN 1992:2015 (3.1.2)'s Code of standard In this investigation the chemical reaction between cement, ESP and SDA and long-term strength and durability property of concrete not tested due to time and laboratory equipment constraints.

The scope of this study be limited to investigate possibility of partial replacing cement with recycle wastes, eggshell powder and sawdust ash.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

2.1 INTRODUCTION

Concrete- composite construction material, Cement + Coarse Aggregate + Fine Aggregate + Water + Chemical Admixtures. In its simplest form, concrete is a mixture of paste and aggregates. The word concrete comes from the Latin word "concretus" (meaning compact or condensed). Concrete solidifies and hardens after mixing with water and placement due to a chemical process known as hydration. The water reacts with the cement, which bonds the other components together, eventually creating a robust stone-like material. Concrete is used more than any other man-made material in the world. As of 2006, about 7.5 cubic kms of concrete are made each year—more than one cubic meter for every person on Earth.**[5]**

The cement and concrete technology have shown various advancements during the past years. One of the best advancements is the use of industrial by-product and domestic wastes materials as a cement replacement to alleviate environmental and economic impact of cement production. Cement replacing materials were reported to improve different properties of the concrete. Eggshell and saw dust are some of these by-product materials. The eggshell is found from poultries, hatcheries, homes, restaurants, hotels, and fast food centers **[6].** Whereas Sawdust or wood dust is an industrial waste obtained as by-products from cutting, sawing or grinding of timber in the form of fine particle recently they have been studied for their feasibility as a cement replacing materials in some parts of the world and has been found to improve some of the properties of concrete.**[4]** The performance of concrete has been investigated by different tests on concrete. Those include unit weight, workability, flexural strength, compressive strength, and tensile strength.

This chapter is, therefore, dedicated in discussing about different performance criteria of concrete, eggshell powder and Sawdust ash.

2.2 CONCRETE

2.2.1 STRENGTH OF CONCRETE

Strength of concrete is commonly considered its most valuable property, although in many practical cases other characteristics, such as durability and permeability, may in fact be more important. Nevertheless, strength usually gives an overall picture of the quality of concrete because it is directly related to the structure of the hardened cement paste [7]. The strength of concrete is dependent on many things. The hydration reaction, water to Cement ratio, aggregate's type, amount and size, water content, cement content, curing condition, cement type, compaction method used etc. have an effect on the strength of concrete.

Strength at any W/C ratio depends on the degree of hydration of the cement and its physical and chemical properties. The decrease in the water content of the concrete results in a higher strength of the concrete. The water required for the hydration reaction is less than that of the mixing water; the extra water provided is used to make the concrete more workable. The compaction of the fresh concrete reduces the amount of entrapped air and therefore increases the strength of the concrete. It is found that for each 1% of air entrapped there will be a 5 to 6% loss on strength.[8]

Curing temperature affects the hydration of cement and hence the duration of strength gains. Cubes kept at about 10^0C will have their 7day strength reduced by 30 % and their 28day strength by 15%. Different pozzolanic materials have different effect on strength. But most of them including eggshell powder and waste glass powder have been found to improve the strength of concrete especially due to the secondary reaction. [8]

2.2.2 PROPORTIONING OF CONCRETE INGREDIENTS

Proportioning the concrete ingredients is selecting the suitable ingredients among the available materials and determining the most economical combination that will produce concrete with certain minimum performance characteristics. It is the process of arriving at the right combination of cement, aggregates, water, and admixtures for making concrete [9].

The purpose of mix proportioning is to obtain a product that will perform according to certain predetermined requirements. Conventionally, these requirements are the workability of fresh concrete, the strength of hardened concrete at a specified age, satisfying the performance requirements at the lowest possible cost [9]

There are different methods of mix designing such as: ACI Committee 211 method, DOE method, arbitrary proportion, fineness modulus method, maximum density method, high strength concrete mix design, mix design based on flexural strength, Road note No.4 (grading curve method), mix design for pumpable concrete. Out of the above methods, some of them are not very widely used these days because of some difficulties or drawbacks in the procedures for arriving at the satisfactory proportions. ACI committee 211 method and DOE methods are commonly used [10].

2.2.3 SUSTAINABILITY OF CONCRETE

These days' sustainability plays the major role in every aspect of human activities. Many technologies came to an end because they were not in harmony with the idea of sustainable development. Sustainability is concerned about the world we will be leaving behind for future generations, that is, to our children and their children. It focuses on the social, environmental and economic issues of human activities.

Concrete is by far the most widely used materials worldwide next to water, is not free from some negative environmental impacts. Its popularity carries with it a great cost in terms of environmental aspects. Environmental problems associated with concrete can have varied origins.

Worldwide, over ten billion tons of concrete are being produced each year. Such volumes require vast amounts of natural resources for aggregate and cement production. In addition to this it is estimated that one ton of Portland cement production releases about one ton of CO_2. Each of the constituents of concrete release a certain amount of CO_2 as shown on the Figure 2.1. CO_2 emission by process step in cubic yard of concrete, 20 MPa (3,000 psi)

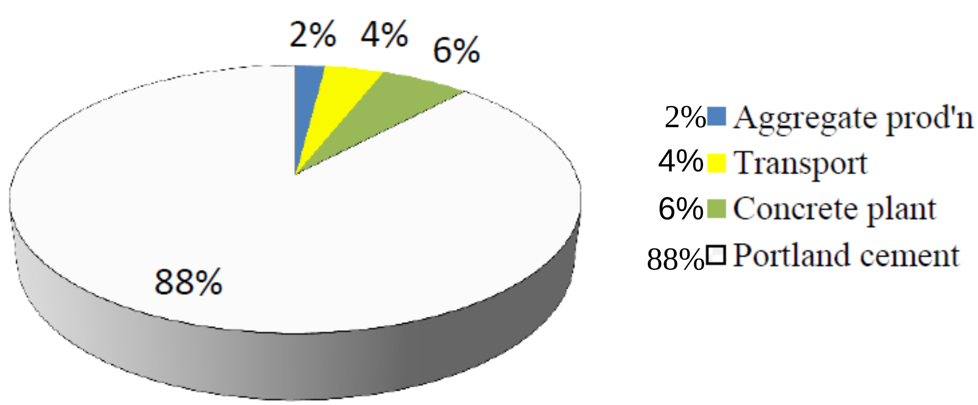


Figure 2-1 Relative Amount of CO_2 production from different plants

Therefore, concrete industry has become the victim of its own success. However most of the environmental problems associated with concrete come from the cement in it. This means that the final product i.e. concrete is environmental friendly material by itself **[1].** This guides us to play on the concrete constituents which cause the problem. One of the constituent which causes the largest environmental impact is Portland cement. Therefore, if we are able to minimize the amount of Portland cement in the concrete, we will be able to minimize the environmental impact of the concrete industry as a whole.

Many ways were suggested to increase the compliance of the industry to the demand of sustainable development. Increased use of supplementary cementitious materials, increased reliance on recycled materials, improved sustainability and mechanical property and reuse of wash water are some of the methods.

The issue of sustainability and energy conservation are assisting in changing the Portland cement industry by lowering and partially replacing its cement production with supplementary cementing materials (SCMs), which are a byproduct of another industry **[11].**

2.3 LITERATURES ABOUT EGGSHELL

In the past decade recycled materials have been added to concrete in an effort to reduce post-consumer wastes and industrial by-products entering the landfills. One of these materials could be waste chicken eggshells which contain a very pure form of calcium carbonate or limestone frequently called calcite ($CaCO_3$). Re-use of limestone-based eggshells would promote recycling of waste and prevent its diversion to landfills. Consumption of eggs in restaurants and households are minor compared to the majority of eggs utilized in egg breaking plants for mass production of liquid eggs for use in food and non-food related products **[11]**.

The outer cover of the egg, eggshell consists of several mutually growing layers of $CaCO_3$, the innermost layer-maxillary 3 layer grows on the outermost egg membrane and creates the base on which palisade layer constitutes the thickest part of the eggshell. The weight of an average egg is about 60 gram, while the empty shell corresponds to 11% of the egg weight **[12]**.

The eggshell quality can be affected by several factors such as; type of hen strain/breed/genetics, age, nutritional diet, and stress related to population density. Brown eggs are larger, heavier and have thicker shells than white eggs; however, the shell color is not an indication of the internal quality of an egg since brown eggs are not healthier than white eggs [13].

In one study, the percentage of calcium carbonate in brown eggs is found to be 96–97 % in weight and 3–4 % weight of organic matter, while in other investigations white eggs were found to have 94 % weight of calcium carbonate content with 6 % weight of organic matter and other minor compounds. Based on these findings, the calcium carbonate content of white and brown eggs can be considered equivalent. However, the calcium carbonate content of brown eggs is greater than white eggs [14]

2.3.1 INGREDIENTS OF CEMENT, EGGSHELL POWDER AND SAW DUST ASH

Cement, the constituents of concrete, has a negative impact on the environment. But the demand for concrete increases from time to time. Since a sustainable environment is an issue for future generation, there is a need to search an alternative material that replaces cement without affecting the environment and without affecting the strength of concrete. For sustainable development, it is necessary to use industrial and agricultural wastes. Industrial wastes like ground granulated blast furnace slag, silica fume, fly ash and agricultural wastes like eggshell powder, bone ash, rice husk ash, coconut shell, etc. has been used to replace cement. Hence cement production can be reduced so as carbon dioxide from cement industry.

Eggshell which is a waste from households, cafeterias, restaurants, food industries is disposed to the landfill or to the environment. Eggshell waste is cost center when they exposed to the environment and grinding one eggshell will produce about 5 grams of eggshell powder.[15]

Eggshell which composed of calcium carbonates is used as cement replacement material. It has about 93.7 percent of $Ca (CO)_3$ which is very similar to cement[11].

The CaO content of eggshell that examined during the investigation of its chemical composition makes it an alternative material for concrete production by replacing cement. According to Okonkwo et al,[11] eggshell contains about 93.7 percent of $Ca(Co)_3$ which is very similar to Portland cement.

Significant Amounts of researches were conducted all over the world to study the suitability of eggshell powder as cement replacing material within a certain percentage. Using eggshell powder is not only eco-friendly but also increases the strength of concrete up to certain percentages of replacement.

The behavior of eggshell powder concretes can be compared with lime stone replaced concretes. Limestone reacts with the alumina pastes of cement to form a calcium mono-carbo aluminate hydrate phase and contributes to strength change. The use of this eggshell waste instead of natural lime to replace cement in concrete can have benefits like minimizing use of cement, conserving natural lime and utilizing waste material [16].

Sawdust or wood dust is an industrial waste obtained as by-products from cutting, sawing or grinding of timber in the form of fine particle. The physical and chemical properties of sawdust vary significantly depending on several factors; especially the species of wood by nature, sawdust particles are porous and absorb most of the water leaving insufficient water for the setting of cement. It is also presumed that if sawdust particles take up enough water during hydration, they could aid the hydration process particularly in the inner parts of concrete that is not possible to cure with water thus eliminating the need for curing since water deposited in sawdust particles are being harvested by cement particles [4].

Table 2-1: Chemical composition of Cement, eggshell powder and Saw dust ash.

	Chemical composition weight %							
Chemical	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	K_2O	Na_2O	SO_3
OPC[1]	64.67	21.03	6.16	2.58	2.62	0.61	0.34	2.03
PPC[1]	42	30	8.5	5.4	1.4	-	-	2.6
Eggshell powder[1]	61.71	0.61	0.07	0.63	0.36	0.22	-	1.32
Saw Dust Ash[17]	9.6	65.3	4	2.23	5.8	0.11	0.07	-

2.3.2 EGGSHELL REPLACEMENT IN CONCRETE

2.3.2.1 EGGSHELL POWDER AS FINE AGGREGATE REPLACEMENT IN CONCRETE

Raji & Samuel, [18] Uses eggshell as a fine aggregate in concrete production. The replacement of fine aggregate is done in 100%. Finally, the result indicated that the compressive strength of eggshell replaced fine aggregate concrete is below the control mix but it can be used as a light concrete where low dead load of structures required. Generally, the researcher concluded that eggshell cannot replace fine aggregate at 100 percent

NeimaYesuf [2] studied the effect of egg and lime on the compressive strength of mortar. The egg shell as partial fine aggregate replacement was studied by replacing egg shell by 0%, 1%, 2.5%, 5%, 7.5%, 10%, 12.5%, 15%, 17.5% and 20% and effects on the compressive strength of mortar was studied.

On the experiments, by the addition of eggshell with the volume of 5% of the fine aggregate, the compressive strength of the mortar has increased by more than 13% compared to the mortar made with only cement, sand and water keeping the same water cement and sand to cement ratio.

2.3.2.2 EGGSHELL POWDER AS CEMENT REPLACEMENT IN CONCRETE

Yu et al,[19] studied the effects of different curing methods on concrete strength. The cement in this study were replaced by eggshell powder from 5-15 percent of the weight of cement. The curing was done in full water and in open air. Water cured concrete shows higher strength than air-cured concrete. The insufficient moisture available in air-cured concrete is the reason for low strength development of air-cured concrete. The low amount of moisture for concrete slows down the hydration process and the formation of C-S-H, which is necessary for strength development. The other finding of this study was the optimal replacement of cement by eggshell is 15%, beyond this percentage the compressive strength of concrete can be reduced.

Bysani Mythili et al. [20] carried out a Study on Limited Substitution of Egg Shell Powder with Cement in Concrete. A 28 days' compressive strength of cement mortar in addition to concrete properties as: compressive strength, split tensile strength and flexural strength was tested. In their work, cement mortar of mix proportion 1:3 was used in which cement was partially replaced with eggshell powder. The cement is part replaced with egg shell powder as 5%, 10%, 15%, 20%, 25% and 30% half-hour by weight of cement. There was a pointy decrease in compressive strength on the far side five-hitter egg shell powder substitution.

The admixtures used are Saw dirt ash, ash and small oxide to reinforce the strength of the concrete combine with 5% egg shell powder as partial replacement for cement. It was concluded that replacement of 5% Egg shell powder + 22% of Micro silica are often superimposed with none reduction in compressive strength properties of typical concrete. Also, replacement of 5% of Egg shell powder + 12% Micro silica replacement in cement yields similar flexural strength as in typical concrete. And replacement of 5% Egg shell powder + 15% Micro silica replacement in cement yields higher Split Tensile strength as compared with conventional samples.

Sargunan S. and Senthil K. [3] studied on Optimization of Cement Concrete using Eggshell Powder. An attempt was made to evaluate the effect of incinerated (burned) egg shell powder (IESP) and raw egg shell powder (ESP) as a partial cement replacement. The effects of ESP with concrete in both the form were determined with 20%, 30%, 40% and 50% cement replacement. The grained material was incinerated in furnace at laboratory for 900 ^{0}C, 1 hour and the incinerated egg shell ash was taken after 5 hours cooling.

M.Mohamedansari et al, [21] conducted Research at M.A.M engineering technology in India concluded that 10-15 percent replacement of cement by eggshell powder increases the compressive strength of concrete. But replacement beyond 15 percent reduces the strength of concrete

Yerramala[16] studied the Properties of concrete with eggshell powder when eggshell powder is used as a cement replacement material. They replace cement from5%-15% and each percentage are their own influence on the properties of concrete. Compressive strength test was done for 1, 7 and 28 days of curing. The compressive strength for 5 % replacement was higher than the control mix, but as the percentages of replacement increases the compressive strength decreases.in addition split tensile of concrete strength is comparable up to 10% replacement, but as the percentages increase the split tensile strength has lower value than control mix. Finally, they concluded that the optimum amount of replacement for maximum strength is 5% since the strength of 5% replacement mix is greater than the strength of the control mix and addition of fly ash improves the strength of concrete.

D.Gowsika, etal.,[22] studied the use of eggshell powder as cement replacement in mortar and M 20 grade concrete. For mortars, cement was replaced by Eggshell powder at percentages of 5, 10,15,20,25 percent by weight of cement and compressive strength tests of mortars were done after 28 days of curing. The result indicated that compressive strength of mortars beyond 5 percent replacement was decreased. On this same research, for M 20 grade of concretes cement is replaced by eggshell powder by 5 percent. for this experiment admixtures like sawdust ash, micro silica and fly ash were used to enhance the strength of the concrete. The test result shows that, replacement of 5 percent eggshell powder and 20 percent micro silica gives good result without reducing compressive strength of control mix and the flexural strength of 5 percent eggshell powder and 10 percent micro silica is similar to the control mix, while Replacement of 5 percent eggshell powder and 10 percent micro silica gives higher split tensile strength compared to other combinations.

Mtallib & Rabiu,[23] studied the effects of eggshell ash on setting time of cement. The percentages of eggshell ash used for this study were 0%, 0.1%, 0.5%, 1%, 1.5%, 2% and 2.5 %. In the presence of the eggshell setting time of cement decreases which means eggshell ash is used as an accelerator. This is not the only finding of this research, as the ash content increases the setting time decreases or the greater accelerating effect. From the above research outputs, we can conclude that eggshell powder can be suitable to replace cement. Not only it replaces cement but also it improves various properties of concrete

Praveen Kumar et al.[24] has done Experimental Study on Partial Replacement of Cement with Egg Shell Powder. They investigated the combination of Egg shell with silica fumes in different combinations to find the feasibility of using Egg shell as an alternate to cement in concrete. Egg shell powder replaces 10%, 20% and 30% in addition with the silica fume by 5%, 10% and 15% of weight of cement in the M30 concrete.

Based on the results they obtained, they conclude that the compressive strength of concrete with egg shell powder increases up to 15% without silica fume. Addition of silica fume also enhances the strength but in economical point of view only the egg shell powder replacement is sufficient enough for getting higher strength. The split tensile strength of the egg shell powder concrete decreases with the addition of egg shell powder while, the flexural strength of the egg shell concrete increases with the addition of egg shell powder up to 15 percent.

Finally, from the experimental work result they conclude that egg shell powder alone can be replaced as cement which increases the strength parameters meanwhile reduces the cement usage

2.3.3 AVAILABILITY OF EGGSHELL IN ETHIOPIA

Eggs are popular all over the world in their protein content. The production of egg increases year by year since the consumption of egg increases. According to FAO (Food and agricultural organization united nation, 2019) report china (31,284,000metric tones) is the first in production of egg followed by the United States (6152875.5 metric tons) and India (4704250 metric tons). It is estimated that roughly 90 million tons of hen eggs are generated throughout the world every year. In order to assess the amount of eggshell waste produced in Ethiopia it is necessary to know the amount of eggs produced in Ethiopia. According to food and agricultural organization report (FAO), the Annual per capita egg consumption in Ethiopia is 0.4Kg, which is the lowest among other countries. Egg production increases from year to year.2015 (54861tone), 2016 (54395 tones) and 2017 (55000 tones)[26].

The weight of an average egg is about 60 grams, while the empty shell corresponds to 11% of the egg weight [12]. Recently the demand for eggs increased. To increase the consumption of egg the government of Ethiopia plans to produce 3.9 billion eggs in 2020. As the consumption of egg increases so does eggshell waste, this is problem to the environment. Generally, the poultry sector in Ethiopia is popping up. [27].

2.4 LITERATURES ABOUT SAW DUST

Determined the compressive strength of concrete made with varying percentages of waste wood ash (WWA). They reported that compressive strength generally increased with age but decreased with the increase in the WWA content. Comparisons of the strength of WWA concrete with those of the control (plain) concrete of corresponding ages showed that the strength of WWA concrete was generally less than that of the plain concrete [28].

Udoeyoet al.[29] Studied the influence of wood ash (WA) on the slump of concrete. He used wood ash as partial replacement of cement in varying percentages (0, 10, 20, 30, and 40%) in concrete mixture proportion of 1:2:4. Test result showed that mixtures with greater wood ash content require greater water content to achieve a reasonable workability.

Jeson.P et al.[17] Carried out the test experimental study on properties of concrete by partial replacement of cement with silica powder and fine aggregate with saw dust ash. In this experiment natural sand was partially replaced (5%, 10%, and 15%) with SDA. Compressive strength and Tensile strength (cubes and cylinders) on 7, 14 and 28 days of age were compared with those of concrete made with natural fine aggregate. Based on the study carried outon the strength behaviour of saw dust the following conclusions are drawn i.e.in the project it is observed by 5%, 10% and 15% partial replacement of Fine Aggregate with Saw Dust Ash and 25% partial replacement of Cement with Silica Powder, the 5% of Compressive Strength is more than the Conventional Concrete Target Strength. The other percentage mix has a low Compressive and Tensile Strength this may be due to low bulk density of Saw Dust Ash. But literature says that Saw Dust Ash give good strength if replacement with fine aggregate on concrete.

Mageswari et al.[4] Has carried the experiment by replacing natural sand with SDA (5%, 10%, 15%, 20%, 25% and30%). Along with that it was concluded that water requirement increases as the SDA content increases. The compressive strength of cubes and cylinders of the concrete for all mix increases with age of curing and decreases as the SDA content increases. The Tensile strength of cubes and cylinders of the concrete for all mix increases with age of curing and decreases as the SDA content increases. The Flexural strength of the beam of the concrete for all mix increases with age of curing and decreases as the SDA content increases.

SDA is available in significant quantities as a waste and can be utilized for making concrete.

This will go a long way to reduce the quantity of waste in our environment. The optimum replacement level in fine aggregate with SDA is 10%. Workability of the concrete decreased as the percentages of SDA replacement increased. So, there is a possibility that 10% of SDA can be used in the field purpose.

Obilade et al. [30] conducted experiments to check the validity of using sawdust ash as partial replacement for cement in concrete. The experiments were run with partial replacement of cement with Saw dust ash (SDA) in 0%, 5%, 10%, 15%, 20%, 25%, and 30%. The compressive strength test of the sample was carried out and the compressing factor values were recorded to be 0.91, 0.89, 0.88, 0.87, 0.86, 0.86 and 0.85 respectively. The bulk densities of the concrete cubes were recorded at interval of 7, 14 and 28 days for the same SDA percentages mentioned earlier the trend shows a decrease in the densities with increasing percentages.

From the investigation carried out, the optimum addition of SDA as partial replacement for cement ranges up to 15%. The compressive strength of the concrete, however, took a dip when percentage SDA replacement increased. From the study it was further recommended that the use of local recycled materials like SDA as pozzolanas should be encouraged more in this sector to enhance material usage efficiency and reduce the usage of sand or silica as a fine aggregate in concrete mixtures.

Batt et al.[31] Carried out his experimentation with the Partial Replacement of Wood Ash with Ordinary Portland Cement and Foundry Sand as Fine Aggregate. His team recorded the observations of the compressive strength, Split tensile strength, Flexural test, Water absorption, Soundness, Carbonation, Bulk Density and Drying Shrinkage at 7, 28 and 56 days.

The strength parameters obtained were quite better than the attaining target of M20. The results for compressive strength were much significant. The optimum level of replacement with wood ash produced positive results. Water absorption favored the new substitution. The new mixture was now able to handle load more effectively and did not result in sudden failures – the concrete mix was thus, more ductile. Incorporation of wood ash enhanced the quality of paste, thereby increasing both split tensile strength and flexural strength of concrete.

Muhammad Habib.[33] As the percentage of Saw Dust Ash increases, the compressive strength of concrete tends to increase up to the percentage of 5 and 10% and then start's decreasing as the saw dust ash is increased from 15 to20%.The splitting tensile strength of Saw Dust Ash concrete increases up to the percentage of 5% and10% and then it starts decreasing as the percentage of SDA increases. The strength of 5% and 10% Saw Dust Ash concrete is more than normal concrete. This shows that till10% Saw Dust Ash concrete can be used in the replacement of cement. This increase in strength in Saw Dust Ash concrete is due to presence of Silica and pozzolanic reactions in Saw Dust Ash.

2.5 LITERATURES ON HYBRIDS THOSE REPLACE INGREDIENTS OF CONCRETE

A lot of experimental work was carried out on plain concrete having different types of hybrids to study their improved engineering properties in compressive strength, tensile strength, flexural strength etc. some of such investigations are described as follows;

Kumar Shaik et. al[1] had a studied Experimental Study on Concrete by Partial Replacement of Fine Aggregate with Fly Ash and Egg Shell Powder. They investigated the suitability of fly ash and egg shell powder as partial replacement for fine aggregate in the production of low-cost and light weight concrete for M30 and M40 concrete. An attempt was made to find the optimum usage of fly ash and egg shell powder in normal concrete by replacing the river sand 7%, 14%, 21%, 28% & 35% by weight at various proportions and the mix is designated as M0, M1, M2, M3, M4 and M5 respectively. Tests were conducted to study compressive strength, split tensile strength and flexural strength of 7th day and 28th day strength.

From the experiment the Compressive strength was higher than normal concrete up to 21% FA and ESP replacement at 7th and 28th days of curing ages for both M30 and M40. The replacements of FA and ESP greater than 28% (M30) and 21% (M40) had lower strength than normal concrete At the same time the weight of the cubes are reduced up to 7% per cube.

The Split tensile strength of FA and ESP M30 and M40 concrete were comparable with normal concrete up to 35% FA and ESP replacements. However, concrete with above 21% and 14% FA and ESP replacement had lower split tensile strength than normal concrete for M30 and M40 respectively.

The Flexural strength of FA and ESP M30 and M40 concrete were comparable with normal concrete up to 35% FA and ESP replacements. However, concrete above 14% FA and ESP replacement had lower flexural strength than normal concrete at both M30 and M40 concrete.

Compressive strength, splitting tensile strength and flexural strength of fine aggregate partially replaced with FA and ESP concrete continued to increase at certain level at 7 and 28 days and the differential strength between the FA and ESP concrete specimens and normal concrete specimens became more distinct after 28 days. It was concluded that FA and ESP could be used in structural concrete.

Narayanaswamyet et al, [15] Undergo experimental study on the effect of eggshell powder and silica fume on M40 grade of concrete. They compare concretes having only eggshell powder replacement from 5-15 percent and concretes having both eggshell powder and silica fume the percentage of eggshell here is 5-15%and percentages of silica fume is 2.5%-7.5% by weight of cement. Finally, they found out that strength of concrete having eggshell powder is enough since the addition of silica fume doesn't give a broad difference in strength and also silica fume is expensive material to replace cement.

Asman, et al.,[25]studied the combined effect of eggshell powder and rice husk ash on mechanical properties of concrete. The test result indicated that using 2% eggshell powder and 8% RHA result in very low workability and not good to use for road construction of. 4% eggshell and 6% RHA results in good workability when they replace cement, which is classified as low degree of workability but used to construct a road, while concretes having 6 % eggshell powder and 4 % RHA is classified as medium degree of workability and also used to construct a road. But the combined effect of RHA and ESP on strength development of the concrete is low.

Nayak et al. **[32]**executed compressive strength test, tensile strength test, flexural strength test for the study on strength of concrete due to partial replacement of cement with saw-dust and steel fibre. The compressive strength test was done for 3, 7, 28, 56 days for normal and SDA concrete and FRSDA concrete tests were done on 3,7,28 days. The split tensile test for the concrete cylinders were done for 3, 7, 28, 56 days for normal, SDA, FRSDA concrete.

Flexural strength test was done for 28 days for normal, SDA, FRSDA concrete. The workability of concrete decreases significantly with the increase of SDA content in concrete mixes. It was also seen that at 20% SDA + 1% SF the compressive strength increases & again it is decreased at 20% SDA + 1.5% SF.

CHAPTER THREE

MATERIALS AND RESEARCH METHODOLOGY

3.1 MATERIALS USED

Materials that have been used during examining the characteristics of concrete containing hybrid of eggshell powder and sawdust ash are eggshell powder, sawdust ash, natural aggregate, washed sand, Pozzolana Portland cement, potable water, mixing and placing equipment with specification used for the conventional concrete. For control mix ordinary C20/25 concrete, which contains natural aggregate, washed sand, pozzolana Portland cement, and potable water. In addition to examining workability, the compressive, tensile and flexural strength of the partially replaced concrete: mixer, vibrator, standard cubic and cylinder mold and universal testing machines have been used.

3.1.1 CEMENT

In this study locally available PPC cement, Dangote 32.5R cement grade, has been used for the preparation of the paste and concrete specimens. Fineness has been tested by taking 100 gm of it.

3.1.2 FINE AGGREGATE

The fine aggregate which used in the concrete productions is natural sand quarried from chewaka and brought Jimma for selling is preferred. In order to investigate its properties for the required application, different tests has been carried out which include: silt content, sieve analysis and fineness modules, specific gravity and absorption capacity, moisture content and unit weight.

3.1.3 COARSE AGGREGATE

The coarse aggregates used are with maximum aggregate sizes of 20 mm. In order to investigate its properties different tests which, include sieve analysis, specific gravity and absorption capacity, moisture content and unit weight have carried out.

3.1.4 EGGSHELL POWDER

In this research, 5.48 kg of ejected eggshells powder as a solid waste has been collected to investigate the effect of eggshell powder and saw dust ash on concrete production by implementing the following process.

The ejected eggshell as a solid waste was collected from Star cafeteria which found at Merkato of Jimma town and Variety café, Nigussie palace and Time burger house which are found at Ferenj arada of Jimma town. Due to higher calcium carbonate content of brown eggs over white eggs only brown eggshells was collected **[18]**.

3.1.5 SAWDUST ASH

For this research 5.48Kg sawdust ash has been used. The Cordia Africana (wanza) sawdust collected from wood manufacturing firm found in Jimma and used without any pre-treatment. The wood manufacturing firm use different plants for manufacturing planks or furniture but I have order them to collect for me Cordia Africana (wanza) sawdust byproduct and there are different sizes of sawdust, coarser and finer but in the study, sawdust used was finer sawdust.

The detail of concrete mix design proportion has been presented on Appendix –D.

Table 3-1: Total volume of Material used for the research

Sample size	V (m^3) (1 sample)	1.7V (m^3) with wastage)	# days (7,14,28)	testable sample/day	group of tests (0,5,10,15) %	total V of concret e
Cube $=0.15^3=$	0.0034	0.0057	3	3	4	0.207
Cylinder $=0.2*(\pi*0.1^2)/4=$	0.0016	0.0027	3	3	4	0.096
Beam =0.1*0.1*0.5=	0.005	0.0085	3	3	4	0.306
					Total (m^3)	**0.609**

Table 3-2: Mass of Ingredients of Concrete used for the research mix ratio (1:1.9:3)

Total Volume of concrete	Ingredients of concrete	Ratio of ingredients	Unit Weight (Kg/m^3)	Mass (Kg)
0.609	Cement	(1/5.9)	1440	**146.08**
0.609	Fine Aggregate	(1.9/5.9)	1600	324.63
0.609	Coarse Aggregate	(3/5.9)	1560	474.77

Table 3-3: Mass of Egg shell powder and Saw Dust Ash used for the research

Total mass(M) of cement (Kg)	Mass of cement for each group tests (Kg) =1/4*M	Mass of ESP&SDA 2.5%+2.5% =5%	Mass of ESP&SDA 5%+5% =10%	Mass of ESP&SDA 7.5%+7.5% =15%	**Total mass of each (ESP/SDA)**
146.08	36.521	1.83	3.65	5.48	**5.48 Kg each**

Figure 3-1: Some of Ingredients and Equipment for preparation of samples

3.2 DATA REQUIREMENT

For the experimental analysis of the cubes, cylinders, and beams samples constructed by the plain concrete of with and without Hybrid of ESP and SDA, the available universal testing machine was used for finding the following mechanical properties.

1. Compressive strength
2. Split tensile strength
3. Flexural tensile strength

3.3 RESEARCH DESIGN

After reviewing, organizing literature of different journals, select a comparative and experimental study of ordinary concrete and concrete of its ingredients partially replaced with saw dust, egg shell powder and its Hybrids. This would be based on the expectation of chemical composition may improve a concrete property.

The experimental research seeks to test effect of Hybrids of saw dust and egg shell powder as partially replacing cement of concrete and determine dependent variables; such as workability, split tensile strength, compressive strength, flexural strength, and stress-strain relationship.

The amount and kind of fine aggregate and coarse aggregates was constant, but the quantity of cement, Eggshell Powder and Sawdust Ash has been varied. The experimental test be conducted in different steps. After the experimental result, the optimal amount of the Hybrids in percent with other ingredients of concrete be determined.

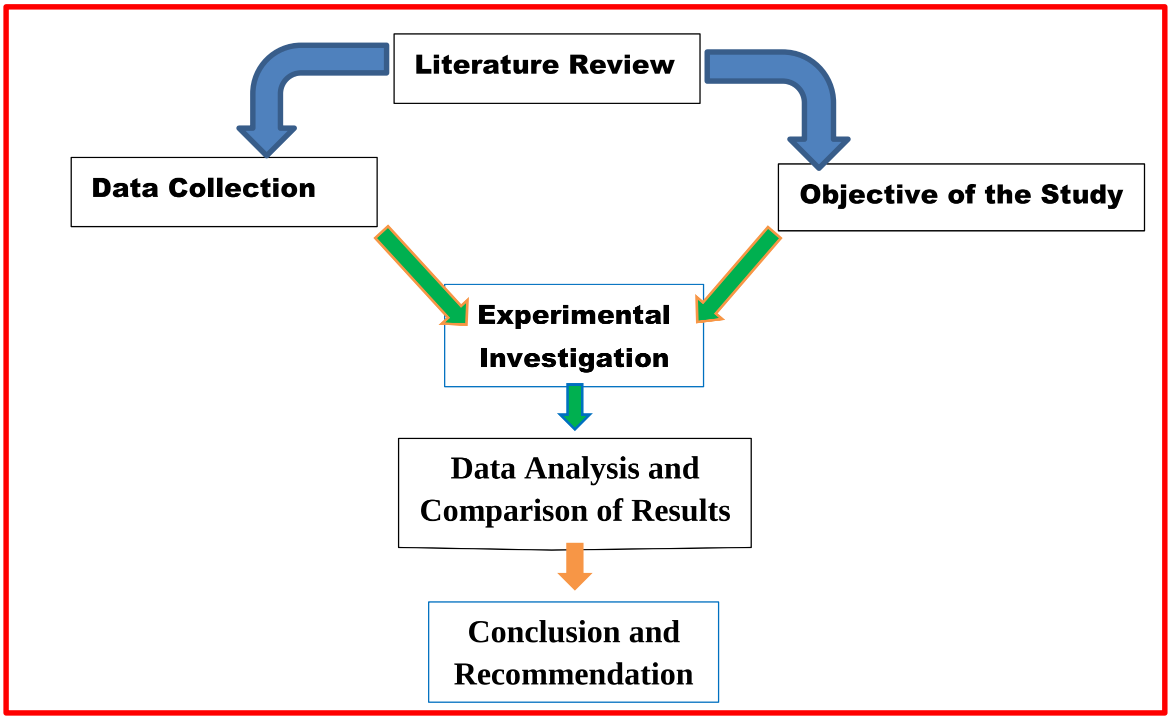


Figure 3-2: Research Design and Procedure

3.4 STUDY VARIABLES

3.4.1 DEPENDENT VARIABLE

- Performance of Concrete(like workability, compressive strength, flexural strength and split tensile strength)due to partial replacement of cement with Hybrid Eggshell powder and Sawdust Ash

3.4.2 INDEPENDENT VARIABLE

- Percentage of Cement Replacing material (2.5%ESP/2.5%SDA ,5%ESP/5%SDA,7.5%ESP/7.5%SDA)

3.5 STUDY POPULATION

The number of population in this research was several cylinders, cubes and beam samples to be used for C20/25 ordinary concrete and concrete with hybrid. The percentage of Hybrid instead of cement (0%, 5%, 10%, and 15%) in the concrete and three sample was cast for each @ 7^{th}, 14^{th} and 28^{th} day test.

Therefore, total number of 36 samples of cylindrical, 36 samples of a cube and 36 beams was cast and tested.

Table 3-4: Summary of Total population of specimens for the research

S. No	Types of specimen	Types and number of tests @ 7^{th},14^{th}&28^{th} days			Total # samples
		Compressive strength	Flexural strength	Split tensile strength	
1	H-0% (0%+0%) +C100%	9	9	9	27
2	H-5% (2.5%+2.5%) +C95%	9	9	9	27
3	H-10% (5%+5%) +C90%	9	9	9	27
4	H-15%(7.5%+7.5%)+C85%	9	9	9	27
					108

3.6 DATA COLLECTION PROCESSING

Eggshell waste and sawdust collected from locally available cafes, hotels and company (furniture firm) which are found at Jimma town, Oromia Region, South western Ethiopia.

3.6.1 EGGSHELL POWDER

After the waste eggshell collected from different cafes and burger houses, it has been washed by tap water to remove the internal organics left in the shell and also to remove debris which found on the surface of the eggshell. Then after washing has done, the wet eggshell has been putted into the oven for 24hours at a temperature of 105±5℃ to remove the moisture and to dry it. After the eggshell dried in the oven, it grinded manually using mill and then after using the electronic grinding machine to make it fine as like cement and then the grinded particles sieved through 75µm sieve. The sieved eggshell powder was used as cement replacement material in concrete production for this experiment.

In order to get eggshell powder, the representative sample, washing, drying, grinding of the eggshell manually and using small mill machine having a capacity of 85 gram at a time has shown below figure 3.3.

Figure 3-3: Procedural Preparation of eggshell powder

3.6.2 SAWDUST ASH

Sawdust has been used in concrete, but not widely. Although it is seriously limited by its low compressive strength, it has also serious limitations that must be understood before it is subject to use. Sawdust is organic material as a result of this it will affect the setting and hydration reaction of cement. Within these limitations, the advantages that sawdust concrete offers considerable reduction in weight of the structure, thereby reducing the dead loads transmitted to the foundation, low cost when compared to normal weight concrete, reduce damage and prolong life of formwork due to lower pressure being exerted, easier handling, mixing and placing as compared with normal weight concrete, improved sound absorbent properties due to its high void ratio [32].

So, after collection of sawdust has been done, the sawdust was putted into the furnace of JiT, at highway laboratory for 4 hours at a temperature of 550℃ to form ash. It grinded using mortar manually to the fineness of cement and then the grinded particles sieved through 75**µ**m sieve. The sieved Sawdust ash powder used as cement replacement material in concrete production for this experiment.

Figure 3-4: Procedural Preparation of Sawdust ash

3.7 DATA PROCESSING AND ANALYSIS

Before starting the analysis, data sorted into different groups to make suitable for the comparison of results. All specimens were coded before starting experimentation and also quality control check was done for completeness and consistency of the data. All the relevant data were collected from the sources. After collecting and recording the laboratory results for the compressive strength test, split tensile strength test and flexural strength test, comparing of outputs with relative to the available national and international standards and specifications has been done.

Finally, the quantitative data collected from experimental investigations processed using available Microsoft office packages and present the results of analysis by using different graphs, tables, and charts as required.

3.8 MATERIALS AND TESTS FOR PROPERTIES OF MATERIALS

3.8.1 TESTS ON CEMENT AND HYBRID REPLACING CEMENT

A Pozzolana Portland Cement (PPC) Dangote product cement with 32.5R grade was used for all mix of concrete specimens’ preparation. It is bought from one of building construction materials shop which found jimma town, Yetebaberut. The physical property of cement with and without addition of hybrid of Egg shell powder and sawdust ash discussed below:

The fineness, normal consistency test and setting time for Cement without and with partially replacing hybrid were tested as discussed below.

A. NORMAL CONSISTENCY OF CEMENT AND HYBRID BLENDED WITH CEMENT

This test was carried out to determine the amount (percentage) of mixing water required for preparing blended cement paste of standard consistency (satisfactory workability). The usual range of water-cement ratio for normal consistency is between 26%-33% [8].Many of the properties of concrete are affected by its water content. The physical requirements of cement paste like setting and soundness depends on the water content of the neat cement paste. Therefore it is necessary to define and study the water content at which to do these tests. This is defined in terms of the normal consistency of the paste which is measured according to ASTM C 187. The amount of water required to achieve a normal consistency as defined by a penetration of 10 ± 1 mm of the Vicat plunger (ASTM C 187) is expressed as a percentage by weight of the dry cement. The test is very sensitive to the conditions under which it is being carried out, particularly the temperature and the way the cement is compacted into the mould. The test does not correlate to the quality of the cement; it only measures the plasticity of cement paste.

Different trials, as shown on APPENDIX A-1, were carried out with different water - cement ratio until the proportional of water in mix achieved for a paste that the rod of Vi-cat apparatus settles 10±1 mm below the original surface within 30 seconds.

The Water- cement (consistency test) analysis has been calculated as follow;

$$P = (W/C)*100\%$$

Where: P= %age of normal water-cement ratio for consistency

W = weight of water for desired penetration (gm)

C = Weight of cement taken (gm)

Figure 3-5: Asymptote the plunger to paste and measure penetration depth after 30second

B. FINENESS OF CEMENT AND HYBRID BLENDED WITH CEMENT

To determine the fineness of cement by sieving through sieve, of standard 90micron sieve size, finer cement will increase the rate of hydration. This leads to higher rate of heat evolution & strength gain. Finer cement will decrease the amount of bleeding but it increase gypsum requirement ,which control proper setting , and water requirement for workability (which leads to higher drying shrinkage & cracking) The test is used to check proper grinding of cement. The fineness, expressed as the percentage be carried out gently and continuously for 15 minutes. The calculation of fineness percentage was calculated using;

$$\text{Fineness (\%)} = (W_2/W_1)*100\%$$

Where: W_1 (gm) = weight of the cement before sieving

W_2 (gm) = weight of the cement residue after sieving

Figure 3-6: Samples for testing Fineness of samples and sieving for 15minutes

C. SETTING TIME OF CEMENT AND HYBRID BLENDED WITH CEMENT

When hydraulic cement is in contact with water, it reacts rapidly and hydration process starts and forms cement paste. This cement paste is plastic but as time goes up this cement paste starts to dry or set this is called the setting time of cement. The initial setting time is the time available for mixing and placing of concrete, at this time concrete is plastic which can be molded into any shapes. But as time increases this plastic starts to dry and concrete gains its strength this time is called final setting time. ASTM C 595 recommends to use ASTM C 191 the method of measuring setting time of cement. The initial setting time was determined when the needle penetration is 25mm and the final set time was calculated as per the JiT construction materials testing laboratory manual. In this study time of setting was done both for control mix and for the blended cement with hybrid of eggshell powder and sawdust ash. The amount of water used to determine the setting time of cement was the water content that gives the standard consistency of the paste. Setting time tests were applied by using Automatic Vi-cat needle apparatus and cement paste mixer, and then four samples were conducted on the cement pastes made with the percentage addition of hybrid from 0% up to 15% content by 5% increments by weight of cement. The cement paste was prepared carefully by using 85% water that gave acceptable normal consistency then fill it in the mold and allow it to remain in a moist room for 30 minutes then the penetration depth tests were recorded at the regular time interval of 15 minute.

Initial setting time in minutes was taken when the initial set needle penetrated into the paste to a depth of 25mm and for final setting time the researcher estimated by using the equation according to Jimma University, JIT, Construction materials testing laboratory manual.

Final setting time (in minutes) = 90+ 1.2 x (initial setting time)

Ethiopian standard recommends the initial setting time for cement not to be less than 45 minutes and final setting time not to exceed 10 hours [8]. So the results obtained fit with this specification.


Figure 3-7: Measuring penetration depth after putting under cabinet for 30minutes

D. CHEMICAL COMPOSITION OF HYBRID OF ESP AND SDA

Chemical composition Table 3.5 shows the approximate oxide composition of hybrid of Egg shell powder and Sawdust ash, which tested at Geological survey of Ethiopia which found in Sar bet, Addis Ababa, Ethiopia.

Table 3-5: Chemical Composition of Hybrid of ESP and SDA

Oxide	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	K_2O	Na_2O	SO_3	TiO_2	H_2O	LOI
Hybrid of ESP + SDA	30.64	16.52	8.40	1.38	2.56	69.67	0.64	71.67	0.20	6.83	23.86

3.8.2 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.

3.8.3 FINE AGGREGATE

The fine aggregate used for this investigation was collected from Chewaka River. The natural river sand have maximum size of 4.75mm diameter. Each physical properties of the fine aggregate required for the mix design as per the specification was done in the laboratory. Since the aggregate be extracted from the riverside; it's full of dust film on their surface. For this reason, the fine aggregates were washed thoroughly and dried in the air outside the laboratory to saturated surface dry (SSD) state before any test was carried out. The physical property tests done on the fine aggregates has been discussed below:

A. SILT CONTENT OF FINE AGGREGATE

According to ASTM C 33 states, the material in fine aggregates which is finer than 75µm is generally regarded as silt. This silt in the sand for the concrete has a severe effect on the quality of the concrete. It mainly affects the workability of the concrete, and also results in the reduction of strength. According to the Ethiopian standard it is recommended to wash or reject if the silt content exceeds a value of 6% **[8].**

According to Jimma construction materials laboratory manual at 30-page procedure were conducted by glass jar 100ml capacity and added ¾ of water, then shake vigorously for about minute, leave the silt being of finer particle than sand was settle above the sand in a layer as the measure the thickness of silt layer to calculate the percentage of silt content such formulas used.

Average values of silt content (%) = $(V_2/V_1)*100$

Where: V_1 =Volume of sample (silt+ sand)(ml), V_2 =Volume of silt after 3hr. (ml)

Figure 3-8: shaking sample of fine aggregate in jar to determine silt content

The detailed test result Values are presented under Table 4.4 of Chapter 4 of this document.

B. Sieve Analysis of fine aggregate (sand)

Sieve analysis is also called gradation test. It is a mechanism for the determination of the particle size distribution of the aggregate. It is also used to determine the fineness modulus [FM] on the index to the fineness coarseness and uniformity of aggregates. For detail test result presented on APPENDIX B, Table B-2.

Figure 3-9: Arranging of sieves for sieve Analysis of Fine Aggregate

C. Fineness Modulus

According to the requirement of ESC-D3-201 the fineness modulus of sand shall not be less than 2.0 and more than 3.5. Fineness modulus is often computed using the sieve analysis results.

The fineness modulus is the sum of the total percentages coarser than each of a specified series of sieves, divided by 100.

$$\text{Fineness Modulus} = (\Sigma \text{ Cumulative Percentage Retained on sieves})/100$$

The result of the fineness modulus of the fine aggregate which is presented in APPENDIX B, Table B-2 is 2.4 which is in the upper lower limit value of the standard.

D. Moisture content of fine aggregate

During the concrete mix design process, an aggregate was considered to be as free from water and never absorbing moisture from the environment. If sand was used without conducting a test for moisture content and water absorption, the initially considered water per cement ratio will be getting abnormal and the strength of concrete will be jeopardized. So, to know the required quantity of water that is necessary to get the desired compressive strength and the workability of fresh concrete, the tests should have to be conducted.

According to the test method of ASTM C-566 moisture content of sand was carryout and

Calculated as

$$\frac{(\text{Weight of original sample - weight of oven dry sample})*100}{\text{Weight of oven dry sample}}$$

The test result is 0.5% as calculated briefly on APPENDIX B, Table B-1.The moisture contents should be within 0% to 10%. The sand used to produce the concrete is within the limits.

E. Specific gravity and absorption Capacity of Fine Aggregate

A specific gravity of a material means the ratio between the weight of the substance and that of the same volume of water. Aggregates, however, have pores that are both permeable and impermeable; whose structure (size, number, and continuity pattern) affects water absorption, permeability, and a specific gravity of the aggregates **[8].**

According to ASTM C 128-93 (Reapproved 2001) standard test method, the bulk specific gravity (SSD) and apparent specific gravity results obtained from the experiment are 2.57 and 2.66 respectively and the absorption capacity was found to be 2%. And detail result presented under Appendix –B of this document. According to ASTMC33/C33M (2011), the limitation for absorption capacity ranges from 0.2 to 2 % for fine aggregates. As a result, the aggregate is within ASTM limits.

$$\%\text{ water Absorption} = \frac{\text{Weight in air of the SSD aggregate - weight in air of oven drier aggregate}}{\text{Weight in air of oven drier aggregate.}}$$

Figure 3-10: Removal of air bubbles by using rod and fill with water the pycnometer

F. 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. From this the compacted and loose unit weight of fine aggregate used in this study was 1577.8 kg/m3 and 1245.5 kg/m3 respectively. Detail result presented under Appendix –B of this document.

Figure 3-11: Compacting and balancing the mass of Compacted Fine Aggregate

3.8.4 COARSE AGGREGATE

According to ACI 211.4R-93, (1997) the coarse aggregate will influence significantly the properties of the concrete strength. For this reason, a coarse aggregate should be chosen that is sufficiently hard, free of cracks, clean, and free of surface coatings.

The particle size of coarse aggregate larger than 5mm or between 9.5mm and 37.5mm it consist one or a combination of crushed stone. However, According to (ACI 2114R, 2002) gradation of coarse aggregate for high strength concrete depends on the grade of concrete. Based on this the size of the coarse aggregate used for this experiment is (20mm) maximum size and (which retains 100 % on 9.5mm sieve size) aggregate. Smaller aggregate sizes are also considered to produce higher concrete strengths because of less severe concentrations of stress around the particles (ACI 363R 92, 1997).

A. Sieve Analysis of coarse aggregate helps to know particle size distribution of aggregate

Figure 3-12: Adding of sample of Coarse Aggregate for sieve Analysis

B. Moisture content of coarse aggregate

To know the required quantity of water that is required to get the desired strength and the workability of concrete, the tests should have to be conducted. The moisture content of course aggregates was determined by oven drying a sample of coarse aggregate (2000gm) in an oven at a temperature of 110^0c for 24hrs and dividing the weight difference by the oven-dry weight. The average moisture content found was 0.4%. For detail, look Appendix-C.

C. Specific Gravity and Absorption Capacity of coarse aggregate

A specific gravity of a material is the ratio between the weight of the material and that of the same volume of water. For test done according to ASTM C 128-93 (2001), standard test method, the bulk specific gravity (SSD) was 2.82 and the absorption capacity was 0.90%.

Figure 3-13: Jolting of saturated Coarse and inserting to oven of surface dried Coarse Aggregate

D. Unit weight of Coarse aggregate

Unit weight can be defined as the weight of a given volume of graded aggregate, it is also known as bulk density. The unit weight tests of the coarse aggregate samples were carried out according to ASTM C-29. Detail test result presented @ Appendix-C.

From this the compacted and loose unit weight of coarse aggregate used in this study was 1676.5 kg/m^3 and 1510.6 kg/m^3 respectively fulfill the requirements.

Figure 3-14: Compacting and balancing the mass of Compacted Coarse Aggregate

3.9 CONCRETE MIX DESIGN AND SPECIMEN PREPARATIONS

3.9.1 MIX RATIO DESIGN

Concrete is a composite mixture which consists of cement, sand and aggregate. Concrete mix design is the procedure for finding the right quantities of these materials to achieve the desired strength. Accurate concrete mix design makes concrete construction economical. In order to calculate the right amount of cement, sand and aggregate required in $1m^3$ of concrete; knowing the grade of concrete comes first. The C20/25 concrete grade with 25MPa Cubic compressive strength was used.

The mix design for C20/25 used in this study have a ratio of proportion 1:1.89:3.02, indicate cement, fine aggregates and coarse aggregates respectively. The steps for the mix design done based on ACI code are listed as follow.

Table 3-6: Cement, Sand, Gravel and water used for cast of $1m^3$ Concrete

	Cement	**Sand**	**Gravel**	**Water**
Weight in Kg	370	697.309	1116.1154	197.895
Ratio, approximately rounded	1	2	3	0.5

The detail calculation steps attached on Appendix- D

3.10 TESTS CONDUCTED ON CONCRETE

The main tests conducted on this research are basically divided into two. These are tests performed on fresh concrete used to test workability of concrete and tests done on hardened concrete which include compressive strength test, flexural strength test and split tensile strength test.

3.10.1 WORKABILITY TEST

The workability of a concrete mix is the relative ease with which concrete can be placed, compacted and finished without separation or segregation of the individual materials. Workability is important because of two reason.

- If the concrete mixture is too wet, coarse aggregates settle at the bottom of concrete mass and as a result concrete becomes non-uniform composition and
- If the concrete mixture is too dry it will be difficult to handle and place it in position

There are various types of workability testing methods implemented both in the laboratory and at site. These are Slump cone test, Compaction factor test, Vee-bee Consistometer test and flow meter test. Among this slump cone test and compaction factor test found in the laboratory of Jimma Institute of Technology were conducted for this research.

A. Slump Test

It is the most common method for measuring the workability of freshly mixed concrete. It can be performed both in lab and at site. Uniformity of the concrete regarding workability and quality aspects can be assessed from batch to batch by observing the nature in which the concrete slumps. The test was carried out by using a steel mould called Slump cone as per ASTM C-143 specification. Standard slump cone 300mm high with a bottom diameter of 200mm and 100mm upper diameter was used.

The mould is cleaned and freed from any surface moistures and then the concrete is placed in three layers. Each layer is tamped 25 times with a standard tamping rod (16 mm diameter, 600mmlength). Immediately after filling, the cone is slowly lifted and the concrete is allowed to subside.

The decrease in the height of the center of the slumped concrete is called slump and it has measured from the top of the slump cone apparatus to the top of concrete. Slump test is not very suitable for very wet or very dry concrete.

Figure 3-15: Measuring Slump of fresh concrete

B. Compaction Factor Test

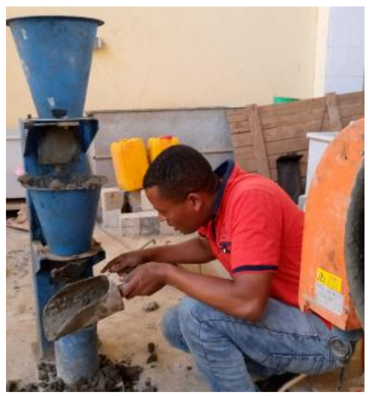
Compaction factor test is an alternative way of measuring workability of concrete and its use is confined to large jobs where there is a site laboratory.

The following Figure 3.6 shows the apparatus used for compaction factor test for workability of concrete found in the laboratory. Calculate the value of compaction factor using the following formula.

$$\text{Compacting factor} = \frac{M2-M1}{M3-M1} \quad <1$$

Where M_1 is mass of empty cylinder, M_2 is mass of cylinder with partially compacted fresh concrete and M_3 is the mass of the cylinder fully compacted fresh concrete with three layers and each layers 25 blows.

1st add fresh concrete to cones



2nd pass concrete to cylinder

3rd weight non compacted

4th compact it

5th weight of compacted

Figure 3-16: Compaction factor test procedures

3.10.2 COMPRESSIVE STRENGTH TEST

Concrete structures are designed to resist compressive stress. It has great practical and economic significance because the sections and sizes of the concrete structures are determined by it. It is also the most common type of destructive test for concrete.

Cubes of specimen (150×150×150 mm) was cast for C20/25 grade of concrete without and with hybrid of ESP and SDA. Then in the 7^{th}, 14^{th} and 28^{th} days of the curing period the concrete cube specimen was removed from the curing tanker and then placed in dry surface until the specimen was surface dried. Then to determine the density or unit weight, the specimen was weighted before the destructive test. And, these cubes were tested on compression testing machine as per ASTM C39 standards. This test was done by using universal testing machine that can apply maximum load of 2000KN and records the peak load and the corresponding compressive stress of concrete.

The specimen was tested by a compression testing machine. The cube is centrally placed between the plates of a compression-testing machine and the load is applied such that the stress increases at a given constant rate until failure. Loading rate for 150 mm cube was 140 kg/cm_2 per minute until the specimen fails.

Compressive strength is determined from basic formula by dividing the peak load of the specimen by cross section area of the specimen.

$$\text{Compressive str } (\sigma) = \frac{\text{Peak load}}{\text{cross sectional area}} = \frac{\text{P}}{\text{A}} = \frac{\text{P}}{150*150}(MPa) \text{ \_\_\_\_\_\_\_\_\_\_ (Eqn.3.1)}$$

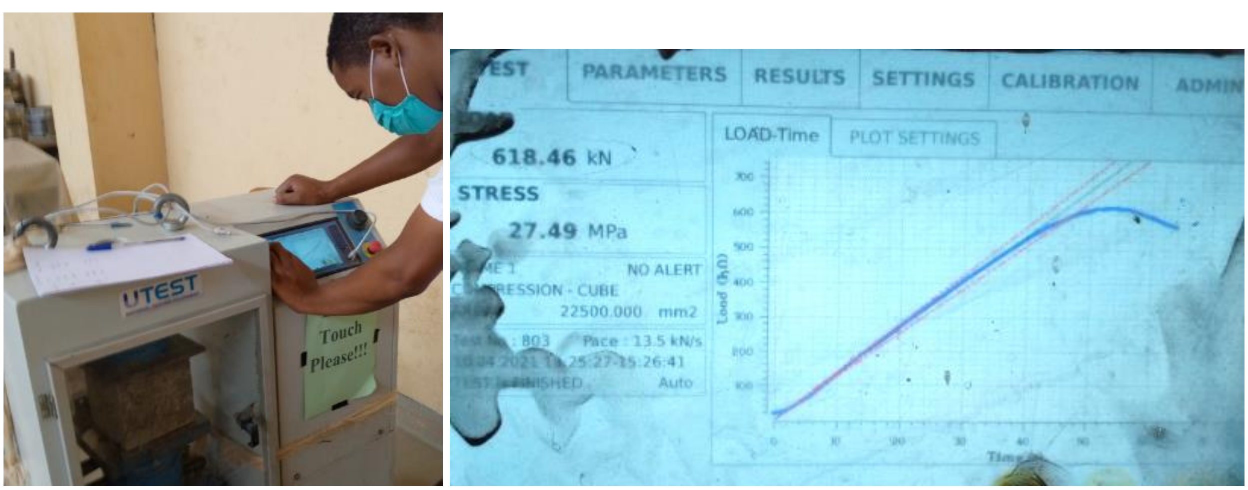


Figure 3-17: Compressive strength test setup of the hybrid under UTM and the displayed result

In this study ACI 301 specification for structural concrete is used as compliance criteria to check the feasibility of using hybrid of ESP/SDA as partial replacement in concrete production. ACI 301 states that;

"The strength level of concrete will be considered satisfactory When: the averages of all sets of three consecutive compressive strength test results molded and cured in accordance with the requirements of ASTM C31M equal or exceed fc´ (specified strength); and no individual strength test falls below fc′ by more than 3.5MPa when fc´ is 35MPa or less, or by more than 0.1times fc´ when fc´ is more than 35 MPa."

A. ES EN 1992-2015 STANDARD FOR COMPRESSIVE STRENGTH OF CONCRETE AT VARIOUS AGES

For early day strength of moist cured concrete ACI 209 gives a formula to calculate the expected compressive strength at specified dates

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 ES EN 1992-2015 the compressive strength of concrete at various ages $f_{cm}(t)$ may be estimated from following Expressions.

$f_{cm}(t) = \beta_{cc}(t) f_{cm(@\ t=28)}$……..…………………………...ES EN 1992-2015 (3.1.2(6))---------(Eqn.3.2)

$\beta cc(t) = \exp\{s[1-(28/t)^{0.5}]\}$

$fck(t) = f_{cm}(t) - 8$ (MPa) for $3 < t < 28$ days..... .. ..ES EN 1992-2015 (3.1.2(5)) ----------- (Eqn.3.3)

$fck(t) = fck$ for $t \geq 28$ days………………………......ES EN 1992-2015 (3.1.2(5))---------(Eqn.3.4)

Where: $f_{cm}(t)$ is the mean concrete compressive strength at an age of *t* days, f_{cm} is the mean compressive strength at 28 days according to Table 3.1,$\beta_{cc}(t)$ is a coefficient which depends on the age of the concrete t, t is the age of the concrete in days, s is a coefficient which depends on the type of cement:

= 0.20 for cement of strength Classes CEM 42.5 R, CEM 52.5 N and 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 Research the following parameters has been used;

- Concrete grade C20/25 (at 28th day, fck=20Mpa, fcu=25Mpa and fcm=fck+8 =28Mpa)
- Cement of strength Classes = CEM **32.5 R,** S **=0.25**
- f_{cm} (@ t=28) = 28Mpa………………ES EN 1992-2015 (Table 3.1)---------------(Eqn.3.5)

Table 3-7: ES EN Code's Cubic, cylindrical and mean Compressive strength at 7th, 14th, 28th

time (t) ,days	βcc(t)	fcm(t)= βcc(t)*fcm(t=28)	fck(t)= fcm(t)-8	fcu(t)= fck(t)*1.25
7th	0.78	21.81	13.81	**17.26**
14th	0.90	25.25	17.25	**21.56**
28th	1	28	20	**25**

B. Compressive Stress-Strain Relationship of Concrete

Stress-strain is the most important property of material it represents the relationship between the material internal stress caused by applied force and the corresponding strain derived from the deformation of the material. The property is unique for each material and is usually expressed graphically through a stress-strain curve. A complete stress-strain is necessary for the non-linear analysis of the concrete member. It influences the accuracy of the analytical results of ultimate stress distribution in ductility and load-carrying capacity.

The stress and strain relations for cube specimens on 7th, 14th and 28th days determined by using dial gauge and universal testing machine. Gradually applied axial load Compressive load has been recorded for each the change in the depth of the cube under UTM which measured using gauge measures and recorded at. The axial stresses are calculated by using the basic formula. It is calculated at various axial loading condition.

$$\sigma = \frac{P}{A} \text{---} \quad \text{(Eqn.3.6)}$$

Where P-is the gradually applied load (N). A-is the actual area of the concrete (mm^2).

The corresponding normal strain is found by using Empirical formula written Ethiopian code of standard for concrete ES EN 1992-2015 (3.1.5(1)).

Figure 3-18: setting dial gauge and Record load for interval of each 50 count of the dial

A. Stress-strain relation for non-linear structural analysis

The relation between σc and εc shown in Figure 3.19 (compressive stress and shortening strain shown as absolute values) for short term uniaxial loading is described by the following expression;

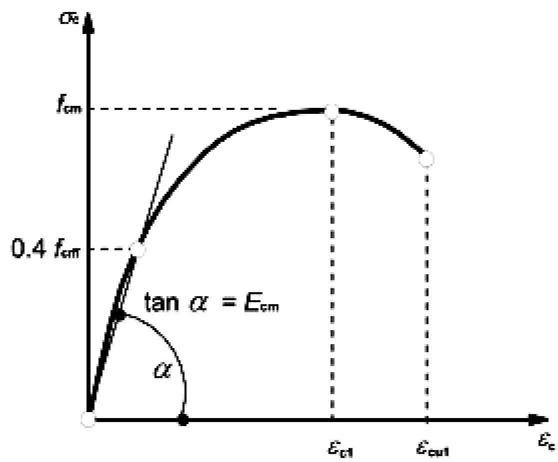


Figure 3-19: Schematic representative of the stress-strain relation of structural analysis

B. ES EN 1992-2015 STANDARD FOR STRESS - STRAIN OF CONCRETE AT VARIOUS AGES

$$\frac{\sigma}{f_{cm}} = \frac{k\eta-\eta^2}{1+(k-2)\eta}$$ ES EN 1992-2015 (3.1.5(1))-------(Eqn.3.7)

Where:

$f_{ck} = f_{cu}/1.25$ EN 1992-2015 (Table 3.1)---------(Eqn.3.8)

$f_{cm} = f_{ck}+8$ EN 1992-2015 (Table 3.1)---------(Eqn.3.9)

$E_{cm} = 22[(f_{cm})/10]^{0.3}$ EN 1992-2015 (Table 3.1) ----- (Eqn.3.10)

$\varepsilon c1(^0/_{00}) = \mathrm{Min}(0.7 * f_{cm}^{0.3}, 2.8)$ EN 1992-2015 (Table 3.1) ------(Eqn.3.11)

$\varepsilon_{cu}(^0/_{00}) = 3.5 \leq C50/60$ .... EN 1992-2015 (Table 3.1) -------- (Eqn.3.12)

$k = 1.05\, E_{cm} \times |\varepsilon_{c1}| / f_{cm}$ ....ES EN 1992-2015 (3.1.5(1)) ------ (Eqn.3.13)

$\eta = \varepsilon_c / \varepsilon_{c1}$ .... ES EN 1992-2015 (3.1.5(1)) ------- (Eqn.3.14)

By using experimentally obtained average peak cubic compressive stress ($f_{cu,peak}$)-Strain($\varepsilon_{c,peak}$) at peak stress calculated as following;

Table 3-8: Calculated Stains for experimentally obtained Compressive Stress at 7th, 14th, 28th

7th day						
Sample	fcu,peak (Mpa)	fck(Mpa)	fcm(Mpa)	Ecm(Mpa)	εc,peak	εcu1
H-0	**20.05**	16.04	24.04	29000	**0.0019**	0.0035
H-5	**19.05**	15.24	23.24	28000	**0.0019**	0.0035
H-10	**17.94**	14.35	22.35	28000	**0.0018**	0.0035
H-15	**16.27**	13.01	21.01	27000	**0.0018**	0.0035
14th day						
Sample	fcu,peak (Mpa)	fck(Mpa)	fcm(Mpa)	Ecm(Mpa)	εc,peak	εcu1
H-0	**24.52**	19.62	27.62	30000	**0.0020**	0.0035
H-5	**22.15**	17.72	25.72	29000	**0.0019**	0.0035
H-10	**22.40**	17.92	25.92	29000	**0.0019**	0.0035
H-15	**19.10**	15.28	23.28	28000	**0.0019**	0.0035
28th day						
Sample	fcu,peak (Mpa)	fck(Mpa)	fcm(Mpa)	Ecm(Mpa)	εc,peak	εcu1
H-0	**28.77**	23.02	31.02	31000	**0.0020**	0.0035
H-5	**26.22**	20.98	28.98	30000	**0.0020**	0.0035
H-10	**25.02**	20.02	28.02	30000	**0.0020**	0.0035
H-15	**23.35**	18.68	26.68	30000	**0.0019**	0.0035

Table 3-9: Empirical Derived Equations to determine stains at gradual compressive Stress

Sample	7th day Quadratic Equation for each **Stain** at each **Stress**
H-0%	$277008.31\varepsilon i^2-[1518.7-466.07\sigma i/20.05]\varepsilon i+\sigma i/20.05 = 0$
H-5%	$277008.31\varepsilon i^2-[1543.31-490.68\sigma i/19.05]\varepsilon i+\sigma i/19.05 = 0$
H-10%	$308641.98\varepsilon i^2-[1638.8-527.68\sigma i/17.94]\varepsilon i+\sigma i/17.94 = 0$
H-15%	$308641.98\varepsilon i^2-[1742.47-631.36\sigma i/16.27]\varepsilon i+\sigma i/16.27 = 0$

Sample	14th day Quadratic Equation for each **Stain** at each **Stress**
H-0%	$250000\varepsilon i^2-[1284.67-284.67\sigma i/24.52]\varepsilon i+\sigma i/24.52=0$
H-5%	$277008.31\varepsilon i^2-[1374.72-322.09\sigma i/22.15]\varepsilon i+\sigma i/22.15=0$
H-10%	$277008.31\varepsilon i^2-[1359.38-306.74\sigma i/22.4]\varepsilon i+\sigma i/22.4=0$
H-15%	$277008.31\varepsilon i^2-[1539.27-486.64\sigma i/19.1]\varepsilon i+\sigma i/19.1=0$

Sample	28th day Quadratic Equation for each **Stain** at each **Stress**
H-0%	$250000\varepsilon i^2-[1131.39-131.39\sigma i/28.77]\varepsilon i+\sigma i/28.77=0$
H-5%	$250000\varepsilon i^2-[1201.37-201.37\sigma i/26.22]\varepsilon i+\sigma i/26.22=0$
H-10%	$250000\varepsilon i^2-[1258.99-258.99\sigma i/25.02]\varepsilon i+\sigma i/25.02=0$
H-15%	$277008.31\varepsilon i^2-[1349.04-296.4\sigma i/23.35]\varepsilon i+\sigma i/23.35=0$

3.12.2 SPLITTING TENSILE STRENGTH TEST

One of the common methods used to measure the tensile strength of concrete is split tensile strength test. The test was conducted as per ASTM C-496 specification for split tensile strength.

The samples were casted by using a steel cylinder moulds having 100mm diameter and 200mm length. After 24 hours the samples were removed from the moulds and placed in curing tank for 7 days of curing and 28 days of curing period. The cylinders were tested using compression testing machine having 2000 KN capacity. The test was conducted by placing the cylinder sample in opposite direction to its longitudinal axis and the load is gradually applied and peak load versus stress was recorded. The stress was determined by using the following formula;

$$\text{Splitting tensile stress} = \frac{2P}{\pi dl} \text{ -- (Eqn.3.15)}$$

Where: P-Peak load (N), d- diameter of cylinder (mm), and l- length of cylinder (mm)

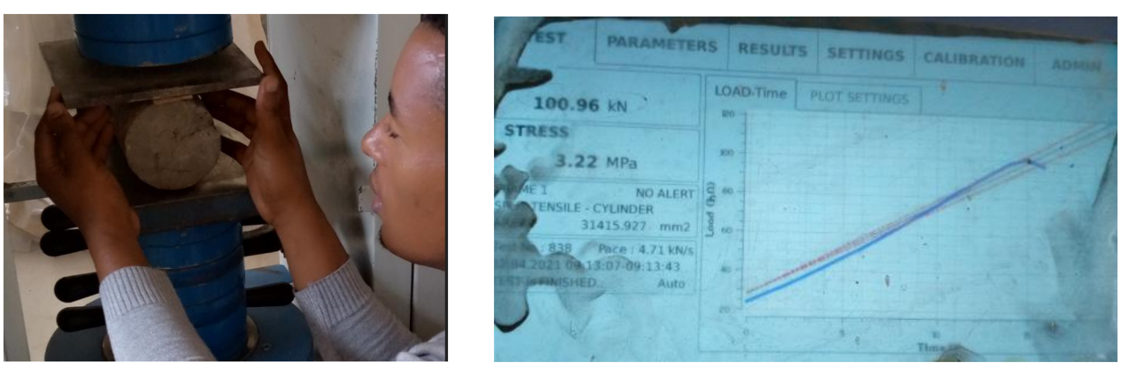


Figure 3-20: Splitting tensile strength test setup and sample test result

A. ES EN 1992-2015 STANDARD FOR SPLITTING TENSILE STRENGTH OF CONCRETE AT VARIOUS AGES

Tensile strength is determined as the splitting tensile strength, $f_{ct,sp}$, an approximate value of the axial tensile strength, f_{ct}, may be taken as:

$f_{ct} = 0.9\, f_{ct,sp}$……………………………….ES EN 1992-2015 (3.1.2(8)) -------- (Eqn.3.16)

Tensile strength with time is strongly influenced by curing and drying conditions as well as by the dimensions of the structural members.

$f_{ctm}(t) = (\beta_{cc}(t))^{\alpha}.f_{ctm}$...ES EN 1992-2015 (3.1.2(9)) ------ (Eqn.3.17)

$\beta_{cc}(t)= \exp\{s[1-(28/t)^{0.5}]\}$……………ES EN 1992-2015 (3.1.2(5)) ------- (Eqn.3.18)

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

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

f_{ctm} (@ t=28) = 2.2…………………………..ES EN 1992-2015 (Table 3.1) --- (Eqn.3.19)

Table 3-10: ES EN Code's Mean, Characteristic and Splitting Tensile strength at 7th, 14th, 28th

time (t) ,days	βcc(t)	α	$f_{ctm}(t) = (\beta_{cc}(t))^{\alpha}.f_{ctm}$ (t=28)	$f_{ctk,0.95}(t) = 1.3 \times f_{ctm}$	$f_{ct,sp} = f_{ct}/0.9$
7th	0.78	1	1.72	2.24	**2.5**
14th	0.90	1	1.98	2.57	**2.8**
28th	1	2/3	2.2	2.86	**3.1**

3.12.3 FLEXURAL TENSILE STRENGTH TEST

The concrete beam specimen with standard size of 100 mm x 100 mm x 500 mm was loaded at one third point from the support and at its interior location by a gradual increasing load at failure. The specimen was loaded gradually increasing the bending load using a bending testing machine According to ASTM C 42 the failure load (loading value at which the concrete cracks heavily) was then recorded and used to determine the tensile stress at which the member failed

A three-point loaded flexural strength testing machine having 2000KN was used. The beam sample was marked at 10cm from each end and at the mid span.

Figure 3-21: Flexural strength setup and crack pattern due to loading

The flexural stress (strength) when one of point load is form moment at the another point load;

$$\sigma = \frac{MY}{I} = \frac{\frac{P}{2} * \frac{L}{3} * \frac{d}{2}}{\frac{b * d^3}{12}} = \frac{P * L}{b * d^2} \text{------------------------------------ (Eqn.3.20)}$$

Where

σ -Flexural stress (MPa), M-Maximum bending moment at the point of rupture (Nmm), Y-maximum distance from the neutral axis to either to the top or to the bottom extreme edge of the beam cross section.(mm), I-moment of inertia of the cross section about the neutral axis. (mm^4), P -failure load (N), L- length of the beam b/n support (mm), and (b x d) are cross sections of the beam (mm x mm).

A. ES EN1992-2015 STANDARD FOR FLEXURAL TENSILE STRENGTH OF CONCRETE AT VARIOUS AGES

The mean flexural tensile strength of reinforced concrete members depends on the mean axial tensile strength and the depth of the cross-section. The following relationship may be used:

$f_{cm,fl}$= max {(1.6 – h/1000)f_{ctm}; f_{ctm}}………ES EN 1992-2015 (3.1.8(1)) -------- (Eqn.3.21)

Where:

h is the total member depth in mm =(100mm)

f_{ctm} is the mean axial tensile strength

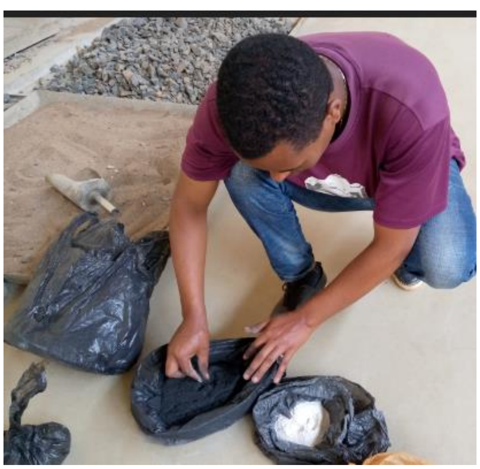
Table 3-11: ES EN Code's Mean and Characteristic Flexural Tensile strength at 7th, 14th, 28th

time (t) ,days	$f_{ctm}(t)= (\beta_{cc}(t))^{\alpha}.f_{ctm}$ (t=28)	$(1.6 – h/1000)f_{ctm}$	$f_{cm,fl}$	$f_{ctk,0.95}$ (t) =1.3 x f_{ctm}	$f_{ct,fl} = f_{ct}/0.9$
7th	1.72	2.58	2.58	3.35	3.73
14th	1.98	2.97	2.97	3.86	4.29
28th	2.2	3.3	3.3	4.29	4.77

3.13 MIXING AND CASTING OF THE SPECIMEN

A nominal mix of the proportions (1:1.89:3.02) (Cement: Fine aggregate: Coarse aggregate) by weight, with a cement content of 370 kg/$m^3$and a water-cement ratio of 0.5 was maintained throughout the study.

All the required materials for preparing the concrete were weighed as per the required proportions based on the mix design the sand and cement with required percentage of hybrid are dry mixed. Then the coarse aggregate added with little amount of water step by step. Finally, the paste is evenly distributed and remaining amount of water added to mix until getting evenly mixed hybrid concrete.



A. Ingredients ready for mix

B. Mixing of Ingredients

C. Compacting of fresh concrete

D. Coding of sample

Figure 3-22: Sample Preparation

First of all, the moulds made of cast iron were used to prepare the specimens of size150 x150x150 mm for cubes, 100 x100x500mm beams and cylinders of 100mm diameter and 200mm long.

The wooden moulds are made for beam as per the specifications to maximize number of molds since there is limited number of molds are available in the laboratory. During the placing ofconcrete in the moulds, the moulds were placed on the appropriate place and compacted until the specified conditions were attained. After 24 hours the specimens were removed from the moulds, then date of casting is written on the concrete specimens and immediately submerged in to water for curing in the curing tank. After 7,14 and 28 days of curing, the specimens were taken out and tested using the cube crushing test, tensile test, and the two-point bending test.

Figure 3-23: Demolding specimen for curing

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 EXPERIMENTAL TEST RESULTS OF CEMENT AND HYBRIDS BLENDED WITH CEMENT

4.1.1 NORMAL CONSISTENCY OF CEMENT AND HYBRID BLENDED WITH CEMENT

This test is done to determine the quantity (%age) of mixing water required for preparing pastes of standard consistency (satisfactory workability).

Table 4-1: Results of Water-Cement ratio for Normal consistency of sample of pastes

Code of specimen	H-0%	H-5%	H-10%	H-15%
Water-Cement ratio (%) (for Normal Consistency)	29	30	32	33
Variation with respect to H-0%	0%	3.4%	10.3%	13.8%
Penetration Depth (mm)	10.5	10	9	9
ASTM C 187 Code limit (mm)	10±1	10±1	10±1	10±1

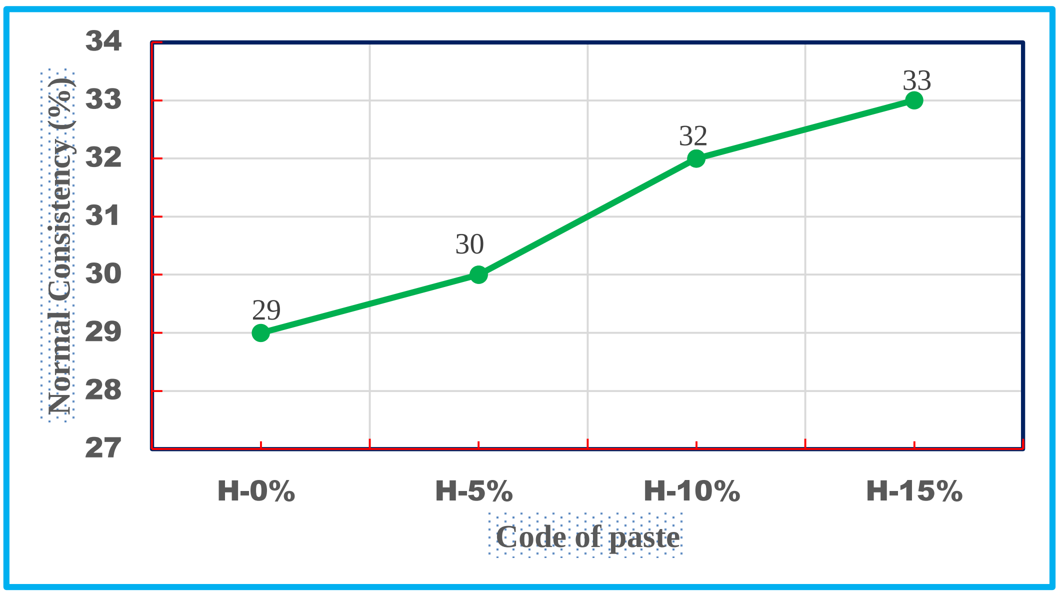


Figure 4 -1: Normal Consistency For paste of Hybrids

As it can observed from Table 4.1 and Figure 4-1 for constant water cement percentage ratio, the penetration depth decreases as the hybrid content increases. This indicates that the water requirement of cement with hybrid is higher, with respect to cement without hybrid. The range of water to cement ratio for normal consistency lies between 26 % up to 33%.The test result for normal consistency of blended paste is satisfies the requirement of the specification.

4.1.2 FINENESS OF CEMENT AND HYBRID BLENDED WITH CEMENT

Based on retained amount after passing through 90µm sieve, as the amount of hybrid increase the fineness is decrease. The Sieve cleaned gently with bristle brush to avoid damage to the mesh and sieving carried out gently and continuously for 15 minutes.

Table 4-2: Mean Fineness of cement without and with different percentage of Hybrid

Code of specimen	H-0%	H-5%	H-10%	H-15%
Mean Fineness (%)	0.05	0.94	1.12	2.16
Variation with respect to H-0%	0%	1.8%	2.1%	4.2%
IS Allowable limit of the standard for PPC	≤ 5	≤ 5	≤ 5	≤ 5

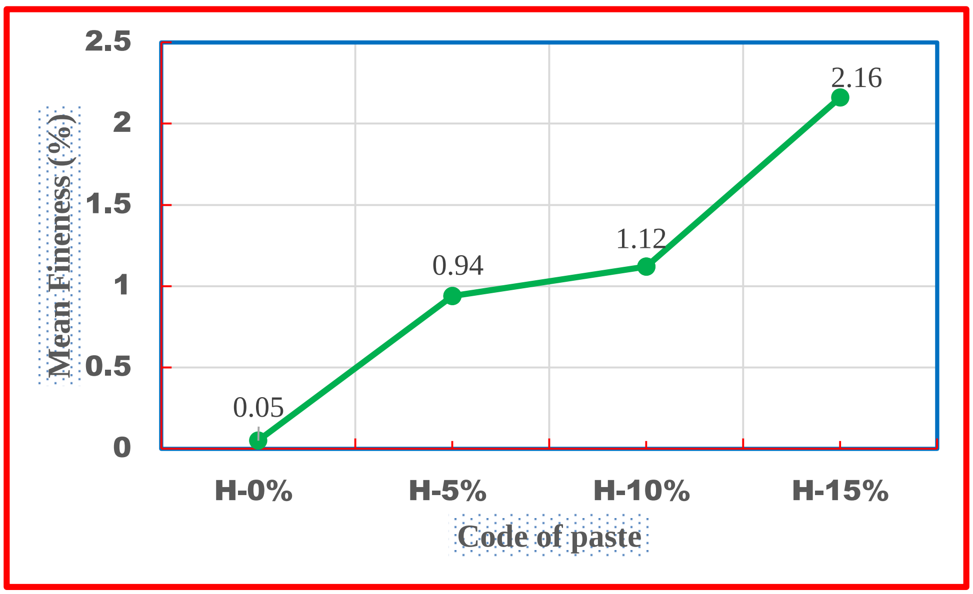


Figure 4 -2: Mean Fineness percentage For powder of Hybrids

As seen on Table 4.2 and Figure 4-2, the H-0% sample is finer than other cement blended samples. According to the test result, cement with hybrid is coarser than cement without hybrid.

4.1.3 SETTING TIME OF CEMENT AND HYBRID BLENDED WITH CEMENT

This portion determines the time of setting of the pastes. The results of adding Hybrid of ESP and SDA to cement are presented in Table 4-3.It shows that the increment of Hybrid of ESP and SDA to cement results in decreasing of both initial and final setting time. i.e the one which has more hybrid of ESP and SDA, its setting time will be fast. From this point of view when Hybrid of ESP and SDA used in the concrete production some kind of retarded admixture must added.

Table 4-3: Setting Time of blended paste

Code of Sample	H-0%	H-5%	H-10%	H-15%
Penetration depth (mm)	25	25	25	25
Initial Setting Time (minutes)	120	95	75	60
Final Setting Time (minutes)	234	204	180	162

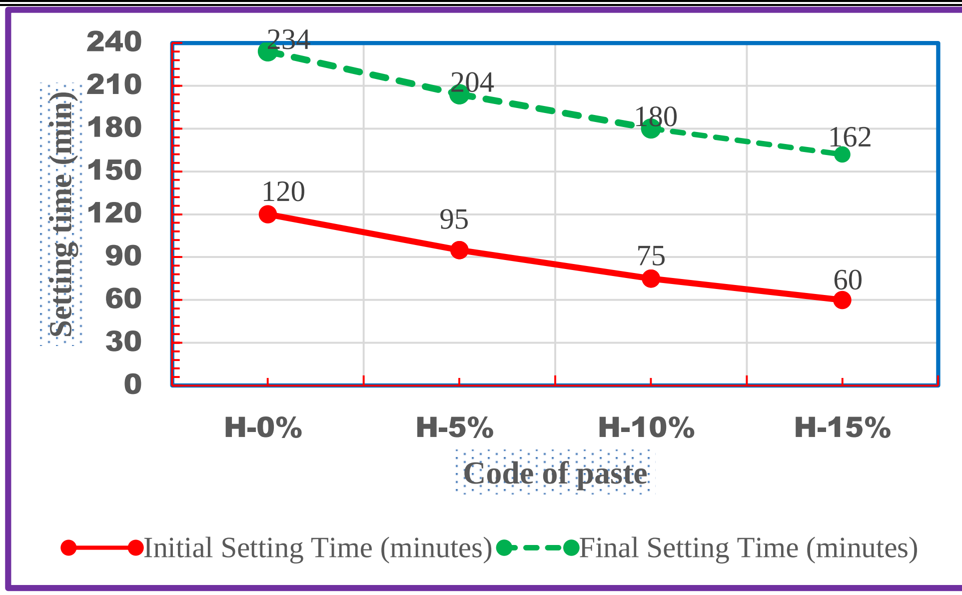


Figure 4 -3: Setting time For paste of Hybrids

4.2 EXPERIMENTAL TEST RESULTS ON PROPERIES OF FINE AGGREGATE

4.2.1 SILT CONTENT OF FINE AGGREGATE

The sand silt content determined before any physical properties of fine aggregate laboratory experiment material that used to determine quality of sand in concrete mix. The presence of silt in sand that used to make concrete has no impact on the quality of the resulting concrete since the amount of silt in the sand or fine aggregate is below the maximum permitted value of the specification.

Table 4-4: Particle Size distribution Fine aggregate

DESCRIPTION	Sample 1	Sample 2	Sample 3
Volume of sample (silt+ sand) V_1. (ml)	75	75	75
Volume of silt after 3hr V_2. (ml)	2.5	2	2
% silt content by volume =(V2/V1)*100	3.33	2.67	2.67
Mean % of silt content	2.89		

4.2.2 PARTICLE SIZE DISTRIBUTION OF FINE AGGREGATE

The fine aggregate grading, upper and lower limits bounds are shown in Figure 4.4 and the detailed cumulative percentage passing, percentage retained, fineness modulus and the requirement range as per ASTM 33 are shown under Appendix -B, Table B-2.

Table 4-5: Particle Size distribution Fine aggregate

Sieve Dia	Wt of Sieve (gm)	Wt of Sieve & Retained (gm)	Wt of Retained (gm)	Retained%	Cumm. Retained %	Cumm. Passing %	Cumulative Passing % ASTM 33
9.5mm	585	585	0	0.0	0	100	100
4.75mm	426	434	12	0.6	0.6	99.4	95-100
2.36mm	388	407	103	5.2	5.75	94.25	80-100
1.18mm	372	432	206	10.3	16.05	83.95	50-85
600µm	325	486	470	23.5	39.55	60.45	25-60
300µm	301	493	780	39.0	78.55	21.45	10-30
150µm	272	321	412	20.6	99.15	0.85	2-10
Pan	243	254	17	0.9	100	0	0

Fineness Modulus= (Σ Cumulative Percentage Retained)/100

FM= (0.6+5.75+16.05+39.55+78.55+99.15)/100= 2.4

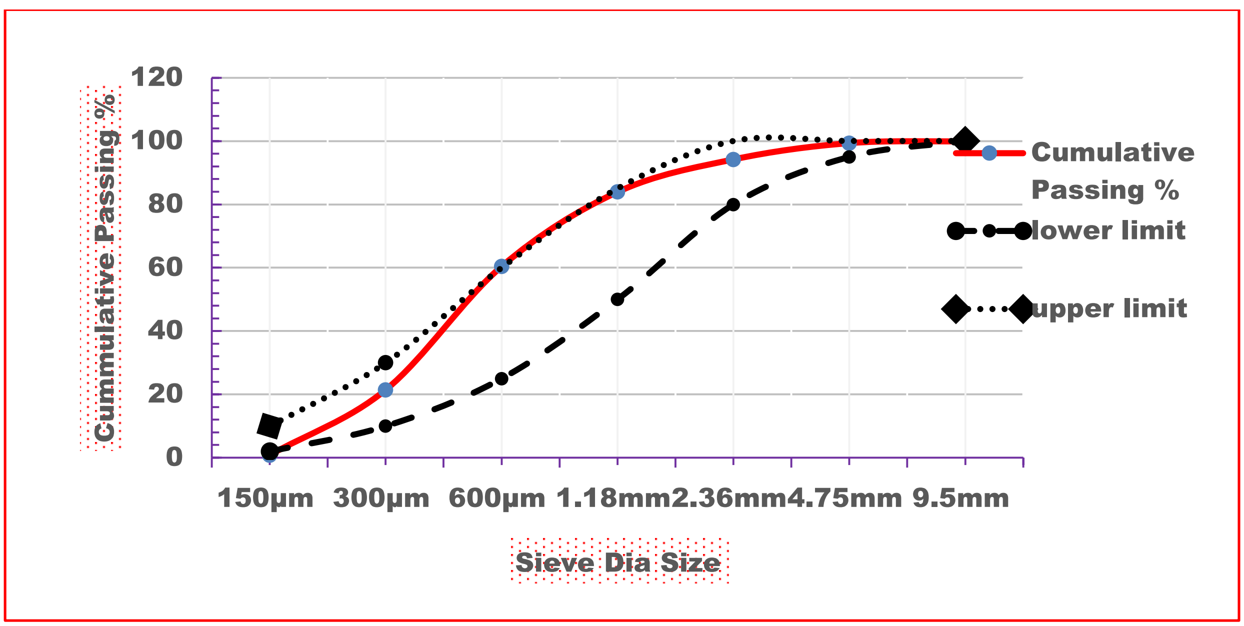


Figure 4 -4: Gradation curve of the fine aggregate used with ASTM 33 limit

Therefore, the fine aggregate sample used was well graded type.

4.2.3 ABSORPTION CAPACITY, SPECIFIC GRAVITY, MOISTURE CONTENTAND UNIT WEIGHT

Based on the test conducted for one of concrete making material, fine aggregate, the following table summarizes its properties as shown below on Table 4.6: And the detail is presented at Appendix B, Table B-2.

Table 4 -6: Summary Physical properties of fine aggregate

S. No	Description		Method	Test result	Allowable limit	Standard
1	Absorption Capacity (%)		ASTM C-128	2%	0.2% -2 %	ASTM C-128
2	Relative density (specific gravity)					
	A. Apparent Specific Gravity		ASTM C-128	2.66	2.4-3.0	ASTM C-128
	B. Bulk Specific Gravity (SSD)		ASTM C-128	2.57	2.4-2.9	ASTM C-128
	C. Bulk Specific Gravity (OD)		ASTM C-128	2.52	2.3-2.9	ASTM C-128
3	Mean of silt content		ASTM C-33	2.89%	≤ 6%	ASTM C33
4	Moisture content		ASTM C-33	0.5%	0%- 10%	ASTM C-33
5	Unit weight(kg/m^3)	Compacted	ASTM C-33	1577.8	1320–1680	ASTM C-33
		Loose	ASTM C-33	1245.5	1320–1680	ASTM C-33

4.3 EXPERIMENTAL TEST RESULTS ON PROPERIES OF COARSE AGGREGATE

4.3.1 PARTICLE SIZE DISTRIBUTION OF COARSE AGGREGATE

According to the test method of ASTM C-136 sieve analysis of the coarse aggregate was carried out and the test result shown in Table 4.7 as shown below.

Table 4-7: Average grading test for Coarse Aggregate

Sieve Dia	Wt of Retained (gm)	Cumulative Retained %	Cumulative Passing %	Cumulative Passing % Specification (ASTM C-136)	Remark
25mm	0	0	100	100	OK
19mm	791	8	92	90-100	OK
12.50mm	5258	60	40	20-55	OK
9.50mm	2810	89	11	0-15	OK

4.75mm	1128	100	0	0-5	OK
Pan	11	100	0		

From the Figure 4-5 the gradation of coarse aggregate used is within the upper and lower limit of the ASTM C-136 standards. Therefore, the coarse aggregate sample used for the research study was well graded type of aggregate. The cumulative percentage of passing, percentage retained and the range of requirement as per the specification are briefly tabulated under Appendix -C, table C-2.

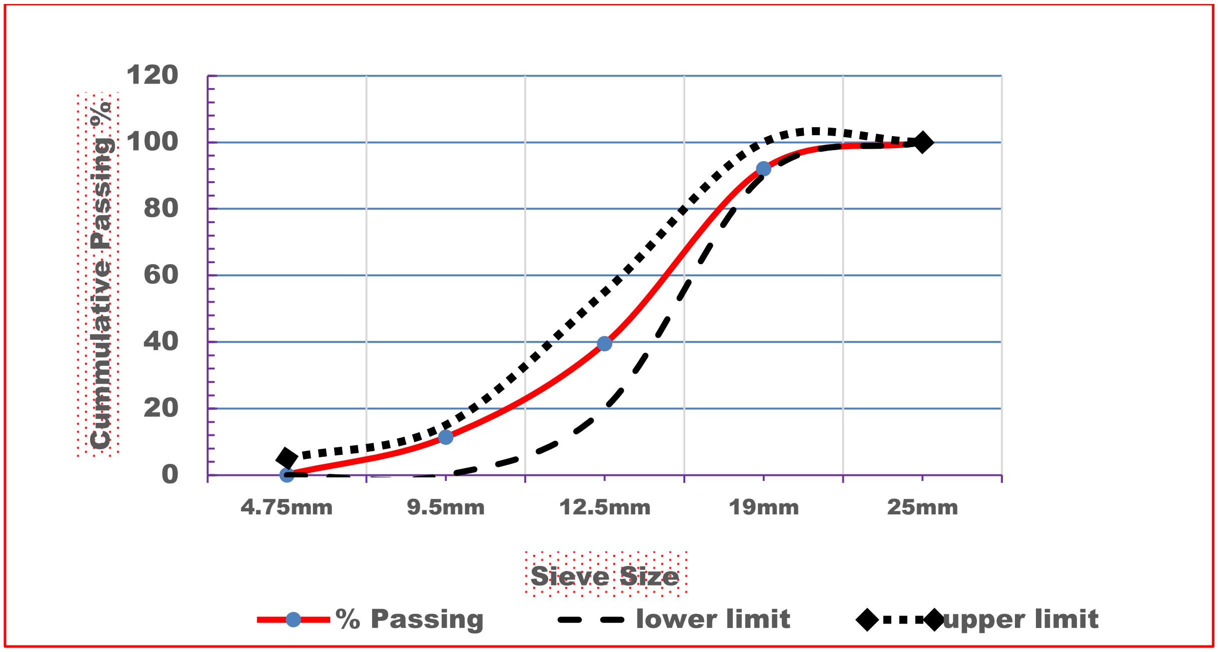


Figure 4 -5: Gradation curve of coarse aggregate used with ASTM C-136 limit

4.3.2 ABSORPTION CAPACITY, SPECIFIC GRAVITY, MOISTURE CONTENTAND UNIT WEIGHT

Based on test conducted for one of concrete making material, coarse aggregate, the following table summarizes its properties as shown below on Table 4.8. For detail refer Appendix C, Table C-3.

Table 4 -8: Summary of Physical coarse aggregate properties

S. No	Description	Method	Test result	Allowable limit	Standard
1	Absorption Capacity (%)	ASTM C-127	0.90%	0.5% -1%	ASTM C-127
2	Relative density (specific gravity)				
	A. Apparent Specific Gravity	ASTM C-127	2.87	2.4-2.9	ASTM C-127
	B. Bulk Specific Gravity (SSD)	ASTM C-127	2.82	2.4-3.0	ASTM C-127

	C. Bulk Specific Gravity (OD)		ASTM C-127	2.79	2.3-2.9	ASTM C-127
3	Moisture content		ASTM C-33	0.4%	0%- 10%	ASTM C-33
4	Unit weight(kg/m^3)	Compacted	ASTM C-33	1676.5	1320–1680	ASTM C-33
		Loose	ASTM C-33	1510.6	1320–1680	ASTM C-33

4.4 TESTS ON FRESH CONCRETE

4.4.1 WORKABILITY TEST RESULTS

Slump cone test and compaction factor test are done on fresh concrete for knowing the workability of the concrete and the results are discussed as follows.

A. Slump Test

The vertical distance between the original and displaced position of the center of the top surface of the concrete is measured and reported as the slump. All cement replacement by hybrid of ESP and SDA results slump value between 25mm to 50 mm. Which have low workability.

Table 4 -9: The slump test result on fresh concrete

Code of Sample	H-0%	H-5%	H-10%	H-15%	Remark
Slump height (mm)	33	31	28	26	All are low workable

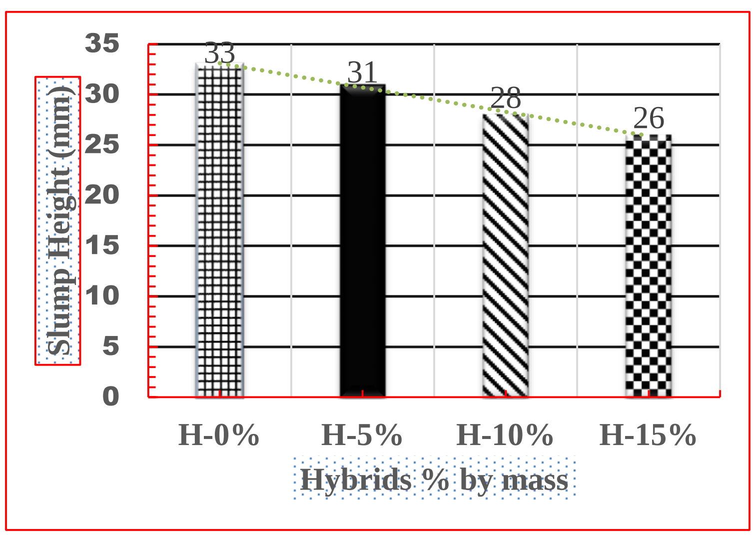


Figure 4 -6: Slump test procedure and test result

As shown in Figure 4.6 the workability of fresh concrete decrease with increasing hybrid replacement percentage..

B. Compaction factor test

Consistency is the term used to denote the degree of wetness or fluidity of concrete. Wet concrete is more workable than dry (stiff) concretes, but concrete of the same witness (consistency) may differ in workability

Table 4- 10: Compaction factor test Result

Code of Sample	H-0%	H-5%	H-10%	H-15%	Remark
Compaction Factor	0.843	0.835	0.827	0.822	All are dry consistency

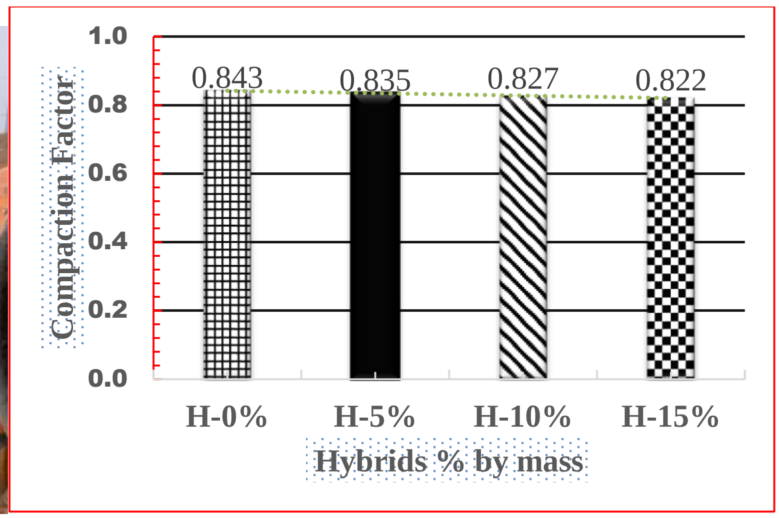


Figure 4 -7: Compaction factor test Conducting and test result

In the compaction factor test, it was shown that, the addition of Hybrid of ESP and SDA make fresh concrete become dry. The detail data presented at Appendix E,Table E-1.

4.5 MECHANICAL TESTS ON HARDENED CONCRETE

4.5.1 UNIT WEIGHT OF SPECIMENS

The Unit Weight of all specimens calculated based on the average mass of specimens on the 7^{th}, 14^{th} and 28^{th} days age of curing. The average mass and unit weight of Cube, cylinder and Beam listed in Table 4.11 to Table 4.13 and the rest details presented under Appendix F, table F-1 to table F-3 respectively. The result show that as all the casted samples are normal weighted, neither light weight nor heavy weight since all have about 24 KN/m^3. Code of Standard used is ES EN 1991 (Table A-1).

Table 4- 11: Mass and Unit weight of specimens (Cube =150x150x150mm) of concrete

	7th day		14th day		28th day	
Code of Sample	Avg. Mass (Kg)	Unit Wt (KN/m³)	Avg. Mass (Kg)	Unit Wt (KN/m³)	Avg. Mass (Kg)	Unit Wt (KN/m³)
H-0%	8.36	24.29	8.42	24.29	8.45	24.56
H-5%	8.41	24.44	8.47	24.44	8.54	24.83
H-10%	8.55	24.86	8.42	24.86	8.32	24.19
H-15%	8.36	24.29	8.42	24.29	8.45	24.56

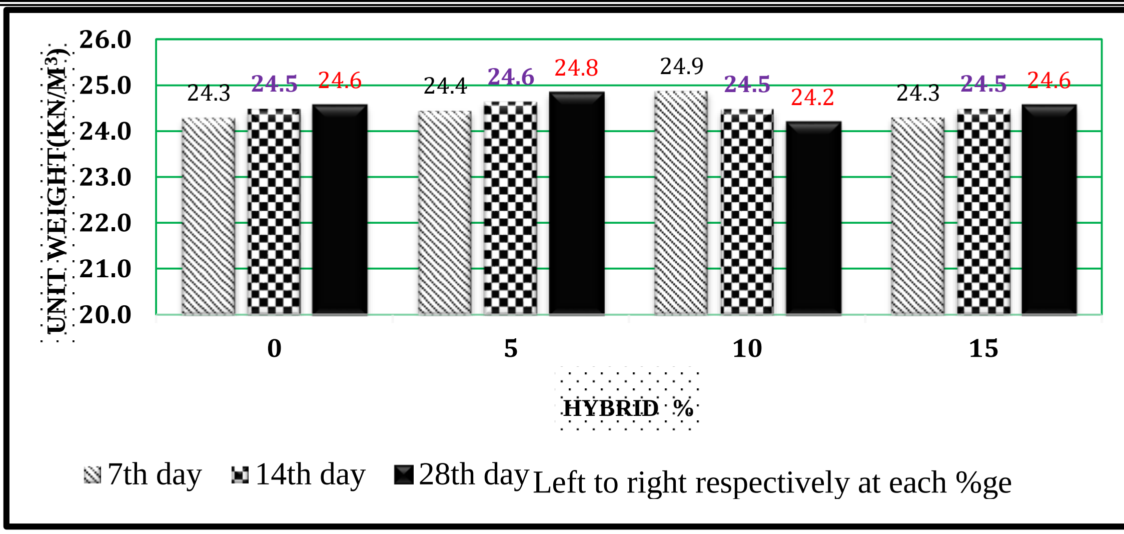


Figure 4 -8: Unit weight of Cubes versus hybrids percentage

As seen on Table 4-11and Figure 4-8 the unit weight of all Cube concrete specimens all with and without the hybrid of ESP and SDA at all curing are almost equal to 24KN/m^3. Therefore, all are considered as normal weight concrete which are neither light weight nor Heavy weight as per ES EN 1991 (Table A-1) Code of standard.

Table 4- 12: Mass and Unit weight of specimens (Cylinder =100x200mm) of concrete

	7th day		14th day		28th day	
Code of Sample	Avg. Mass (Kg)	Unit Wt (KN/m³)	Avg. Mass (Kg)	Unit Wt (KN/m³)	Avg. Mass (Kg)	Unit Wt (KN/m³)
H-0%	3.86	24.13	3.89	24.27	3.88	24.23
H-5%	3.85	24.06	3.92	24.48	3.86	24.13
H-10%	3.84	24.00	3.87	24.17	3.87	24.19
H-15%	3.86	24.13	3.93	24.54	3.90	24.37

As seen on Table 4-12 and Figure 4-9 the unit weight of all Cylinder concrete specimens, all with and without the hybrid of ESP and SDA at all curing are almost equal to 24KN/m^3. Therefore, all are considered as normal weight concrete which are neither light weight nor Heavy weight as per ES EN 1991 (Table A-1) Code of standard.

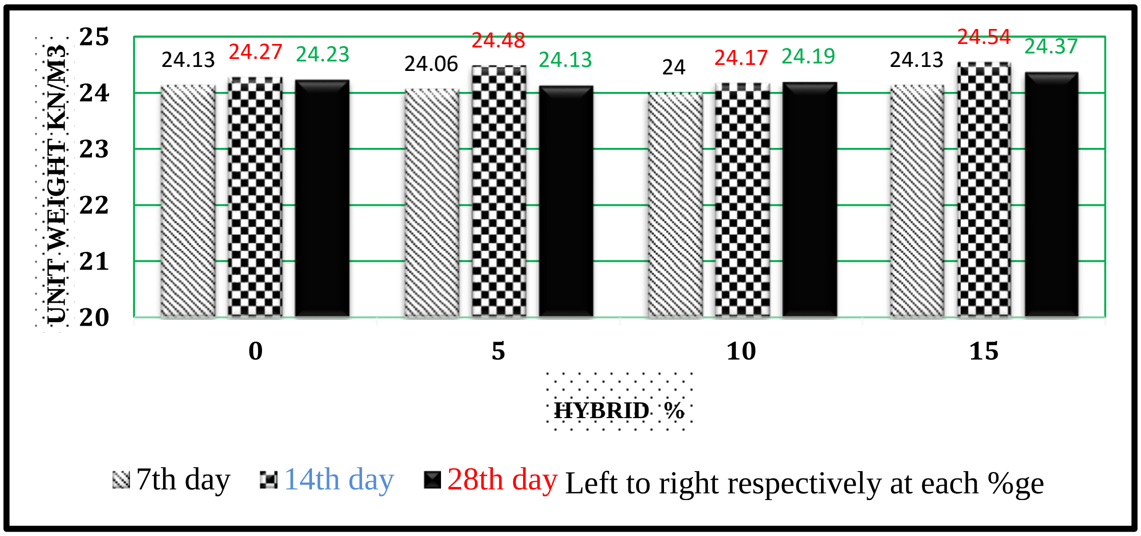


Figure 4 -9: Unit weight of Cylinders versus hybrids percentage

Table 4- 13 Mass and Unit weight of specimens (Beam =100x100x500mm) of concrete

	7th day		**14th day**		**28th day**	
Code of Sample	Avg. Mass (Kg)	Unit Wt (KN/m³)	Avg. Mass (Kg)	Unit Wt (KN/m³)	Avg. Mass (Kg)	Unit Wt (KN/m³)
H-0%	12.53	24.53	12.35	24.22	12.56	24.64
H-5%	12.43	24.38	12.32	24.16	12.30	24.14
H-10%	12.65	24.81	12.47	24.47	12.40	24.33
H-15%	12.36	24.31	12.28	24.10	12.57	24.66

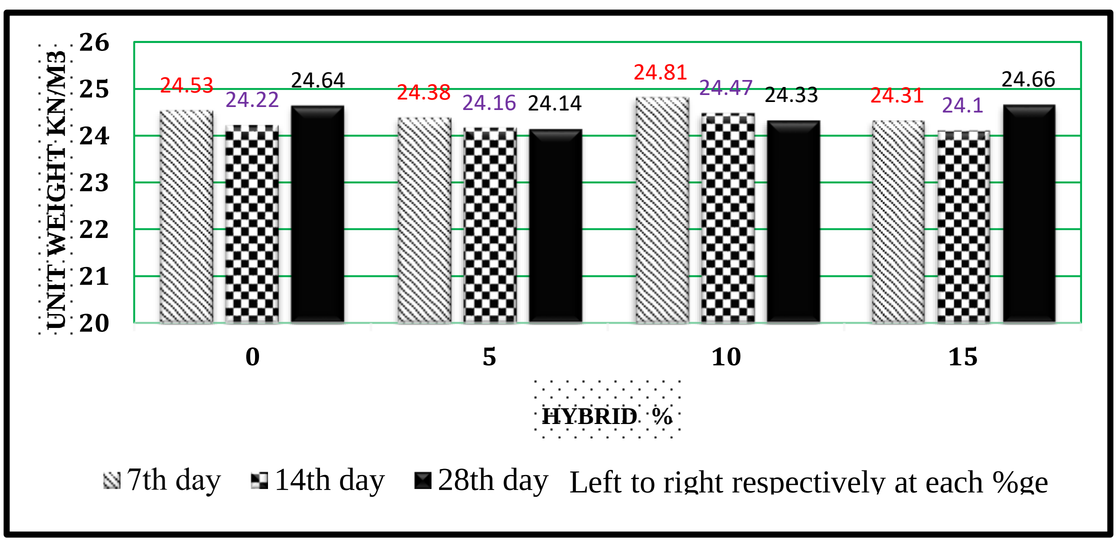


Figure 4 -10: Unit weight of Beam versus hybrids percentage

As seen above, the unit weight of all concrete specimens all with and without the hybrid of ESP and SDA are almost equal to 24KN/m^3. Therefore, all are considered as normal weight concrete which are neither light weight nor Heavy weight as per ES EN 1991 (Table A-1) Code of standard.

4.5.2 COMPRESSIVE STRENGTH EXPERIMENTAL TEST RESULT

It is the most common type of destructive test for concrete and most concrete structures are designed to resist compressive stress.

The 7th, 14th, and 28th -day experimentally investigated Compressive stress results be compared with ES EN 1992 (2015) empirically recommended Compressive Stress value for ordinary concrete on respective test days. Detailed result of compressive strength test for each specimen and percentage of hybrid is fully listed under Appendix G, Table G-1.And summarized as follow.

Table 4- 14: Average Compressive Stress and Variation from Standard stress Value

Code of Samples	**C. Strength at 7th day**		**C. Strength at 14th day**		**C. Strength at 28th day**	
	Max. Avg. Compressive stress(MPa)	Variation From Standard (%)	Max. Avg. Compressive stress(MPa)	Variation From Standard (%)	Max. Avg. Compressive stress(MPa)	Variation From Standard (%)
Standard	17.3	0.0%	21.6	0.0%	25.0	0.0%
H-0%	20.0	15.9%	24.5	13.5%	28.8	15.1%
H-5%	19.1	10.1%	22.1	2.5%	26.2	4.9%
H-10%	17.9	3.7%	22.4	3.7%	25.0	0.1%
H-15%	16.3	-6.0%	19.1	-11.6%	23.3	-6.6%

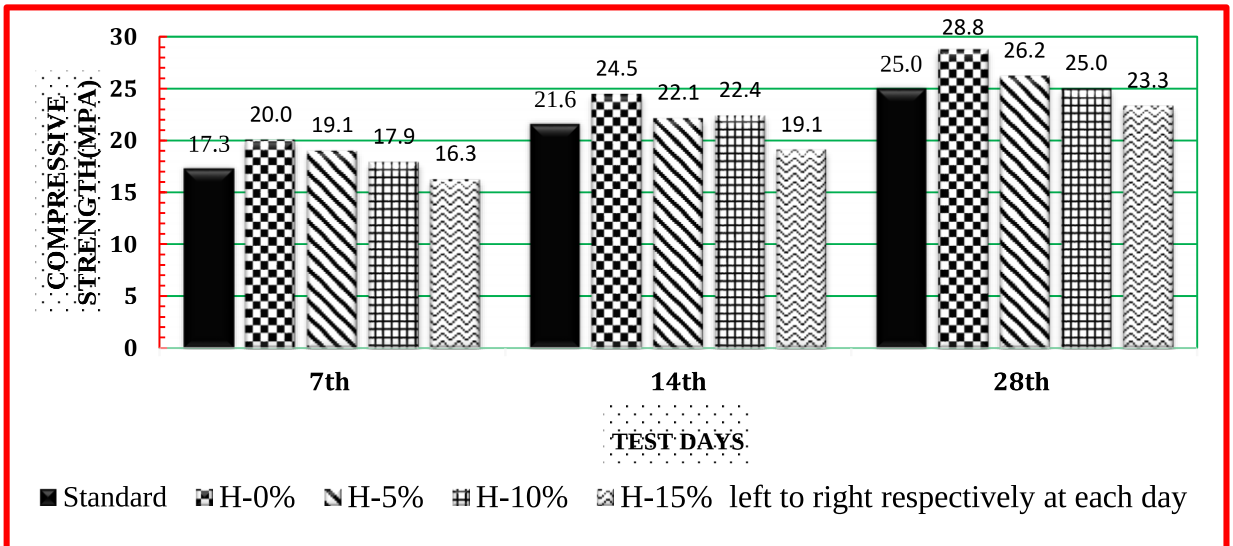


Figure 4 -11: Compressive Strength versus curing day

Based on compressive strength result show in Table 4.14 above, it was clearly observed that,

- As the date of curing increases the compressive strength of concrete increases.
- Compressive strength result of H-0% to H-10% found that fulfill the strength requirement of ES EN 1992's Code of standard for all 7th, 14th and 28th days of curing.
- However, the percentage of variation from the Standard result shows negative for hybrid mix of H-15% for all 7th, 14th and 28th days of curing. Which mean, it is not fulfill the strength requirement of ES EN 1992's Code of standard
- In general, it can be concluded that the replacing of cement up to 10% by weight with hybrid of ESP and SDA possible Since up to 10% replacement fulfill the compressive strength requirement of ES EN 1992's Code of standard.

4.5.3 COMPRESSIVE STRESS - STRAIN BEHAVIOR OF SPECIMENS

Maximum average compressive Stress and the corresponding compressive strain are summarized for all mixes shown in Table 4-15. And the stress-strain curve as seen on Figure 4.12 to Figure 4.14 to illustrate peak compressive stress and the corresponding strain for 7th, 14th and 28th -days test result. The detailed cube stress -strain relation for 7th, 14th and 28th -days test are listed under appendix G, Table G-2 to G-13. There is additional stress-time curve photos for some of individual samples and for all Hybrid percentage presented under Appendix G, Figure G-1.

Table 4- 15: Maximum average compressive Stress and the corresponding compressive strain

Code of Samples	**C. Strength at 7th day**		**C. Strength at 14th day**		**C. Strength at 28th day**	
	Max. Avg. Compressive stress(MPa)	Corresponding Strain	Max. Avg. Compressive stress(MPa)	Corresponding Strain	Max. Avg. Compressive stress(MPa)	Corresponding Strain
Standard	17.3	0.00180	21.6	0.00190	25	0.00200
H-0%	20.0	0.00190	24.5	0.00199	28.8	0.00206
H-5%	19.1	0.00190	22.1	0.00204	26.2	0.00200
H-10%	17.9	0.00181	22.4	0.00191	25.0	0.00200
H-15%	16.3	0.00180	19.1	0.00190	23.3	0.00191

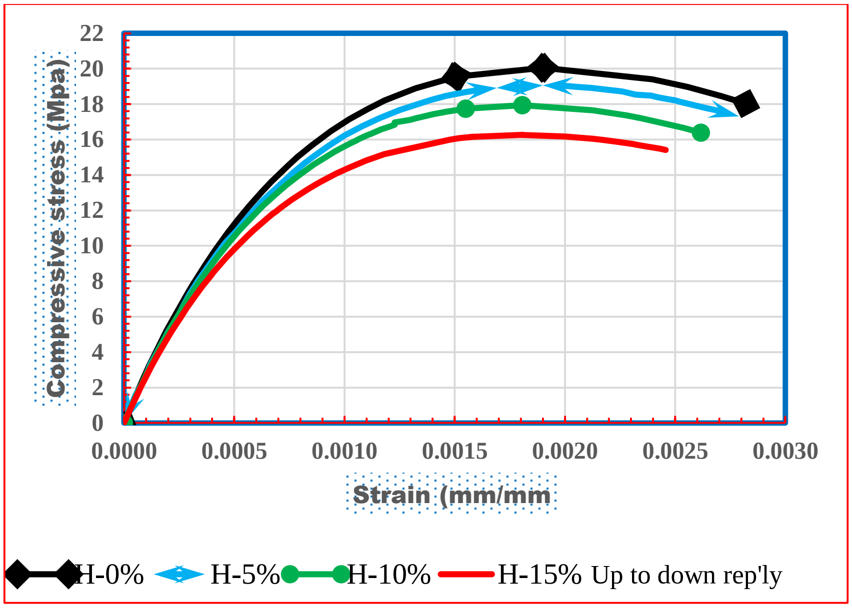


Figure 4 -12: Stress-strain curve for 7th -day compressive strength test

As shown in Table 4-15 and Figure 4-12 all samples have parabolic curve and (H-0%,H-5%,H-10%,and H-15%) have strains of (1.9,1.9,1.8,1.8)‰ respectively at peak stress which are greater than or equal to 1.8‰ which is the requirement of ES EN 1992-2015 (3.1.5) code standard.

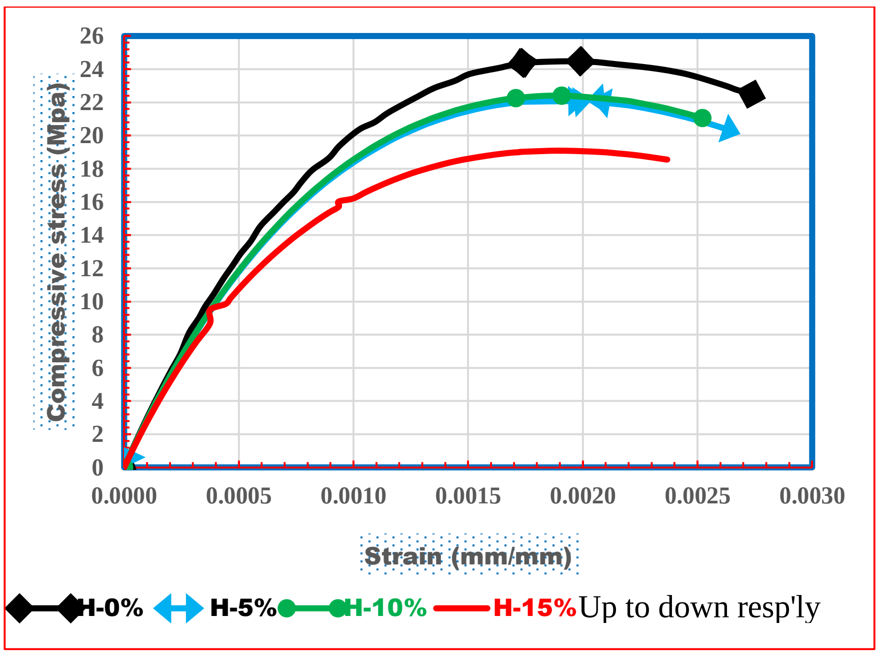


Figure 4 -13: Stress-Strain curve for 14th-day compressive strength test

As shown in Table 4-15 and Figure 4-13 all samples have parabolic curve and (H-0%,H-5%,H-10%,and H-15%) have strains of (2.0,2.2,1.9,1.9)‰ respectively at peak stress which are greater than or equal to 1.9‰ which is the requirement of ES EN 1992-2015(3.1.5) code standard.

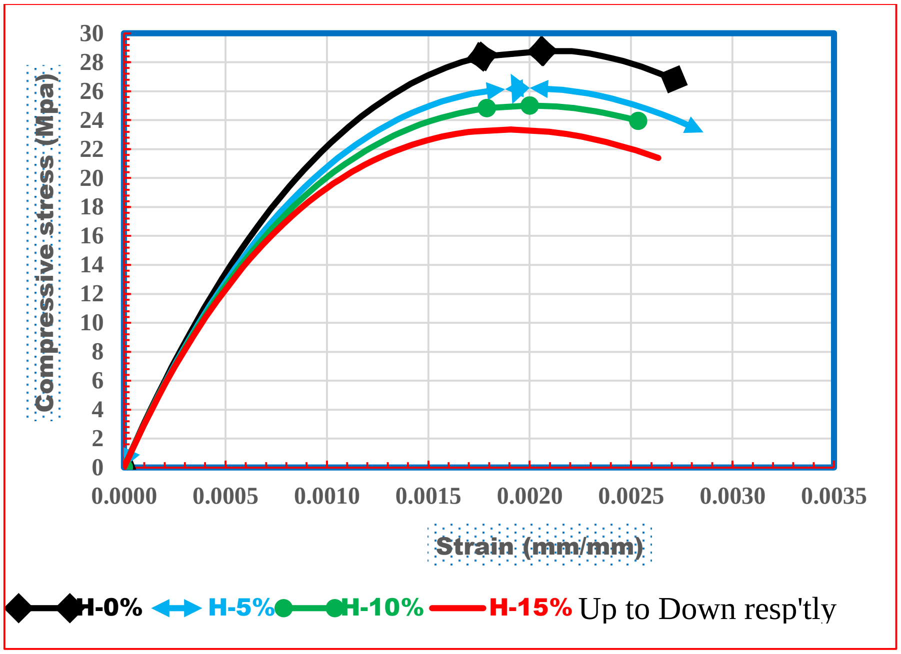


Figure 4 -14: Stress-Strain curve for 28th-day compressive strength test

- In general, it can be concluded that Compressive stress- strain Curve for hybrid of Specimens (H-0% to H-15%) at all 7th, 14th, and 28th day of curing have similar stress-strain Curve shape of ES EN 1992-2015 (3.1.5) 's Code of standard.

4.5.4 SPLITTING TENSILE STRENGTH EXPERIMENTAL TEST RESULT

A measure of the ability of material to resist a force that tends to pull it apart. The split tensile strength test results on 7, 14 and 28 days are shown in the Table 4.16. The detail split test results are tabulated under appendix G, Table G-14.

Table 4- 16: Average Splitting Tensile Stress and Variation from Standard stress Value

Code of Specimen	7th		14th		28th	
	Max. Avg. Tensile stress(MPa)	Variation from standard	Max. Avg. Tensile stress(MPa)	Variation from standard	Max. Avg. Tensile stress(MPa)	Variation from standard
Standard	2.50	0.0%	2.80	0.0%	3.10	0.0%
H-0%	2.64	5.6%	3.04	8.6%	3.59	15.8%
H-5%	2.56	2.4%	3.01	7.5%	3.29	6.1%
H-10%	2.51	0.4%	2.96	5.7%	3.22	3.9%
H-15%	1.75	-30.0%	2.13	-23.9%	2.39	-22.9%

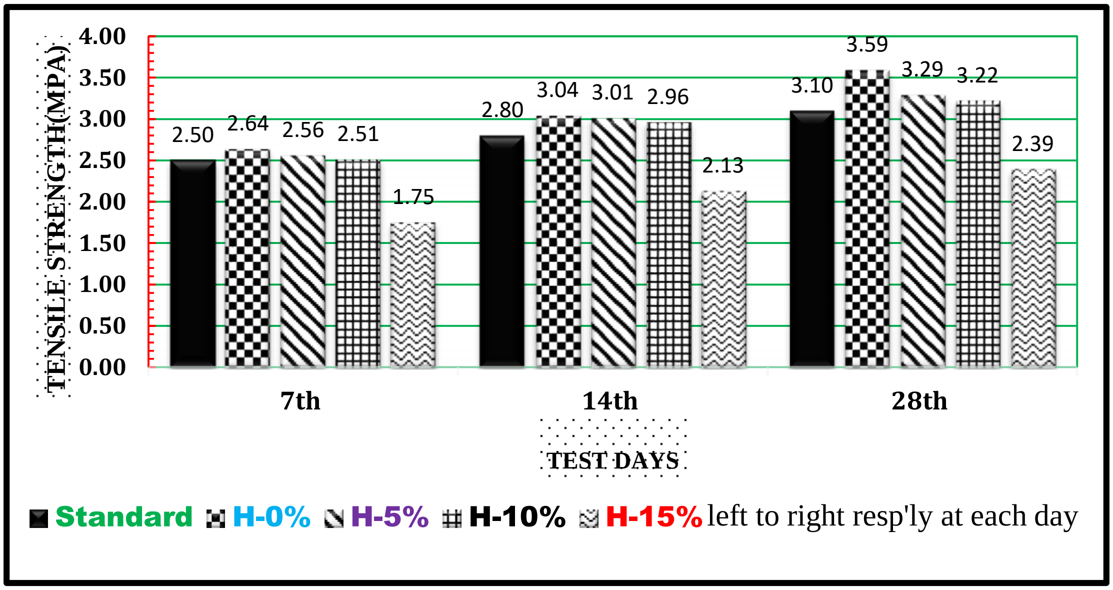


Figure 4 -15: Splitting Tensile Strength versus Curing day

- Hybrid mix of H-15% is not fulfill the strength requirement of ES EN 1992's Code
- In general, it can be concluded that the Replacing of cement up to 10% by weight with hybrid of ESP and SDA possible Since up to 10% replacement fulfill the splitting tensile strength requirement of ES EN 1992's Code of standard.

4.5.5 FLEXURAL TENSILE STRENGTH EXPERIMENTAL TEST RESULT

Flexural test evaluates the tensile strength of concrete indirectly. It tests the ability of unreinforced concrete beam to withstand failure in bending. The average flexural tensile strength test results for 7th, 14th and 28th days of curing are shown in Table 4.17. The detail flexural tensile test results are tabulated under appendix G, Table G-15.

Table 4- 17: Average Flexural Tensile Stress and Variation from Standard stress Value

Code of Specimens	7th		14th		28th	
	Max. Avg. Flexural Tensile stress(MPa)	Variation standard's (%)	Max. Avg. Flexural Tensile stress(MPa)	Variation standard's (%)	Max. Avg. Flexural Tensile stress(MPa)	Variation standard's (%)
Standard	3.73	0.0%	4.29	0.0%	4.77	0.0%
H-0%	3.77	1.1%	4.41	2.8%	4.80	0.6%
H-5%	3.74	0.3%	4.36	1.6%	4.78	0.2%
H-10%	3.76	0.8%	4.45	3.7%	4.77	0.0%
H-15%	3.71	-0.5%	4.19	-2.3%	4.49	-5.9%

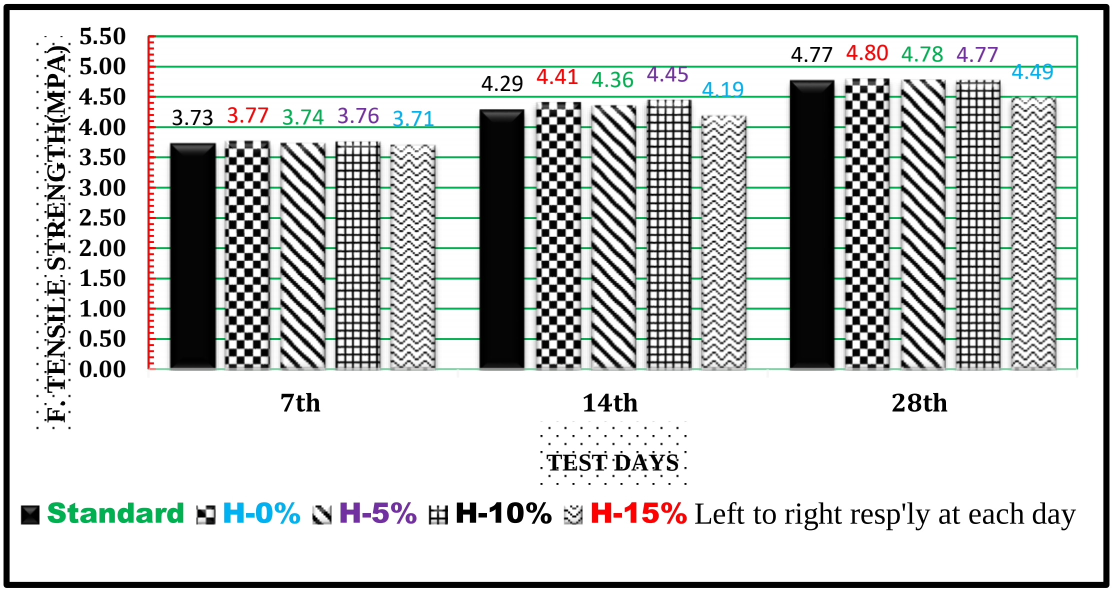


Figure 4 -16: Flexural Tensile Strength versus Curing day

- The percentage of variation from the Standard result shows negative for hybrid mix of H-15% for all 7th, 14th and 28th days of curing. Which mean, it is not fulfill the strength requirement of ES EN 1992's Code of standard i.e the results are less 3.73, 4.29 &4.77Mpa at 7th, 14th and 28th curing days respectively.
- In general, it can be concluded that the Replacing of cement up to 10% by weight with hybrid of ESP and SDA possible Since up to 10% replacement fulfill the Flexural tensile strength requirement of ES EN 1992's Code of standard.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

In this research, the suitability of eggshell powder and sawdust ash was experimentally investigated and depending on the test results obtained the following conclusions were drawn.

From the chemical properties test made, the content of calcium oxide and silicon oxide of the Hybrid of eggshell powder and sawdust ash in the limit of recommendations. Therefore hybrid of ESP and SDA can be used as replacement material of cement because of its pozzolanic properties. The output test results revealed that for the normal consistency of the paste with constant water to cement ratio, penetration depth is decrease as Hybrid of ESP and SDA content increased. Therefore, as a conclusion, the water requirement for the cement that partially replaced with Hybrid of ESP and SDA is higher than the cement without the Hybrid of ESP and SDA.

After the completion of testing and analysis, the following conclusions can be deduced;

- The workability of the concrete reduced as Hybrid of ESP and SDA content increased due to higher water demand of ESP and SDA than cement. So, it is better to use retarder admixture for the fast setting time and lose of plasticity property of fresh concrete.
- The result of mechanical strength test with reference of ES EN 1992's strength requirement at 28th day on the concrete in which cement is partially replaced showed that for compressive strength there was increment in 4.9% for H-5, and 0.1% for H-10 and reduction in 6.6% for H-15% , for splitting tensile strength test result shows that increment in 6.1% for H-5% and 3.9% for H-10 but reduction with 22.9% for H-15% and For flexural tensile strength there was increment in 0.2% for H-5, and neither increment nor decrement for H-10 and reduction in 5.9% for H-15%.
- All percentage of hybrid have parabolic Compressive stress- strain curve at all days of curing as like ES EN 1992‘s Code of standard.
- In general, it can be concluded that the replacing of cement up to 10% by weight with hybrid of ESP and SDA fulfill the Compressive, Splitting Tensile and Flexural tensile of C20/25 concrete strength requirement of ES EN 1992‘s Code of standard.

5.2 RECOMMENDATIONS

The investigation revealed that replacement of cement by hybrid of ESP and SDA in concrete met the strength requirement of code of standard. So it is beneficial in environmental aspect. And based on the results of this research investigation, the following recommendations were forwarded:

- Concerned bodies like municipalities, wood manufacturing factories, poultries, hotels, restaurants, cafeterias and residents should be aware about potential of hybrid of ESP and SDA as cement replacing materials. The eggshell and sawdust should be collected and supply for the purchaser rather than disposing as land fillers and the cement factory should blend them to cement at final production.
- Since during using of Hybrid of Eggshell powder and sawdust ash as partial replacement of cement the workability of fresh concrete is reduced it is recommended to use retarder admixture to retard the setting time.

The uses of Hybrid of ESP and SDA in concrete production not known especially in Ethiopia, therefore to extend this research to a wider perspective researcher recommends as more studies and research needs to be carried out in this area and the following were recommended for future studies:

- Studies should be made by different fineness of hybrid of ESP and SDA and different ratios of ESP to SDA as cement partial replacing materials in concrete.
- And also for further study it will be best if the effect of hybrid of Egg shell Ash and raw saw dust on property of concrete checked.
- Detail study on durability and permeability of concrete by partial replacing cement with Hybrid of ESP and SDA should be made.

As limitation and as recommendation for Jimma University, Jimma Institute of Technology, it is best if strain gauge is bought to validate the experimental test results

REFERENCES

[1]. Kumar Shaik Akhil and Mastan International VR Prasath. **Experimental Study on Concrete by Partial Replacement of Fine Aggregate with Fly Ash and Egg Shell Powder. Journal & Magazine of Engineering, Technology, Management and Research**, A Peer Reviewed Open Access International Journal. 2015;2(2):214-220.

[2]. Yesuf, N. **The Effect of Egg and Lime on the Compressive Strength of Mortar** Addis Ababa University School of Graduate Studies; 2014;4(2):55-59

[3]. Sargunan, S.and Senthil K.**Optimization of Cement Concrete Using Eggshell Powder**. Asian Journal of Research in Social Sciences and Humanities. 2016;6(8):696-715.

[4]. https://www.researchgate.net/publication/336892528_A_feasibility_study_on_composite_bricks_from_sawdust_and_boiler_ash_using_cement_as_a_binder

[5]. Meyer, C. **Concrete as a Green Building Material. Construction Materials Mindess Symposium**; New york, USA: Columbia University. 2005;2(2):1-6.

[6]. Tekele B.H. **Bagasse ash as a cement replacing material.** International Journal of Engineering Trends and Technology. 2014;14(2):64-68.
https://www.researchgate.net/publication/305281723_Bagasse_ash_as_a_cement_replacing_material

[7]. Neville, A.M. Properties of Concrete. 5th ed. Cambridge: Pearson Prentice Hall,: Library of Congress Cataloging-in-Publication Data;2012.

[8]. Dinku,A. Construction Materials Laboratory Manual.1st Ed. Addis Ababa: Addis Ababa University Printing Press; 2002.

[9]. http://www.jce-ieb.org/doc_file/3702001.pdf

[10]. Shetty, M.S. **Concrete Technology Theory and Practice**: Pune Ministry of Defense; 2005; 3(1):2-5, and 35-36 p.

[11]. Okonkwo, E. **The Effects of Eggshell Ash on Strength Properties of Cement-Stabilized Lateritic**. International Journal of Sustainable Construction Engineering & Technology. 2012;3(1)11-19.

[12]. Stadelman, W.J. Eggs and Egg Products. In: Francis FJ, editor. Encyclopedia of Food Science and Technology. 2nd ed. New York: John Wiley & Sons; 2000. p. 593–599.

[13]. Silversides, T. A. **The Effect of Storage and Strain of Hen on Egg Quality**. The Journal of Poultry Science.2000;79(12):1725–1729.

[14]. Beck, K.et al.**Experiment On the Use of Eggshell Lime and Tuffeau Powder to Formulate an Appropriate Mortar for Restoration Purposes**., Geological Society, London, Special Publications. 2010;331(1):137-145.

[15]. Narayanaswamy, P., Prakash, M., &Satyanarayanan, K. **Experimental study on partial replacement of cement with egg shell powder and silica fume**. *Rasayan Journal of Chemistry,* April 2017;*10*(2), 442-449.

[16]. Yerramala, A. **Properties of Concrete with Eggshell Powder as Cement Replacement.** The Indian Concrete Journal. August 2014;41(3):PP 94-102.

[17]. Dixson ,P., Karthikeyan, S. and Manikandan,G.**Experimental Study On Properties Of Concrete By Partial Replacement Of Cement With Silica Powder And Fine Aggregate With Saw Dust Ash**International Journal of Civil Engineering and Technology (IJCIET) Volume8, Issue 3, March 2017; pp. 680–687 Article ID: IJCIET_08_03_068

[18]. Raji, S., &Samuel, A. T. **Egg Shell As A Fine Aggregate In Concrete For sustainable construction**. *International journal of science and technology research,* September ,2015;*4*(09), 8-13.

[19]. Yu, T. Y., Ing, D. S., & Choo, C. S. (). **The Effect of Different Curing Methods on the Compressive Strength of Eggshell Concrete**. *Indian Journal of Science and Technology,* February ,2017;*10*(6), 1-4.

[20]. Bysani, M.ChennupatiSobha Rani NaralasettiSrinivasarao. **Study on Limited Substitution of Egg Shell Powder with Cement in Concrete**. International Journal of Scientific Engineering and Technology Research. 2017;6(4):0763-0766.

[21]. M., M. A., M., D. K., J., M. C., & G., D. **Replacement of Cement using Eggshell powder**. *SSRG International Journal of Civil Engineering (SSRG – IJCE),* March,2016*3*(3), 1-2.

[22]. D.Gowsika, S.Sarankokila, &K.Sargunan.**Experimental Investigation of Egg Shell Powder as Partial Replacement with Cement in Concrete**. *International Journal of Engineering Trends and Technology (IJETT),* Aug. 2014;*14*(2), 65-68.

[23]. Mtallib, M., &Rabiu, A. **Effects of eggshell ash (ESA) on setting time of cement**. *Nigerian journal of technology,*September 2009*, 28*(2), 30-38.

[24]. Praveen Kumar R.,Ravindraraj.B., Vijaya Sarathy.R and Jose. **Experimental Study on Partial Replacement of Cement with Egg Shell Powder.** International Journal of Innovations in Engineering and Technology. 2015;5(2)11-19.

[25]. Asman, N. S., Dullah, S., Ayog, J. L., Amaludin, A., Amaludin, H., Lim, C. H., &Baharum, A. **Mechanical Properties of Concrete Using Eggshell Ash and Rice Husk Ash As Partial Replacement Of Cement**. 2017;*MATEC Web of Conferences 103* (pp. 1-6). EDP Sciences. doi:10.1051/matecconf/20171030100

[26]. Food and agricultural organization united nation. (2019). Livestock Primary. Retrieved Feb. 5, 2021, from FAOSTAT: http://www.fao.org/faostat/en/#data/QL

[27]. Boere, A., Vernooij, A., Duns, H., Legesse, M., & Kidane, D. **Investment opportunities in the Ethiopian Poultry sub-sector"Ethiopian Netherlands business event** 5–6 November 2015, Rijswijk..

[28]. https://www.jchps.com/issues/Volume%208_Issue%204/jchps%208(4)%2048%20sk%2038%20Greesan.pdf

[29]. Udoeyo, F., Inyang, H., Young,D., and Oparadu, E.**Potential of Wood Waste Ash as an Additive in Concrete**. Journal of Materials in Civil Engineering Volume8, Issue 3, August2006,18(4): 605-611.pp. 41–57

[30]. Obilade,V.**Use of Saw Dust Ash as Partial Replacement for Cement In Concrete** International Journal of Engineering Science Invention, ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726 www.ijesi.org Volume 3 Issue 8 ǁ August 2014 ǁ PP.36-40

[31]. Amir Shafi Batt and Anshul Garg **Replacement Of Wood Ash With Ordinary Portland Cement And Foundry Sand As Fine Aggregate** published in: Journal of Civil & Environmental Engineering August 2014;Volume 7/ Issue 2 ;PP.36-40

[32]. Ambika Nahak and Mrs. Sabita Dash **A Study On Strength Of Concrete With Partial Replacement Of Cement With Saw Dust Ash And Steel Fibre**International Journal of EngineeringResearch & Technology (IJERT) ISSN: 2278-0181 IJERTV4IS030285,March-2015;Vol. 4 Issue 03;pp 45-48

[33]. Muhammad ,H. **Effect of Saw Dust Ash as a Partial Replacement of Cement on Fresh and Hardened Properties of Concrete**International Research Journal of Innovations in Engineering and Technology (IRJIET), 2019;Volume 3, Issue 3, pp 25-28,

[34]. Alemshet M.**Effects Of Using Sawdust As A Partial Replacment Of Fine Aggregate For The Production Of Hollow Concrete Block Around Jimma.,**Jimma University School of Graduate Studies [MSc Thesis], Jimma, Ethiopia.; November, 2017;pp 68,

[35]. ASTMC-78. (2004). strandard test for flexural srtength of concrete (Using Simple Beam with middle thrid span of length). USA:american society test matrials.

[36]. ASTMC-128. (2004). Standard Test Mehods for specific gravit and absorptin capacity of fine aggregate ASTM C-128. USA: ASTM.

[37]. ASTMC-143. (2004). Standard Test Method for Slump of Hydraulic-Cement Concrete C 143/ C143M. USA: American Society Tests for Materials.

[38]. ASTMC-192/C192M. (2007). Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory C 192/C 192M. USA: ASTMC-192/C192M.

[39]. ASTMC33/C33M. (2011). Standard Specification for Concrete Aggregates ASTM. USA: ASTMC-33.

[40]. ASTM C 150. Standard Specification for Portland Cement. West Conshohocken, United States2011.

[41]. ASTM C 151. Standard Test Method for Autoclave Expansion of Portland Cement. Philadelphia, USA2000.

[42]. ASTM C 618. Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete. West Conshohocken, PA 19428-2959, United States2000.

APPENDICES

APPENDIX –A: PROPERTIES OF CEMENT AND HYBRIDS BLENDED WITH CEMENT

A-1: Normal Consistency Test on Pastes of cement and hybrids blended with cement

Table A-1: Trial Water-Cement ratio and Penetration depth of pastes

Consistency with H-0% (0%+0%) +C100%					
Trial	Weight of cement(gm)	Weight of Hybrid (gm)	Percentage of water	Water added (gm)	Penetration (mm)
1	400	0	26%	104	7
2	400	0	28%	112	8.5
3	400	0	29%	116	10.5

Consistency with H-5% (2.5%+2.5%) +C95%					
Trial	Weight of cement(gm)	Weight of Hybrid (gm)	Percentage of water	Water added (gm)	Penetration (mm)
1	380	20	28%	106.4	7
2	380	20	29%	110.2	8
3	380	20	30%	114	10

Consistency with H-10% (5%+5%) +C90%					
Trial	Weight of cement(gm)	Weight of Hybrid (gm)	Percentage of water	Water added (gm)	Penetration (mm)
1	360	40	30%	108	6.5
2	360	40	31%	111.6	7.5
3	360	40	32%	115.2	9

H-15%(7.5%+7.5%)+C85%					
Trial	Weight of cement(gm)	Weight of Hybrid (gm)	Percentage of water	Water added (gm)	Penetration (mm)
1	340	60	31%	105.4	6.5
2	340	60	32%	108.8	7
3	340	60	33%	112.2	9

A-2: Setting Time Test

Table A-2: Initial Setting Time of pastes

Initial Setting Time (For Normal consistency of 0.85*W/C)							
H-0% @W/C=0.85*29%		**H-5% @W/C=0.85*30%**		**H-10% @W/C=0.85*32%**		**H-15% @W/C=0.85*33%**	
Time (min)	Penetration depth (mm)	Time (min)	Penetration depth (mm)	Time (min)	Penetration depth (mm)	Time (min)	Penetration depth (mm)
30	40	30	33	30	35	30	30
45	35	45	30	45	32	45	27
60	33	60	28	60	30	**60**	**25**
75	30	75	27	**75**	**25**		
90	28	**90**	**26**				
105	26	**105**	**23**				
120	**25**						

A-3: Fineness of Cement without and with different percentage of hybrid

Table A-3: Mean Fineness percentage of pastes

Sample	**Trial**	**Wt before sieving (W1) (gm)**	**Wt retained (W2) (gm)**	**Fineness (%) (w2/w1)*100**	**Mean Fineness (%)**	**IS Allowable limit of the standard for PPC**
H-0 (Cement only)	1	100	0.0410	0.041	0.05	≤ 5
	2	100	0.0315	0.0315		
	3	100	0.0711	0.0711		
H-5	1	100	0.2000	0.2	0.94	≤ 5
	2	100	1.7031	1.7031		
	3	100	0.9031	0.9031		
H-10	1	100	1.1200	1.12	1.12	≤ 5
	2	100	1.2500	1.25		
	3	100	1.0043	1.0043		
H-15	1	100	2.9040	2.904	2.16	≤ 5
	2	100	1.4300	1.43		
	3	100	2.14	2.14		

A-4 Chemical Composition of Hybrid of Egg Shell powder and Sawdust Ash

	GEOLOGICAL SURVEY OF ETHIOPIA	Doc.Number: GLD/F5.10.2	Version No: 1
	GEOCHEMICAL LABORATORY DIRECTORATE		Page 1 of 1
Document Title:	Complete Silicate Analysis Report	Effective date:	May, 2017

Issue Date: -10/06/2021

Customer Name:-Tesfaye Seifu

Request No:- GLD/RQ/970/21

Report No:- GLD/RN/526/21

Sample type :-Ash

Sample Preparation: - 200 Mesh

Date Submitted :-04/05/2021

Number of Sample:- One(01)

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

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

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
TS-01	16.52	8.40	1.38	30.64	2.56	0.64	5.44	1.06	1.59	0.20	6.83	23.86

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

Analysts	Checked By	Approved By	Quality Control
Lidet Endeshaw			
Yirgalem Abrehem	Tizita Zemene	Yohannes Getachew	Gosa Haile
Nigist Fikadu			

APPENDIX –B: PHYSICAL PROPERTIES OF FINE AGGREGATE

Table B-1: Moisture Content, Absorption Capacity and Specific gravity of sand result

Description	Sample 1	Sample 2	Sample 3	Mean
Mass of Saturated Surface Dry Sample in Air (gm)	500	500	500	--
Mass of Oven Dry Sample in Air (A) (gm)	490	487	493	--
Mass of pycnometer + Water (B) (gm)	1500	1500	1500	--
Mass of pycnometer + Water + Sample (C) (gm)	1790	1830	1790	--
Moisture Content (W)=((500- A)/A)*100	2.04%	2.67%	1.42%	**0.5%**
Absorption Capacity = (500-A)*100 /A	2.00%	2.60%	1.40%	**2.00%**
Apparent Specific Gravity =A/(A+B-C)	2.45	3.10	2.43	**2.66**
Bulk Specific Gravity = A/(500+B-C)	2.33	2.86	2.35	**2.52**
Bulk Specific Gravity (SSD) = 500/(500+B-C)	2.38	2.94	2.38	**2.57**

Table B-2: Particle size distribution for fine aggregates (**Mass Taken = 2000 gram)**

Sieve Dia, mm	**Mass retained (gm)**				**% Retain**	**% cumulative retain**	**% Passing**	**% Passing ESC.D3 Spec**
	Sam 1	**Sam 2**	**Sam 3**	**Avg.**				
9.5	0	0	0	0	0	0	100	100
4.75	10	14	13	12	0.62	0.62	99.38	95-100
2.36	110	100	98	103	5.13	5.75	94.25	80-100
1.18	208	212	197	206	10.28	16.03	83.97	50-85
0.6	485	446	479	470	23.5	39.53	60.47	25-60
0.3	814	769	756	780	38.98	78.51	21.49	10-30
0.15	357	441	438	412	20.59	99.1	2	2-10
pan	16	19	15	17	0.83	99.93	0	0
Total	2000	2000	1996	1999		240		

Fineness Modulus = (Σ Cumulative Percentage Retained)/100 =240/100

FM=240/100 =**2.4**

Table B-3: Unit Weight for Fine aggregates

Compacted Unit Weight							
Sample	**Mass of cylinder (Kg)**	**Mass of cylinder and sample(Kg)**	**Height of Cylinder (mm)**	**Diameter of Cylinder (mm)**	**Mass of sample (Kg)**	**Volume of Container (m^3)**	**Unit weight (Kg/m^3)**
1	1.051	9	180	180	7.95	0.005	1589.8
2	1.051	8.81	180	180	7.76	0.005	1551.8
3	1.051	9.01	180	180	7.96	0.005	1591.8
						Mean	**1577.8**
Loose Unit Weight							
1	1.051	7.130	180	180	6.08	0.005	1215.8
2	1.051	7.210	180	180	6.16	0.005	1231.8
3	1.051	7.495	180	180	6.44	0.005	1288.8
						Mean	**1245.5**

APPENDIX –C: PHYSICAL PROPERTIES OF COARSE AGGREGATE

Table C-1: Moisture Content, Absorption Capacity and Specific gravity of Grave result

Description	**Sample 1**	**Sample 2**	**Sample 3**	**Mean**
M_W=Mass of saturated aggregate in water (gm)	1296	1297	1298	--
M_{SSD}=Mass of saturated surface aggregate dry in Air (gm)	2011	2009	2010	--
M_D=Weight in air of oven dried aggregate (gm)	1992	1991	1993	--
Moisture Content (W)=((2000- M_D)/ M_D)*100	0.40%	0.45%	0.35%	**0.40%**
Absorption Capacity = ((M_{SSD}-M_D) /M_D)*100	0.95%	0.90%	0.85%	**0.90%**
Apparent Specific Gravity =M_D/(M_D-M_W)	2.86	2.87	2.87	**2.87**
Bulk Specific Gravity =M_D/(M_{SSD}-M_W)	2.79	2.80	2.80	**2.79**
Bulk Specific Gravity (SSD) = M_{SSD}/(M_{SSD}-M_W)	2.81	2.82	2.82	**2.82**

Table C-2: Particle size distribution for Coarse aggregates **(Mass Taken = 10000 gram)**

Sieve Size, mm	**Mass retained (gm)**				**% Retain**	**% cumulative retain**	**% Passing**	**% Passing ASTM Spec**
	Sam 1	**Sam 2**	**Sam 3**	**Avg.**				
25	0	0	0	0	0	0	100	100
19	790	780	804	791	8	8	92	90-100
12.50	5315	5210	5250	5258	53	60	40	20-55
9.50	2790	2850	2790	2810	28	89	11	0-15
4.75	1100	1150	1135	1128	11	100	0	0-5
pan	5	9	19	11	0	100	0	
Total	10000	9999	9998	9999		356.77		

Table C-3: Unit Weight

Compacted Unit Weight							
Sample	**Mass of cylinder (Kg)**	**Mass of cylinder and sample(Kg)**	**Height of Cylinder (mm)**	**Diameter of Cylinder (mm)**	**Mass of sample (Kg)**	**Volume of Container (m^3)**	**Unit weight (Kg/m^3)**
1	1.6770	18.440	240	230	16.76	0.01	1676.3
2	1.6770	18.445	240	230	16.77	0.01	1676.8
3	1.6770	18.440	240	230	16.76	0.01	1676.3
						Mean	**1676.5**

Loose Unit Weight							
1	1.6770	16.872	240	230	15.20	0.01	1519.5
2	1.6770	16.489	240	230	14.81	0.01	1481.2
3	1.6770	16.988	240	230	15.31	0.01	1531.1
						Mean	**1510.6**

APPENDIX –D: CONCRETE MIX DESIGN METHOD ACI STANDARD

Using the above aggregate determined data and the following concrete data the mix design has been calculated as following;

- Grade of concrete = C20/25
- Cubic Characteristics strength (fcu) =25MPa and
- Cylindrical Characteristics strength (fck) or (*f*'c)=20MPa
- Target mean strength (fcm) or *f*'cr = fck+8 = 20+8=28Mpa….. As per **ES EN 1992-2015**
  Or *f*'cr = *f*'c + 8.3 Mpa (1200Psi) = 20+8.3= 28.3Mpa…As per **ACI 214-02 Table 4.2**

Step 1: Choice of Slump Based on type of Construction (From **ACI, 2000, Table 5.14**)

For Beams and columns (25mm -100mm) and For Slabs (25mm-75mm)

- Let's use slump of = **50mm**

Step 2: Maximum aggregate size selection

- Selected Maximum Aggregate size = **20mm**

Step 3: Approximated Mixing **water and air** content selection**.** Based on slump value estimated above on step 2 for Non- air Entrained. (From **ACI, 2000, Table 3.8**)

For Slump 50 mm and For Maximum Aggregate Size of 20mm

Slump	Water
30 to 50 (mm) →	↓ 185 Kg/m^3

- Unadjusted Mixing Water Quantity =**185Kg/m^3**

Step 4: Water-Cement Ratio (From **ACI, 211.1.81, Table 3.1**)

Average compressive Strength at 28 days (MPa)	Effective Water-Cement ratio (by mass) (Non Air- Entrained Concrete)
30 →	0.55
25 →	0.62

Using linear interpolation, For Target mean strength, *f*'cr =28.3Mpa,

∴ Effective Water-Cement ratio (by mass) = $0.55+\frac{0.62-0.55}{25-30}*(28.3-30)$ **= 0.57**

Step-5: Cement content: Using result of Step 3 and Step 4

∴ γcement = $\frac{W}{W/C} = \frac{185}{0.57}$ **=370 Kg/m^3 ≥ 360…………OK!**

Where 360 kg/m^3 is the minimum cement content for C20/25 with maximum size of 20mm

Step-6: Coarse Aggregate content:

- Determine Volume of (From **ACI, 211.1.81, Table 3.11**)
  - For Fineness Moduli of Sand = 2.4 (Determined under sieve Analysis of Fine agg.) and
  - Unit Weight of Coarse Aggregate =1676Kg/m^3 (Determined under Unit wt. of Coarse agg.)

Maximum Size of Aggregate (mm)	Volume (for For Fineness Moduli of Sand = 2.4
20 →	0.66

∴ Mass of coarse aggregate = Volume*Unit Weight =0.66*1676=1106.16Kg

Step 8: Fine Aggregate content:

- Determine unit weight of fresh concrete (From **ACI, 211.1.81, ,Table 11.9**)

Maximum Size of Aggregate (mm)	Unit weight of fresh concrete (Non-air-entrained concrete (Kg/m^3)

20 →	2355

∴ γF.A = γconc. – (γcement + γwater + γC.A)

= 2355-(370+185+1106.16)

γF.A =693.84**Kg/m^3**

Total quantity before adjusted of water

S.No	Ingredient	Unit Weight (Kg/m^3)	Absolute Volume (Air=20,000)
1	Cement	370	370*1000/2.9=127,586.2
2	Sand	693.84	(1000,000-AV(air+water+cement+CA))*2.47/1000=679.64
3	Gravel	1106.16	1106.16*1000/2.82=392,255.3
4	Water	185	185*1000/1=185,000

Step 8: Adjusted Batch Weight of Aggregate for field condition:

- Absorption Capacity of F.A =0.5% , ∴ γF.A=693.84+5%*693.84=697.3 **Kg/m^3**
- Absorption Capacity of C.A = 0.9% , ∴ γC.A=1106.16+9%*1106.16=1116.12 **Kg/m^3**
- Water Amount based on moisture content =

γwater -γF.Aun*(moisture cont- absorption) -γC.Aun*(moisture cont- absorption)

185-693.84*(5% - 9%) – 1106.16*(4% - 1.32%) = 197.895 **Kg/m^3**

Total quantity before adjusted of water

S.No	Ingredient	Unit Weight (Kg/m^3)	Ratio	Mass (kg)
1	Cement	370	1	20.41
2	Sand	697.31	1.885	38.46
3	Gravel	1116.12	3.017	61.56
4	Water	197.895	0.535	10.92

APPENDIX –E: COMPACTION FACTOR TEST RESULTS

Table E-1: Compaction factor

Mix No	Percentage of Hybrid added	empty cylinder Mass(g) (M1)	Partially compacted Mass (g) (M2)	Fully Compacted mass(g) (M3)	Compaction factor (M2-M1)/(M3-M1)
1	H-0%	500	13419	14808	0.843
2	H-5%	500	11719.5	13539	0.835
3	H-10%	500	11635	13645	0.827
4	H-15%	500	10958	13306.5	0.822

APPENDIX –F: MASS AND UNIT WEIGHT OF SPECIMENS

Table F-1: Mass and Unit Weight of Cubes (150x150x150mm) for Compressive Strength Test

Date of test	Code of Sample	Sample	Mass (kg)	Avg. Mass (Kg)	Unit Weight (kN/m^3)	Code's Standard Value (KN/m^3)	∴Type of Concrete)
7th	**H-0%**	1	8.147	8.36	**24.29**	**24**	**NORMAL**
		2	8.564				
		3	8.356				
	H-5%	1	8.607	8.41	**24.44**	**24**	**NORMAL**
		2	8.182				
		3	8.435				
	H-10%	1	8.7	8.55	**24.86**	**24**	**NORMAL**
		2	8.232				
		3	8.73				
	H-15%	1	8.094	8.36	**24.29**	**24**	**NORMAL**
		2	8.448				
		3	8.527				
14th	**H-0%**	1	8.247	8.42	**24.48**	**24**	**NORMAL**
		2	8.564				
		3	8.456				
	H-5%	1	8.707	8.47	**24.63**	**24**	**NORMAL**
		2	8.182				
		3	8.535				
		1	8.7	8.42	**24.48**	**24**	**NORMAL**

	H-10%	2	8.232				
		3	8.33				
	H-15%	1	8.194	8.42	**24.48**	**24**	**NORMAL**
		2	8.448				
		3	8.627				
28th	**H-0%**	1	8.515	8.45	**24.56**	**24**	**NORMAL**
		2	8.587				
		3	8.244				
	H-5%	1	8.907	8.54	**24.83**	**24**	**NORMAL**
		2	8.182				
		3	8.535				
	H-10%	1	8.7	8.32	**24.19**	**24**	**NORMAL**
		2	8.232				
		3	8.03				
	H-15%	1	8.515	8.45	**24.56**	**24**	**NORMAL**
		2	8.587				
		3	8.244				

Table F-2: Mass and Unit Weight of Cylinders (100x200mm) for Splitting Tensile Strength Test

Date of test	Code of Sample	Sample	Mass (kg)	Avg. Mass (Kg)	Unit Weight (kN/m³)	Code's Standard Value (KN/m³)	∴Type of Concrete
7th	**H-0%**	1	3.77	3.86	**24.13**	**24**	**NORMAL**
		2	3.87				
		3	3.95				
	H-5%	1	3.88	3.85	**24.06**	**24**	**NORMAL**
		2	3.78				
		3	3.9				
	H-10%	1	3.97	3.84	**24.00**	**24**	**NORMAL**
		2	3.69				
		3	3.87				
	H-15%	1	3.86	3.86	**24.13**	**24**	**NORMAL**
		2	3.85				
		3	3.88				

14th	**H-0%**	1	3.85	3.89	**24.27**	**24**	**NORMAL**
		2	3.87				
		3	3.94				
	H-5%	1	3.98	3.92	**24.48**	**24**	**NORMAL**
		2	3.78				
		3	4				
	H-10%	1	3.97	3.87	**24.17**	**24**	**NORMAL**
		2	3.88				
		3	3.76				
	H-15%	1	3.96	3.93	**24.54**	**24**	**NORMAL**
		2	3.85				
		3	3.98				
28th	**H-0%**	1	3.86	3.88	**24.23**	**24**	**NORMAL**
		2	3.91				
		3	3.87				
	H-5%	1	3.92	3.86	**24.13**	**24**	**NORMAL**
		2	3.83				
		3	3.84				
	H-10%	1	3.95	3.87	**24.19**	**24**	**NORMAL**
		2	3.79				
		3	3.88				
	H-15%	1	3.977	3.90	**24.37**	**24**	**NORMAL**
		2	3.879				
		3	3.85				

Table F-3: Mass and Unit Weight of Beam (100x100x500mm) for Flexural Tensile Strength Test

Date of test	Code of Sample	Sample	Mass (kg)	Avg. Mass (Kg)	Unit Wt (kN/m^3)	Code's Standard Value (KN/m^3)	∴Type of Concrete
7th	**H-0%**	1	11.654	12.53	**24.58**	**24**	**NORMAL**
		2	12.848				
		3	13.086				
	H-5%	1	11.86	12.43	**24.38**	**24**	**NORMAL**
		2	12.175				

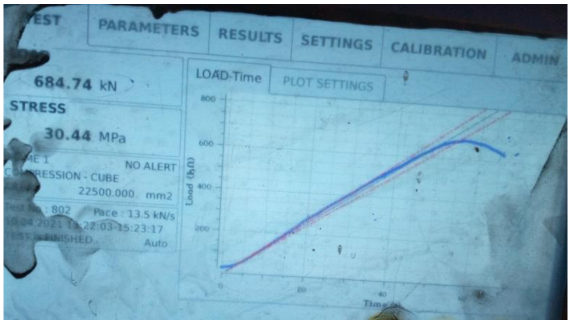
		3	13.247				
	H-10%	1	12.429	12.65	**24.81**	**24**	**NORMAL**
		2	11.654				
		3	13.86				
	H-15%	1	11.952	12.39	**24.31**	**24**	**NORMAL**
		2	14.979				
		3	10.238				
14th	**H-0%**	1	10.667	12.35	**24.22**	**24**	**NORMAL**
		2	13.983				
		3	12.388				
	H-5%	1	12.115	12.32	**24.16**	**24**	**NORMAL**
		2	12.776				
		3	12.056				
	H-10%	1	12.529	12.47	**24.47**	**24**	**NORMAL**
		2	11.737				
		3	13.149				
	H-15%	1	12.052	12.28	**24.10**	**24**	**NORMAL**
		2	11.798				
		3	12.997				
28th	**H-0%**	1	11.663	12.56	**24.64**	**24**	**NORMAL**
		2	13.012				
		3	12.998				
	H-5%	1	11.067	12.30	**24.14**	**24**	**NORMAL**
		2	13.976				
		3	11.865				
	H-10%	1	13.026	12.40	**24.33**	**24**	**NORMAL**
		2	11.937				
		3	12.241				
	H-15%	1	12.712	12.57	**24.66**	**24**	**NORMAL**
		2	11.998				
		3	12.998				

APPENDIX –G: HARDENED CONCRETE TEST RESULTS

Table G-1: Average Peak Compressive Stress and Strain on 7th, 14th And 28th Days

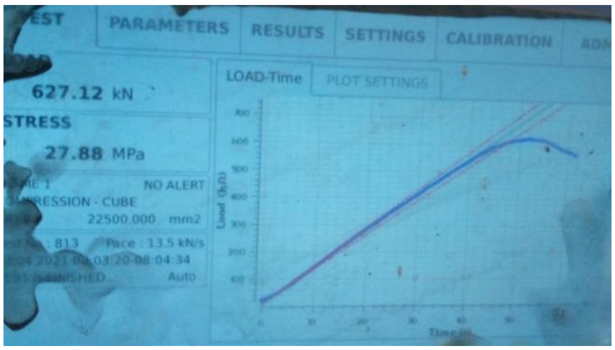
Date of test	Code of Sample	Sample	Peak load (kN)	Com. stress (MPa)	Avg comp. strength	Code's Empirical Strength (MPa)	Remark (Exp'tal ≥ Emp'cal)	Avg strain
7th	H-0%	1	435.94	19.38	20.05	17.26	OK	0.00190
		2	461.90	20.53				
		3	455.50	20.24				
	H-5%	1	457.00	20.31	19.05	17.26	OK	0.00190
		2	390.00	17.33				
		3	439.00	19.51				
	H-10%	1	396.00	17.60	17.94	17.26	OK	0.00181
		2	368.00	16.36				
		3	447.00	19.87				
	H-15%	1	300.00	13.33	16.27	17.26	NOT OK	0.00180
		2	475.00	21.11				
		3	323.00	14.36				
14th	H-0%	1	549.36	24.42	24.52	21.56	OK	0.00199
		2	580.55	25.80				
		3	525.30	23.35				
	H-5%	1	506.00	22.49	22.15	21.56	OK	0.00204
		2	517.00	22.98				
		3	472.00	20.98				
	H-10%	1	426.00	18.93	22.40	21.56	OK	0.00191
		2	539.00	23.96				
		3	547.00	24.31				
	H-15%	1	469.00	20.84	19.10	21.56	NOT OK	0.00190
		2	348.00	15.47				
		3	472.00	20.98				
28th	H-0%	1	646.31	28.72	28.87	25	OK	0.00206
		2	618.00	27.47				
		3	**684.74**	**30.43**				
	H-5%	1	594.00	26.40	26.22	25	OK	0.00200
		2	**618.00**	**27.47**				
		3	558.00	24.80				
		1	529.00	23.51	25.02	25		0.00200

	H-10%	2	**627.00**	**27.87**			**OK**	
		3	533.00	23.69				
	H-15%	1	**483.00**	**21.47**	**23.30**	**25**	**NOT OK**	**0.00191**
		2	534.00	23.73				
		3	559.00	24.84				

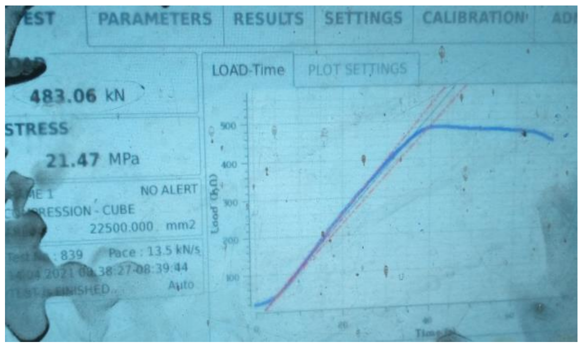


H-0% 28th

H-5% 28th



H-10% 28th



H-15% 28th

Figure G-1: Some of Experimental Compressive Peak loads and Peak stresses

Table G-2: Stress - Strain of Cubic Test Result on 7th Day For Control

	7th Day Control (H-0%) Compressive Data							
Cross sec. of Samples (mm^2)	**Load (KN)**			**Compressive Stress (Mpa)**				**Strain**
	Samp 1	Samp 2	Samp 3	Samp 1	Samp 2	Samp 3	Average	
22500	0	0	0	0	0	0	**0**	**0**
22500	17	21	19	0.76	0.93	0.84	**0.84**	**0.00003**
22500	25	29	22	1.11	1.29	0.98	**1.13**	**0.00004**
22500	37	42	39	1.64	1.87	1.73	**1.75**	**0.00006**
22500	46	73	58	2.04	3.24	2.58	**2.62**	**0.00009**
22500	57	89	73	2.53	3.96	3.24	**3.24**	**0.00011**
22500	73	120	90	3.24	5.33	4.00	**4.19**	**0.00015**
22500	89	140	120	3.96	6.22	5.33	**5.17**	**0.00019**

22500	106	180	153	4.71	8.00	6.80	**6.50**	**0.00025**
22500	125	198	169	5.56	8.80	7.51	**7.29**	**0.00029**
22500	138	211	176	6.13	9.38	7.82	**7.78**	**0.00031**
22500	167	235	200	7.42	10.44	8.89	**8.92**	**0.00037**
22500	188	250	222	8.36	11.11	9.87	**9.78**	**0.00041**
22500	200	278	248	8.89	12.36	11.02	**10.76**	**0.00047**
22500	221	290	265	9.82	12.89	11.78	**11.50**	**0.00052**
22500	242	304	280	10.76	13.51	12.44	**12.24**	**0.00057**
22500	266	312	302	11.82	13.87	13.42	**13.04**	**0.00062**
22500	280	330	310	12.44	14.67	13.78	**13.63**	**0.00067**
22500	294	355	332	13.07	15.78	14.76	**14.53**	**0.00074**
22500	300	363	349	13.33	16.13	15.51	**14.99**	**0.00078**
22500	310	385	364	13.78	17.11	16.18	**15.69**	**0.00085**
22500	327	399	386	14.53	17.73	17.16	**16.47**	**0.00094**
22500	339	408	410	15.07	18.13	18.22	**17.14**	**0.00102**
22500	355	421	421	15.78	18.71	18.71	**17.73**	**0.00111**
22500	367	432	430	16.31	19.20	19.11	**18.21**	**0.00118**
22500	394	443	439	17.51	19.69	19.51	**18.90**	**0.00132**
22500	419	452	448	18.62	20.09	19.91	**19.54**	**0.00151**
22500	436	462	456	19.38	20.53	20.24	**20.05**	**0.00190**
22500	431	445	434	19.16	19.78	19.29	**19.41**	**0.00240**
22500	424	422	434	18.84	18.76	19.29	**18.96**	**0.00256**
22500	413	411	421	18.36	18.27	18.71	**18.44**	**0.00271**
22500	403	405	409	17.91	18.00	18.18	**18.03**	**0.00282**

Table G-3: Stress -Strain of Cubic Test Result on 7th Day for H-5%

	7th Day H-5% Compressive Data							
Cross sec. of Samples (mm2)	**Load (KN)**			**Compressive Stress (Mpa)**				**Strain**
	Samp 1	Samp 2	Samp 3	Samp1	Samp 2	Samp 3	Average	
22500	0	0	0	0	0	0	**0**	**0**
22500	20	13	20	0.89	0.58	0.89	**0.79**	**0.00003**
22500	33	48	22	1.47	2.13	0.98	**1.53**	**0.00005**
22500	46	72	44	2.04	3.20	1.96	**2.40**	**0.00009**
22500	66	88	70	2.93	3.91	3.11	**3.32**	**0.00012**
22500	83	103	116	3.69	4.58	5.16	**4.47**	**0.00017**
22500	110	114	124	4.89	5.07	5.51	**5.16**	**0.00020**
22500	127	136	138	5.64	6.04	6.13	**5.94**	**0.00024**
22500	147	155	146	6.53	6.89	6.49	**6.64**	**0.00027**

22500	163	173	158	7.24	7.69	7.02	**7.32**	**0.00030**
22500	184	196	168	8.18	8.71	7.47	**8.12**	**0.00034**
22500	198	218	179	8.80	9.69	7.96	**8.81**	**0.00038**
22500	212	236	195	9.42	10.49	8.67	**9.53**	**0.00042**
22500	224	252	211	9.96	11.20	9.38	**10.18**	**0.00046**
22500	244	269	219	10.84	11.96	9.73	**10.84**	**0.00051**
22500	269	284	240	11.96	12.62	10.67	**11.75**	**0.00057**
22500	296	297	255	13.16	13.20	11.33	**12.56**	**0.00063**
22500	328	322	267	14.58	14.31	11.87	**13.59**	**0.00072**
22500	348	324	284	15.47	14.40	12.62	**14.16**	**0.00077**
22500	369	327	294	16.40	14.53	13.07	**14.67**	**0.00082**
22500	372	330	314	16.53	14.67	13.96	**15.05**	**0.00086**
22500	399	333	326	17.73	14.80	14.49	**15.67**	**0.00093**
22500	413	337	345	18.36	14.98	15.33	**16.22**	**0.00100**
22500	422	345	364	18.76	15.33	16.18	**16.76**	**0.00108**
22500	427	355	380	18.98	15.78	16.89	**17.21**	**0.00116**
22500	436	367	390	19.38	16.31	17.33	**17.67**	**0.00125**
22500	442	375	413	19.64	16.67	18.36	**18.22**	**0.00139**
22500	447	381	418	19.87	16.93	18.58	**18.46**	**0.00146**
22500	452	385	424	20.09	17.11	18.84	**18.68**	**0.00155**
22500	455	388	428	20.22	17.24	19.02	**18.83**	**0.00162**
22500	456	390	431	20.27	17.33	19.16	**18.92**	**0.00169**
22500	457	390	439	20.31	17.33	19.51	**19.05**	**0.00190**
22500	456	389	439	20.27	17.29	19.51	**19.02**	**0.00201**
22500	455	388	438	20.22	17.24	19.47	**18.98**	**0.00206**
22500	454	387	436	20.18	17.20	19.38	**18.92**	**0.00212**
22500	452	382	430	20.09	16.98	19.11	**18.73**	**0.00226**
22500	451	380	426	20.04	16.89	18.93	**18.62**	**0.00229**
22500	449	377	425	19.96	16.76	18.89	**18.53**	**0.00232**
22500	446	376	425	19.82	16.71	18.89	**18.47**	**0.00239**
22500	444	374	424	19.73	16.62	18.84	**18.40**	**0.00242**
22500	440	373	424	19.56	16.58	18.84	**18.33**	**0.00245**
22500	438	371	420	19.47	16.49	18.67	**18.21**	**0.00250**
22500	435	370	419	19.33	16.44	18.62	**18.13**	**0.00252**
22500	432	368	400	19.20	16.36	17.78	**17.78**	**0.00264**
22500	429	367	397	19.07	16.31	17.64	**17.67**	**0.00268**
22500	424	364	397	18.84	16.18	17.64	**17.56**	**0.00271**
22500	420	363	397	18.67	16.13	17.64	**17.48**	**0.00273**
22500	413	363	397	18.36	16.13	17.64	**17.38**	**0.00276**
22500	408	363	397	18.13	16.13	17.64	**17.30**	**0.00279**

Table G-4: Stress -Strain of Cubic Test Result on 7th Day for H-10%

	7th Day H-10% Compressive Data							
Cross sec. of Samples (mm2)	Load (KN)			Compressive Stress (Mpa)				Strain
	Samp 1	Samp 2	Samp 3	Samp 1	Samp 2	Samp 3	Average	
22500	0	0	0	0.00	0.00	0.00	**0.00**	**0.00000**
22500	17	15	13	0.76	0.65	0.58	**0.66**	**0.00002**
22500	25	24	26	1.11	1.07	1.16	**1.11**	**0.00004**
22500	37	34	44	1.64	1.49	1.94	**1.69**	**0.00006**
22500	46	48	50	2.04	2.14	2.22	**2.13**	**0.00007**
22500	57	62	55	2.53	2.75	2.44	**2.57**	**0.00009**
22500	73	82	60	3.24	3.63	2.66	**3.18**	**0.00011**
22500	89	101	66	3.96	4.47	2.94	**3.79**	**0.00013**
22500	106	114	72	4.71	5.08	3.21	**4.34**	**0.00015**
22500	125	141	105	5.56	6.27	4.65	**5.49**	**0.00020**
22500	138	162	142	6.13	7.19	6.31	**6.54**	**0.00024**
22500	177	181	155	7.87	8.03	6.87	**7.59**	**0.00029**
22500	188	203	178	8.36	9.02	7.92	**8.43**	**0.00033**
22500	200	218	202	8.89	9.67	8.97	**9.18**	**0.00036**
22500	210	230	213	9.33	10.24	9.47	**9.68**	**0.00039**
22500	224	255	248	9.96	11.31	11.02	**10.76**	**0.00044**
22500	246	278	257	10.93	12.35	11.41	**11.56**	**0.00048**
22500	256	297	292	11.38	13.19	12.96	**12.51**	**0.00054**
22500	272	313	312	12.09	13.91	13.85	**13.28**	**0.00058**
22500	285	308	346	12.67	13.68	15.40	**13.92**	**0.00062**
22500	296	359	370	13.16	15.94	16.45	**15.18**	**0.00071**
22500	305	373	405	13.56	16.59	18.00	**16.05**	**0.00077**
22500	314	393	419	13.96	17.47	18.62	**16.68**	**0.00083**
22500	320	404	423	14.22	17.96	18.80	**17.00**	**0.00085**
22500	325	420	436	14.44	18.65	19.38	**17.49**	**0.00090**
22500	326	441	449	14.49	19.61	19.96	**18.02**	**0.00095**
22500	330	458	457	14.67	20.37	20.31	**18.45**	**0.00099**
22500	335	480	468	14.89	21.33	20.80	**19.01**	**0.00105**
22500	338	491	476	15.02	21.82	21.16	**19.33**	**0.00109**
22500	340	506	480	15.11	22.47	21.33	**19.64**	**0.00113**
22500	344	507	488	15.29	22.55	21.69	**19.84**	**0.00115**
22500	348	510	499	15.47	22.67	22.18	**20.10**	**0.00119**
22500	350	512	510	15.56	22.74	22.67	**20.32**	**0.00122**
22500	353	513	521	15.69	22.82	23.16	**20.55**	**0.00126**
22500	367	516	530	16.31	22.93	23.54	**20.93**	**0.00132**

22500	373	519	531	16.58	23.05	23.60	**21.07**	**0.00135**
22500	386	522	533	17.16	23.20	23.71	**21.36**	**0.00141**
22500	394	528	536	17.51	23.47	23.82	**21.60**	**0.00147**
22500	410	531	540	18.22	23.58	24.00	**21.94**	**0.00157**
22500	424	533	545	18.84	23.70	24.22	**22.25**	**0.00171**
22500	426	539	547	18.93	23.96	24.31	**22.40**	**0.00191**
22500	422	539	532	18.76	23.96	23.64	**22.12**	**0.00217**
22500	415	536	532	18.44	23.81	23.64	**21.97**	**0.00224**
22500	403	535	527	17.91	23.77	23.42	**21.70**	**0.00234**
22500	400	533	525	17.78	23.70	23.33	**21.60**	**0.00237**
22500	399	531	522	17.73	23.58	23.20	**21.51**	**0.00240**
22500	398	525	519	17.69	23.32	23.07	**21.36**	**0.00244**
22500	397	524	514	17.64	23.28	22.84	**21.26**	**0.00247**
22500	395	522	504	17.56	23.20	22.40	**21.05**	**0.00252**

Table G-5: Stress -Strain of Cubic Test Result on 7th Day for H-15%

	7th Day H-15% Compressive Data							
Cross sec. of Samples (mm2)	**Load (KN)**			**Compressive Stress (Mpa)**				**Strain**
	Samp 1	Samp 2	Samp 3	Samp 1	Samp 2	Samp 3	Average	
22500	0	0	0	0.00	0.00	0.00	**0.00**	**0.00000**
22500	25	23	20	1.11	1.02	0.89	**1.01**	**0.00004**
22500	48	40	31	2.13	1.78	1.38	**1.76**	**0.00007**
22500	58	46	34	2.58	2.04	1.51	**2.04**	**0.00008**
22500	85	71	56	3.78	3.16	2.49	**3.14**	**0.00012**
22500	95	87	78	4.22	3.87	3.47	**3.85**	**0.00015**
22500	110	99	95	4.89	4.40	4.22	**4.50**	**0.00018**
22500	115	123	111	5.11	5.47	4.93	**5.17**	**0.00022**
22500	124	138	138	5.51	6.13	6.13	**5.93**	**0.00025**
22500	136	150	154	6.04	6.67	6.84	**6.52**	**0.00029**
22500	149	178	159	6.62	7.91	7.07	**7.20**	**0.00032**
22500	159	200	163	7.07	8.89	7.24	**7.73**	**0.00036**
22500	168	215	173	7.47	9.56	7.69	**8.24**	**0.00039**
22500	178	220	178	7.91	9.78	7.91	**8.53**	**0.00041**
22500	195	226	190	8.67	10.04	8.44	**9.05**	**0.00044**
22500	206	233	193	9.16	10.36	8.58	**9.36**	**0.00047**
22500	221	243	199	9.82	10.80	8.84	**9.82**	**0.00050**
22500	234	250	207	10.40	11.11	9.20	**10.24**	**0.00053**
22500	240	263	210	10.67	11.69	9.33	**10.56**	**0.00056**
22500	242	276	217	10.76	12.27	9.64	**10.89**	**0.00059**

22500	244	285	222	10.84	12.67	9.87	**11.13**	**0.00061**
22500	246	300	228	10.93	13.33	10.13	**11.47**	**0.00064**
22500	247	317	231	10.98	14.09	10.27	**11.78**	**0.00067**
22500	248	325	234	11.02	14.44	10.40	**11.96**	**0.00069**
22500	249	333	237	11.07	14.80	10.53	**12.13**	**0.00071**
22500	250	357	244	11.11	15.87	10.84	**12.61**	**0.00076**
22500	253	364	251	11.24	16.18	11.16	**12.86**	**0.00079**
22500	256	378	259	11.38	16.80	11.51	**13.23**	**0.00084**
22500	260	383	268	11.56	17.02	11.91	**13.50**	**0.00087**
22500	263	389	274	11.69	17.29	12.18	**13.72**	**0.00091**
22500	264	410	277	11.73	18.22	12.31	**14.09**	**0.00096**
22500	266	424	284	11.82	18.84	12.62	**14.43**	**0.00102**
22500	267	446	287	11.87	19.82	12.76	**14.81**	**0.00110**
22500	269	464	291	11.96	20.62	12.93	**15.17**	**0.00118**
22500	289	472	319	12.84	20.98	14.18	**16.00**	**0.00148**
22500	291	473	321	12.93	21.02	14.27	**16.07**	**0.00152**
22500	294	474	322	13.07	21.07	14.31	**16.15**	**0.00158**
22500	300	475	323	13.33	21.11	14.36	**16.27**	**0.00180**
22500	296	473	323	13.16	21.02	14.36	**16.18**	**0.00200**
22500	293	471	319	13.02	20.93	14.18	**16.04**	**0.00213**
22500	291	470	317	12.93	20.89	14.09	**15.97**	**0.00218**
22500	288	469	315	12.80	20.84	14.00	**15.88**	**0.00223**
22500	288	464	315	12.80	20.62	14.00	**15.81**	**0.00227**
22500	287	462	314	12.76	20.53	13.96	**15.75**	**0.00230**
22500	286	461	312	12.71	20.49	13.87	**15.69**	**0.00233**
22500	286	457	310	12.71	20.31	13.78	**15.60**	**0.00238**
22500	285	454	310	12.67	20.18	13.78	**15.54**	**0.00241**
22500	284	453	308	12.62	20.13	13.69	**15.48**	**0.00243**
22500	282	453	306	12.53	20.13	13.60	**15.42**	**0.00246**

Table G-6: Stress - Strain of Cubic Test Result on 14th Day for H-0%

	14^{th} Day Control (H-0%) Compressive Data							
Cross sec. of Samples (mm^2)	**Load (KN)**			**Compressive Stress (Mpa)**				**Strain**
	Samp 1	Samp 2	Samp 3	Samp 1	Samp 2	Samp 3	Average	
22500	0	0	0	0	0	0	**0**	**0**
22500	21	24	17	0.93	1.07	0.76	**0.92**	**0.00003**
22500	34	33	29	1.51	1.47	1.29	**1.42**	**0.00005**
22500	49	48	38	2.18	2.13	1.69	**2.00**	**0.00007**

22500	60	61	58	2.67	2.71	2.58	**2.65**	**0.00009**
22500	78	81	76	3.47	3.60	3.38	**3.48**	**0.00012**
22500	100	99	97	4.44	4.40	4.31	**4.39**	**0.00015**
22500	123	113	111	5.47	5.02	4.93	**5.14**	**0.00018**
22500	133	139	126	5.91	6.18	5.60	**5.90**	**0.00021**
22500	155	160	148	7.73	7.11	6.58	**6.84**	**0.00025**
22500	174	179	172	8.71	7.96	7.64	**8.10**	**0.00028**
22500	196	201	194	9.38	8.93	8.62	**8.98**	**0.00032**
22500	211	215	207	10.27	9.56	9.20	**9.67**	**0.00035**
22500	231	228	230	10.93	10.13	10.22	**10.43**	**0.00039**
22500	246	252	252	11.73	11.20	11.20	**11.38**	**0.00043**
22500	264	275	265	12.49	12.22	11.78	**12.16**	**0.00047**
22500	281	293	276	13.38	13.02	12.27	**12.89**	**0.00051**
22500	301	309	295	14.04	13.73	13.11	**13.63**	**0.00055**
22500	316	330	310	15.20	14.67	13.78	**14.55**	**0.00059**
22500	342	354	329	15.91	15.73	14.62	**15.42**	**0.00066**
22500	358	369	343	16.44	16.40	15.24	**16.03**	**0.00070**
22500	370	388	354	16.80	17.24	15.73	**16.59**	**0.00074**
22500	378	400	366	17.51	17.78	16.27	**17.19**	**0.00077**
22500	394	415	379	18.44	18.44	16.84	**17.91**	**0.00082**
22500	415	436	400	18.76	19.38	17.78	**18.64**	**0.00089**
22500	422	453	415	19.64	20.13	18.44	**19.41**	**0.00094**
22500	442	474	434	20.67	21.07	19.29	**20.34**	**0.00102**
22500	465	485	446	21.02	21.56	19.82	**20.80**	**0.00109**
22500	473	500	456	21.51	22.22	20.27	**21.33**	**0.00115**
22500	484	516	468	21.91	22.93	20.80	**21.88**	**0.00122**
22500	493	530	476	22.31	23.56	21.16	**22.34**	**0.00128**
22500	502	539	490	22.84	23.96	21.78	**22.86**	**0.00135**
22500	514	553	498	23.16	24.58	22.13	**23.29**	**0.00144**
22500	521	561	505	23.78	24.93	22.44	**23.72**	**0.00151**
22500	535	572	513	24.04	25.42	22.80	**24.09**	**0.00164**
22500	541	577	519	24.42	25.64	23.07	**24.38**	**0.00174**
22500	549	581	525	24.27	25.80	23.35	**24.47**	**0.00199**
22500	546	578	524	23.87	25.69	23.29	**24.28**	**0.00215**
22500	537	574	519	23.60	25.51	23.07	**24.06**	**0.00230**
22500	531	570	510	23.47	25.33	22.67	**23.82**	**0.00241**
22500	528	568	497	23.33	25.24	22.09	**23.56**	**0.00249**
22500	525	547	487	23.07	24.31	21.64	**23.01**	**0.00262**
22500	519	544	481	22.71	24.18	21.38	**22.76**	**0.00267**
22500	511	539	473		23.96	21.02	**22.49**	**0.00274**

Table G-7: Stress - Strain of Cubic Test Result on 14th Day for H-5%

	14th Day H-5% Compressive Data							
Cross sec. of Samples (mm2)	Load (KN)			Compressive Stress (Mpa)				Strain
	Samp 1	Samp 2	Samp 3	Samp 1	Samp 2	Samp 3	Average	
22500	0	0	0	0.00	0.00	0.00	**0.00**	**0.00000**
22500	17	16	16	0.76	0.72	0.73	**0.74**	**0.00003**
22500	26	60	24	1.15	2.66	1.07	**1.63**	**0.00006**
22500	47	90	43	2.10	3.99	1.91	**2.67**	**0.00009**
22500	73	110	73	3.25	4.87	3.25	**3.79**	**0.00013**
22500	86	128	95	3.82	5.71	4.20	**4.58**	**0.00016**
22500	108	142	108	4.78	6.31	4.82	**5.30**	**0.00019**
22500	135	170	127	6.00	7.53	5.66	**6.40**	**0.00024**
22500	160	193	153	7.11	8.59	6.80	**7.50**	**0.00029**
22500	183	216	184	8.14	9.58	8.18	**8.63**	**0.00034**
22500	210	244	215	9.33	10.86	9.56	**9.91**	**0.00040**
22500	229	272	250	10.17	12.08	11.12	**11.12**	**0.00046**
22500	263	294	273	11.70	13.07	12.12	**12.30**	**0.00053**
22500	299	314	292	13.30	13.96	13.00	**13.42**	**0.00060**
22500	321	335	316	14.26	14.90	14.07	**14.41**	**0.00066**
22500	341	354	328	15.17	15.73	14.56	**15.16**	**0.00072**
22500	362	370	351	16.09	16.45	15.59	**16.05**	**0.00078**
22500	377	401	366	16.74	17.84	16.28	**16.95**	**0.00086**
22500	392	404	389	17.43	17.95	17.28	**17.55**	**0.00091**
22500	408	408	401	18.12	18.11	17.81	**18.01**	**0.00096**
22500	419	419	411	18.61	18.61	18.27	**18.50**	**0.00101**
22500	429	429	421	19.07	19.07	18.73	**18.96**	**0.00106**
22500	447	447	434	19.88	19.88	19.30	**19.68**	**0.00116**
22500	458	458	439	20.33	20.33	19.49	**20.05**	**0.00121**
22500	474	474	444	21.06	21.06	19.72	**20.61**	**0.00130**
22500	482	482	447	21.40	21.42	19.88	**20.90**	**0.00136**
22500	483	483	452	21.48	21.47	20.07	**21.00**	**0.00138**
22500	485	485	453	21.56	21.56	20.14	**21.09**	**0.00140**
22500	488	487	455	21.67	21.64	20.22	**21.18**	**0.00142**
22500	488	491	456	21.71	21.82	20.26	**21.26**	**0.00144**
22500	489	493	459	21.75	21.90	20.41	**21.35**	**0.00146**
22500	491	499	462	21.82	22.17	20.53	**21.51**	**0.00151**
22500	493	505	464	21.90	22.44	20.60	**21.65**	**0.00155**
22500	499	509	465	22.17	22.62	20.68	**21.82**	**0.00161**
22500	503	512	468	22.36	22.76	20.79	**21.97**	**0.00169**

22500	504	514	470	22.40	22.84	20.89	**22.04**	**0.00173**
22500	505	516	471	22.44	22.93	20.93	**22.10**	**0.00202**
22500	506	517	472	22.49	22.98	20.98	**22.15**	**0.00204**
22500	506	514	472	22.49	22.84	20.98	**22.10**	**0.00202**
22500	503	503	470	22.36	22.36	20.89	**21.87**	**0.00218**
22500	499	499	468	22.17	22.17	20.80	**21.71**	**0.00225**
22500	496	496	466	22.05	22.05	20.72	**21.61**	**0.00229**
22500	494	494	462	21.94	21.94	20.53	**21.47**	**0.00234**
22500	490	490	450	21.79	21.79	19.99	**21.19**	**0.00243**
22500	487	487	448	21.63	21.63	19.91	**21.06**	**0.00246**
22500	477	477	445	21.21	21.21	19.80	**20.74**	**0.00255**
22500	468	468	443	20.79	20.79	19.68	**20.42**	**0.00262**
22500	462	462	439	20.53	20.53	19.53	**20.19**	**0.00267**
22500	460	461	436	20.45	20.50	19.38	**20.11**	**0.00269**

Table G-8: Stress - Strain of Cubic Test Result on 14th Day for H-10%

	14th Day H-10% Compressive Data							
Cross sec. of Samples (mm2)	**Load (KN)**			**Compressive Stress (Mpa)**				**Strain**
	Samp 1	Samp 2	Samp 3	Samp 1	Samp 2	Samp 3	Average	
22500	0	0	0	0.00	0.00	0.00	**0.00**	**0.00000**
22500	17	15	13	0.76	0.65	0.58	**0.66**	**0.00002**
22500	25	24	26	1.11	1.07	1.16	**1.11**	**0.00004**
22500	37	34	44	1.64	1.49	1.94	**1.69**	**0.00006**
22500	46	48	50	2.04	2.14	2.22	**2.13**	**0.00007**
22500	57	62	55	2.53	2.75	2.44	**2.57**	**0.00009**
22500	73	82	60	3.24	3.63	2.66	**3.18**	**0.00011**
22500	89	101	66	3.96	4.47	2.94	**3.79**	**0.00013**
22500	106	114	72	4.71	5.08	3.21	**4.34**	**0.00015**
22500	125	141	105	5.56	6.27	4.65	**5.49**	**0.00020**
22500	138	162	142	6.13	7.19	6.31	**6.54**	**0.00024**
22500	177	181	155	7.87	8.03	6.87	**7.59**	**0.00029**
22500	188	203	178	8.36	9.02	7.92	**8.43**	**0.00033**
22500	200	218	202	8.89	9.67	8.97	**9.18**	**0.00036**
22500	210	230	213	9.33	10.24	9.47	**9.68**	**0.00039**
22500	224	255	248	9.96	11.31	11.02	**10.76**	**0.00044**
22500	246	278	257	10.93	12.35	11.41	**11.56**	**0.00048**
22500	256	297	292	11.38	13.19	12.96	**12.51**	**0.00054**
22500	272	313	312	12.09	13.91	13.85	**13.28**	**0.00058**

22500	285	308	346	12.67	13.68	15.40	**13.92**	**0.00062**
22500	296	359	370	13.16	15.94	16.45	**15.18**	**0.00071**
22500	305	373	405	13.56	16.59	18.00	**16.05**	**0.00077**
22500	314	393	419	13.96	17.47	18.62	**16.68**	**0.00083**
22500	320	404	423	14.22	17.96	18.80	**17.00**	**0.00085**
22500	325	420	436	14.44	18.65	19.38	**17.49**	**0.00090**
22500	326	441	449	14.49	19.61	19.96	**18.02**	**0.00095**
22500	330	458	457	14.67	20.37	20.31	**18.45**	**0.00099**
22500	335	480	468	14.89	21.33	20.80	**19.01**	**0.00105**
22500	338	491	476	15.02	21.82	21.16	**19.33**	**0.00109**
22500	340	506	480	15.11	22.47	21.33	**19.64**	**0.00113**
22500	344	507	488	15.29	22.55	21.69	**19.84**	**0.00115**
22500	348	510	499	15.47	22.67	22.18	**20.10**	**0.00119**
22500	350	512	510	15.56	22.74	22.67	**20.32**	**0.00122**
22500	353	513	521	15.69	22.82	23.16	**20.55**	**0.00126**
22500	367	516	530	16.31	22.93	23.54	**20.93**	**0.00132**
22500	373	519	531	16.58	23.05	23.60	**21.07**	**0.00135**
22500	386	522	533	17.16	23.20	23.71	**21.36**	**0.00141**
22500	394	528	536	17.51	23.47	23.82	**21.60**	**0.00147**
22500	410	531	540	18.22	23.58	24.00	**21.94**	**0.00157**
22500	424	533	545	18.84	23.70	24.22	**22.25**	**0.00171**
22500	426	539	547	18.93	23.96	24.31	**22.40**	**0.00191**
22500	422	539	532	18.76	23.96	23.64	**22.12**	**0.00217**
22500	415	536	532	18.44	23.81	23.64	**21.97**	**0.00224**
22500	403	535	527	17.91	23.77	23.42	**21.70**	**0.00234**
22500	400	533	525	17.78	23.70	23.33	**21.60**	**0.00237**
22500	399	531	522	17.73	23.58	23.20	**21.51**	**0.00240**
22500	398	525	519	17.69	23.32	23.07	**21.36**	**0.00244**
22500	397	524	514	17.64	23.28	22.84	**21.26**	**0.00247**
22500	395	522	504	17.56	23.20	22.40	**21.05**	**0.00252**

Table G-9: Stress - Strain of Cubic Test Result on 14th Day for H-15%

	14th Day H-15% Compressive Data							
Cross sec. of Samples (mm2)	**Load (KN)**			**Compressive Stress (Mpa)**				**Strain**
	Samp 1	Samp 2	Samp 3	Samp 1	Samp 2	Samp 3	Average	
22500	0	0	0	0.00	0.00	0.00	**0.00**	**0.00000**
22500	17	21	11	0.76	0.93	0.49	**0.73**	**0.00003**
22500	20	36	18	0.89	1.60	0.80	**1.10**	**0.00004**

22500	30	54	28	1.33	2.40	1.24	**1.66**	**0.00006**
22500	42	82	42	1.87	3.64	1.87	**2.46**	**0.00009**
22500	56	96	49	2.49	4.27	2.18	**2.98**	**0.00011**
22500	75	113	99	3.33	5.02	4.40	**4.25**	**0.00016**
22500	99	133	123	4.40	5.91	5.47	**5.26**	**0.00020**
22500	123	151	138	5.47	6.71	6.13	**6.10**	**0.00024**
22500	138	173	150	6.13	7.69	6.67	**6.83**	**0.00028**
22500	150	184	178	6.67	8.18	7.91	**7.59**	**0.00032**
22500	178	208	200	7.91	9.24	8.89	**8.68**	**0.00037**
22500	200	226	215	8.89	10.04	9.56	**9.50**	**0.00037**
22500	215	230	220	9.56	10.22	9.78	**9.85**	**0.00044**
22500	220	242	226	9.78	10.76	10.04	**10.19**	**0.00046**
22500	226	254	233	10.04	11.29	10.36	**10.56**	**0.00049**
22500	233	260	243	10.36	11.56	10.80	**10.90**	**0.00051**
22500	243	266	250	10.80	11.82	11.11	**11.24**	**0.00053**
22500	250	273	263	11.11	12.13	11.69	**11.64**	**0.00056**
22500	263	277	276	11.69	12.31	12.27	**12.09**	**0.00059**
22500	276	282	285	12.27	12.53	12.67	**12.49**	**0.00062**
22500	285	289	300	12.67	12.84	13.33	**12.95**	**0.00066**
22500	300	295	317	13.33	13.11	14.09	**13.51**	**0.00071**
22500	317	303	325	14.09	13.47	14.44	**14.00**	**0.00075**
22500	325	311	333	14.44	13.82	14.80	**14.36**	**0.00079**
22500	333	314	357	14.80	13.96	15.87	**14.87**	**0.00084**
22500	357	316	364	15.87	14.04	16.18	**15.36**	**0.00089**
22500	364	319	378	16.18	14.18	16.80	**15.72**	**0.00094**
22500	378	321	383	16.80	14.27	17.02	**16.03**	**0.00094**
22500	383	323	389	17.02	14.36	17.29	**16.22**	**0.00100**
22500	389	325	410	17.29	14.44	18.22	**16.65**	**0.00106**
22500	410	327	424	18.22	14.53	18.84	**17.20**	**0.00115**
22500	416	329	446	18.49	14.62	19.82	**17.64**	**0.00124**
22500	424	331	454	18.84	14.71	20.18	**17.91**	**0.00129**
22500	436	334	462	19.38	14.84	20.53	**18.25**	**0.00138**
22500	446	338	463	19.82	15.02	20.58	**18.47**	**0.00145**
22500	450	340	466	20.00	15.11	20.71	**18.61**	**0.00150**
22500	459	342	467	20.40	15.20	20.76	**18.79**	**0.00158**
22500	464	344	470	20.62	15.29	20.89	**18.93**	**0.00166**
22500	467	345	471	20.76	15.33	20.93	**19.01**	**0.00172**
22500	469	348	472	20.84	15.47	20.98	**19.10**	**0.00190**
22500	468	347	469	20.80	15.42	20.84	**19.02**	**0.00207**
22500	467	346	464	20.76	15.38	20.62	**18.92**	**0.00216**

22500	466	346	462	20.71	15.38	20.53	**18.87**	**0.00220**
22500	465	344	461	20.67	15.29	20.49	**18.81**	**0.00224**
22500	465	343	457	20.67	15.24	20.31	**18.74**	**0.00228**
22500	463	341	454	20.58	15.16	20.18	**18.64**	**0.00233**
22500	461	340	453	20.49	15.11	20.13	**18.58**	**0.00236**
22500	461	339	453	20.49	15.07	20.13	**18.56**	**0.00237**

Table G-10: Stress - Strain of Cubic Test Result on 28th Day for Control

	28th Day Control (H-0%) Compressive Data							
Cross sec. of Samples (mm2)	**Load (KN)**			**Compressive Stress (Mpa)**				**Strain**
	Samp 1	Samp 2	Samp 3	Samp 1	Samp 2	Samp 3	Average	
22500	0	0	0	0	0	0	**0**	**0**
22500	19	17	17	0.84	0.76	0.76	**0.79**	**0.00002**
22500	25	20	28	1.11	0.89	1.24	**1.08**	**0.00003**
22500	40	34	39	1.78	1.51	1.73	**1.67**	**0.00005**
22500	58	45	56	2.58	2.00	2.49	**2.36**	**0.00008**
22500	71	68	72	3.16	3.02	3.20	**3.13**	**0.00010**
22500	92	89	95	4.09	3.96	4.22	**4.09**	**0.00013**
22500	118	114	117	5.24	5.07	5.20	**5.17**	**0.00017**
22500	145	130	133	6.44	5.78	5.91	**6.04**	**0.00020**
22500	156	148	164	6.93	6.58	7.29	**6.93**	**0.00023**
22500	182	174	188	8.09	7.73	8.36	**8.06**	**0.00028**
22500	208	202	210	9.24	8.98	9.33	**9.19**	**0.00032**
22500	230	228	236	10.22	10.13	10.49	**10.28**	**0.00036**
22500	248	243	253	11.02	10.80	11.24	**11.02**	**0.00040**
22500	274	271	268	12.18	12.04	11.91	**12.04**	**0.00044**
22500	289	297	296	12.84	13.20	13.16	**13.07**	**0.00048**
22500	310	312	323	13.78	13.87	14.36	**14.00**	**0.00053**
22500	331	325	345	14.71	14.44	15.33	**14.83**	**0.00057**
22500	354	347	364	15.73	15.42	16.18	**15.78**	**0.00061**
22500	372	365	388	16.53	16.22	17.24	**16.67**	**0.00066**
22500	402	387	417	17.87	17.20	18.53	**17.87**	**0.00072**
22500	421	404	434	18.71	17.96	19.29	**18.65**	**0.00077**
22500	435	417	457	19.33	18.53	20.31	**19.39**	**0.00081**
22500	445	430	470	19.78	19.11	20.89	**19.93**	**0.00085**
22500	463	438	488	20.58	19.47	21.69	**20.58**	**0.00089**
22500	488	471	513	21.69	20.93	22.80	**21.81**	**0.00097**
22500	496	488	533	22.04	21.69	23.69	**22.47**	**0.00102**

22500	520	510	558	23.11	22.67	24.80	**23.53**	**0.00111**
22500	541	525	571	24.04	23.33	25.38	**24.25**	**0.00117**
22500	556	536	588	24.71	23.82	26.13	**24.89**	**0.00123**
22500	580	551	607	25.78	24.49	26.98	**25.75**	**0.00132**
22500	605	560	624	26.89	24.89	27.73	**26.50**	**0.00141**
22500	618	577	634	27.47	25.64	28.18	**27.10**	**0.00150**
22500	629	586	651	27.96	26.04	28.93	**27.64**	**0.00159**
22500	637	594	660	28.31	26.40	29.33	**28.01**	**0.00166**
22500	641	603	673	28.49	26.80	29.91	**28.40**	**0.00176**
22500	646	611	685	28.72	27.14	30.43	**28.77**	**0.00206**
22500	644	615	683	28.62	27.33	30.36	**28.77**	**0.00221**
22500	642	617	680	28.53	27.42	30.22	**28.73**	**0.00224**
22500	638	618	675	28.36	27.47	30.00	**28.61**	**0.00229**
22500	632	617	671	28.09	27.42	29.82	**28.44**	**0.00236**
22500	628	616	664	27.91	27.38	29.51	**28.27**	**0.00241**
22500	624	610	661	27.73	27.11	29.38	**28.07**	**0.00246**
22500	611	600	657	27.16	26.67	29.20	**27.67**	**0.00255**
22500	601	585	652	26.71	26	28.98	**27.23**	**0.00264**
22500	589	573	649	26.18	25.47	28.84	**26.83**	**0.00271**

Table G-11: Stress - Strain of Cubic Test Result on 28th Day for H-5%

	28th Day H-5% Compressive Data							
Cross sec. of Samples (mm2)	**Load (KN)**			**Compressive Stress (Mpa)**				**Strain**
	Samp 1	Samp 2	Samp 3	Samp 1	Samp 2	Samp 3	Average	
22500	0	0	0	0.00	0.00	0.00	**0.00**	**0.00000**
22500	20	17	19	0.89	0.76	0.84	**0.83**	**0.00003**
22500	30	20	28	1.33	0.89	1.24	**1.16**	**0.00004**
22500	55	34	50	2.44	1.51	2.22	**2.06**	**0.00007**
22500	85	45	85	3.78	2.00	3.78	**3.19**	**0.00011**
22500	100	68	110	4.44	3.02	4.89	**4.12**	**0.00014**
22500	125	89	126	5.56	3.96	5.60	**5.04**	**0.00017**
22500	157	114	148	6.98	5.07	6.58	**6.21**	**0.00022**
22500	186	130	178	8.27	5.78	7.91	**7.32**	**0.00026**
22500	213	148	214	9.47	6.58	9.51	**8.52**	**0.00031**
22500	244	174	250	10.84	7.73	11.11	**9.90**	**0.00037**
22500	266	202	291	11.82	8.98	12.93	**11.24**	**0.00042**
22500	306	228	317	13.60	10.13	14.09	**12.61**	**0.00049**
22500	348	243	340	15.47	10.80	15.11	**13.79**	**0.00055**

22500	373	271	368	16.58	12.04	16.36	**14.99**	**0.00061**
22500	397	297	381	17.64	13.20	16.93	**15.93**	**0.00067**
22500	421	312	408	18.71	13.87	18.13	**16.90**	**0.00072**
22500	438	325	426	19.47	14.44	18.93	**17.61**	**0.00077**
22500	456	347	452	20.27	15.42	20.09	**18.59**	**0.00083**
22500	474	365	466	21.07	16.22	20.71	**19.33**	**0.00089**
22500	487	387	478	21.64	17.20	21.24	**20.03**	**0.00094**
22500	499	404	490	22.18	17.96	21.78	**20.64**	**0.00099**
22500	520	417	505	23.11	18.53	22.44	**21.36**	**0.00105**
22500	532	430	510	23.64	19.11	22.67	**21.81**	**0.00109**
22500	551	438	516	24.49	19.47	22.93	**22.30**	**0.00114**
22500	560	471	520	24.89	20.93	23.11	**22.98**	**0.00122**
22500	562	488	525	24.98	21.69	23.33	**23.33**	**0.00126**
22500	564	510	527	25.07	22.67	23.42	**23.72**	**0.00131**
22500	567	525	529	25.20	23.33	23.51	**24.01**	**0.00135**
22500	568	536	530	25.24	23.82	23.56	**24.21**	**0.00137**
22500	569	551	534	25.29	24.49	23.73	**24.50**	**0.00142**
22500	571	560	537	25.38	24.89	23.87	**24.71**	**0.00145**
22500	573	577	539	25.47	25.64	23.96	**25.02**	**0.00151**
22500	580	586	541	25.78	26.04	24.04	**25.29**	**0.00157**
22500	585	594	544	26.00	26.40	24.18	**25.53**	**0.00163**
22500	590	603	550	26.22	26.80	24.44	**25.82**	**0.00171**
22500	592	610	555	26.31	27.11	24.67	**26.03**	**0.00180**
22500	593	615	557	26.36	27.33	24.76	**26.15**	**0.00188**
22500	594	618	558	26.40	27.47	24.80	**26.22**	**0.00200**
22500	589	618	555	26.18	27.47	24.67	**26.10**	**0.00216**
22500	580	617	548	25.78	27.42	24.36	**25.85**	**0.00229**
22500	577	616	542	25.64	27.38	24.09	**25.70**	**0.00234**
22500	574	610	537	25.51	27.11	23.87	**25.50**	**0.00240**
22500	570	600	523	25.33	26.67	23.24	**25.08**	**0.00251**
22500	566	585	521	25.16	26.00	23.16	**24.77**	**0.00258**
22500	555	573	518	24.67	25.47	23.02	**24.39**	**0.00265**
22500	544	562	515	24.18	24.98	22.89	**24.01**	**0.00272**
22500	537	554	511	23.87	24.62	22.71	**23.73**	**0.00277**
22500	535		507	23.78		22.53	**23.16**	**0.00286**

Table G-12: Stress - Strain of Cubic Test Result on 28th Day for H-10%

	28th Day H-10% Compressive Data							
Cross sec. of Samples (mm^2)	Load (KN)			Compressive Stress (Mpa)				Strain
	Samp 1	Samp 2	Samp 3	Samp 1	Samp 2	Samp 3	Average	
22500	0	0	0	0.00	0.00	0.00	**0.00**	**0.00000**
22500	20	17	18	0.89	0.76	0.80	**0.81**	**0.00003**
22500	29	28	30	1.29	1.24	1.33	**1.29**	**0.00004**
22500	38	39	44	1.69	1.73	1.96	**1.79**	**0.00006**
22500	55	56	68	2.44	2.49	3.02	**2.65**	**0.00009**
22500	67	72	84	2.98	3.20	3.73	**3.30**	**0.00011**
22500	73	95	130	3.24	4.22	5.78	**4.41**	**0.00015**
22500	77	117	144	3.42	5.20	6.40	**5.01**	**0.00017**
22500	83	133	167	3.69	5.91	7.42	**5.67**	**0.00020**
22500	87	164	188	3.87	7.29	8.36	**6.50**	**0.00023**
22500	104	188	218	4.62	8.36	9.69	**7.56**	**0.00027**
22500	123	210	232	5.47	9.33	10.31	**8.37**	**0.00031**
22500	138	236	261	6.13	10.49	11.60	**9.41**	**0.00035**
22500	145	253	317	6.44	11.24	14.09	**10.59**	**0.00040**
22500	156	268	347	6.93	11.91	15.42	**11.42**	**0.00044**
22500	167	296	368	7.42	13.16	16.36	**12.31**	**0.00049**
22500	179	323	399	7.96	14.36	17.73	**13.35**	**0.00054**
22500	181	345	417	8.04	15.33	18.53	**13.97**	**0.00058**
22500	199	364	435	8.84	16.18	19.33	**14.79**	**0.00062**
22500	219	358	447	9.73	15.91	19.87	**15.17**	**0.00064**
22500	247	417	454	10.98	18.53	20.18	**16.56**	**0.00073**
22500	260	434	464	11.56	19.29	20.62	**17.16**	**0.00077**
22500	287	457	473	12.76	20.31	21.02	**18.03**	**0.00083**
22500	317	470	480	14.09	20.89	21.33	**18.77**	**0.00089**
22500	346	488	483	15.38	21.69	21.47	**19.51**	**0.00095**
22500	373	513	490	16.58	22.80	21.78	**20.39**	**0.00103**
22500	386	533	497	17.16	23.69	22.09	**20.98**	**0.00109**
22500	419	558	501	18.62	24.80	22.27	**21.90**	**0.00119**
22500	423	571	504	18.80	25.38	22.40	**22.19**	**0.00123**
22500	436	588	507	19.38	26.13	22.53	**22.68**	**0.00129**
22500	449	590	509	19.96	26.22	22.62	**22.93**	**0.00133**
22500	457	593	510	20.31	26.36	22.67	**23.11**	**0.00136**
22500	468	595	514	20.80	26.44	22.84	**23.36**	**0.00140**
22500	476	597	518	21.16	26.53	23.02	**23.57**	**0.00144**
22500	480	600	520	21.33	26.67	23.11	**23.70**	**0.00146**

22500	488	603	524	21.69	26.80	23.29	**23.93**	**0.00151**
22500	499	607	526	22.18	26.98	23.38	**24.18**	**0.00157**
22500	510	614	529	22.67	27.29	23.51	**24.49**	**0.00165**
22500	521	617	530	23.16	27.42	23.56	**24.71**	**0.00173**
22500	525	620	531	23.33	27.56	23.60	**24.83**	**0.00179**
22500	529	627	533	23.51	27.87	23.69	**25.02**	**0.00200**
22500	525	627	532	23.33	27.87	23.64	**24.95**	**0.00213**
22500	521	623	532	23.16	27.69	23.64	**24.83**	**0.00222**
22500	519	622	527	23.07	27.64	23.42	**24.71**	**0.00228**
22500	516	620	525	22.93	27.56	23.33	**24.61**	**0.00232**
22500	515	617	522	22.89	27.42	23.20	**24.50**	**0.00237**
22500	513	610	519	22.80	27.11	23.07	**24.33**	**0.00242**
22500	508	609	514	22.58	27.07	22.84	**24.16**	**0.00248**
22500	505	607	504	22.44	26.98	22.40	**23.94**	**0.00253**

Table G-13: Stress - Strain of Cubic Test Result on 28th Day for H-15%

	28th Day H-15% Compressive Data							
Cross sec. of Samples (mm2)	**Load (KN)**			**Compressive Stress (Mpa)**				**Strain**
	Samp 1	Samp 2	Samp 3	Samp 1	Samp 2	Samp 3	Average	
22500	0	0	0	0.00	0.00	0.00	**0.00**	**0.00000**
22500	17	18	19	0.76	0.80	0.84	**0.80**	**0.00003**
22500	20	30	28	0.89	1.33	1.24	**1.16**	**0.00004**
22500	30	44	50	1.33	1.96	2.22	**1.84**	**0.00006**
22500	42	68	85	1.87	3.02	3.78	**2.89**	**0.00010**
22500	56	84	110	2.49	3.73	4.89	**3.70**	**0.00013**
22500	75	130	126	3.33	5.78	5.60	**4.90**	**0.00017**
22500	99	144	148	4.40	6.40	6.58	**5.79**	**0.00020**
22500	123	167	178	5.47	7.42	7.91	**6.93**	**0.00025**
22500	138	188	214	6.13	8.36	9.51	**8.00**	**0.00029**
22500	150	218	250	6.67	9.69	11.11	**9.16**	**0.00035**
22500	178	232	291	7.91	10.31	12.93	**10.39**	**0.00040**
22500	200	261	317	8.89	11.60	14.09	**11.53**	**0.00046**
22500	215	317	340	9.56	14.09	15.11	**12.92**	**0.00053**
22500	220	347	368	9.78	15.42	16.36	**13.85**	**0.00059**
22500	226	368	381	10.04	16.36	16.93	**14.44**	**0.00062**
22500	233	399	408	10.36	17.73	18.13	**15.41**	**0.00068**
22500	243	417	426	10.80	18.53	18.93	**16.09**	**0.00073**
22500	250	435	452	11.11	19.33	20.09	**16.84**	**0.00079**

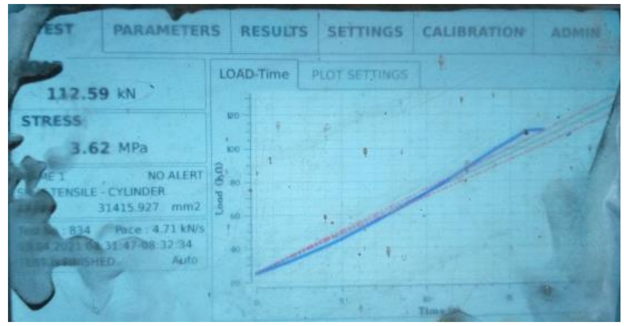
22500	263	447	466	11.69	19.87	20.71	**17.42**	**0.00083**
22500	276	454	478	12.27	20.18	21.24	**17.90**	**0.00087**
22500	285	464	490	12.67	20.62	21.78	**18.36**	**0.00091**
22500	300	473	505	13.33	21.02	22.44	**18.93**	**0.00096**
22500	317	480	510	14.09	21.33	22.67	**19.36**	**0.00101**
22500	325	483	516	14.44	21.47	22.93	**19.61**	**0.00103**
22500	333	490	520	14.80	21.78	23.11	**19.90**	**0.00106**
22500	357	497	525	15.87	22.09	23.33	**20.43**	**0.00112**
22500	364	501	527	16.18	22.27	23.42	**20.62**	**0.00115**
22500	378	504	529	16.80	22.40	23.51	**20.90**	**0.00118**
22500	383	507	530	17.02	22.53	23.56	**21.04**	**0.00120**
22500	389	509	534	17.29	22.62	23.73	**21.21**	**0.00123**
22500	410	510	537	18.22	22.67	23.87	**21.59**	**0.00129**
22500	424	514	539	18.84	22.84	23.96	**21.88**	**0.00134**
22500	446	518	541	19.82	23.02	24.04	**22.30**	**0.00142**
22500	464	520	542	20.62	23.11	24.09	**22.61**	**0.00149**
22500	467	524	544	20.76	23.29	24.18	**22.74**	**0.00153**
22500	472	526	545	20.98	23.38	24.22	**22.86**	**0.00157**
22500	476	529	550	21.16	23.51	24.44	**23.04**	**0.00163**
22500	479	530	555	21.29	23.56	24.67	**23.17**	**0.00170**
22500	480	531	557	21.33	23.60	24.76	**23.23**	**0.00173**
22500	483	534	559	21.47	23.73	24.84	**23.35**	**0.00191**
22500	479	532	555	21.29	23.64	24.67	**23.20**	**0.00209**
22500	475	532	548	21.11	23.64	24.36	**23.04**	**0.00218**
22500	474	527	542	21.07	23.42	24.09	**22.86**	**0.00226**
22500	472	525	521	20.98	23.33	23.16	**22.49**	**0.00238**
22500	471	522	518	20.93	23.20	23.02	**22.39**	**0.00240**
22500	467	519	515	20.76	23.07	22.89	**22.24**	**0.00244**
22500	454	514	511	20.18	22.84	22.71	**21.91**	**0.00252**
22500	433	504	507	19.24	22.40	22.53	**21.39**	**0.00263**

Table G-14: Splitting Tensile Strength on 7th, 14th and 28th Days

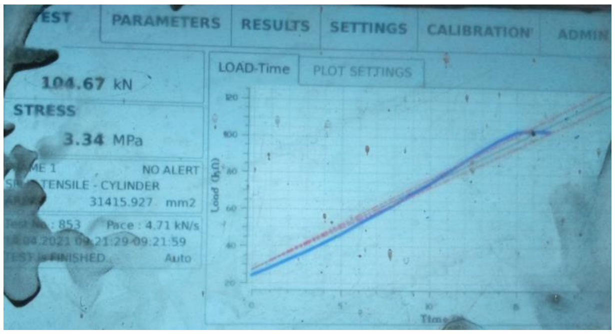
Date of test	Code of Sample	Sample	Peak load (kN)	Splitting T. Stress (MPa)	Avg Experimental S.T. Stress (MPa)	Code's Empirical Strength (MPa)	Remark (Exp'tal ≥ Emp'cal)
7th	**H-0%**	1	81.87	2.61	2.64	2.24	**OK**
		2	80.44	2.56			

		3	86.3	2.75			
	H-5%	1	84.5	2.69	2.56	2.24	**OK**
		2	76.68	2.44			
		3	79.69	2.54			
	H-10%	1	85.38	2.72	2.51	2.24	**OK**
		2	73.8	2.35			
		3	77.24	2.46			
	H-15%	1	53.48	1.70	1.75	2.24	**NOT OK**
		2	60.93	1.94			
		3	50.91	1.62			
14th	**H-0%**	1	91.18	2.90	3.04	2.60	**OK**
		2	93	2.96			
		3	102	3.25			
	H-5%	1	90.5	2.88	3.01	2.60	**OK**
		2	103.84	3.31			
		3	89.08	2.84			
	H-10%	1	87.75	2.79	2.96	2.60	**OK**
		2	98.54	3.14			
		3	92.45	2.94			
	H-15%	1	67.53	2.15	2.13	2.60	**NOT OK**
		2	63.8	2.03			
		3	69.18	2.20			
28th	**H-0%**	1	107.59	3.42	3.59	2.87	**OK**
		2	**120.87**	**3.85**			
		3	109.45	3.48			
	H-5%	1	**112.59**	**3.58**	3.29	2.87	**OK**
		2	100.96	3.21			
		3	96.27	3.06			
	H-10%	1	**104.67**	**3.33**	3.22	2.87	**OK**
		2	99.08	3.15			
		3	99.91	3.18			
	H-15%	1	**74.22**	**2.36**	2.39	2.87	**NOT OK**
		2	75.33	2.40			
		3	75.5	2.40			

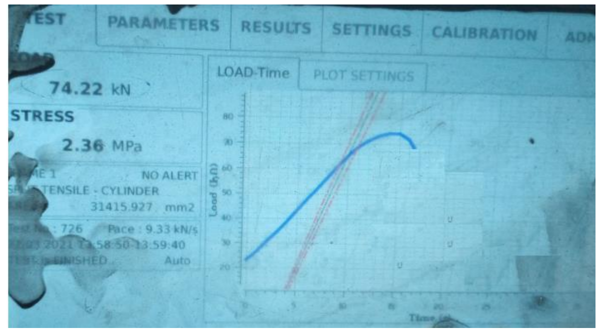
H-0% 28th



H-5% 28th



H-10% 28th



H-15% 28th

Figure G-2: Some of Experimental Compressive Peak loads and Peak stresses

Table G-15: Flexural Tensile Strength on 7th, 14th and 28th Days

Date of test	Code of Sample	Sample	Load (KN)	Avg. Load (KN)	Stress σ=PL/bd^2	Code's Standard Value (KN/m^3)	Remark (Exp'tal ≥ Emp'cal)
7th	**H-0%**	1	12.76	12.55	**3.77**	**3.73**	**OK**
		2	12.2				
		3	12.69				
	H-5%	1	12.76	12.45	**3.74**	**3.73**	**OK**
		2	12.2				
		3	12.39				
	H-10%	1	11.59	12.54	**3.76**	**3.73**	**OK**
		2	12.98				
		3	13.06				
	H-15%	1	11.39	12.37	**3.71**	**3.73**	**NOT OK**
		2	11.85				
		3	13.87				
14th	**H-0%**	1	14.32	14.69	**4.41**	**4.29**	**OK**

		2	15.73				
		3	14.02				
	H-5%	1	12.86	14.52	**4.36**	**4.29**	**OK**
		2	16.34				
		3	14.365				
	H-10%	1	13.89	14.83	**4.45**	**4.29**	**OK**
		2	15.94				
		3	14.67				
	H-15%	1	12.99	13.97	**4.19**	**4.29**	**NOT OK**
		2	13.99				
		3	14.925				
28th	**H-0%**	1	15.89	16.01	**4.80**	**4.77**	**OK**
		2	16.04				
		3	16.09				
	H-5%	1	14.89	15.92	**4.78**	**4.77**	**OK**
		2	16.54				
		3	16.34				
	H-10%	1	15.29	15.90	**4.77**	**4.77**	**OK**
		2	16.14				
		3	16.28				
	H-15%	1	16.53	14.97	**4.49**	**4.77**	**NOT OK**
		2	12.39				
		3	15.98				