JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

CONSTRUCTION ENGINEERING AND MANAGEMENT CHAIR

EFFECT OF FLY ASH ON PROPERTIES OF HIGH STRENGTH CONCRETE

A Thesis Submitted to the School of Graduate Studies of Jimma University Institute of Technology, Faculty of Civil and Environmental Engineering in partial fulfillment of the requirement for the degree of Master of Science in Construction Engineering and Management.

By

Temesgen Fantu

January, 2020

Jimma, Ethiopia

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TEMESGEN FANTU FARACHO

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DECLARATION

I declare that this research proposal entitled "EFFECT OF FLY ASH ON PROPERTIES OF HIGH STRENGTH CONCRETE" is my original work and has not been submitted as a requirement for the award of any degree in our university or elsewhere.

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ABSTRACT

In high rise structures, high strength concrete has been successfully used in various countries across the world. High-strength concrete is used for resisting high compressive load and improved strength. But, the Cement content of the mix proportion for high-strength concrete is particularly high compared with conventional concrete strength. On the other hand, the production of cement involves the emission of large amounts of carbon-dioxide gas into the atmosphere; which aggravates global warming. So, because of this adverse impact on the environment, it needs to see another cementitious material. Fly ash is by product of coal burning, such material are used as partial replacement of cement in high strength concrete which reduce carbon-dioxide gas emission in to atmosphere and also minimizing the negative impact on the environment which released from industrial waste disposal as land fill. The objective of this study was to investigate the effect of fly ash on high strength concrete properties.

Experimental laboratory tests were conducted. Slump height is measured to determine the workability of fresh concrete. The Cube size is (150mmx150mmx150mm) which is used for testing compressive strength for the age of 7, 14 and 28 days of curing. The percentage replacement of cement with fly ash varies from 0% to 30% by the increment of 5%. The total numbers of samples conducted are one hundred twenty six (126).

The result of the study shows that the replacement of cement by fly ash up to10% increases the slump values. However, the replacement of cement beyond 10% by fly ash decreases the workability of fresh concrete. Regarding density and compressive strength, the replacement of cement by fly ash decreased the density of concrete. Besides, the compressive strength of concrete becomes improved and increased when the cement is replaced by fly ash up to 10%. At the curing age of 28th days, the concrete containing 5% and 10% fly ash as cement, gained 1.66% and 2.97% of strength respectively. So, this study suggests that partial replacement of cement by fly ash up to 10% increases the capacity of high strength concrete and workability of fresh concrete, So that the optimum percentage of fly ash to replace cement is 10% for high strength concrete.

Keywords: Compressive Strength, Density, Fly Ash, High Strength Concrete, Workability.

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ACRONYMS

ACI	American Concrete Institute
ASTM	American Society for testing material
C-55	55 Mega Pascal compressive strength
CA	Course Aggregate
CO_2	Carbon dioxide
FA	Fine Aggregate
FM	Fineness Modulus
GGBS	Ground Granulated Blast Furnace Slag
HPC	High performance concrete
HRWRs	High rang water reducer
HSC	High strength concrete
JiT	Jimma Institute of Technology
LOI	Loss on ignition
MK	Metakaolin
MPa	Mega Pascal
NSC	Normal strength concrete
OPC	Ordinary Portland cement
SCMs	Supplementary cementitious Material
SF	Silica Fume
SPs	Super plasticizes
SSD	Saturated Surface Dry
UHSC	Ultra High Strength Concrete
W/C	Water Cement Ratio

CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Nowadays concrete is widely used construction material for various types of structures due to its strength, durability, fire resistance, and availability. The Ordinary Portland Cement (OPC) is one among the most ingredients used for the assembly of concrete. Inappropriately, the production of cement involves a large amount carbon-dioxide gas emission into the atmosphere, due to this it is a major contributor for the global warming and greenhouse effect, hence it is unavoidable either to search for another cementitious material or partially replace it. The look for any such material, which can be used as a supplementary for cement, should lead to global sustainable development and the lowest possible impact on the environment. When we used industrial by-products are used as a partially replaced by cement it results considerable energy and cost saving (Siddamreddy Anil Kumar Reddy, 2013).

High Strength Concrete is needed in engineering projects that have concrete parts that have to resist high compressive loads. HSC is typically used in the erection of high rise structures. Furthermore, HSC also permits reinforced or pre-stressed concrete girders to span greater lengths than conventional strength concrete girders. High Strength Concrete enables to build the superstructures of long-span bridges and to enhance the durability of bridge decks (Sarada. G, 2017).

According to M.A. Megat Johari, (2011) Supplementary cementitious material (SCMs) such as fly ash, ground granulated blast-furnace slag, silica fume, and metakaolin as part of binders for concrete has been increasing throughout the world, particularly in the construction of high strength and high-performance concrete. From this, due to it's the potential ability of these materials uses to enhance the properties and performance of concrete thought their filler effect, as well as pozzolanic reaction.

Based on this, the achievement of high strength and durable concrete structures; the use of supplementary cementitious materials (SCMs) and super-plasticizers (SPs) are responsible for the production of high strength concrete. Also, cementitious material content and mix composition parameters like water cementitious material ratio have a significant bearing on the improvement of HSC (Saha, et al., 2014).

Therefore, this research investigated the properties of high strength concrete by adding fly ash by weight of cement, which helped the improvement of workability of fresh concrete, compressive strength and density of high strength concrete by reducing consumption of natural resources needed for cement production and environmental pollution due to cement production.

1.2 Statement of the Problem

High strength concrete refers to any concrete having a specified compressive strength which is greater than normal strength concrete. It is required in engineering projects that have concrete components that must resist high compressive loads. HSC is typically used in the erection of high rise structures across the world. It has been used in components such as columns especially on lower floors where the loads will be greater, shear walls and foundations (Sarada. G, 2017).

Nowadays, in Ethiopia the construction of high rise building is increasing significantly in recent year in some cities of the country, especial in Addis Ababa. Besides, the demand of high strength concrete significantly increases. However, to produce high strength concrete the cement content of mix proportions of high-strength concrete required higher cement particularly compared with conventional concrete strength. The use of high amount of cement in the concrete structure results in emission of CO_2 as well as using up high levels of energy resources in the production of cement. By replacing cement with a material of pozzolanic characteristic, such as the coal ash (fly ash), the growing demand of cement can be fulfilled by minimizing environmental pollution as a result of cement production. (Jatale, 2013).

Generation of fly ash is highly increasing every year with an increase number of industries those use combustible coal for thermal power plants to produce electricity for fulfilling industries energy demand in the country, especially Ayka Addise Textile and Investment Groups Company have been used 60 tons coal to manufacture textile per day, from those 17% was fly ash. The Ayka Addise Textile and Investment Groups coal waste estimated annually around more than 3723 m^3, this caused environmental problems. So, because of those adverse impacts on the environment, it needs to see another cementitious material. The search for any cementitious material, which can be used as an alternative for cement, enhance the properties of high strength concrete, reduce the effect of CO_2 emission on the environment from cement production besides minimizing the environmental impact of fly ash which released from industrial waste as land fill.

Therefore, this research study investigated the use of fly ash as a partial replacement of ordinary Portland cement and evaluated the properties of C-55 high strength concrete.

1.3 Research Questions

The research questions of these studies are as follow:-

1. What is the effect of fly ash on the workability of high strength concrete?
2. What are the effects of fly ash on the compressive strength of C-55 high strength concrete?
3. What is the effect of fly ash on the unit weight of high strength concrete?
4. What is the optimum percentage value of fly ash?

1.4 Objectives of Study

1.4.1 General Objective

❖ The main objective of this study is to investigate the properties of high strength concrete using fly ash as partial replacement of cement.

1.4.2 Specific Objective

➢ To evaluate the workability of fresh concrete using fly ash in high strength concrete.

➢ To evaluate the compressive strength of C-55 high strength concrete using fly ash.

➢ To determine the density of high strength concrete using fly ash.

➢ To determine the optimum percentage value of fly ash.

1.5 Significance of the Study

The benefits of introducing high strength concrete (HSC) using fly ash in the construction industry are, used to reduce an adverse environmental impact during production of cement on the environment.

Generally, the significance of this study, to improve high strength concrete properties, to reduce CO_2 emission by using fly ash as an alternative cementitious material and Proper disposal of fly ash from the environment. Also, partially replace cement with fly ash, could preserve the non-renewable resources required for the production of cement, and obtain sustainable concrete construction.

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

1.6 Scope of Study

This study focused on the investigation of the effect of fly ash on high strength concrete properties such as the workability of fresh concrete, compressive strength and density of hardened concrete for C-55 grade of high strength concrete.

CHAPTER TWO

LITERATURE REVIEW

This chapter focuses on a review of literature on development of HSC, materials for high strength concrete, the effect of fly ash material and other types of mineral admixtures on properties of high strength concrete.

2.1 Introduction

Concrete is a mixture of Portland cement, water, and aggregates, with or without admixtures. Portland cement and water to form a paste that hardens due to chemical reactions between the cement and water. Paste qualities are directly related to the number of water users about the amount of cement. The better the quality of concrete obtained used the less water. Reduced water content results in improved strength and durability and reduced permeability and shrinkage (Nawy, 2008).

The definition of high-strength concrete has changed with time and geographical location due to lack of a standard criterion for the strength that is required to qualify as a high strength concrete, because of this, High-strength concrete is often considered a relatively new material; its development has been gradual over many years (Mohammad, et al., 2008).

This concrete type is a dense, homogeneous and having improved engineering properties and durability as compare to conventional concrete. The use of chemical and mineral admixtures in HSC having significant effects and HSC is a most economic concrete using locally available normal ingredients according to ACI 211.4R-93. HSC can be used in the columns of High-Rise Buildings, Parking Garages, Bridge decks, and other installations requiring improved compressive strength and density. For HSC usually selected pozzolanic and chemical admixtures are employed, and attainment of low water to cementitious material ratio is considered essential (Santush, 2018).

2.2 Development of High Strength concrete

High Strength concrete was first achieved in the year 1930s in Japan, this high strength concrete in the year 1930s with 28 days curing, the compressive strength of 120Mpa was obtained, and this result was obtained by the combinations of vibrating and pressing process without using any mineral admixture and chemicals, super plasticizer was developed in the year of 1960 in West Germany and Japan, which was very effective chemical admixtures for reducing the water content in concrete. By using super plasticizer, it is possible to decrease the water to cement ratio while maintaining the workability of this high strength concrete, so this type of technique will be applied very widely and in many bridges, high rise buildings, and precast concrete (Bharatkumaranaik T, 2017).

2.2.1 Classification of concrete strength

Table 2.1: Classification of concrete strength (James, A.F. and William, C.P. 1994)

Parameter	Strength, Mpa.	Water-cement ratio
Conventional concrete	<50	>0.45
High-strength concrete	50-100	0.45-0.30
Very-high-strength concrete	100-150	0.30-0.25
Ultra-high-strength concrete	>150	<0.25

According to ACI 363R-92 for many years, concrete with compressive strength in excess of 6000 psi (41MPa) was available at only a few locations. But, in recent years, the applications of high-strength concrete have increased, and high-strength concrete has now been used in many parts of the world. The growth has been possible as a result of recent developments in material technology and higher-strength concrete demand, due to this the definition of high strength concrete has changed over the years, According to ACI 363R-92 the lower limit of high strength concrete although 6000psi (41MPa) or greater was selected.

2.3 Materials for High Strength Concrete Production

2.3.1 Introduction

The selection of materials for effective construction of high-strength concrete is achieved by carefully selecting, managing, and proportioning all of the materials. To attain higher strength concretes, most favorable proportions must be selected, considering the cement and fly ash characteristics, aggregate quality, paste quantity, aggregate-paste collaboration, admixture type, and dosage rate, and mixing. Assessing cement, fly ash, chemical admixture, and aggregate from various potential sources in varying proportions will indicate the optimum combination of materials (ACI 211 4R-93, 1997).

2.3.2 Cement

High strength concrete has raw materials of the highest quality without any compromises for marginal or lower qualities. From this to determine high strength concrete with long lasting compressive strength and other mechanical properties use high quality raw materials and well-proportioned the ingredients.

Generally, all types of Portland cement proved to be suitable in the production of concrete of compressive strength up to 60MPa on the 28th day of age. But, to achieve higher strength with respective increase in workability and performance it is necessary to study and design reactions between mineral and chemical admixture. With regard to Portland cement, the use of blended hydraulic cement is common for high strength concrete production. This cement type is a mixture of Portland cement and other supplementary cementitious materials, also called mineral admixtures. Benefits of Blended hydraulic cement lay in a lower rate of heat development, higher strength, lower permeability, increased durability and overall performances (Ramesh, et al., 2018).

2.3.3 Aggregates

The properties of the aggregate are decisive for the compressive strength of HSC. In normal strength concrete (NSC), the aggregate has higher strength and stiffness than the cement paste. Reduced water-cement ratio, therefore, causes a great improvement in the compressive strength of cement paste. From this, both fine and coarse aggregate used for high strength concrete should, at a minimum, meet the requirements of ASTM C 33 (ACI 363R-92, 1997).

Table 2.2: Ranges in physical properties for normal weight aggregates used in concrete (ACI Bulletin E1-99, 1999).

Sr. No.	Property	Typical ranges
1	Fineness modulus of fine aggregate	2.3 to 3.1
2	Nominal maximum size of coarse aggregate	37.5 to 9.5 mm (1-1/2 to 3/8 in.)
3	Absorption	0 to 8%

4	Bulk specific gravity		2.30 to 2.90
5	Dry-rodded bulk density of coarse aggregate		1280 to 1920 kg/m3
6	Surface moisture content	Coarse aggregate	0 to 2%
		Fine aggregate	0 to 10%

2.3.3.1 Coarse Aggregate

Though aggregates smaller than 12.5 mm is generally recommended for HSC, 20 mm coarse aggregates are the most commonly used aggregate for the variety of applications in construction works. Keeping this in view crushed, angular, the graded coarse aggregate of nominal maximum size 20 mm has been adopted. Coarse aggregates were thoroughly cleaned with water to make free from dust and other impurities before being used in concrete making (Saha, et al., 2014).

In the proportioning of the water for high strength concrete, the aggregate requires special consideration since they occupy the largest volume of any ingredient in the concrete, and they greatly affect the strength and other properties of the concrete. Usually, high strength concretes are produced with normal-weight aggregates. However, there have been reports of high strength concrete produced using lightweight aggregates for structural concrete and heavyweight aggregate for high-density concrete (ACI-211, mix desige, 1997).

2.3.3.2 Fine Aggregate

The shape and surface texture of fine aggregate has a greater influence on the water demand of concrete because fine aggregates contain a much higher surface area for a given weight. Rounded and smooth fine aggregate particles are better from the viewpoint workability than sharp and rough particles (Sarada. G, 2017).

Fine aggregate with rounded particle shape and smooth texture have been found to require less mixing water in concrete and for this reason, are preferable in high strength concrete. The optimum gradation of fine aggregate for high strength concrete is determined more by its effect on water requirement than on physical packing. Sand with a fineness module (FM) below 2.5 gave the concrete a sticky consistency, making it difficult to compact. Sand with an FM of about 3.0 gave the best workability and compressive strength (ACI 363R-92, 1997).

2.3.4 Water

Water is a key ingredient in the production of concrete. The function of water used in concrete is two: the first is to react chemically with the cement, which will finally set and harden, and the second function is to lubricate all other materials and make the concrete workable by providing the necessary flow properties needed for ease of placement and compaction (El-mahadi, 2002). From this, the acceptability of the water for high strength concrete is not a major concern if potable water is used. Otherwise, the water should be tested for suitability by ASTM C94 (ACI-211, mix desige, 1997).

2.3.5 Admixtures

Admixtures are widely used in the production of HSC. It consists of mineral admixtures, air-entraining agents and chemical admixture. Significant increases in compressive strength, control of the rate of hardening, accelerated strength gain, improved workability, and durability are contributions that can be expected from the admixture or admixtures are chosen (ACI 363R-92, 1997).

2.3.5.1 Chemical Admixtures

Types of chemical admixtures are seven which are used in construction industry in order to improve the properties of concrete in its fresh state, Such as, Water-reducing admixtures, Retarding admixtures, Accelerating admixtures, Water-reducing and retarding admixtures, Water-reducing and accelerating admixtures, Water-reducing, high range admixtures, and Water-reducing, high range, and retarding (ASTM C494, 2001).

According to Archuleta, et al., (1986) Chemical admixtures such as super plasticizers (high range water reducer) increase concrete strength by reducing the mixing water requirement for a constant slump, dispersing cement particles, with or without a change in mixing water content and permitting more efficient hydration.

The effect of superplasticizers on the hardened property of concrete is that it improves the strength of the concrete and it contributes to the improvement in the properties of hardened concrete rather than improving the workability, compact ability and facilitates reduction in water per cement ratio (Shetty, 2005).

The use of super plasticizers has today become an integral part of all HPCs and is considered to be the most essential feature in producing HSC. HRWRs are moreover known as super plasticizers, super water reducers and super fluidizers, due to their higher competence over conventional water reducer admixture in improving workability and flow of concrete mixes (Nawy, 2008).

Addition of HRWR in high strength concrete may serve the purpose of increasing strength at the slump or increasing slump. However, the method of addition carefully attention requires should distribute the admixture throughout the concrete. Adequate mixing is critical to uniform performance (ACI 363R-92, 1997).

High range water reducing admixtures, also known as super plasticizers admixtures, are most effective in concrete mixtures that are rich in other cementitious materials and cement. HRWR helps in dispersing cement particles, and they can be reduce mixing water requirement by up to 30 percent, thereby increasing compressive strengths (ACI-211, mix desige, 1997).

2.3.5.2 Mineral Admixtures

Supplementary cementitious materials are finely divided cementitious material other than Portland cement, consisting mainly of fly ash, ground blast furnace slag, silica fume, and have been considered in the production of high strength concrete because of the required high cementitious material content and low water-cement ratio. These materials can help control temperature rise in concrete at early ages and many reduce the water demand for a given workability. However, early strength gain of the concrete may be decreased (ACI-211, mix desige, 1997).

2.4 Requirements of Ingredients for High Strength Concrete

HSC places more strict requirements on material selection, constantly meets requirements for workability and strength development over that for lower strength concrete. Therefore, the production of HSC may or may not require special materials, but it requires materials of the highest quality and their optimum proportions. In the production of HSC, the use of strong, sound and clean aggregates is essential. The requirements of ingredient materials and the basic considerations in producing HSC are described in the table 2.3 below: (Rashid and Mansur, 2009).

Table 2.3: Requirement of Ingredients for High Strength Concrete

Material	Requirements
Cement	Portland cement Greater cement content (8 to 10 sacks per cu. yd. of concrete)
Fine aggregate	Sand with rounded particle shape Higher FM (around 3.0) Smaller sand content or coarser sand Grading is not critical for concrete strength
Coarse aggregate	The preferred coarse aggregate size is (10 – 12 mm) Aggregate type depending on the concrete strength targeted According to ASTM limit concrete strength has little effect due to gradation of aggregate.
Admixtures (chemical & mineral)	To select type of admixture it depends on the property of the concrete. Optimum dosage
Overall basic considerations	Quality materials The quality of cement improved the strength as well as aggregate. Cement paste and denser aggregate packing is good. The bond between cement paste and aggregate is improved the strength.

2.5 Effect of Mineral Admixture on High Strength Concrete

2.5.1 Fly Ash

Fly ash is finely divided residue resulting from the combustion of powdered coal and transported by the flue gases and collected by electrostatic precipitator and it is the most widely used pozzolanic material all over the world (Shetty, 2005). Fly ash is a kind of ash is extracted from flue gases through Electrostatic Precipitator in dry form. This ash is fine material & possesses good pozzolanic property (Ntpcieg, 2007).

Fly ash is used to partially replace Portland cement (by up to 60% by mass). A fly ash property depends on the type of coal and burnt processes. In general, siliceous fly ash is pozzolanic, while calcareous fly ash has latent hydraulic properties (Akshay Kumar, 2015).

2.5.1.1 Production of Fly Ash

In the production of fly ash, coal is first pulverized in grinding mills before being blown with air into the burning zone of the boiler. In this zone the coal combusts producing heat with temperatures reaching approximately 1500°C. At this temperature the noncombustible inorganic minerals (such as quartz, calcite, gypsum, pyrite, feldspar and clay minerals) melt in the furnace and fuse together as tiny molten droplets. These droplets are carried from the combustion chamber of a furnace by exhaust or flue gases. Once free of the burning zone, the droplets cool to form spherical glassy particles called fly ash. The fly ash is collected from the exhaust gases by mechanical and electrostatic precipitators (Tomas, 2014).

2.5.1.2 Pozzolanic Properties of fly ash

Fly Ash is a pozzolanic material which is defined as siliceous and aluminous material which in itself possesses little or no cementitious value, chemically react with Calcium Hydroxide (lime) in presence of water at ordinary temperature and form soluble compound comprises cementitious property similar to cement. The Pozzolana term came from Roman. About 2,000 years ago, Roman used volcanic ash along with lime and sand to produce mortars, which possesses superior strength characteristics (Ntpcieg, 2007).

2.5.1.3 Categories of Fly Ash

Fly ash classified in two classes for high strength concrete. Class F fly ash is normally produced from burring anthracite coal and has pozzolanic properties, but little or no cementitious properties. Class C fly ash is normally produced from burning lignite or sub-bituminous coal, and in addition to having pozzolanic properties, has some cementitious properties (ACI 363R-92, 1997).

According to ASTM C618, Fly ash can be classified into three main categories as Class N, Class F, and Class C.

A. Class N Fly Ash

Raw or calcined natural pozzolans that consist of 70% of silicon oxide (SiO_2), plus aluminum oxide (Al_2O_3), plus Iron oxide (Fe_2O_3). This class fly ash consists of less than 4% of sulfur trioxide (SO_3), moisture content less than 3% and loss ignition less than 10%. It contains some diatomaceous earth; shales and opaline cherts; tuffs and volcanic ashes or pumicites, calcined or uncalcined; and numerous materials demanding calcination to encourage satisfactory properties, such as some clays and shales (ASTM C618).

B. Class F Fly Ash

Class F fly ash normally produced from burning anthracite or bituminous coal that consists of 70% of silicon oxide (SiO_2), plus aluminum oxide (Al_2O_3), plus Iron oxide (Fe_2O_3). This class Fly ash consists of less than 5% of sulfur trioxide (SO_3), moisture content less than 3% and loss ignition less than 6%. This class fly ash has pozzolanic properties (ASTM C618).

C. Class C Fly ash

Class C fly ash normally produced from lignite or sub-bituminous coal that consists of 50% of silicon oxide (SiO_2), plus aluminum oxide (Al_2O_3), plus Iron oxide (Fe_2O_3). This class Fly ash consists of less than 4% of sulfur trioxide (SO_3), moisture content less than 3% and loss ignition less than 10%. According to ASTM C 618 these class of fly ash, in addition having some cementitious and pozzolanic properties.

Meanwhile, this paper investigates the production of high strength concrete by partially replacing cement with class F fly ash, the physical and chemical property of Class F fly ash are determined from experimental lab results.

2.5.1.2 Physical Properties of Class F Fly Ash

The fineness, particle-size distribution, and density of fly ash particles influence the properties of freshly mixed, unhardened concrete and the strength development of hardened concrete, due to the particle size influence on the water requirements of the concrete mixture. Also, fly ashes produced at different power plants or one plant with different coal sources may have different colors (ACI 232, 2002).

Fly ash is produced as a by-product of burning coals which have been crushed and ground to a fineness of 70 to 80 percent passing a 75 µm (No. 200) sieve. Reactivity of fly ash is related directly to the quantity passing this sieve since the coarser particles generally do not react rapidly in concrete (ACI 232, 2002). Various Researchers investigates the physical properties of Class F fly ash as shown in the Table 2.4 below:

Table 2.4: Physical Properties of Class F Fly Ash

Sr. No.	Physical Properties	(Khairul N, et al., 2007).	(Dasarathy, et al., 2018).	Dr. T.U.S Vara Lakshmi and Prof. S. Adiseshu. (2016)
1	Colour	Whitish Grey	Grey (Blackish)	Grey (Blackish)
2	Specific Gravity	2.28	2.13	1.89

2.5.1.3 Chemical Properties of Class F Fly Ash

Various Researchers investigate the chemical properties of Class F fly ash as shown in the Table2.5 below. Whereas, the last column of the table indicates that chemical property of fly ash used for this investigation, which was delivered from Ayka Addis Textile Factory, found in Alemgena 20km west of Addis Abeba, Ethiopia.

Table 2.5: Chemical Properties of Class F Fly Ash obtained from three different literatures described table 2.5;

Sr. No.	Chemical composition	(Khairul N, et al., 2007).	Dasarathy, et al., 2018).	Dr. T.U.S Vara Lakshmi and Prof. S. Adiseshu. (2016)
		Weight (%)		
1	Silica Oxide (SiO_2)	59.00	58.55	58.00
2	Iron Oxide (Fe_2O_3)	3.70	3.44	3.90
3	Alumina (Al_2O_3)	21.00	28.20	28.60
4	Calcium Oxide (CaO)	6.90	2.23	3.60
5	Magnesium Oxide (MgO)	1.40	0.32	1.91
6	Total Sulphur (SO_3)	1.00	0.07	1.80
7	Loss on ignition (LOI)	4.62	4.17	2.00
8	SiO_2+Al_2O_3+Fe_2O_3	83.7	90.19	90.50

2.5.2 Silica Fume

Silica fume is a byproduct of the production of silicon and ferrosilicon alloys. These by product waste material similar to fly ash, but its particle size 100 times smaller than fly ash due to this results much faster pozzolanic reaction and higher surface to volume ratio. Silica fume is used to increase strength and durability of concrete, but generally requires the use of super plasticizers for workability (Akshay Kumar, 2015).

Addition of silica fume at a replacement level of up to 10% tends to improve the workability of HSC. And also the effect of SF is to enhance the compressive strength of the concrete at all ages, particularly between the ages of 28 and 90 days (M.A. Johari M., et al., 2011).

2.5.3 GGBS or GGBF (Ground Granulated blast-furnace slag)

Ground Granulated Blast furnace Slag (GGBS) is a byproduct from the blast furnaces used to make iron. These operate at a temperature of about 1500 degrees centigrade. Concrete made with GGBS cement sets more slowly than concrete made with ordinary Portland cement, depending on the amount of GGBS in the cementitious material, but also continues to gain strength over a longer period in production conditions. This results in lower heat of hydration and lower temperature rises, but may also affect construction schedules where quick setting is required (D. Suresh, 2015).

The compressive strength of GGBS under direct compression, a concrete mix of grade M60 was designed. A total of 56 cubes were casted under various mix, 10%GGBS, 20%GGBS, 30% GGBS, 40%GGBS and 50% GGBS are tested under direct compression. Based on the results, the optimum percentage of GGBS replacing cement is 40% for getting maximum compressive strength and obtained maximum compressive strength is 72.31N/mm^2. The maximum increase in compressive strength is about 12.72% as compared to that of the conventional mix at the age of 28 days (Ramesh, 2018).

2.5.4 Metakaolin

Kaolin is a white and soft, plastic clay composed dominantly of fine rained platy mineral aggregate kaolinite. The effect of MK is to reduce the workability of HSC with greater reducing effects at higher replacement levels and the general effect of

MK is to enhance the strength of the HSC, except for the MK15%, concrete at the age of 1 day. At the replacement levels of 5%, the maximum contribution of MK to the HSC strength occurs at the age of 1 day, while at higher replacement levels of 10% and 15%, the maximum contribution to strength takes place between the age of 14 and 28 days (M.A. Megat Johari, 2011).

2.6 Effect of Fly Ash on Properties of High Strength Concrete

2.6.1 Workability

Using fly ash in the mix design for concrete leads to a significant improvement of fresh concrete properties, such as workability and pump ability so that it allows optimizing of the water-cement ratio. Particular, the obtained mixtures are more homogeneous with a low risk of particle segregation and water bleeding. This improvement is due to the ash spherical shape that enables particles to flow each other more easily, reducing the friction between the particles (Nicola, 2014).

Fly ash particles are generally spherical in shape and reduce the water requirement for a given slump. The spherical shape helps to reduce friction between aggregates and between concrete and pump line and thus increases workability and improve pump ability of concrete. Fly ash use in concrete increases fines volume and decreases water content and thus reduces bleeding of concrete (Subramani, 2015) .

The workability of high strength concrete, the value of slump is increased from 10 mm to 100 mm with the change in the percentage of chemical admixture, and also the value of slump increased with a decrease in the content of mineral admixture (Sarada. G, 2017). The workability of fresh concrete decreases the percentage of fly ash increases in concrete. Based on the result optimum replacement is 50% fly ash is obtained maximum slump compared to all mixes, Although the workability of fly ash replaced concrete is decreased, to compare with conventional concrete (Bharatkumaranaik, T., et al., 2017). Fly ash addition to the concrete was established to increase the workability of the concrete as the dosage increases from 0% to 40% (Mustafa, 2018).

2.6.2 Compressive Strength

The compressive strengths of the high strength concrete vary with change in percentage of fly ash in the concrete mix since the replacement percentage of fly ash increases the compressive strength decreases (Sarada. G, 2017). And also compressive strength of concrete increases as super plasticizer dosage increases, up to a dosage which causes a concrete mix to become segregated and unworkable. The addition of too much super plasticizer to a high strength concrete mix may result in significant retardation of concrete hardening. The brand of super plasticizer used affects both the workability and the compressive strength of high strength concrete (Archuleta, 1986) .

The compressive strength of high strength concrete, for 28 days is going on decreasing with the incremental increase of fly ash content of 10%, 20%, 30%, 40%, and 50%. It is observed the 7^{th} and 28^{th} days; the compressive strength of fly ash concrete was decreased, by conventional concrete. However, compared to all ages of concrete 7 and 28 days, the concrete strength is varying in compressive strength. The maximum compressive strength found in 28 days of specimens. For replacement of fly ash based concrete is decreased that early strength and later strength will be increased (Bharatkumaranaik T, et al., 2017).

According to Saha, et al., (2014) the replacement of fly ash up to 30%, all the concrete mixes exhibited strengths exceeding or equal to 40MPa at both the ages. Hence the proper use of fly ash has tremendous potential in producing high strength and high-performance concrete. However, a higher proportion of fly ash like 40% can also be adopted if the specified age for designing mixes is considered as 90 days. Based on a numerical analysis of the record of this work, optimum fly ash replacements have been calculated as 10% and 17% at 28 and 90 days respectively.

Concrete samples incorporating fly ash exhibited higher values of compressive strength relative to the control sample. Mixes with 10% and 20% fly ash significantly gained strength as compared to the other mixes. The compressive strength of cubes was observed to increase with the age of concrete that is from day 1 to day 28 and also the replacement level of cement could be increased to above 10% as there was an increase in compressive strength values for the 20%, 30% and 40% FA content. Results demonstrated that high compressive strength up to 122MPa could be realized after 28^{th} days with a high percentage of fly ash (Mustafa, A.B. and Mohd, S.J. 2018).

2.6.3 Density of Concrete

Normal weight concrete, as is used in pavements and bridges, has a density of 140 to150 lb/ft^3 (2240 to 2400 kg/m^3). The density of concrete varies with the relative density of the aggregate, the amount of air present in the paste, and the amount of water and cement in the mixture. The density of non-air entrained, high-strength concrete is often over150 lb/ft^3 (2400 kg/m^3) (Nawy, 2008).

According to (Nurzal, 2018). The longer the drying time, the density increases, due to the chemical reaction between cement and water (hydration) which causes the concrete become hard after some time, besides, water absorption increases. Drying time of 7th, 14th, and 28th days increased density value and reached maximum density value in 28th days drying time.

CHAPTER THREE
METHODOLOGY AND MATERIALS

3.1 Methodology

3.1.1 Study Area

The study was conducted at Oromia regional state of Jimma zone, southwestern Ethiopia which is located 346 km by road southwest of Addis Ababa. Its geographical coordinates are between 7° 13'- 8° 56N latitude and 35°49'-38°38'E longitude with an estimated area of 19,506.24. The town is found in an area of average altitude, of about 5400 ft. (1780 m) above sea level.

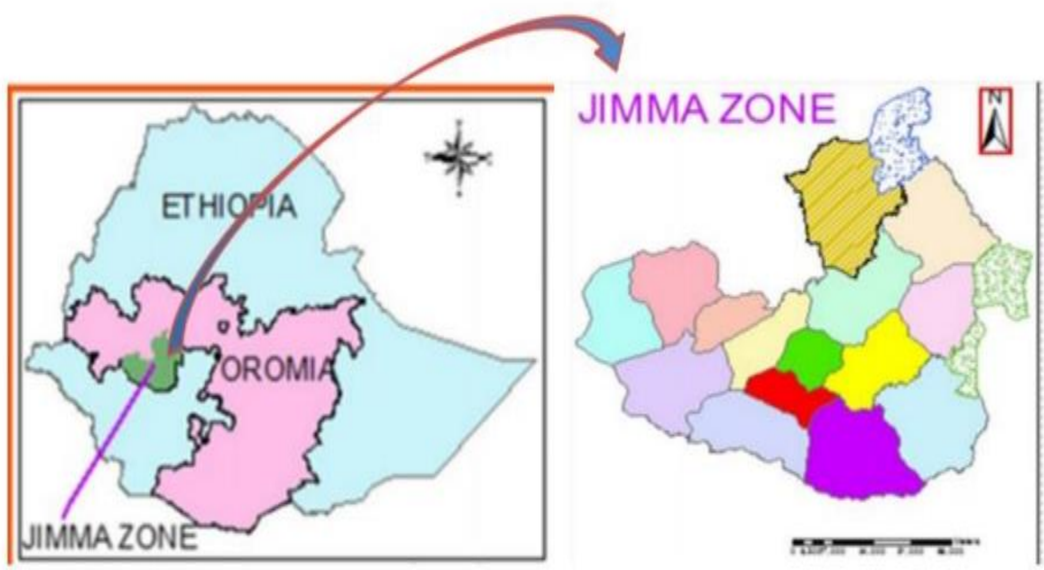


Figure 3.2: Map of study Area (Jimma Town)

3.1.2 Study Design

This research used an experimental research design method to investigate the effect of fly ash on properties of C-55 high strength concrete and find the optimum percentage value used without compromising the compressive strength of concrete. The study was made by conducting different experimental works on the properties of materials and test on the end result of the concrete specimen. The properties of the materials for the concrete were studied in order to verify the suitability of the materials for the concreting work. The high strength concrete was prepared by the weight of cement partially replaced with fly ash by different proportions and keeping the other ingredients is constant.

3.1.3 Sample size and Sampling procedures

This study was carried out based on standard methods to select all laboratory tests. The sampling procedure was taken according to ASTM and the ACI method. The samples for the compressive strength of control group were nine (9) for the 7thday, 14th day, and 28thday with a cube size of 150mmx150mmx150mm used and for each percentage of fly ash replacement is nine (9). In this study, the ratio of 0%, 5%, 10%, 15%, 20%, 25% and 30% of fly ash replaced with cement at the age of 7th, 14th and 28th days within a total of 126 samples was used for all mix. From the experimental investigations, the optimum replacement percentage of fly ash to cement was determined for the concrete mix.

Table3.1: Sample size

S. N.	Tests	Sample size (mm)	%Replacement of fly ash	Number of sample (Days)			Curing and Testing Time	Remark
				7th	14th	28th		
1	Compressive strength	Cube of 150x150 x150	0%	3	3	3	After 7,14, and 28 days	By comparing the results of different tests with the reference concrete, were given conclusions and recommendations
			5%	3	3	3		
			10%	3	3	3		
			15%	3	3	3		
			20%	3	3	3		
			25%	3	3	3		
			30%	3	3	3		
2	Density	Cube of 150x150 x150	0%	3	3	3	After 7,14, and 28 days	
			5%	3	3	3		
			10%	3	3	3		
			15%	3	3	3		
			20%	3	3	3		
			25%	3	3	3		
			30%	3	3	3		

3.1.4 Study Variables

3.1.4.1 Independent Variable

- Percentage Replacement of fly ash
- Physical properties of fly ash

3.1.4.2 Dependent variable

- Properties of High strength concrete using fly ash

3.1.5 Data Collection Process

The specimens that are placed in laboratory for different curing and testing time with different percentage ratio of fly ash usage partially replace with ordinary Portland cement, such as 0%, 5%, 10%, 15%, 20%, 25% and 30% were tested in their sequential order of curing and casting time, then the data were registered with their code tagged on it for 7th, 14th and 28th days.

3.1.6 Data Sources

The sources of data for this research were collected from both primary and secondary data sources to get precise and accurate information that makes the final findings more reliable.

The primary data for this research were the results obtained from the experimental investigation. The results of the experiment were the workability of fresh concrete, the density and compressive strength of hardening concrete.

The secondary data for this research were obtained from the kinds of literature which are related to the effect of fly ash on properties of high strength concrete and other related books and standard documents to support the research with accepted theories, and standards.

3.1.7 Experimental Procedure

The materials such as cement, fine aggregate, coarse aggregate and fly ash was brought to the place where the experiment is conducted. Fly ash, it collecting from Ayka Addis textile and investment group, which is located at 20km West of Addis Abeba Sebeta town around Alemgena. Then fine and coarse aggregate was washed to free from impurities and dirt. After that, certain material tests were done to check the properties of materials; all tests are based on standards.

After testing of materials is finished and results are collected, mixing design was proceed for C-55 grade of concrete by adding percentage value fly ash, such as 5%, 10%, 15%, 20%, 25% and 30% by weight of cement. Then these materials were properly mixed and samples were taken for strength tests, such as compressive strength, by compacting with recommended layers, for 7th, 14th and 28th days.

Finally, by collecting the results from the laboratory this research paper was compared and contrasted the effect of fly ash on properties of high strength concrete and gave recommendations and conclusions about the optimum percentage of fly ash that must be used in high strength concrete. The experimental sample procedures described below chart 3.2:

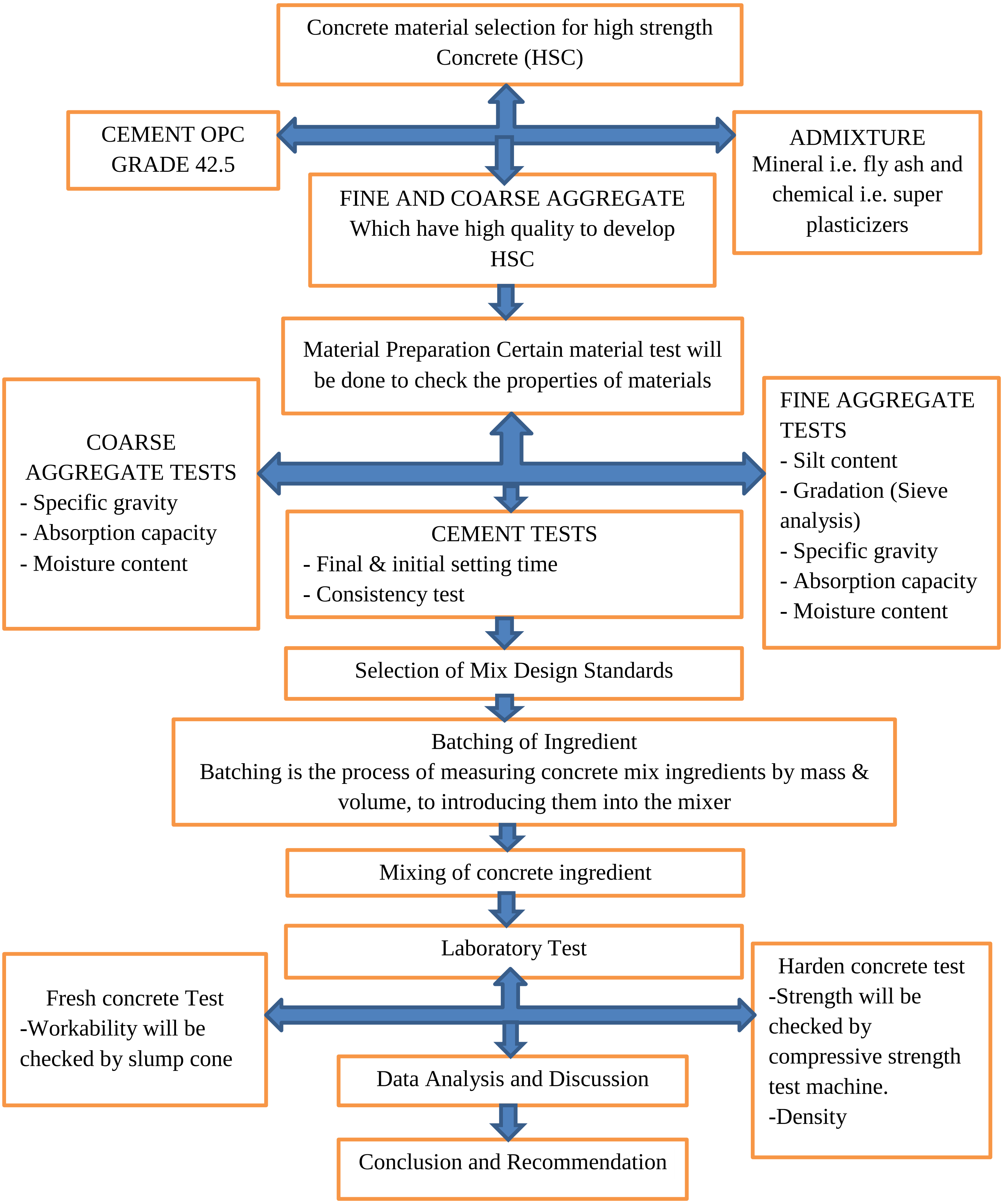


Figure 3.2: Experimental Laboratory frame work

3.1.8 Data Processing and Analysis

Before starting the analysis sorted data into the different groups, to make suitable for the comparison of results. All specimens were coded before starting experimentation and a quality control check is mandatory for completeness and consistency of the data.

All the relevant data were collected from the sources. After collecting and recording the laboratory results found from the compressive strength test, compare the output with the available national and international standards and specifications. Finally present the results of analysis by using different graphs, tables, and charts as required.

3.2 Materials Used for the Study

3.2.1 Materials Selection

Table 3.2: Materials used for this study

S.N	Material used for this laboratory experiment	
1.	Cement	Type of Cement used in the concrete mix was Dangote-Ordinary Portland cement (OPC) whose Cement Grade 42.5R which is commercially available cement.
2.	Coarse aggregate	“Agaro” crushed stone 19mm maximum aggregate size that was used in Jimma Town.
3.	Sand	The sand was used in this experiment was worabe sand
4.	Water	Drinkable water (potable water)
	Admixture Used For the Experiment	
5.	Fly ash	Mineral admixture
6.	Super plasticizer	Chemical admixture

3.2.2 Material Preparation

The physical characteristics of concrete making materials (Cement, fine aggregate, coarse aggregate and fly ash) used for the research were examined and an appropriate mix design was made.

3.2.2.1 Cement Used For the Experiment

Type of Cement used to produce the samples for this study was Ordinary Portland cement (OPC) whose Cement Grade 42.5N which is available in the market. The specific gravity of the Dangote OPC was known to have 3.15**.** The physical property of cement with fly ash has been discussed below:

A. Normal Consistency Test

Normal consistency water of cement paste was taken into consideration in preparation of paste for setting time test. Consistency and setting time were investigated by using Vi-cat needle apparatus. This test is done to determine the amount of water required to prepare cement paste for setting time test. Different trials were carried out with different water - cement ratio until the proportional of water in mix achieved for a paste that the rod of Vicat apparatus settles 10±1 mm below the original surface within 30 seconds. The usual range of water - cement ratio for normal consistency is between 26% and 33%.

B. Initial and final setting time

Setting time tests were applied by using Automatic Vi-cat needle apparatus and cement paste mixer, and then seven samples were conducted on the cement pastes made with the percentage addition of fly ash 0% up to30% 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 tests were recorded at the regular time interval of 15 minute.

Figure 3.3: Dangote ordinary Portland cement (OPC)

3.2.2.2 Fine Aggregate

The fine aggregate used for this investigation was obtained from the local source, Worabe, Gurage Zone of Southern Ethiopia which is located 343 km from Jimma town, it is extracted from "omo" river was used to prepare the concrete samples. The aggregate is 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 of 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% (Abebe Dinku, 2002). In this study, fine aggregate that used have a silt content of 2.5% and this value was within the range of the standard and it passes the requirement.

B. Sieve Analysis of fine aggregate

This is a procedure 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. These properties of the aggregate greatly affect the property of the concrete. According to ASTM C33 (standard specification for concrete aggregates), sand with a fineness modulus between 2.3 and 3.1 considered to be as good sand or a good fine aggregate. However depending upon their size; crush sand can be classified as coarse sand when fineness modulus is between 2.9 to 3.1, medium sand with a fineness modulus of 2.6 to 2.9, fine sand with a fineness modulus of 2.2 to 2.6.

Fine aggregate with a fineness modulus (FM) in the range of 2.5 to 3.2 is preferable for high strength concretes. Concrete mixtures made with a fine aggregate that has an FM of less than 2.5 may be sticky and results in poor workability and higher water requirement. It is sometimes possible to blend sands from different sources to improve their grading and their capacity to produce high strengths (ACI2114R-93, 1998). From this, the FM of fine aggregate for this study is 3.0 within the range. The sieve analysis test results described below Table 3.3:

Table 3.3: Sieve Analysis Test Result and Standard Requirement for Fine Aggregate

Sieve Analysis of fine Aggregate						
Sieve Size (mm)	Mass Retained	%Retained	Cumulative %Retained	Finer Passing	ASTM Limit	
					Lower	Upper
9.5	0	0	0	100	100	100
4.75	0	0	0	100	95	100
2.36	240	12	12.3	87.7	80	100
1.18	415	20.8	33.1	66.95	50	85
0.6	664	33.2	66.3	33.75	25	60
0.3	430	21.5	87.8	12.25	10	30
0.15	160	8	95.8	4.25	2	10
Pan	80	4				

$$F.M = \frac{\sum \text{Cumulative retained } \%}{100}$$

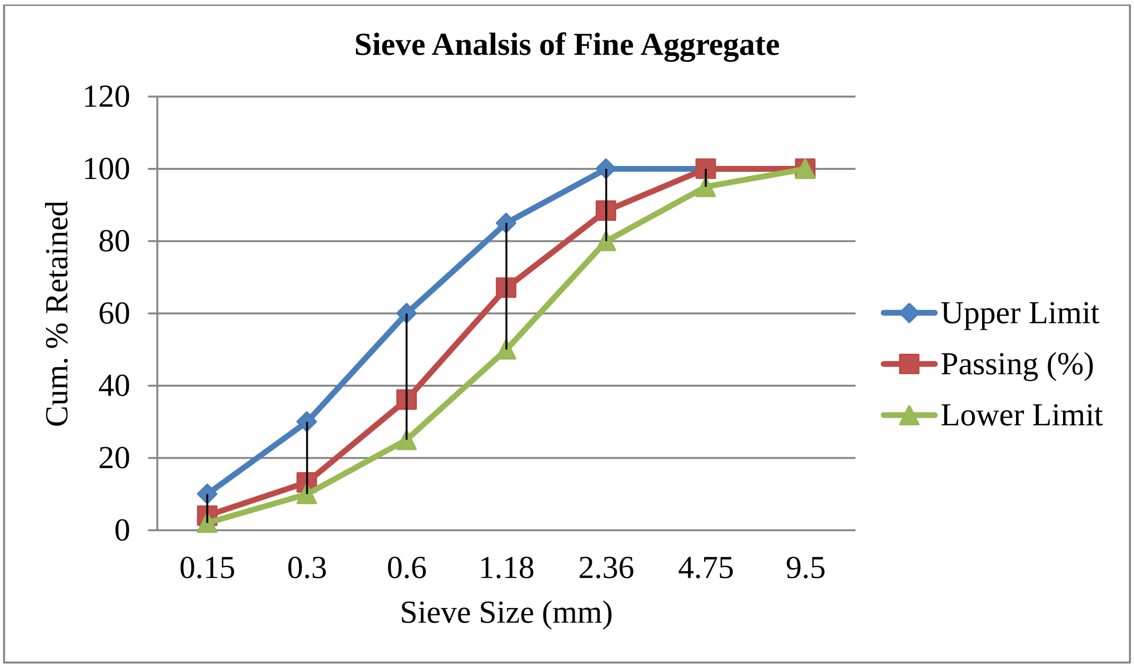


Figure 3.4: Particle Size Distribution of Fine Aggregate

C. 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. The water to cement ratio of concrete affects the strength and the workability of the concrete. The increase of the water to cement ratio results in a decrease in the strength of the concrete and an increase of workability. The aggregates in concrete are assumed to be inert materials. As a result of this property of aggregates the design water to cement ratio of the mix changes. To correct for these discrepancies, the moisture content of aggregates has to be determined (Abebe Dinku, 2002). Therefore, it is important to determine both the absorption capacity and the moisture content of the aggregate.

The moisture content of fine aggregates was determined by oven drying a sample of fine aggregate (500gm) in an oven at a temperature of 110 0c for 24hrs and dividing the weight difference by the oven-dry weight. According to ACI Bulletin E1-99, (1999) the surface moisture content is 0 to 10% for fine aggregate, based on this the average moisture content fine aggregate for this study was 1.57% within the standard limit.

D. 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 1565.6 kg/m^3 and 1347.75 kg/m^3 respectively.

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 (Abebe Dinku, 2002).

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 2.5 and 2.55 respectively and the absorption capacity was found to be 1.68%. 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 limitations.

Based on the test conducted for concrete making materials such as fine aggregate the following table summarizes their properties below Table 3.4:

Table 3.4: Summery of fine aggregate properties

No.	Materials Properties		Fine Aggregate
1	Gradation		It's According to Ethiopian/ASTM C 33-93
2	Aggregate Type		Uncrushed
3	Silt Content (%)		2.5
5	Moisture Content (%)		1.57
6	Unit Weight (kg/m^3)	Compacted	1565.6
		Loose	1347.75
7	Absorption Capacity (%)		1.57
8	Fineness Modulus		3
9	Specific Gravity	Bulk	2.42
		Bulk (SSD)	2.5
		Apparent	2.55

3.2.2.3 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. Properties of coarse aggregate affect mixing water demand and aggregate mortar bond features. Smaller size aggregate has been shown to provide higher strength potential.

Using the quality of aggregate and the right type cannot be overemphasized. Generally the volume of concrete occupy by the fine and coarse aggregate 60% to 70% respectively due to this strongly influence the fresh and hardened properties of concrete. 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 (19mm) 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. Moisture content of coarse aggregate

During the concrete mix design process, an aggregate was considered to be as free from water and never absorbing moisture from the environment. Of course, the aggregate 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 exposed. So, to know the required quantity of water that is required to get the desired compressive strength and the workability of fresh concrete, the tests should have to be conducted. The water to cement ratio of concrete affects the strength and the workability of the concrete. The increase of the water to cement ratio results in a decrease in the strength of the concrete and an increase of workability. The aggregates in concrete are assumed to be inert materials. As a result of this property of aggregates the design water to cement ratio of the mix changes. To correct for these discrepancies, the moisture content of aggregates has to be determined (Abebe Dinku, 2002). Therefore, it is important to determine both the absorption capacity and the moisture content of the aggregate.

The moisture content of course aggregates was determined by oven drying a sample of coarse aggregate (500gm) 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 0.975%.

B. 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 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. According to ACI Bulletin E1-99, (1999) the rodded bulk density of coarse aggregates used for concrete generally ranges from 1280 to 1920 kg/m^3 , from this the compacted and loose unit weight of fine aggregate used in this study was 1605.73 kg/m^3 and 1440.33 kg/m^3 respectively fulfill the requirements.

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. 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 (Abebe Dinku, 2002).

According to ASTM C 128-93 (2001), standard test method the bulk specific gravity (SSD) 2.82 and the absorption capacity was found to be 0.655%.

Based on the test conducted for concrete making materials such as coarse aggregate the following table summarizes their properties below Table 3.5:

Table 3.5: Summery of coarse aggregate Properties

No.	Materials Properties		Coarse Aggregate
1	Gradation		It's According to Ethiopian/ASTM C 33-93
2	Aggregate Type		Crushed
4	Maximum Aggregate Size (mm)		19
5	Moisture Content (%)		0.975
6	Unit Weight (kg/m^3)	Compacted	1605.7
		Loose	1440.33
7	Absorption Capacity (%)		0.655
9		Bulk	2.77

	Specific Gravity	Bulk (SSD)	2.835
		Apparent	2.875

3.2.2.4 Water

In this study, water was used for mixing the concrete and curing of the specimens, the water type that used was potable water.

3.2.2.5 Fly Ash

Fly ash, a by-product of coal combustion, is widely used as a cementitious and pozzolanic ingredient in Portland cement concrete. Fly ash used in concrete, in two ways either as blended with cement or as a separately batched material. The use of fly ash in concrete is increasing because it improves some properties of concrete and often results in lower cost concrete (ACI 232, 2002).

Based on this fly ash used passing 75 (sieved by 75 microns) and retained on the pan was used as a powder which acts as a cement replacement agent. The combination of fly ash or increasing in the amount of powder content serves as a segregation resistant and it enhances the stability of the concrete. The specific gravity of used fly ash for this study described below Table 3.6:

Table 3.6: Specific gravity of fly ash

Specific gravity of fly ash			
Sample	**1**	**2**	**Average**
Wt. of sample [gm]	200	200	
Wt. of pycnometer (A)[gm]	573	573	
Weight of pycnometer + Sample(B)[gm]	773	773	
Weight of pycnometer + water + Sample(C)[gm]	1657.3	1660.5	
Weight of pycnometer + water (D)[gm]	1530	1530	
Specific gravity =B-A/(D-A)-(C-B)	2.75	2.87	2.81

Figure 3.5: Accumulation of Waste fly ash at Ayka Addis Textile factory

Figure 3.6: Preparation of fly ash

A. Chemical Composition of Fly Ash

The chemical composition of fly ash fulfill the requirements ASTM C 618 used to classify it is class C or F. The analytic bulk chemical composition analysis used to determine compliance with ASTM C 618. This type of analysis is used as a quality assurance tool (ACI 232, 2002).

For this study fly ash that was collected from the Ayka Addis textile and investment group was checked in its chemical composition to check the classes of fly ash either C or F and to know its cementitious property. The result of Chemical analysis of fly ash was determined at the geological survey of Ethiopia.

Chemical composition test result for the fly ash used in this paper was taken from the 'Geological Survey of Ethiopia Central Geological Laboratory Research'. Detail of main chemicals determined is Ayka Addis textile and investment group Class F fly ash as below Table 3.7:

Table 3.7: Chemical Composition of Class F Fly Ash

Comp.	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
%	47.96	34.66	2.96	3.44	0.88	0.76	<0.01	0.04	0.22	0.55	2.42	5.97

According to ASTM 618 Classifies fly ashes as class F, which must have at least 70 percent (SiO_2 + Al_2O_3 + Fe_2O_3), Based on this the sum of percentage components of SiO_2, Al_2O_3, and Fe_2O_3 is 85.58%, the utilized fly ash in this study is categorized under class F fly ash. ASTM C-618 standard states that the maximum recommended amount of loss on ignition for class F fly ash is 6%. In this case, the laboratory result indicates that the amount of LOI in the fly ash utilized in this study is 5.97%, which is acceptable by the standard.

3.2.2.6 Chemical Admixture

For this research, a locally produced admixture was selected. The local producing factory produces two types of high range water reducing super plasticizer admixtures such as mega flow SP1 (chloride free, super plasticizing admixture based on selected sulphonated naphthalene polymers) and SP4 (chloride free, super plasticizing admixture based on modified Sulphonated naphthalene formaldehyde) around Holota area. The chemical admixture used in this study was mega flow SP1, highly effective water reducing super plasticizer. The recommended dosage is 0.5-3% by weight of cementitious material. This admixture is effective on properties such as workability, strength and so on. According to the manufacturer data this admixture has a shelf life of 12 months when stored under warehouse condition.

3.2.3 Concrete Mix Design and Materials Proportion

As stated ACI 211.1 the procedures for proportioning conventional concrete strength is similar to that required for HSC. The method contains a sequence of steps, which when completed provides a mixture meeting workability and strength requirements based on the combined properties of the individually selected and proportioned components. But, in high strength concrete mixture development, obtaining the optimum proportions is based on a series of trial batches having contents of cementitious materials and different proportions High strength concrete with portland cement and fly ash (ACI-211, mix desige, 1998).

Concrete mix design (Mixture proportioning) refers to the process of determining the quantities of concrete ingredients, to achieve the specified characteristics of the concrete both in the fresh and hardened state. Before the proportioning of a concrete mixture, material characteristics should have to be tested and mixture characteristics and type are selected based on the intended use of the concrete. Concrete mix design can be calculated both in weight and volume method. But, in this paper weighing method of mix design is selected.

Concrete mixes were designed for this research study with the aid ACI 211.4R-93, ACI 363-R guidelines, because high strength concrete is a new material and developed with a trial and error basis to achieve the desired concrete performance. Therefore in this research, the above guidelines were followed to design C-55 concrete grade. For this water to cement ratio was 0.32. Additionally, the slump was 25mm this is the minim limit for high strength concrete. The quantity of concrete material was calculated by using the physical properties of the material.

3.2.4 Materials Quantity Used to Produce Concrete Specimens

There was different material proportions used to conduct the study. Table 3.8: described the quantity of material used to prepare the sample.

Table 3.8: Quantity of Materials in Kg for 1m^3 with Different Percentage Replacement of Fly Ash

% of Replacement fly ash	Cement (kg/m^3)	Fly Ash (kg/m^3)	Fine aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	Water (kg/m^3)
0%	512	0	581.76	1093.65	163.7
5%	486.4	25.6	581.76	1093.65	163.7
10%	460.8	51.2	581.76	1093.65	163.7
15%	435.2	76.8	581.76	1093.65	163.7
20%	409.6	102.4	581.76	1093.65	163.7
25%	384	128	581.76	1093.65	163.7
30%	358.4	153.6	581.76	1093.65	163.7

3.2.5 Concrete Production Process

In this research, concrete was mixed by an electric mobile mixer with the help of manpower.

- The molds and mixing tools and equipment's were cleaned from all dust and molds was coated with releasing agent (oil) to smooth the surface and to prevent sticking of mixed concrete.
- The concrete ingredients prepared, such as; cement, fine aggregate, coarse aggregate, fly ash and water were measured by weight balance.
- After that, the weighted coarse aggregate, the cement, and fine aggregate were added and dry mixed for a minute.
- Then, 50% of total water was added after the blended dry mixed concrete ingredients mixture and then 50% of water added after the mixture was fully blended this was added to the help of delaying the mixture not drying earlier.
- After mixing of concrete ingredients were done, the fresh concrete was checked for workability by filling the standard slump cone with three layer by blowing each layers for 25 times using steel rod.
- Then, filling of different molds, such as cubes for compressive strength were produced, each test mold was filled with three layers by blowing each layer 25 times using steel rod.
- Finally, the concrete molds are kept for 24 hours and then the casted concrete cubes were removed from the mold and placed inside water for curing to take place until the testing age was reached.

Figure 3.7: Concrete mixing and Casting processes

3.2.6 Concrete Test

3.2.6.1 Workability Test

ASTM C 143 describes a standard test method for the slump of Portland cement concrete which has been used to quantify the consistency of plastic concrete. According to ACI 363R-92 reapproved (1997). High strength concrete performance demands a dense, void-free mass with full contact with reinforcing steel. The slump should reflect this need and provide a workable mixture, easy to vibrate, and mobile enough to pass through closely placed reinforcement.

For this study workability test was conducted. The slump test results were conducted to investigate the impact of fly ash usage on workability. The objective of the workability test is to assess whether the concrete is effective enough for easy compaction and placing.

The mixed concrete was checked for workability by filling the standard slump cone with three layers by rodding each layer with 25 times ASTM C143. Then, after checked the slump the mixed concrete was placed in the mold and was well compacted in three layers with the help of a rodding 25 times and to remove the air inside concrete hammering outside the surfaces of the mold.

Figure 3.8: Slump Test Procedures

3.2.6.2 Compressive Strength Test

The purpose of compressive strength tests is used to determine the rate of compressive strength development of hardened concrete; the cubes can be tested to failure in a compression testing machine to measure the strength development of the hardened concrete. After 7th, 14th and 28th days curing period the concrete cubes specimens was removed from the water bath then placed in dry surface until the specimens were surface dried while weighted concrete cubes specimens in order to determine the unit weight of the concrete cube. Finally, the specimens were tested by using a Digital readout, Universal Testing Machine.

Figure 3.9: Compressive strength test

3.2.6.3 Unit Weight Test

The objective of the testing density of hardened concrete was to investigate the effect of fly ash usage on high strength concrete. Based on this, after the 7th, 14th and 28th days curing period the concrete cubes specimens were removed from the water bath then placed in dry surface until the specimens were surface dried while weighted concrete cubes specimens to determine the unit weight of the concrete cubs. Formula for calculating unit weight for hardened concrete described below:

$$\text{Density} = \frac{\text{Mass of Sample (gm)}}{\text{Volume of cube (m}^3\text{)}}$$

Figure 3.10: Density Test

CHAPTER FOUR

RESULT AND DISCUSSIONS

In this experimental research the effect of fly ash on properties of high strength concrete with available construction materials within constant water-cement ratio, with different percentages of fly ash replacing the cement, with and without the addition of chemical admixture. According to the research objective, the effect of fly ash usage on high strength concrete properties, such as workability, compressive strength and density of concrete have been studied at dosages of fly ash 0%, 5%, 10%, 15%, 20%, 25% and 30% replaced by weight of cement.

4.1 Effect of Fly Ash on Workability without Super-plasticizes

Table 4.1: Slump Results of Fresh Concrete

Fly ash	Cement	W/C ratio	Slump value (mm)
0% fly ash	100%	0.32	25
5% fly ash	95%		38
10% fly ash	90%		42
15% fly ash	85%		23
20% fly ash	80%		15
25% fly ash	75%		8
30% fly ash	70%		3

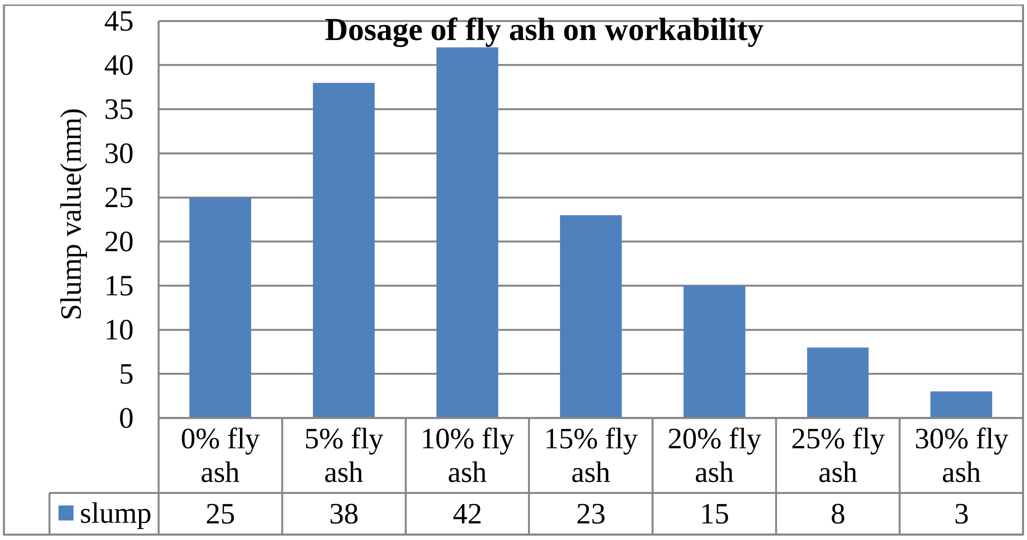


Figure 4.1: Charts for Slump Values of Fresh Concrete

The slump test result was up to 10% increases partial replacement of fly ash with cement due to the ash spherical shape that enables particles to flow each other more easily, reducing the friction between the particles. However, percentage replacement of fly ash greater than 10% decreases the workability of fresh concrete. Generally, slump result increases when the percentage of replacement increases by up to 10% beyond which are slump decreases with further increase. Therefore, it satisfied the prescribed workability of fresh concrete on the standards up to 10% fly ash replaced by cement without adding super plasticizer admixtures.

Figure 4.2: Slump Value Test

4.2 Effect of Fly Ash on Workability with Super-plasticizes

Table4.2: Slump Results of Fresh Concrete

Fly ash	**Cement**	**W/C ratio**	**Slump value (mm)**	**Super-plasticizer (HRWRs)**
0% fly ash	100%	0.32	75	1%
5% fly ash	95%		80	
10% fly ash	90%		82	
15% fly ash	85%		85	
20% fly ash	80%		78	
25% fly ash	75%		60	
30% fly ash	70%		45	

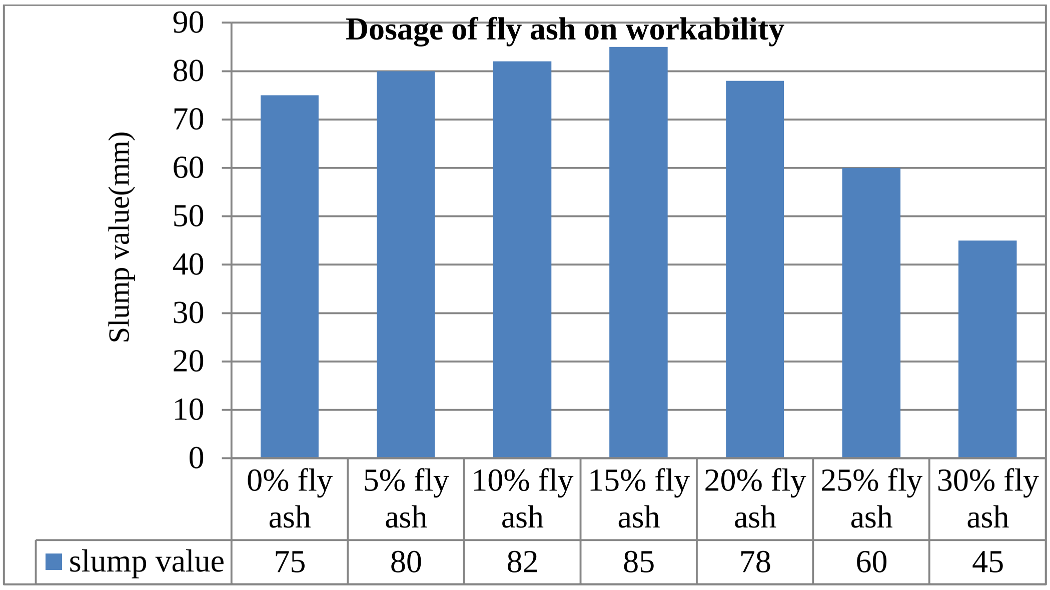


Figure 4.3: Slump value with super plasticizer

The figure 4.3 shows that slump results concrete with super plasticizer admixture increased while partial replacing cement with fly ash were up to 25%, due to super plasticizer admixture dispersing the cement particle on concrete mix and maintaining the workability of high strength concrete. However, percentage of replacement of fly ash greater than 25% decreases the workability of fresh concrete. Generally, slump result increases when the percentage of fly ash replacement increases, while slump decreases the percentage of replacement increases which means beyond 25%. Therefore, it satisfied the prescribed workability of fresh concrete on the standards up to 25% fly ash replaced by cement and with adding super plasticizer admixtures 1% by weight of cement for all percentage replacement of fly ash with cement.

4.4 Effect of Fly Ash on Compressive strength without Super-plasticizes Admixtures

A compressive strength test was conducted to evaluate the strength development of cement concrete mix, and containing a various percentage of fly ash at the age of 7^{th}, 14^{th} and 28^{th} days respectively were tested to determine the effect of fly ash replacing by cement at different replacement percentage on high strength concrete.

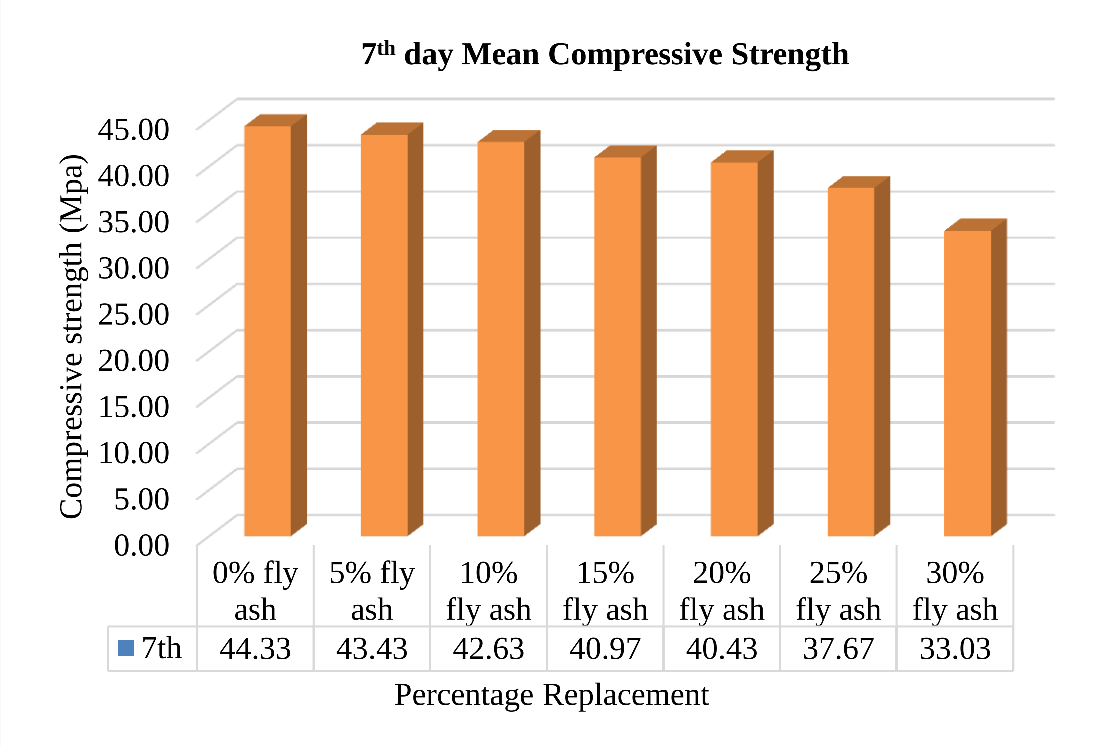


Figure 4.4: 7th Day Mean Compressive Strength without Super Plasticizer

At the age of the seventh day, the compressive strength of concrete without fly ash was more than of that with fly ash replacement. This result shows the compressive strength was reduced by about 2.03%, 3.83%, 7.6%, 8.79%, 15.04%, & 25.49% from reference concrete.

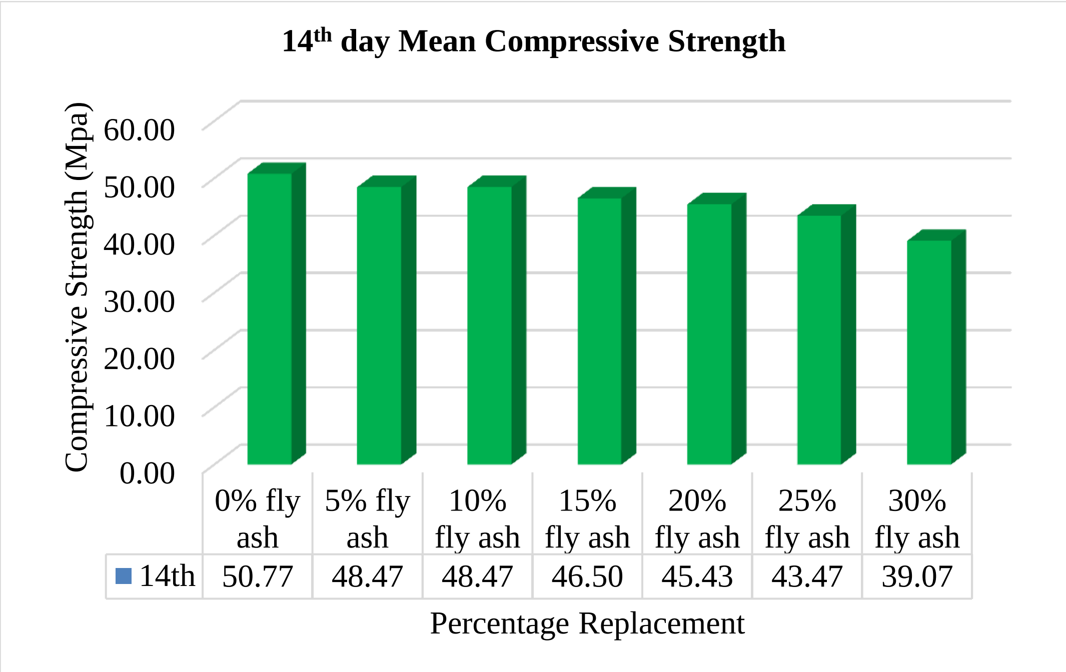


Figure 4.5: 14th Day Mean Compressive Strength without Super Plasticizer

Also at the age of the Fourteen day, the compressive strength of concrete without fly ash is more than of that with fly ash, but the gap in compressive strength is not much as the 7th day. This result shows the compressive strength was reduced by about 4.53%, 4.53%, 8.35%, 10.5%, 14.38%, & 21.86% respectively from reference concrete.

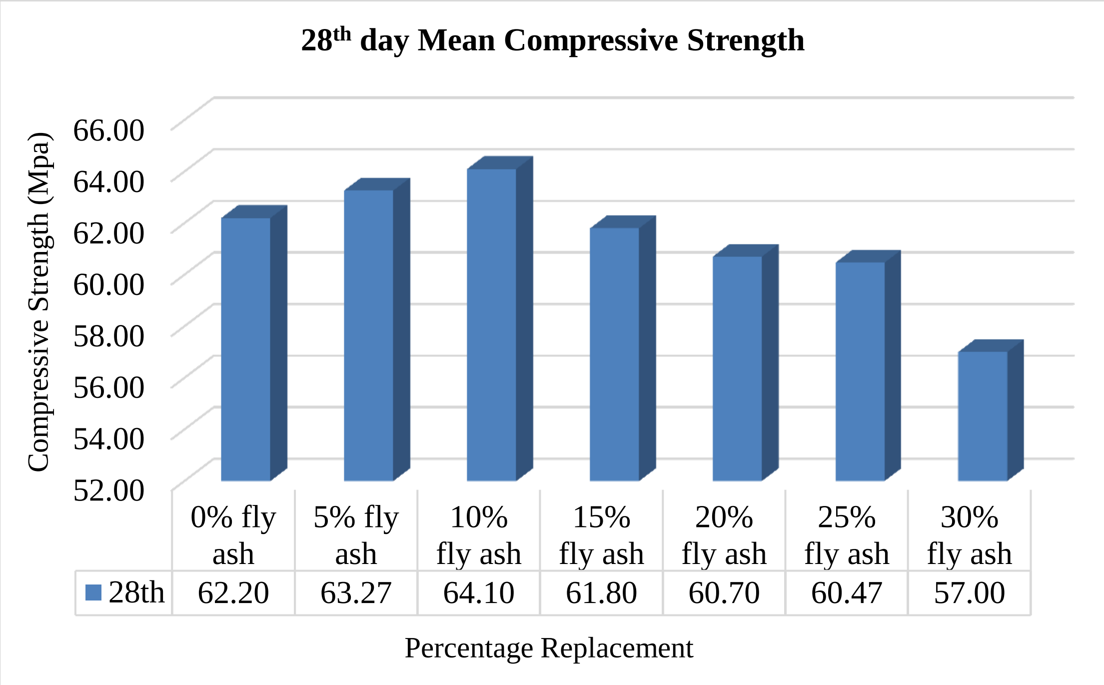
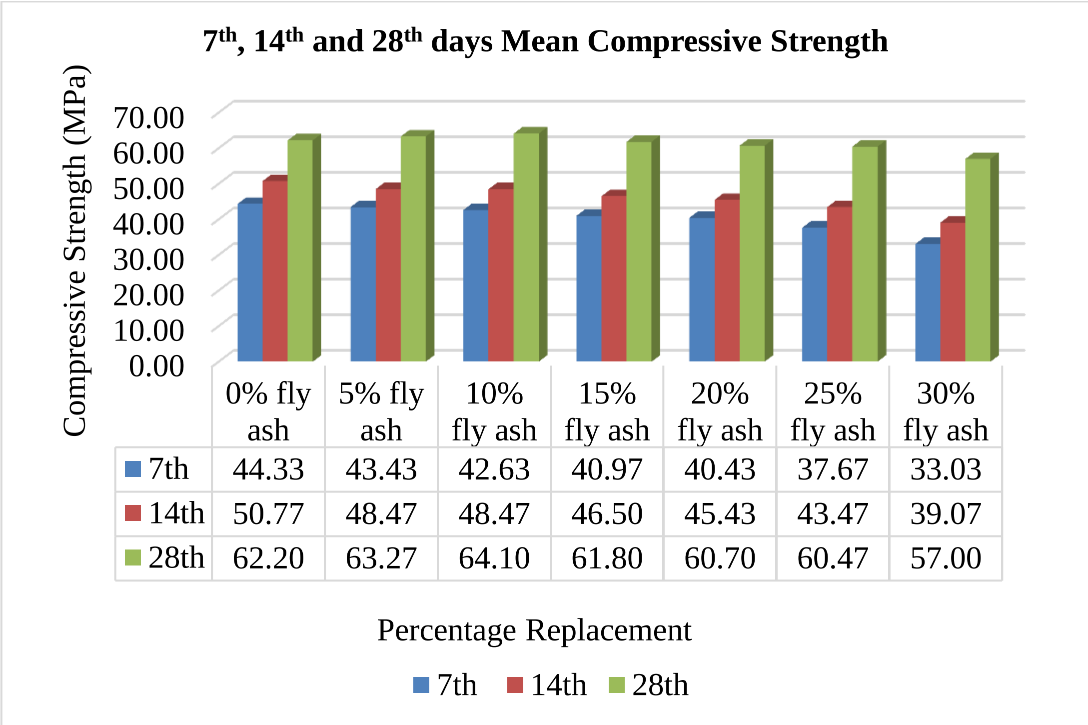


Figure 4.6: 28th Day Mean Compressive Strength without Super Plasticizer

At the age of the twenty-eight day, the compressive strength of concrete with fly ash was higher than of that without fly ash up to 10%. Hence, these results implied as the concrete with fly ash replacement is unable to attain an early time of strength, as normal concrete and the strength increase at later curing age, which is 28th days. The result shows the compressive strength of 5% and 10% fly ash added concrete was higher than reference concrete by 1.66% and 2.97% respectively, but it was reduced by 0.66%, 2.43%, 2.81%, and 8.37% respectively.



	0% fly ash	5% fly ash	10% fly ash	15% fly ash	20% fly ash	25% fly ash	30% fly ash
7th	44.33	43.43	42.63	40.97	40.43	37.67	33.03
14th	50.77	48.47	48.47	46.50	45.43	43.47	39.07
28th	62.20	63.27	64.10	61.80	60.70	60.47	57.00

Figure 4.7: 7th, 14th and 28th days Mean Compressive Strength without Super Plasticizer

Generally in figure 4.7 it is clearly shown that, compressive strength of concrete at 0% fly ash replacement or control mix is greater than 7th and 14th days samples replacing cement by fly ash at different percentage, while 28th age control mix was less than the rest samples replacing cement by fly ash at different percentage. Hence, the age of 7th and 14th days of the compressive strength of concrete with partial replacement of 5%, 10% ,15%, 20%, 25% and 30% fly ash shown reduction over the control by about 2.03%, 3.83%, 7.6%, 8.79%, 15.04%, 25.49% and 4.53%, 4.56%, 8.35%, 10.5%, 14.38%, & 21.86% respectively. However, the compressive strength of concrete at the age of 28 day with partial replacement of fly ash shown improvement up to 10% by about 1.66%, 2.97% but, beyond 10% the mean compressive strength shows that reduction by about 0.66%, 2.43%, 2.81%, and 8.37% over the control sample respectively, due to percentage replacement of fly ash increases.

Figure 4.8: Compressive Strength Test

4.5 Effect of Fly Ash on Compressive strength with Super-plasticizes

A compressive strength test was conducted to evaluate the strength of cement concrete mix and containing a various percentage of fly ash at the age of 7th, 14th and 28th days respectively were tested to determine the effect of fly ash replacing on high strength concrete at different replacement percentage of fly ash.

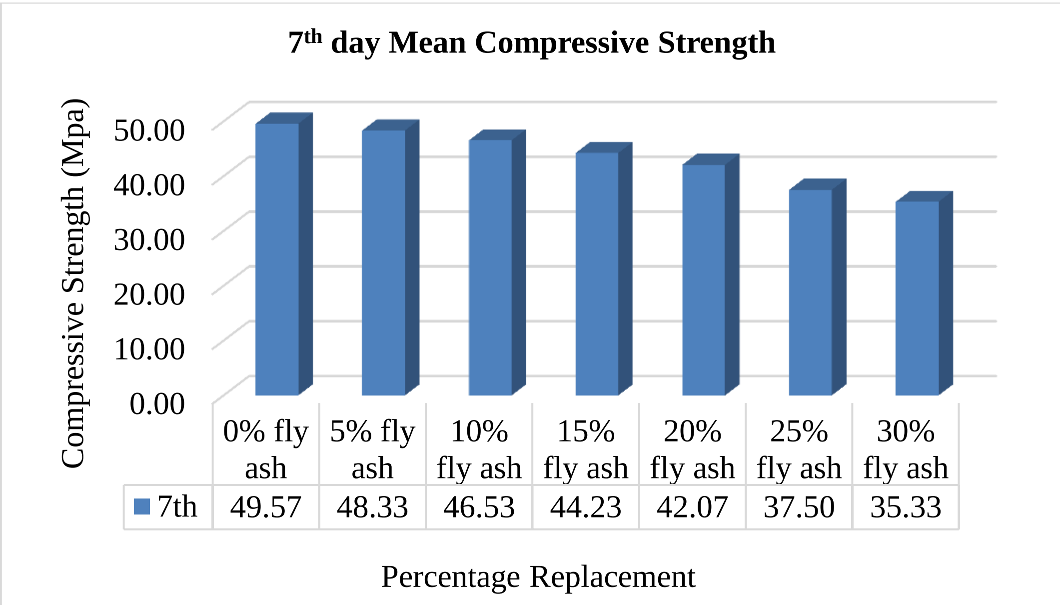


Figure 4.9: 7th Day Mean Compressive Strength with Super Plasticizer

At the age of the seventh day, the compressive strength of concrete without fly ash was more than of that with fly ash replacement and with the addition of super plasticizes. This shows the compressive strength of was reduced by about 2.5%, 6.13%, 10.77%, 15.2%, 24.3%, & 28.72% from reference concrete.

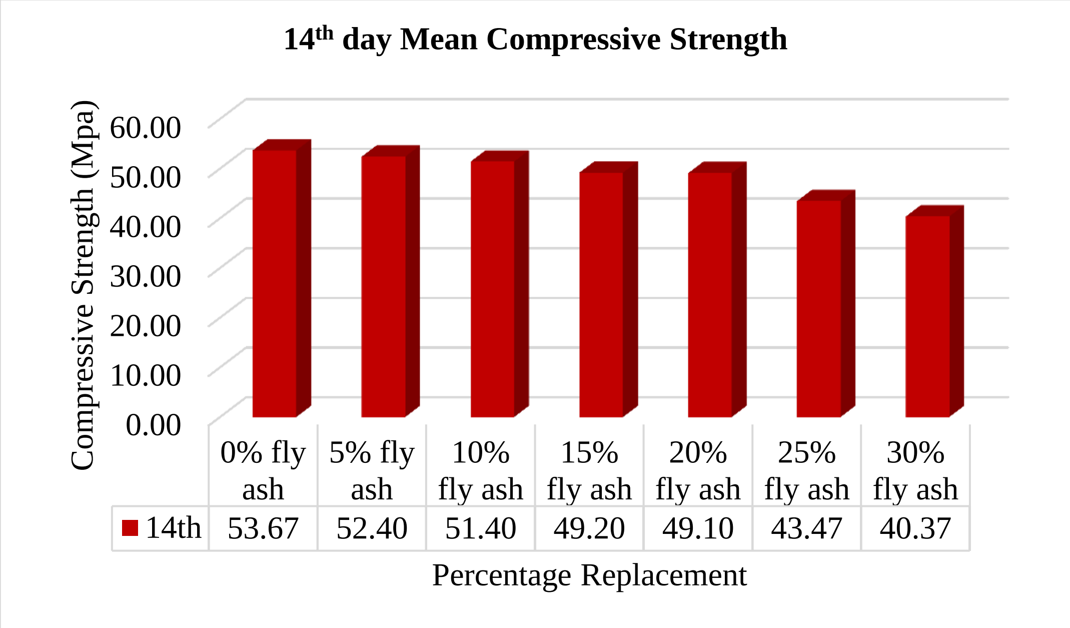


Figure 4.10: 14th Day Mean Compressive Strength with Super Plasticizer

Also at the age of the fourteen-day, the compressive strength of concrete without fly ash is more than of that with fly ash and with the addition of super plasticizes, but the gap in compressive strength is not much as the 7th day. This shows the compressive strength was reduced by about 2.247%, 4.17%, 8.27%, 8.45%, 19%, & 24.78% respectively from reference concrete.

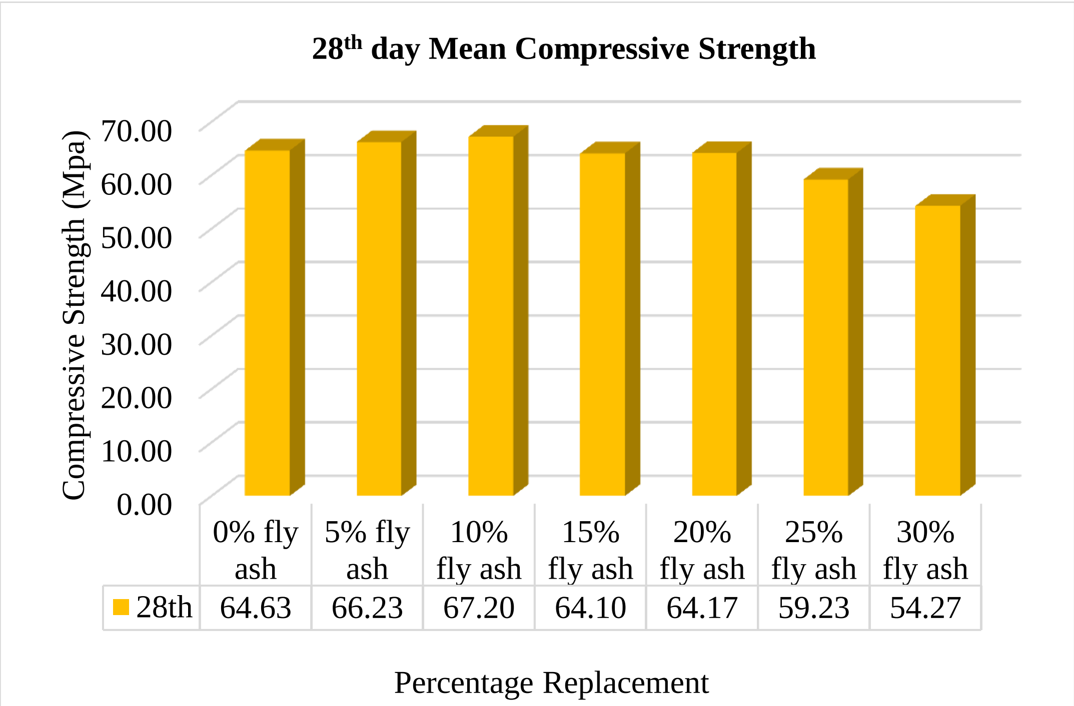
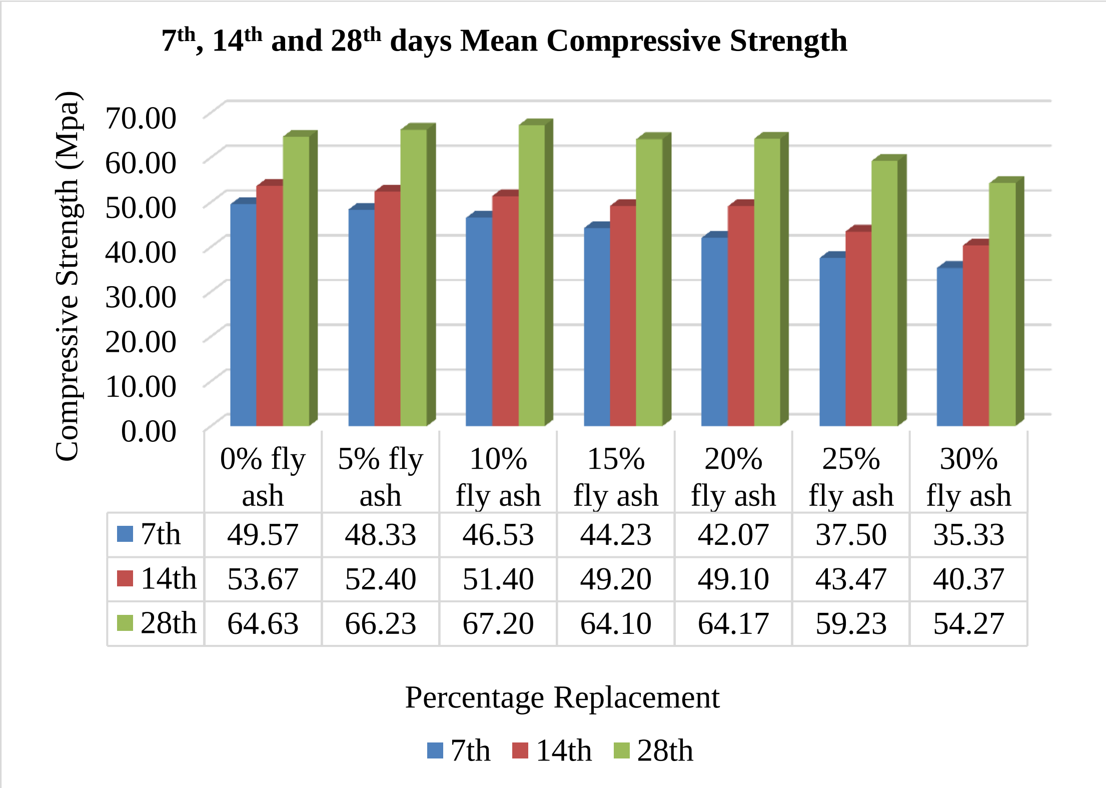


Figure 4.11: 28th Day Mean Compressive Strength with Super Plasticizer

At the age of the twenty-eighth day, the compressive strength of concrete with fly ash was higher than of that without fly ash and with the addition of super plasticizes up to 10%. Hence, these results implied as the concrete with fly ash replacement is unable to attain an early time of strength, as normal concrete. This shows the compressive strength of 5% and 10% fly ash added concrete was higher than reference concrete by 2.42% and 3.89% respectively, but it was reduced by 0.69%, 0.71%, 8.35%, and 16.03% respectively.



	0% fly ash	5% fly ash	10% fly ash	15% fly ash	20% fly ash	25% fly ash	30% fly ash
7th	49.57	48.33	46.53	44.23	42.07	37.50	35.33
14th	53.67	52.40	51.40	49.20	49.10	43.47	40.37
28th	64.63	66.23	67.20	64.10	64.17	59.23	54.27

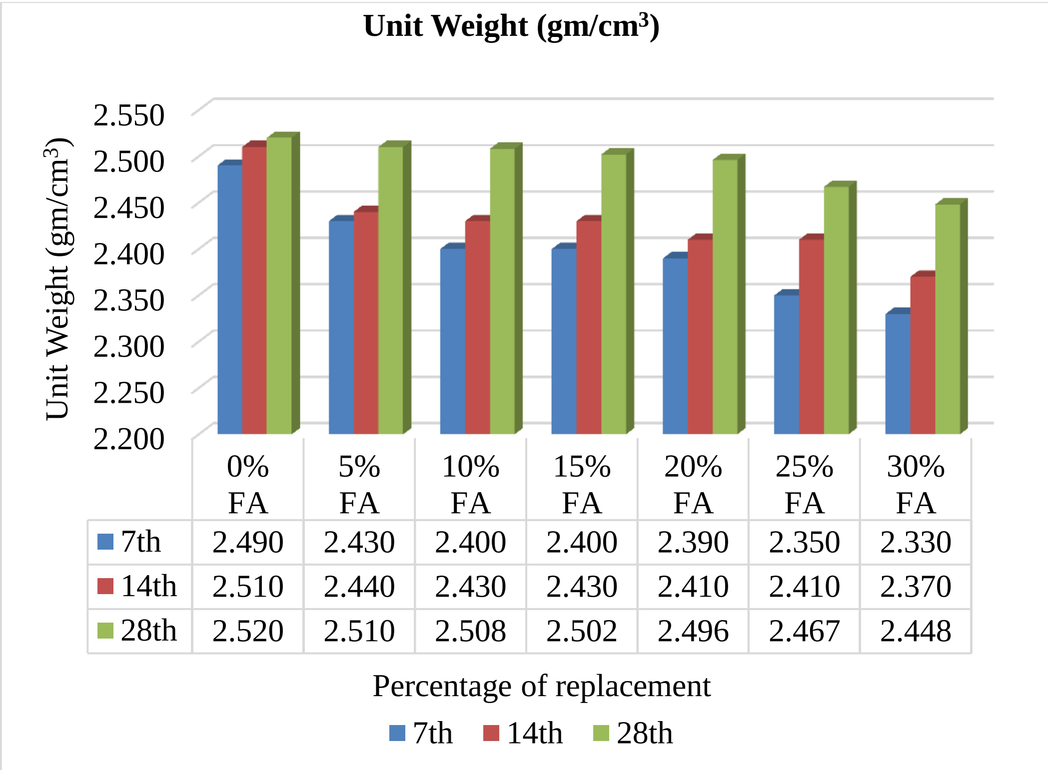
Figure 4.12: 7th, 14th and 28th days Mean Compressive Strength with Super Plasticizer

In figure 4.12 is clearly shown that, A compressive strength of concrete at 0% fly ash replacement or control mix is greater than 7th and 14th days samples replacing cement by fly ash at different percentage, while 28th age control mix was less than the rest samples replacing cement by fly ash at different percentage with the incorporation of super plasticizer admixture. Hence, the age of 7th and 14th days of the compressive strength of concrete with partial replacement cement by 5%, 10%, 15%, 20%, 25% and 30% fly ash had shown reduction over the control sample by about 2.5%, 6.13%, 10.77%, 15.2%, 24.3%, & 28.72% and 2.247%, 4.17%, 8.27%, 8.45%, 19%, & 24.78% respectively. However, the compressive strength of concrete at the age of 28 days with partial replacement of fly ash shown improvement up to 10% by about

2.42% and 3.89% but, beyond 10% replacement of fly ash by cement the mean compressive strength shows that reduction by about 0.69%, 0.71%, 8.35% and 16.03% over the control sample respectively, due to percentage replacement of fly ash increases. Therefore, this indicates that when the percentages of fly ash replacing with cement increases, while the compressive strength of the concrete decreases.

4.6 Unit Weight

The weights and the dimension of the concrete cubes are measured just before testing them for the compressive strength. These tests were conducted at 7^{th}, 14^{th}, and 28^{th} days.



	0% FA	5% FA	10% FA	15% FA	20% FA	25% FA	30% FA
7th	2.490	2.430	2.400	2.400	2.390	2.350	2.330
14th	2.510	2.440	2.430	2.430	2.410	2.410	2.370
28th	2.520	2.510	2.508	2.502	2.496	2.467	2.448

Figure 4.13: Unit Weight Control and Blended Concrete

From the investigation, the age of concrete increases, increase the density of concrete up to 28^{th} day of curing age at all mix. A unit weight of concrete at 0% fly ash replacement or control mix is greater than 7^{th}, 14^{th} and 28^{th} day samples replacing cement by fly ash at different percentage. From this, later age of curing, which is 28^{th} day it was shows a slight reduction of unit weight up to 2.85% was observed when 30% of the cement was replaced by fly ash over the control sample at the 28^{th} curing ages. whereas 0.39%, 0.47%, 0.71%, 0.95% and 2.10% reductions were observed for 5%, 10%, 15%, 20% and 25% fly ash replacement respectively. The low density of the fly ash high strength concrete, due to the specific gravity of fly ash less than ordinary Portland cement, it resulted in a reduction of unit weight of the blended concretes.

Therefore, the concrete with fly ash has a reduction in unit weight. A low-density concrete is beneficial in many ways over a high-density concrete. Using lighter concrete, easy to handle, and also reduces the pressure on formwork.

4.6 Optimum Usage of Fly Ash on High Strength Concrete

From the investigation, the optimum recommended limit of fly ash replacing cement for the mixture with and without high range water reducing chemical admixture to produce acceptable strength of high strength concrete is 10% at the age of 28^{th} days by about 3.89% and the mixture containing high range water reducing admixture to produce acceptable strength of high strength concrete is 10% at the age of 28^{th} days by about 2.97% over the control mix of concrete, since it satisfies high strength concrete properties, such as workability of fresh concrete and compressive value of hardened concrete.

Therefore, the optimum dosage of fly ash is based on the highest ultimate strength that they provide at age 28 days. i.e., 10% fly ash added concrete was provided the highest optimum compressive strength. Dosage with lower or higher than this optimum value will reduce the strength. Since the compressive strength of concrete is improved by the addition of fly ash by the reduction of cement.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. Conclusions

This research has investigated the effect of fly ash on properties high strength concrete such as workability, compressive strength and density. From this the conclusions and recommendations that could be drawn from the results of this study are summarized as follows:

The slump value of the concrete without adding super plasticizer and replacing up to 10% of fly ash by cement is better in its workability than over the control sample and for fly ash concrete which is replaced by more than 10% these slump result is 42mm. when more than 10% of fly ash is replaced by cement, the slump value of concrete becomes decreased and even not satisfied the standard, specifically at the range of 15% and beyond. But, when we applied a super plasticizer, we have observed, better workable concrete until the percentage replacement reaches 25%, those slump result is 60mm.

The compressive strength of fly ash replaced concrete at the age of 7th and 14th days the result shows decreases over the reference sample with different percentage value of fly ash replacement both with and without super plasticizer. However, at later age of curing, which is 28th day, fly ash replaced concrete samples showed better compressive strength value, when the cement is replaced by fly ash up to 10%. The concrete containing 5% and 10% fly ash as cement, gained 1.66% and 2.97% without super plasticizer and 2.42% and 3.89% with super plasticizer of compressive strength respectively. So that, replacing 10% of fly ash by cement on compressive strength, provides a satisfactory result both with and without super plasticizer over the control concrete.

The unit weight of the concretes containing fly ash has shown a slight reduction. It is found that the largest reduction of unit weight has observed when 30% of cement replaced by fly ash by 2.85% from the control sample.

The optimum percentage value of fly ash to replace cement both with and without super plasticizer is 10%. So that, replacing 10% of fly ash by cement, provides us satisfactory concrete mixtures in terms of both workability and compressive strength at the time.

Generally it is concluded that, high strength concrete with fly ash replaced by cement up to 10% good to improve high strength concrete properties such as both workability and compressive strength. When we apply 1% of super plasticizer, generally we can replace up to 25% of fly ash by cement, as the same time satisfying the workability standard slump value, but, the compressive strength value decreases beyond 10% fly ash replaced with cement over the control samples.

5.2 Recommendation

Based on the research study, the following recommendations have forwarded for future study.

- The studies on cement replaced with fly ash in high strength concrete on long term effect, which is beyond 28th days will be recommended for further study.
- This study is done only on 5%, 10%, 15%, 20%, 25% and 30% fly ash replaced with cement. Study on other percentage variation of fly ash will be recommended for future studies.
- This study is done usage of fly ash as partial replacement of cement on high strength concrete properties. For future study it was also recommended on cost analysis.
- This study is done usage of fly ash as partial replacement of cement on high strength concrete properties. Further researchers will be done on the effects of other types of mineral admixtures such as silica fume, GGBF and so on.

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APPENDIX I

MATERIALS TEST RESULTS

1.1 Properties of cement

1.1.1 Consistency Test

Consistency with 0% of fly ash					
Trial	**Weight of cement(gm)**	**Weight of fly ash (gm)**	**Percentage of water**	**Water added (gm)**	**Penetration (mm)**
1	400	0	32%	128	33
2	400	0	31%	124	27
3	400	0	30%	120	11

Consistency with 5% of fly ash					
Trial	**Weight of cement(gm)**	**Weight of fly ash (gm)**	**Percentage of water**	**Water added (gm)**	**Penetration (mm)**
1	380	20	32%	128	33
2	380	20	31%	124	28
3	380	20	30%	120	11

Consistency with 10% of fly ash					
Trial	**Weight of cement(gm)**	**Weight of fly ash (gm)**	**Percentage of water**	**Water added (gm)**	**Penetration (mm)**
1	360	40	32%	128	33
2	360	40	31%	124	29
3	360	40	30%	120	10.5

Consistency with 15% of fly ash					
Trial	**Weight of cement(gm)**	**Weight of fly ash (gm)**	**Percentage of water**	**Water added (gm)**	**Penetration (mm)**
1	340	60	32%	128	33
2	340	60	31%	124	30

3	340	60	30%	120	10

Consistency with 20% of fly ash					
Trial	**Weight of cement(gm)**	**Weight of fly ash (gm)**	**Percentage of water**	**Water added (gm)**	**Penetration (mm)**
1	320	80	32%	128	33
2	320	80	31%	124	31
3	320	80	30%	120	10
Consistency with 25% of fly ash					
Trial	**Weight of cement(gm)**	**Weight of fly ash (gm)**	**Percentage of water**	**Water added (gm)**	**Penetration (mm)**
1	300	100	32%	128	33
2	300	100	31%	124	32
3	300	100	30%	120	9.5

Consistency with 30% of fly ash					
Trial	**Weight of cement(gm)**	**Weight of fly ash (gm)**	**Percentage of water**	**Water added (gm)**	**Penetration (mm)**
1	280	120	32%	128	33
2	280	120	31%	124	33
3	280	120	30%	120	9

1.1.2 Setting Time Test

Setting Time (30% W/C)													
0%F.A (OPC)		**5%FA+95%OPC**		**10%FA+90%OPC**		**15%FA+85%OPC**		**20%FA+80%OPC**		**25%FA+75%OPC**		**30%FA+70%OPC**	
Time (min)	PD (mm)	Time (min)	PD(mm)	Time (min)	PD(mm)	Time (min)	PD(mm)	Time (min)	PD(mm)	Time (min)	PD(mm)	Time (min)	PD(mm)
30	33	30	33	30	35	30	39	30	47	30	47	30	47
45	30	45	30	45	32	45	37	45	44	45	44	45	44
60	28	60	28	60	30	60	34	60	39	60	40	60	41

75	26	75	26	75	27	75	31	75	31	75	30	75	31
90	24	90	24	90	25	90	26	90	27	90	28	90	28
						105	24	105	25	105	25	105	26
										120	18	120	21
PD-Penetration Depth, FA-Fly Ash, OPC- Ordinary Portland Cement													

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 laboratory manual.

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

Sample	Consistency	Initial Setting(min)	Final Setting(min)
0%F.A (OPC)	30%	82.5	189
5%FA+95%OPC		82.5	189
10%FA+90%OPC		90	198
15%FA+85%OPC		97.5	207
20%FA+80%OPC		105	216
25%FA+75%OPC		105	216
30%FA+70%OPC		112.5	225

1.2. Properties of fine aggregate

1.2.1. Silt content

Silt content before Washing			
Sample	Amount of Silt deposit	Amount of clear sand	Silt content (%)
Sample 1	20ml	280ml	7.14
Sample 2	25ml	285ml	8.77
		Mean	7.95
Silt content after Washing			
Sample	Amount of Silt deposit	Amount of clear sand	Silt content (%)
Sample 1	5ml	165ml	3.03
Sample 2	6ml	290ml	2.06

Mean	2.54

Silt content (%)= A/B

Where: A= Amount of silt deposited above the sand (ml)
B= Amount of clean sand(ml)

1.2.2 Sieve analysis

Sieve Analysis of fine Aggregate						
Sieve Size (mm)	**Mass Retained**	**%Retained**	**Cumulative %Retained**	**Finer Passing**	**ASTM Limit**	
					Lower	Upper
9.5	0	0	0	100	100	100
4.75	0	0	0	100	95	100
2.36	240	12	12.3	87.7	80	100
1.18	415	20.8	33.1	66.95	50	85
0.6	664	33.2	66.3	33.75	25	60
0.3	430	21.5	87.8	12.25	10	30
0.15	160	8	95.8	4.25	2	10
Pan	80	4				

$$\text{Finesse modules} = \frac{\sum \text{Cum. Retained (\%)}}{100}$$

1.2.3. Unit weight

1.2.3.1. Compact unit weight of fine aggregate

Compact unit weight of fine aggregate			
Sample	**1**	**2**	**3**
Wt. of cylinder metal(kg)	1.054	1.054	1.054
Wt. of cylinder metal (kg) +wt. Of sample	8.882	8.870	8.894
Wt. Of sample(kg)	7.828	7.816	7.840
Volume of cylinder(m^3)	0.005	0.005	0.005
Unit weight(kg/m^3)	1565.6	1563.2	1568
Mean	**1565.6**		

$$\text{Unit Weight} = \frac{B-A}{C}$$

Where: A=weight of container

B= average weight of sample and container

C=Volume of container

1.2.3.2. Loose unit weight of fine aggregate

Loose unit weight of fine aggregate			
Sample	**1**	**2**	**3**
Wt. of cylinder metal(kg)	1.68	1.68	1.68
Wt. of cylinder metal (kg) +wt. Of sample	8.387	8.491	8.377
Wt. Of sample(kg)	6.7075	6.8118	6.697
Volume of cylinder(m3)	0.005	0.005	0.005
Unit weight(kg/m3)	1341.5	1362.36	1339.4
Mean	**1347.75**		
Unit Weight = $\frac{B-A}{C}$ Where: A=Weight of container B= Average weight of sample and container C=Volume of container			

1.2.4. Specific gravity

Specific gravity of fine aggregate			
Sample	**1**	**2**	**Average**
Wt. of SSD sample (A) [gm]	500	500	
Wt. of pycnometer + sample + water(B)[gm]	1853.4	1855	
Weight of pycnometer + water(C)[gm]	1555	1555	
Wt. of oven dry sample(D)	490.5	493	
Bulk specific gravity=D/(C+A-B)	2.433	2.465	2.449
Bulk specific gravity(SSD)=A/C+A- B	2.48	2.5	2.5
Apparent specific gravity=D/C+D-B	2.55	2.55	2.55
Absorption Capacity(%)=[A-D/D]*100	1.94	1.42	1.68

1.2.5. Moisture content

Sample	1	2
Weight of original sample before dry A (g)	500	500

Weight of oven dry sample B (g)	492.5	492
Moisture content(MC) %=[A-B/B]*100	1.523	1.626
Mean	**1.57%**	

1.3. Properties of coarse aggregate

1.3.1 Unit weight

1.3.1.1 Compact unit weight of coarse aggregate

Compact unit weight of coarse aggregate			
Sample	**1**	**2**	**3**
Wt. of cylinder metal(kg)	1.68	1.68	1.68
Wt. of cylinder metal (kg) +wt. Of sample	17.696	17.705	17.81
Wt. Of sample(kg)	16.017	16.025	16.13
Volume of cylinder(m^3)	0.01	0.01	0.01
Unit weight(kg/m^3)	1601.7	1602.5	1613
Mean	**1605.73**		

$$\text{Unit Weight} = \frac{B-A}{C}$$

Where: A=weight of container

B= average weight of sample and container

C=Volume of container

1.3.1.2. Loose unit weight of coarse aggregate

Loose unit weight of coarse aggregate			
Sample	**1**	**2**	**3**
Wt. of cylinder metal(kg)	1.68	1.68	1.68
Wt. of cylinder metal (kg) +wt. Of sample	16.33	16.04	15.88
Wt. Of sample(kg)	14.65	14.36	14.20
Volume of cylinder(m3)	0.01	0.01	0.01
Unit weight(kg/m3)	1,465	1,436	1,420
Mean	**1440.33**		

1.3.2. Specific gravity

Specific gravity of coarse aggregate			
Sample	**1**	**2**	**Average**
Wt. of pycnometer + sample + water(B)[gm]	5000	5000	
Weight of pycnometer + water(C)[gm]	3238	3242	
Wt. of oven dry sample(A)	4969.5	4965	
Bulk specific gravity=A/(B-C)	2.82	2.82	2.82
Bulk specific gravity(SSD)=B/(B- C)	2.83	2.84	2.835
Apparent specific gravity=A/(A-C)	2.87	2.88	2.875
Absorption Capacity(%)=[B-A/A]*100	0.61	0.70	0.655

1.3.3. Moisture content

Sample	1	2
Weight of original sample before dry A (g)	2000	2000
Weight of oven dry sample B (g)	1981	1980.5
Moisture content(MC) %=[A-B/B]*100	0.96	0.99
Mean	**0.975%**	

1.4. Specific gravity of fly ash

Specific gravity of fly ash			
Sample	**1**	**2**	**Average**
Wt. of sample [gm]	200	200	
Wt. of pycnometer (A)[gm]	573	573	
Weight of pycnometer + Sample(B)[gm]	773	773	
Weight of pycnometer + water + Sample(C)[gm]	1657.3	1660.5	
Weight of pycnometer + water (D)[gm]	1530	1530	
Specific gravity =B-A/(D-A)-(C-B)	2.75	2.87	2.81

1.5. Density Calculation

$$\text{Density} = \frac{\text{Mass of Sample (gm)}}{\text{Volume of cube } (M^3)}$$

APPENDIX II

CHEMICAL COMPOSITION OF FLY 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: -02/10/2019

Customer Name:- Temesgen Fantu

Request No:- GLD/RN/648/19

Report No:- GLD/TR/559/19

Sample type:- Fly ash

Sample Preparation: - 200 Mesh

Date Submitted: - 23/09/2019

Number of Sample:- One(1)

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
FA-01	47.96	34.66	2.96	3.44	0.88	0.76	<0.01	0.04	0.22	0.55	2.42	5.97

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

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APPENDIX III

EXPERIMENTAL RESULT

2.1. The effect of fly ash on workability and compressive strength of high strength concrete without super plasticizer

Effect of 0% Fly ash on Compressive Strength of C-55 High Strength Concrete (Control)										
Sample	Test Age (days)	Dimensions (cm)			W/C	Slump (mm)	Weight (gm)	Volume (cm3)	Failure Load (KN)	Compressive Strength (Mpa)	Unit Weight (gm/cm3)
		L	W	H							
1	7	15	15	15	0.32	25	8460	3,375	989.93	44.00	2.49
2		15	15	15			8410	3,375	980.83	43.60	2.48
3		15	15	15			8480	3,375	1021.09	45.39	2.50
Mean									997.2833	44.33	2.49
1	14	15	15	15	0.32	25	8460	3,375	1122.54	49.90	2.49
2		15	15	15			8490	3,375	1138.29	50.60	2.51
3		15	15	15			8530	3,375	1165.28	51.80	2.52
Mean									1142.037	50.77	2.51
1	28	15	15	15	0.32	25	8475	3,375	1356.49	60.30	2.51
2		15	15	15			8545	3,375	1412.74	62.80	2.52
3		15	15	15			8560	3,375	1428.49	63.50	2.54
Mean									1399.24	62.20	2.52

Effect of 5% Fly ash on Compressive Strength of C-55 High Strength Concrete											
Sample	Test Age (days)	Dimensions (cm)			W/C Ratio	Slump (mm)	Weight (gm)	Volume (cm3)	Failure Load (KN)	Compressive Strength (Mpa)	Unit Weight (gm/cm3)
		L	W	H							
1	7	15	15	15	0.32	38	8170	3,375	971.82	43.20	2.42
2		15	15	15			8235	3,375	1001.06	44.50	2.44
3		15	15	15			8150	3,375	958.33	42.60	2.41
Mean									977.07	43.43	2.43
1	14	15	15	15	0.32	38	8210	3,375	1055.053	46.90	2.43
2		15	15	15			8250	3,375	1129.29	50.20	2.44
3		15	15	15			8235	3,375	1086.55	48.30	2.44

Mean									1090.298	48.47	2.44
1	28	15	15	15	0.32	38	8440	3,375	1437.48	63.90	2.50
2		15	15	15			8445	3,375	1360.99	60.50	2.50
3		15	15	15			8530	3,375	1471.23	65.40	2.53
Mean									1423.233	63.27	2.51

Effect of 10% Fly ash on Compressive Strength of C-55 High Strength Concrete

Sample	Test Age (days)	Dimensions (cm)			W/C Ratio	Slump (mm)	Weight (gm)	Volume (cm3)	Failure Load (KN)	Compressive Strength (Mpa)	Unit Weight (gm/cm3)
		L	W	H							
1	7	15	15	15	0.32	42	8090	3,375	899.83	40.00	2.39
2		15	15	15			8180	3,375	998.82	44.40	2.42
3		15	15	15			8125	3,375	978.57	43.50	2.40
Mean									959.0733	42.63	2.40
1	14	15	15	15	0.32	42	8210	3,375	1088.796	48.40	2.43
2		15	15	15			8190	3,375	1046.06	46.50	2.43
3		15	15	15			8250	3,375	1136.04	50.50	2.44
Mean									1090.299	48.47	2.43
1	28	15	15	15	0.32	42	8490	3,375	1453.23	64.60	2.52
2		15	15	15			8380	3,375	1401.49	62.30	2.48
3		15	15	15			8530	3,375	1471.23	65.40	2.53
Mean									1441.983	64.10	2.51

Effect of 15% Fly ash on Compressive Strength of C-55 High Strength Concrete

Sample	Test Age (days)	Dimensions (cm)			W/C Ratio	Slump (mm)	Weight (gm)	Volume (cm3)	Failure Load (KN)	Compressive Strength (Mpa)	Unit Weight (gm/cm3)
		L	W	H							
1	7	15	15	15	0.32	23	8050	3,375	866.09	38.50	2.39
2		15	15	15			8110	3,375	969.57	43.10	2.40
3		15	15	15			8105	3,375	929.08	41.30	2.40
Mean									921.58	40.97	2.40
1	14	15	15	15	0.32	23	8215	3,375	1046.06	46.50	2.43
2		15	15	15			8195	3,375	1030.31	45.80	2.42
3		15	15	15			8250	3,375	1061.8	47.20	2.44

Mean									1046.057	46.50	2.43
1	28	15	15	15	0.32	23	8430	3,375	1426.23	63.40	2.50
2		15	15	15			8460	3,375	1444.23	64.20	2.51
3		15	15	15			8450	3,375	1419.48	63.10	2.50
Mean									1429.98	63.57	2.50

Effect of 20% Fly ash on Compressive Strength of C-55 High Strength Concrete

Sample	Test Age (days)	Dimensions (cm)			W/C Ratio	Slump (mm)	Weight (gm)	Volume (cm3)	Failure Load (KN)	Compressive Strength (Mpa)	Unit Weight (gm/cm3)
		L	W	H							
1	7	15	15	15	0.32	15	8125	3,375	913.33	40.60	2.40
2		15	15	15			8135	3,375	956.07	42.50	2.41
3		15	15	15			8050	3,375	859.34	38.20	2.38
Mean									909.58	40.43	2.39
1	14	15	15	15	0.32	15	8155	3,375	1030.31	45.80	2.41
2		15	15	15			8140	3,375	987.56	43.90	2.41
3		15	15	15			8190	3,375	1048.31	46.60	2.42
Mean									1022.06	45.43	2.41
1	28	15	15	15	0.32	15	8420	3,375	1421.73	63.20	2.49
2		15	15	15			8405	3,375	1390.25	61.80	2.49
3		15	15	15			8450	3,375	1444.23	64.20	2.50
Mean									1418.737	63.07	2.50

Effect of 25% Fly ash on Compressive Strength of C-55 High Strength Concrete

Sample	Test Age (days)	Dimensions (cm)			W/C Ratio	Slump (mm)	Weight (gm)	Volume (cm3)	Failure Load (KN)	Compressive Strength (Mpa)	Unit Weight (gm/cm3)
		L	W	H							
1	7	15	15	15	0.32	8	7920	3,375	850.35	37.80	2.35
2		15	15	15			7910	3,375	827.85	36.80	2.34
3		15	15	15			7980	3,375	863.84	38.40	2.36
Mean									847.3467	37.67	2.35
1	14	15	15	15	0.32	8	8150	3,375	976.32	43.40	2.41
2		15	15	15			8110	3,375	962.82	42.80	2.40
3		15	15	15			8180	3,375	994.31	44.20	2.42

Mean									977.8167	43.47	2.41
1	28	15	15	15	0.32	8	8350	3,375	1365.49	60.70	2.47
2		15	15	15			8340	3,375	1383.49	61.50	2.47
3		15	15	15			8295	3,375	1331.75	59.20	2.46
Mean									1360.243	60.47	2.47

Effect of 30% Fly ash on Compressive Strength of C-55 High Strength Concrete

Sample	Test Age (days)	Dimensions (cm)			W/C Ratio	Slump (mm)	Weight (gm)	Volume (cm3)	Failure Load (KN)	Compressive Strength (Mpa)	Unit Weight (gm/cm3)
		L	W	H							
1	7	15	15	15	0.32	3	7860	3,375	746.86	33.20	2.33
2		15	15	15			7795	3,375	686.13	30.50	2.31
3		15	15	15			7910	3,375	796.35	35.40	2.34
Mean									743.1133	33.03	2.33
1	14	15	15	15	0.32	3	7995	3,375	888.58	39.50	2.37
2		15	15	15			8060	3,375	904.33	40.20	2.39
3		15	15	15			7950	3,375	843.59	37.50	2.36
Mean									878.8333	39.07	2.37
1	28	15	15	15	0.32	3	8280	3,375	1289.001	57.30	2.45
2		15	15	15			8220	3,375	1226.03	54.50	2.44
3		15	15	15			8290	3,375	1331.8	59.20	2.46
Mean									1282.277	57.00	2.45

2.2. The effect of fly ash on Workability and Compressive Strength of High Strength Concrete with Super plasticizer

Effect of 0% Fly ash on Compressive Strength of C-55 High Strength Concrete (Control) With Super plasitisaizer (HRWRs)

Sample	Test Age (days)	Dimensions (cm)			W/C Ratio	Slump (mm)	Weight (gm)	Volume (cm3)	Failure Load (KN)	Compressive Strength (Mpa)	Unit Weight (gm/cm3)
		L	W	H							
1	7	15	15	15	0.32	75	8420	3,375	1077.55	47.90	2.49
2		15	15	15			8535	3,375	1113.54	49.50	2.53

3		15	15	15			8590	3,375	1154.03	51.30	2.55
Mean									1115.04	49.57	2.52
1	14	15	15	15	0.32	75	8535	3,375	1210.28	53.80	2.53
2		15	15	15			8590	3,375	1241.77	55.20	2.55
3		15	15	15			8471	3,375	1169.78	52.00	2.51
Mean									1207.277	53.67	2.53
1	28	15	15	15	0.32	75	8535	3,375	1457.73	64.80	2.53
2		15	15	15			8590	3,375	1466.72	65.20	2.55
3		15	15	15			8522	3,375	1437.49	63.90	2.53
Mean									1453.98	64.63	2.53

Effect of 5% Fly ash on Compressive Strength of C-55 High Strength Concrete With Super plasitisaizer (HRWRs)											
Sample	Test Age (days)	Dimensions (cm)			W/C Ratio	Slump (mm)	Weight (gm)	Volume (cm3)	Failure Load (KN)	Compressive Strength (Mpa)	Unit Weight (gm/cm3)
		L	W	H							
1	7	15	15	15	0.32	80	8130	3,375	1075.3	47.80	2.41
2		15	15	15			8180	3,375	1084.29	48.20	2.42
3		15	15	15			8190	3,375	1102.33	49.00	2.43
Mean									1087.307	48.33	2.42
1	14	15	15	15	0.32	80	8290	3,375	1183.29	52.60	2.46
2		15	15	15			8133	3,375	1158.54	51.50	2.41
3		15	15	15			8310	3,375	1194.6	53.10	2.46
Mean									1178.81	52.40	2.44
1	28	15	15	15	0.32	80	8410	3,375	1491.5	66.30	2.49
2		15	15	15			8315	3,375	1437.48	63.90	2.46
3		15	15	15			8430	3,375	1540.96	68.50	2.50
Mean									1489.98	66.23	2.48

Effect of 10% Fly ash on Compressive Strength of C-55 High Strength Concrete With Super plasitisaizer (HRWRs)											
Sample	Test Age (days)	Dimensions (cm)			W/C Ratio	Slump (mm)	Weight (gm)	Volume (cm3)	Failure Load (KN)	Compressive Strength (Mpa)	Unit Weight (gm/cm3)
		L	W	H							
1	7	15	15	15	0.32	82	8290	3,375	1041.55	46.30	2.46
2		15	15	15			8130	3,375	1007.82	44.80	2.41
3		15	15	15			8370	3,375	1091.05	48.50	2.48
Mean									1046.807	46.53	2.44
1	14	15	15	15	0.32	82	8230	3,375	1151.79	51.20	2.44
2		15	15	15			8180	3,375	1124.8	50.00	2.42
3		15	15	15			8295	3,375	1192.3	53.00	2.46
Mean									1156.297	51.40	2.45
1	28	15	15	15	0.32	82	8310	3,375	1466.73	65.20	2.46
2		15	15	15			8390	3,375	1518.47	67.50	2.49
3		15	15	15			8415	3,375	1549.96	68.90	2.49
Mean									1511.72	67.20	2.48

Effect of 15% Fly ash on Compressive Strength of C-55 High Strength Concrete With Super plasitisaizer(HRWRs)											
Sample	Test Age (days)	Dimensions (cm)			W/C Ratio	Slump (mm)	Weight (gm)	Volume (cm3)	Failure Load (KN)	Compressive Strength (Mpa)	Unit Weight (gm/cm3)
		L	W	H							
1	7	15	15	15	0.32	85	8295	3,375	1001.07	44.50	2.46
2		15	15	15			8130	3,375	951.58	42.30	2.41
3		15	15	15			8380	3,375	1032.56	45.90	2.48
Mean									995.07	44.23	2.45
1	14	15	15	15	0.32	85	8490	3,375	1109.05	49.30	2.52
2		15	15	15			8402	3,375	1075.3	47.80	2.49

3		15	15	15			8498	3,375	1136.04	50.50	2.52
Mean									1106.797	49.20	2.48
1	28	15	15	15	0.32	85	8275	3,375	1412.74	62.80	2.45
2		15	15	15			8410	3,375	1473.48	65.50	2.49
3		15	15	15			8380	3,375	1439.74	64.00	2.48
Mean									1441.987	64.10	2.51

Effect of 20% Fly ash on Compressive Strength of C-55 High Strength Concrete With Superplasitisaizer (HRWRs)											
Sample	Test Age (days)	Dimensions (cm)			W/C Ratio	Slump (mm)	Weight (gm)	Volume (cm3)	Failure Load (KN)	Compressive Strength (Mpa)	Unit Weight (gm/cm3)
		L	W	H							
1	7	15	15	15	0.32	78	8130	3,375	947.08	42.10	2.41
2		15	15	15			8140	3,375	962.82	42.80	2.41
3		15	15	15			8120	3,375	929.08	41.30	2.41
Mean									946.3267	42.07	2.41
1	14	15	15	15	0.32	78	8395	3,375	1113.55	49.50	2.49
2		15	15	15			8305	3,375	1079.79	48.00	2.46
3		15	15	15			8385	3,375	1120.3	49.80	2.48
Mean									1104.547	49.10	2.48
1	28	15	15	15	0.32	78	8385	3,375	1426.24	63.40	2.48
2		15	15	15			8395	3,375	1444.23	64.20	2.49
3		15	15	15			8430	3,375	1459.98	64.90	2.50
Mean									1443.483	64.17	2.48

Effect of 25% Fly ash on Compressive Strength of C-55 High Strength Concrete With Superplasitisaizer(HRWRs)											
Sample	Test Age (days)	Dimensions (cm)			W/C Ratio	Slump (mm)	Weight (gm)	Volume (cm3)	Failure Load (KN)	Compressive Strength (Mpa)	Unit Weight (gm/cm3)
		L	W	H							
1	7	15	15	15	0.32	60	8120	3,375	843.59	37.50	2.41

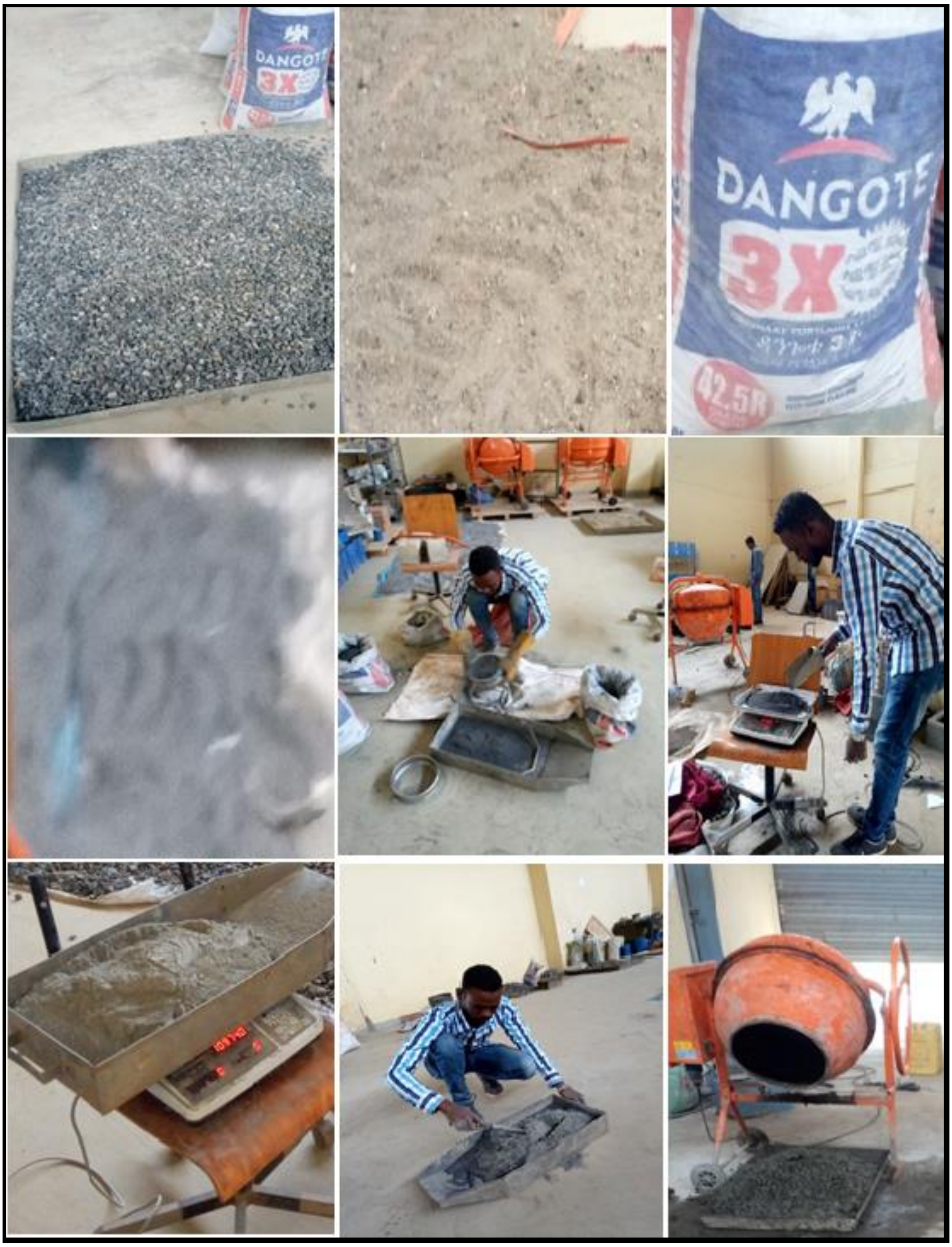
2		15	15	15			8027	3,375	787.36	35.20	2.38
3		15	15	15			8165	3,375	895.34	39.80	2.42
Mean									842.0967	37.50	2.40
1	14	15	15	15	0.32	60	8120	3,375	980.82	43.60	2.41
2		15	15	15			8210	3,375	989.82	44.00	2.43
3		15	15	15			8165	3,375	962.82	42.80	2.42
Mean									977.82	43.47	2.42
1	28	15	15	15	0.32	60	8360	3,375	1327.3	59.00	2.48
2		15	15	15			8380	3,375	1354.25	60.20	2.48
3		15	15	15			8351	3,375	1316	58.50	2.47
Mean									1332.517	59.23	2.48

Effect of 30% Fly ash on Compressive Strength of C-55 High Strength Concrete With Superplasitisaizer(HRWRs)

Sample	Test Age (days)	Dimensions (cm)			W/C Ratio	Slump (mm)	Weight (gm)	Volume (cm3)	Failure Load (KN)	Compressive Strength (Mpa)	Unit Weight (gm/cm3)
		L	W	H							
1	7	15	15	15	0.32	45	7968	3,375	787.35	35.00	2.36
2		15	15	15			8045	3,375	827.85	36.80	2.38
3		15	15	15			7950	3,375	769.35	34.20	2.36
Mean									794.85	35.33	2.37
1	14	15	15	15	0.32	45	8120	3,375	911.08	40.50	2.41
2		15	15	15			8240	3,375	944.83	42.00	2.44
3		15	15	15			8120	3,375	868.34	38.60	2.41
Mean									908.0833	40.37	2.42
1	28	15	15	15	0.32	45	8309	3,375	1241.77	55.20	2.46
2		15	15	15			8320	3,375	1192.3	53.00	2.47
3		15	15	15			8356	3,375	1228.3	54.60	2.48
Mean									1220.79	54.27	2.47

APPENDIX V

SAMPLE PHOTO GALLERY TAKEN DURING THE RESEARCH



Material Preparation

Workability of Fresh Concrete Test

Compressive Strength Test